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GEOLOGY OF THE DE QUEEN AND CADDO GAP QUADRANGLES, ARKANSAS

BY

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ABSTRACT

Location and surface features.—The De Queen and Caddo Gap quadrangles, which embrace an area of almost 2,000 square miles, lie mainly in southwestern Arkansas but include a narrow strip along the eastern border of Oklahoma. The northern three-fourths of the quadrangles lies in the Ouachita Mountain region, and the remainder in the Gulf Coastal Plain.

Rocks of the Ouachita Mountain region.—The rocks in the Ouachita Mountain region include shale, sandstone, chert, and novaculite, with a little limestone and volcanic tuff, and range in age from Cambrian to Pennsylvanian. Their aggregate thickness is about 25,000 feet.

The novaculite (Arkansas novaculite, in part Middle Devonian, in part Upper Devonian, and possibly in part Mississippian), is the rock of chief scientific as well as geographic interest in the quadrangles. It occurs in beds that aggregate a maximum thickness of almost 1,000 feet. It is so resistant that the beds, which are usually inclined at high angles, form the crests of most of the high mountain ridges of the quadrangles. The novaculite is for the most part massive, it breaks with a conchoidal fracture, and the prevailing color is white. It is a fine-grained siliceous rock composed almost entirely of closely fitting microscopic grains of silica and resembles in appearance the white varieties of Carrara marble. Its unusual character has led to many opinions as to its origin. The authors, with other geologists, hold the view that it is a variety of chert and that the silica was deposited by chemical precipitation.

The rocks of the Ouachita Mountain region contain few fossils. Those believed to be of Cambrian age have thus far yielded none. The Ordovician rocks have furnished many species of graptolites but few other fossil forms. The Silurian rocks also contain several species of graptolites. The novaculite and interbedded shale are almost barren of fossils but have yielded conodonts, sporangites, linguloids, and silicified wood. The only identifiable fossils obtained from the Mississippian and Pennsylvanian rocks, which consist of a great succession of sandstone and shale measuring about 18,000 feet in thickness, are one collection of plants; fragmentary unidentifiable plants and invertebrates are found sparingly at a few places.

The succession of Paleozoic rocks is broken by unconformities, so that some formations vary in thickness from place to place, but the variations in thickness and also the disappearance of formations are attributable for the most part to conditions of deposition.

The Paleozoic sediments were deposited in a geosynclinal basin that lay north of a land area occupying the present region of Louisiana and eastern Texas and south of the present Ozark region, which was land during most of Paleozoic time. The sediments were derived mostly from the southern land mass, and the material for the bed of volcanic tuff in the Mississippian rocks was ejected from volcanic vents that were active during a probable mountain-making epoch on the southern land. The shallow-water nature of most of the sediments indicates that the bottom of the geosynclinal basin gradually subsided during their deposition.

The rock strata were deformed by folding and faulting near the middle of the Pennsylvanian epoch, by compressive movements from the south. This deformation has compressed the strata into about half their original horizontal extent.

Sedimentary rocks of Coastal Plain.—The sedimentary rocks of the Coastal Plain are of Upper and Lower Cretaceous age and include gravel, sand, clay, limestone, and some water-laid volcanic tuff, all aggregating a thickness of several hundred feet. The strata lie in a nearly horizontal position, dipping 50 to 100 feet to the mile toward the south. They rest upon the truncated upturned edges of the steeply dipping Paleozoic rocks, which form a floor that has only minor irregularities and undulations. An angular unconformity also separates the Lower Cretaceous from the Upper Cretaceous strata, and a similar unconformity separates the Woodbine and Tokio formations ("Bingen formation" of early reports), both of Upper Cretaceous age.

The Cretaceous sediments, except the beds of tuff, were derived from the Ouachita Mountain region to the north. Notable among them are several beds of gravel of wide extent, the thickest measuring about 100 feet. The beds are composed mostly of pebbles of novaculite derived from outcrops of this rock in the Ouachita Mountains. The tuffaceous material was ejected early in Upper Cretaceous time from volcanic vents at the site of the present diamond mines near Murfreesboro, in the Caddo Gap quadrangle, and from other vents that presumably existed a short distance south of the quadrangles. The rocks filling all the vents, except those near Murfreesboro, are now concealed by Upper Cretaceous strata. The bedded tuff is all water-laid, though portions of the deposits were not well sorted during their deposition.

Igneous rocks.—The intrusive rocks consist of peridotite of early Upper Cretaceous age exposed in four relatively small areas near Murfreesboro. Three forms of the peridotite directly associated with the vents are recognized—massive porphyritic peridotite, breccia, and tuff. After the intrusion and cooling of the porphyritic rock violent explosions followed, breaking up the previously solidified rock. Fragments so produced make up the breccia and tuff.

Physiographic history.—The highest ridges of the Ouachita Mountains in the quadrangles attain an altitude of 2,360 feet above sea level, but 18,000 feet or more of Paleozoic rocks have been removed from above the crests of these ridges. The available evidence indicates the presence of two peneplains called the Ouachita and the Hot Springs. The Ouachita peneplain is marked by the narrow crests of the mountain ridges in the northern parts of the quadrangles. It slopes southward and passes beneath the strata of Lower Cretaceous age, forming the smooth floor upon which the sediments of this age were deposited in the southern parts of the quadrangles. This floor dips southward at rates ranging from 80 to more than 100 feet to the mile.

The Hot Springs peneplain, of Tertiary age, occurs at a lower altitude in the Ouachita Mountain region than the Ouachita peneplain and is marked by the upland level of intermontane basins and by a piedmont plateau (Athens Plateau) south of the mountains. The altitude of the peneplain surface ranges from 750 to 1,250 feet, being highest to the north. Erosion since Tertiary time has greatly dissected this peneplain, and the deepest stream valleys are now 350 feet below it.

Mineral resources.—The most valuable mineral resources of these quadrangles are clay, diamonds, and road material, all of which have been mined. Lead, zinc, and antimony minerals, asphalt, slate, gypsum, building stone, quartz crystals, and limestone for lime have also been mined at times.

Deposits of tripoli, pyrite, marcasite, fuller's earth, iron ore, and manganese ore have been explored.

Diamonds were discovered near Murfreesboro in 1906. Since then mining for diamonds has been carried on intermittently at several mines, and more than 10,000 stones have been recovered. The stones are mostly white, yellow, and brown and range in size from a small fraction of a carat to many carats. Some of them are so small that 250 of them would be required to weigh 1 carat. The largest weighed 40.23 carats. The diamonds are found, for the most part, in the soft weathered portions of the peridotite breccia that occurs in the several extinct volcanic necks near Murfreesboro.

Oil and gas have been prospected for in the Coastal Plain along the southern edge of the quadrangles, but thus far neither of these substances has been found in paying quantities. There is no possibility that either will be found in commercial quantities in the greatly deformed and metamorphosed Paleozoic rocks of the Ouachita Mountain region.

Forests.—The quadrangles have dense forests of yellow pine, oak, and other hard woods, and only a comparatively small proportion of their area has been cleared and put into cultivation. Much of the rugged mountainous region is included in the Ouachita National Forest.

GEOLOGY OF THE DE QUEEN AND CADDO GAP QUADRANGLES, ARKANSAS

By Hugh D. Miser and A. H. Purdue

PRESENT INVESTIGATION

The field study of the geology of the De Queen and Caddo Gap quadrangles extended over a period of many years, and although the scientific and economic results from the study are here set forth fully for the first time in a single report, a number of publications have been issued that have presented some of the more important results. These are listed below.

Purdue, A. H., A new discovery of peridotite in Arkansas: Econ. Geology, vol. 3, pp. 525–528, 1908.

Purdue, A. H., The slates of Arkansas, 95 pp., Arkansas Geol. Survey, 1909; U. S. Geol. Survey Bull. 430, pp. 317–334, 1910.

Purdue, A. H., Structure and stratigraphy of the Ouachita Ordovician area, Ark. [abstract]: Geol. Soc. America Bull., vol. 19, pp. 556–557, 1909.

Purdue, A. H., Recently discovered hot springs in Arkansas [Caddo Gap, Montgomery County, Ark.]: Jour. Geology, vol. 19, pp. 272–275, 1911.

Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: U. S. Geol. Survey Bull. 540, pp. 534–546, 1914.

Miser, H. D., Manganese deposits of the Caddo Gap and De Queen quadrangles, Ark.: U. S. Geol. Survey Bull. 660, pp. 59–122, 1917.

Miser, H. D., and Purdue, A. H., Gravel deposits of the Caddo Gap and De Queen quadrangles, Ark.: U. S. Geol. Survey Bull. 690, pp. 15–29, 1918.

Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas: U. S. Geol. Survey Bull. 691, pp. 271–292, 1918.

Miser, H. D., Mississippian tuff in the Ouachita Mountain region [abstract]: Geol. Soc. America Bull., vol. 31, pp. 125–126, 1920.

Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas: Am. Jour. Sci., 5th ser., vol. 2, pp. 61–89, 1921. Abstract, Geol. Soc. America Bull., vol. 32, pp. 40–41, 1921; Washington Acad. Sci. Jour., vol. 11, pp. 444–445, 1921.

Miser, H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Ark.: Econ. Geology, vol. 17, pp. 662–674, 1922; U. S. Geol. Survey Bull. 735, pp. 279–322, 1923; Smithsonian Inst. Ann. Rept. for 1923, pp. 261–272, 1925.

Miser, H. D., and Ross, C. S., Volcanic rocks in the Upper Cretaceous of southwestern Arkansas and southeastern Oklahoma: Am. Jour. Sci., 5th ser., vol. 9, pp. 113–126, 1925.

Miser, H. D., Lower Cretaceous (Comanche) rocks of southeastern Oklahoma and southwestern Arkansas: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 443-453, 1927.

Miser, H. D., and Honess, C. W., Age relations of the Carboniferous rocks of the Ouachita Mountains of Oklahoma and Arkansas: Oklahoma Geol. Survey Bull. 44, 1927.

Miser, H. D., Structure of the Ouachita Mountains of Arkansas and Oklahoma [abstract]: Washington Acad. Sci. Jour., vol. 18, pp. 266-267, 1928; Geol. Soc. America Bull., vol. 39, pp. 180-181, 1928.

Ross, C. S., Miser, H. D., and Stephenson, L. W., Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas: U. S. Geol. Survey Prof. Paper 154, pp. 175-202, 1929.

The field work was begun in 1907 and continued intermittently until 1925. The work in 1907 was done under a cooperative agreement between the United States Geological Survey and the Arkansas Geological Survey and involved primarily an investigation of the slate deposits of west-central Arkansas but also the mapping of the rocks in the mountainous part of the Caddo Gap quadrangle. In that year A. H. Purdue, State geologist of Arkansas, had charge of the work and was assisted by R. D. Mesler and H. D. Miser. All the subsequent work in the Caddo Gap quadrangle, as well as all in the De Queen quadrangle, was done by the United States Geological Survey. The work since 1907 is briefly outlined below. In 1908 Mr. Purdue, assisted by Mr. Miser, completed the mapping of the rocks of the Caddo Gap quadrangle with the aid of valuable suggestions from C. W. Hayes, chief geologist, J. A. Taff, and E. O. Ulrich, who visited the field for several days. In 1910 Mr. Purdue, assisted by Mr. Miser, reviewed a part of the previous work in the Caddo Gap quadrangle and mapped the rocks in most of the mountainous portion of the De Queen quadrangle. In 1911 these geologists did additional work in both the De Queen and Caddo Gap quadrangles, and in 1912 Mr. Miser, assisted by Mr. Mesler, completed the mapping of the rocks in the De Queen quadrangle and then reviewed some of the earlier work in the Caddo Gap quadrangle. In 1913 Arthur Keith, and Messrs. Purdue and Miser spent several days in a field conference in the Caddo Gap quadrangle. During the conference the first identifiable fossils in the Blaylock sandstone, of Silurian age, were discovered. In 1914 Mr. Miser obtained a small collection of fossil plants from the Stanley shale near Gillham, Ark., also the first fossils from the Arkansas novaculite. In 1916 he made a special study of some of the mineral deposits of the quadrangles, including the deposits of diamonds, manganese ore, gravel, and asphalt, and in 1917 he revisited the diamond mines. An investigation of the volcanic ash and tuff in the "Bingen formation," of Upper Cretaceous age, in the Caddo Gap quadrangle and adjoining areas to the south and southwest was made in 1923 by Clarence S. Ross and Mr. Miser.

Also in that year other fossil plants were collected from the Stanley shale at the earlier discovered locality near Gillham by Mr. Miser. (See pl. 9, *A*.) The aggregate time spent in collecting fossils at this locality was eight days, so scare are the fossils and so difficult are the conditions for collecting them. Besides the above work the authors made frequent reconnaissance studies of adjoining areas, and Mr. Miser was joined in 1923 by C. W. Honess for a field conference of a few days in the De Queen and Caddo Gap quadrangles. In 1925 Mr. Miser joined in the field Messrs. L. W. Stephenson and C. H. Dane for a few days in a study of the "Bingen" (Woodbine and Tokio) and other formations of Upper Cretaceous age in and near the Caddo Gap quadrangle. Mr. Dane was making at that time a special study of the deposits of Upper Cretaceous age in southwestern Arkansas under a cooperative agreement between the United States Geological Survey and the Arkansas Geological Survey. For some of the information on the Tokio formation the present writers are indebted to Mr. Dane.

Much of the writing for the present report was done by Mr. Purdue before his death in 1917, but all the office work on the report since that year has been done by Mr. Miser, with the exception of the chapter on the diamond-bearing peridotite, a large part of which was written by Mr. Ross, to whom the specimens of the peridotite were submitted for microscopic examination, and a part of the description of the volcanic tuff of the Woodbine formation, which also was written by Mr. Ross.

Numerous published papers dealing with the geology of the quadrangles and the surrounding region have been consulted during the preparation of the present report, and many of them are cited at appropriate places in the text. Special mention is here made of a recent valuable report by Honess,[1] which describes in detail the geology and mineral resources of northern McCurtain County, Okla., and parts of the adjoining counties.

That report gives for the first time a full description of an adjacent area whose rocks and complex geologic history are similar to those of the De Queen and Caddo Gap quadrangles. In fact a narrow strip of McCurtain County described by Honess is embraced in the De Queen quadrangle.

Fossils collected by the writers from the Ordovician, Silurian, and Devonian rocks have been studied and reported on by E. O. Ulrich; fossil plants from the Stanley shale (Carboniferous) have been identified by David White; fossil plants from the Woodbine and Tokio formations (Upper Cretaceous) have been reported upon by E. W. Berry; fossil invertebrates from the Trinity formation

[1] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, 1923.

(Lower Cretaceous) have been identified by T. W. Stanton; some fossil invertebrates from the Brownstown marl have been identified by L. W. Stephenson; and fragmentary unidentifiable invertebrate fossils from the Jackfork sandstone have been studied by G. H. Girty and Frank Springer, who have supplied statements concerning them.

LOCATION AND GENERAL RELATIONS

The De Queen and Caddo Gap quadrangles lie between parallels 34° and 34° 30′ north latitude and meridians 93° 30′ and 94° 30′

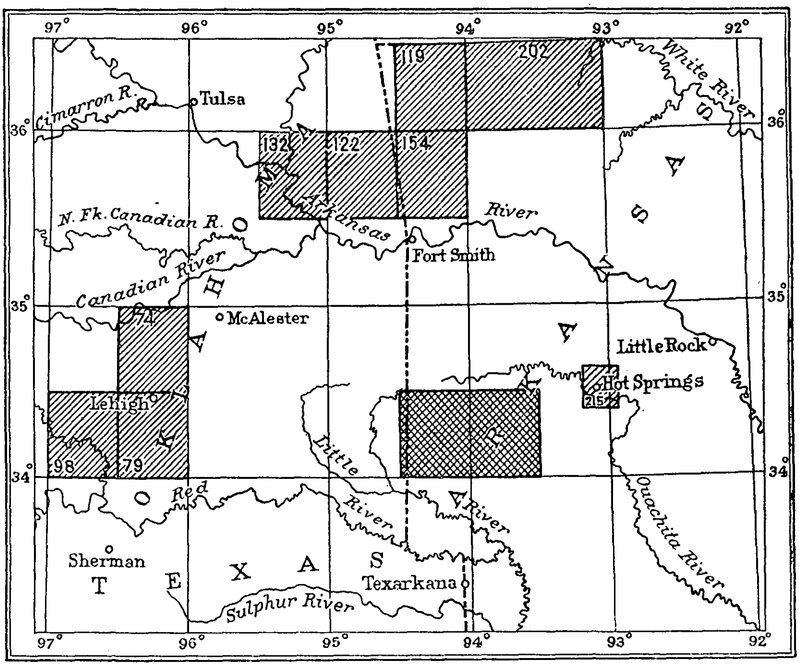
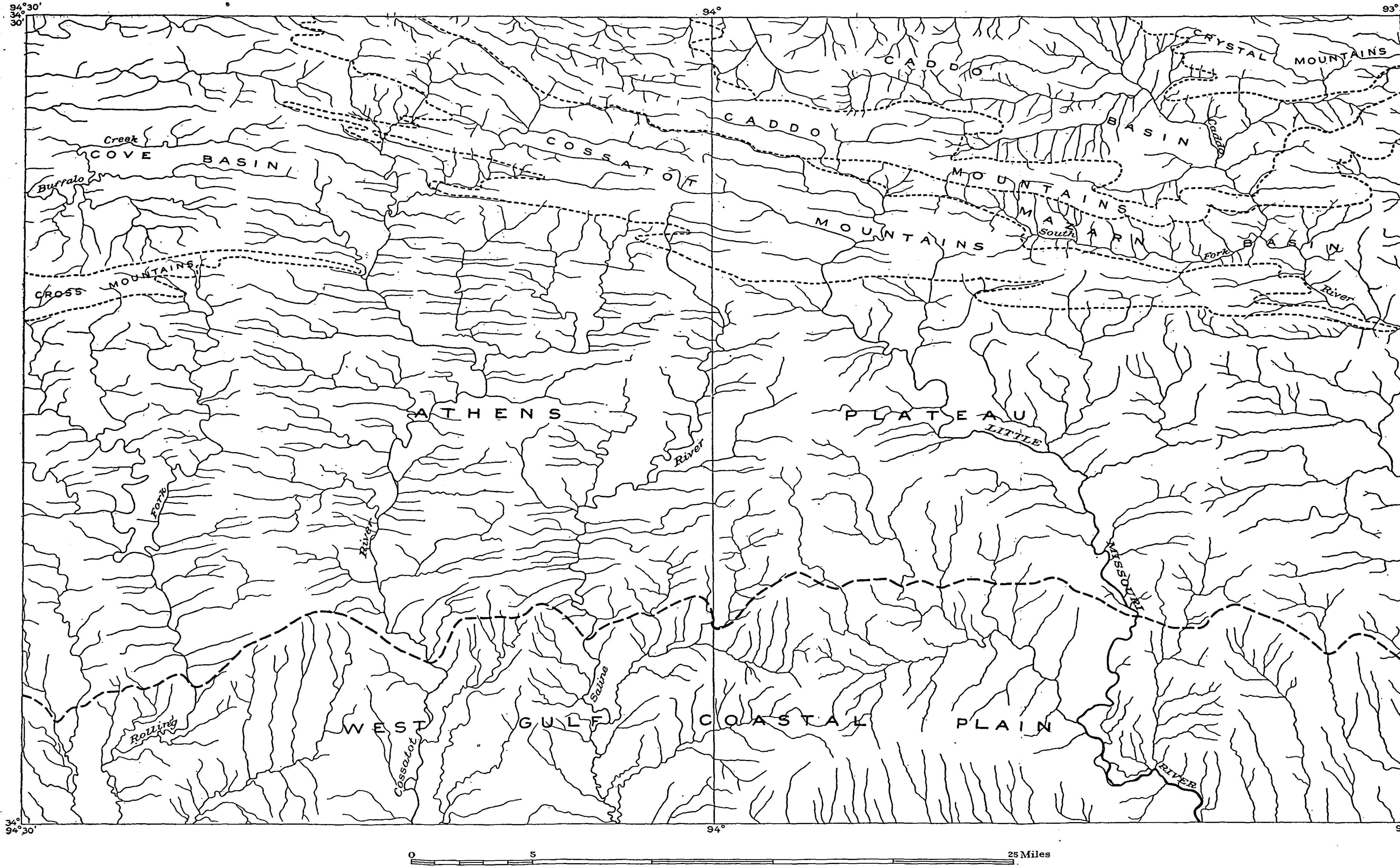


FIGURE 1.—Index map of southwestern Arkansas and parts of adjacent States. The area included in the De Queen and Caddo Gap quadrangles is shown by the darker ruling. Published folios of the Geologic Atlas that describe other areas, indicated by lighter ruling, are as follows: 74, Coalgate; 79, Atoka; 98, Tishomingo; 119, Fayetteville; 122, Tahlequah; 132, Muskogee; 154, Winslow; 202, Eureka Springs-Harrison; 215, Hot Springs

west longitude. Each comprises one-fourth of a "square degree" of the earth's surface, which in their latitude is an area of 986 square miles. The combined area of the two quadrangles is therefore 1,972 square miles. They include large parts of Pike, Polk, Sevier, Howard, and Montgomery Counties and very small strips of Clark and Hempstead Counties, in Arkansas, all of which lie in the southwest quarter of the State, and the De Queen quadrangle embraces on its west side a narrow strip of McCurtain County, in the southeast corner of Oklahoma. (See fig. 1.) The De Queen quadrangle re-



MAP SHOWING THE TOPOGRAPHIC DIVISIONS AND THE DRAINAGE PATTERN OF THE DE QUEEN AND CADDO GAP QUADRANGLES, ARKANSAS AND OKLAHOMA

The topographic divisions north of the West Gulf Coastal Plain form part of the Ouachita Mountain region. The streams in the Ouachita Moumtain region, especially those in the Athens Plateau, illustrate a trellis system. The streams in the West Gulf Coastal Plain illustrate consequent drainage ceives its name from the town of De Queen, in Sevier County, and the Caddo Gap quadrangle receives its name from the gap in the Caddo Mountains through which Caddo River runs.

The north three-fourths of the area is in the Ouachita Mountain region, and the south one-fourth is in the West Gulf Coastal Plain. The Ouachita Mountain region extends from Little Rock, Ark., to Atoka, Okla., a distance of 200 miles, its east half being in Arkansas and its west half in Oklahoma. Its width at most places is between 50 and 60 miles. A region that is less mountainous joins the Ouachita region on the north. As most of this region is a wide, comparatively

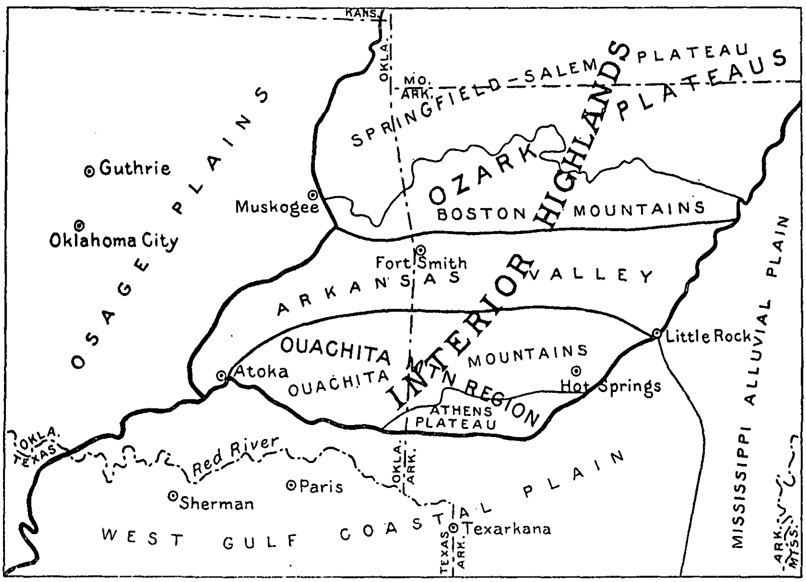


FIGURE 2.—Outline map of the Ouachita Mountain region, showing its relations to the surrounding regions

low valley, lying between the Boston Mountains of the Ozark Plateaus on the north and the Ouachita Mountains on the south, and as it is largely drained by Arkansas River, it is called the Arkansas Valley. On the south and east the Ouachita region is joined by a comparatively low, gently rolling plain, which extends southward to the Gulf of Mexico and is called the West Gulf Coastal Plain.

In their geology and physiographic history the Ouachita Mountain region and the Arkansas Valley are much the same, but they differ markedly from the Ozark Plateaus on the one hand and the West Gulf Coastal Plain on the other. The location of these and other near-by physiographic regions is shown in Figure 2. Figure 3 is a generalized map of the rocks exposed.

GENERAL GEOGRAPHY AND GEOLOGY OF THE OUACHITA MOUNTAIN REGION

SURFACE FEATURES

The Ouachita Mountain region consists of a mountainous area known as the Ouachita Mountains and of a dissected piedmont plateau, known as the Athens Plateau, which lies along their southern

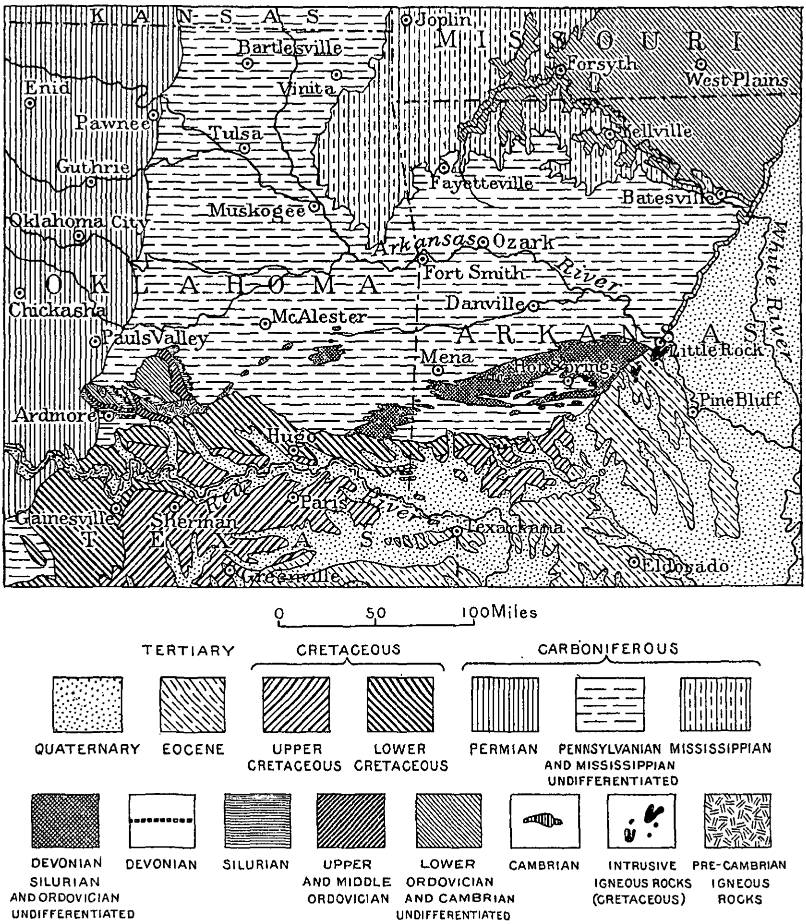


FIGURE 3.—Geologic map of parts of Arkansas, Oklahoma, and adjoining States

border. The term "Ouachita Mountain system" was first applied by J. C. Branner [2] to the east-west ridges that contain the novaculites, or Arkansas whetstone rocks, but in recent years the term has been extended so as to include not only these ridges but also a mountainous belt to the north of them and the Athens Plateau to the

[2] Comstock, T. B., Report on Preliminary Examination of the Geology of Western Central Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 1, p. 59, 1888. Hill, R. T., The Neozoic Geology of Southwestern Arkansas: Idem, vol. 2, pp. 10, 175, 1888.

south of them. The mountains in this region were earlier called by William Darby the "Masserne Mountains,"[3] and this name was used later by Thomas Nuttall,[4] although he spelled it "Mazern."

The Ouachita Mountains comprise many nearly east-west ridges and several intermontane basins. The ridges are narrow and have steep slopes and sharp, straight, even crests. Just west of Little Rock and east of Atoka they are low, scarcely exceeding 750 feet above sea level, or 250 feet above the valleys, but they gradually increase in height westward from Little Rock and eastward from Atoka, and the culminating point is reached in eastern Oklahoma near the Arkansas-Oklahoma line, where the highest point—the west end of Rich Mountain—is between 2,850 and 2,900 feet above sea level. In this part of Oklahoma and the adjoining part of Arkansas the ridges stand about 1,750 feet above the valleys. Some of the principal masses are Jackfork, Windingstair, Buffalo, Seven Devils, and Kiamichi Mountains, in Oklahoma; Rich, Black Fork, and Cross Mountains, in Oklahoma and Arkansas; and Dutch Creek, Irons Fork, Blue, White Oak, Danville, Fourche, Crystal, Trap, and Zigzag Mountains, in Arkansas. Some of these masses are single ridges, and some are small ranges.

The intermontane basins lie mostly in Arkansas but partly in eastern Oklahoma. They are wide valley areas whose upland surfaces range from about 500 to 1,200 feet above sea level, with the height increasing from east to west, and they are channeled by many narrow valleys, which are in most places less than 250 feet below the general level represented by the upland surface. Mena, Ark., north of the De Queen quadrangle; Mount Ida, Ark., north of the Caddo Gap quadrangle; and the southern part of the city of Hot Springs are situated in such basins. Parts of three basins are included in the Caddo Gap and De Queen quadrangles.

The Athens Plateau is a belt of country about 15 miles wide which lies between the mountains of the Ouachita region on the north and the West Gulf Coastal Plain on the south and extends from a point near Arkadelphia, Clark County, Ark., westward across the central part of the Caddo Gap and De Queen quadrangles into Oklahoma, where it ends several miles west of the State line. It takes its name from Athens, in the Caddo Gap quadrangle. When the plateau is viewed from the crests of the mountains on the north it appears to be a practically level plain ending abruptly against the mountains, but when it is crossed very little level country is found; most of it is greatly dissected by narrow, crooked valleys of

[3] Darby, William, The Emigrant's Guide to the Western and Southwestern States and Territories, p. 138, New York, 1818.

[4] Nuttall, Thomas, A Journal of Travels into the Arkansa [sic] Territory during the Year 1819, pp. 110, 121, 148, 152, Philadelphia, 1821.

southward-flowing trunk streams and by many east-west valleys of small tributary streams, which are 350 feet or less below the upland surface. The interstream areas are therefore low east-west, rather even crested ridges. The upland surface of this plateau, formed by the crests of these ridges, ranges from 400 to 1,100 feet above sea level and is lowest at its east end and on its south side and highest on the north side.

DRAINAGE

The northern part of the Ouachita Mountain region is drained by Arkansas River and its tributaries, and the southern part by Red River and its tributaries. The waters of both these streams reach the Gulf by way of the Mississippi. Among the tributaries of Arkansas River that drain the Ouachita Mountain region are Poteau River, in Arkansas and Oklahoma, and Petit Jean Creek and Fourche la Fave River, in Arkansas. Among the streams of the Ouachita region whose waters empty into Red River are Boggy Creek, Kiamichi River, and Glover Creek, in Oklahoma; Little River and Mountain Fork River, in Arkansas and Oklahoma; and Rolling Fork, Cossatot River, Little Missouri River, Caddo River, Ouachita River, and Saline River, in Arkansas. The largest of these streams is Ouachita River, which rises in the western border of Arkansas and flows south of east nearly to the east end of the Ouachita Mountains and thence southeastward across the southern part of the State into Louisiana, where it joins Red River.

The position of the streams in much of the Ouachita Mountain region is dependent on the geologic structure. In general, they flow in courses which for rather long distances are parallel with the ridges bounding the valleys, but many streams in all parts of the province have cut their courses transverse to those of the ridges. In fact, the transverse courses of the large streams and of many of the smaller streams on the southern slope of the province are a conspicuous and rather characteristic feature of the drainage. The trend of most of the ridges is approximately east, whereas Mountain Fork River, Rolling Fork, Cossatot River, Little Missouri River, and some minor streams flow southward, cutting through the ridges in narrow water gaps, some of which are picturesque.

CLIMATE AND VEGETATION

The climate of the region on the whole is mild. It is free from extreme cold in winter but at times suffers intense heat in summer. The rainfall is abundant and commonly reaches a maximum in late spring or early summer and decreases to a minimum in late summer or early fall, when there are occasional droughts. In consequence of its abundant rainfall and its altitude, the region is being reduced by erosion, but it is only at times of heavy rains that the streams carry considerable quantities of detrital material. The precipitation, in spite of the rather poor soil, is sufficient to produce a heavy forest cover over the entire area. Trees are of great variety, but white oak and a yellow or shortleaf pine are the most abundant, the pine predominating. Both grow on the ridges as well as over the less elevated areas. On the ridges the pines are more numerous on the southern slopes than on the northern. Large areas of the forest are virgin and extensive tracts are included in the Ouachita National Forest, formerly called the Arkansas National Forest.

Only a small part of the region has been deforested and put under cultivation, most of the remainder being unfit for farming. Part of the cultivated land is on the uplands, where nearly all the soil is poor, and the rest is on some of the main streams, where the soil as a rule is deep and of good quality. The agricultural lands are suited for general farming, stock raising, and fruit growing.

STRATIGRAPHY

The rocks of the Ouachita Mountain region are nearly all of sedimentary origin, but in its eastern part there are two small areas of igneous rocks accompanied by dikes, one at Magnet Cove, Hot Spring County, and the other at Potash Sulphur Springs, Garland County, Ark.

The sedimentary rocks comprise shale, sandstone, chert, novaculite, tuff, limestone, and conglomerate, the most abundant being named first. Except for their induration into hard rocks they have been only slightly affected by metamorphism, but this process has changed some of the shale to slate and certain beds of sandstone to quartzite. Estimates of the exposed rocks in this region and in the Arkansas Valley indicate an aggregate thickness of about 30,000 feet.

The rocks in the Ouachita region range in age from Cambrian to Pennsylvanian. The rocks of the earlier periods are exposed in several belts. (See fig. 3.) The largest belt extends west by south from Little Rock nearly to the western border of Arkansas. The next largest is mainly in McCurtain County, Okla., though its east end reaches into Arkansas. In general, the oldest strata are exposed near the central portions of these belts and the later formations crop out to the north and south, but on account of the deformation of the strata and the relief of the surface much repetition of older and younger beds occurs in any north-south section across the country.

Many geologic epochs are not represented by rock strata, and no epoch is represented by formations that underlie the whole province, for there have been frequent oscillations, which caused many alternations of deposition and erosion, and some of these changes involved the entire region. As a whole, however, the area now comprised in the Ouachita Mountain region and the Arkansas Valley was a subsiding trough (geosyncline) from Cambrian time nearly to the end of Carboniferous time, when it was deformed and uplifted, and most of it was permanently added to the land. This trough apparently stretched along the northern border of a Paleozoic land area, known as Llanoris, which lay farther south, in Louisiana and eastern Texas, and which is now concealed by Cretaceous and younger rocks. It is believed that most of the enormous amount of detrital material laid down in the Ouachita trough was derived from this land area.

The rocks assigned to the Cambrian system consist chiefly of unfossiliferous, highly crumpled shale, whose only known exposures are in a narrow belt lying between Black Springs and Mount Ida, Montgomery County, Ark.

The Ordovician rocks are best exposed in Arkansas and in McCurtain County, Okla. They consist mainly of shale, with a chert, the Bigfork, near the top, and include two sandstones, the Crystal Mountain and the Blakely. The Crystal Mountain sandstone is at the base of the Ordovician system and is only provisionally assigned to this system, as it has not yielded any fossils. The known aggregate thicknesses of the strata reach 4,450 feet. Graptolites whose remains are preserved in the black shale are the only abundant fossils.

The Silurian system is represented by the Blaylock sandstone and the Missouri Mountain slate, which range in thickness from 50 to 1,800 feet. The Blaylock has yielded a single collection of graptolites.

The Devonian system is represented by the Arkansas novaculite. This formation is thickest in Arkansas and in McCurtain County, Okla., where its known thickness reaches 950 feet. It thins to the north and in places in Arkansas is absent. The only fossils that have been found in the formation came from the middle and upper parts. They consist of conodonts, sporangites, and linguloids, which were collected at Caddo Gap, Ark., and silicified wood, found at Glenwood and Rosboro, Ark. There is a possibility that the uppermost part of the formation may be of Carboniferous age.

The Mississippian series consists of 13,000 to 17,000 feet of sandstone and shale, with a small amount of tuff near the base. Northward in the region the sandstone beds become thinner and the relative amounts of shale increase, thereby indicating that the old land area (Llanoris) to the south was the source of much of the clastic material composing these rocks.

The Pennsylvanian series in the Ouachita Mountain region and the Arkansas Valley is made up largely of shale but includes much sandstone and small amounts of limestone and chert, and in the Arkansas Valley it contains minable coal beds. The aggregate maximum thickness of these sediments, most of which occur only in the Arkansas Valley, approximates 16,000 feet.

The rocks of igneous origin consist of masses of nephelite syenite and related types, which were intruded upward into the sedimentary strata probably early in the Upper Cretaceous epoch.

STRUCTURE

The sedimentary rocks in the Ouachita Mountain region have been subjected to intense lateral compression, which besides lifting the area above the sea, has produced east-west folds in the strata, so that their edges, exposed by erosion, now appear at the surface.

The major structural feature is a pronounced anticline, whose axis extends from a point a few miles southwest of Little Rock, Ark., west by south to the vicinity of Glover, Okla. (See fig. 3.) Its east and west ends are concealed by overlaps of the deposits of the Coastal Plain—the east end by rocks of Cretaceous, Tertiary, and Quaternary age, and the west end by Cretaceous and Quaternary rocks. A low place in this anticline near the Arkansas-Oklahoma line divides it into two parts. The eastern part is known as the Ouachita anticline. Each of these parts is composed of numerous minor folds, and each is therefore really an anticlinorium.

The quadrangles herein described include parts of both these anticlinoria. The Ouachita anticline consists of four prominent subdivisions—three anticlines and a syncline. The syncline, named the Mazarn syncline by L. S. Griswold from the fact that it includes the Mazarn Basin, extends from Fancy Hill post office, in the Caddo Gap quadrangle, eastward to Cove Creek station, in Hot Spring County, beyond this quadrangle. Lying north of the Mazarn syncline and extending throughout the length of the Ouachita anticline is the Crystal Mountain anticline, in which the oldest rocks of the region are exposed. The other two anticlines lie south of the Mazarn syncline, one at each end. The western one is known as the Cossatot anticline and includes the area occupied by the Cossatot Mountains, which extend westward from Glenwood, in the Caddo Gap quadrangle, to the place where they merge with the ridges north of the Mazarn Basin near Fancy Hill. The eastern one is known as the Trap Mountain anticline; it includes the area occupied by the Trap Mountains, which extend eastward from Elm post office, Clark County (east of the Caddo Gap quadrangle), to the vicinity of Malvern. The Crystal Mountain anticline, as defined by the authors of this report, is the same as the Ouachita anticline of Griswold,[5] and the term Ouachita anticline is redefined by them so as to include the Trap Mountain and Cossatot anticlines.

None of these or any other of the major folds are simple units, but each consists of smaller folds overlapping one another lengthwise. The folds, besides being closely compressed, are in many places overturned, some northward and some southward. The overturning has caused the rocks on both sides of the structural axis to dip in the same direction, but as the Arkansas Valley is approached the folds become flatter and are not overturned, and the rocks dip in both directions. A marked structural feature is the overturning of the folds on each side toward the Mazarn syncline, so that northward dips are most numerous north of it, and southward dips south of it. Not uncommonly adjacent folds are nearly equal in height, and the same beds appear and reappear at the surface. Over much of the Ouachita region most of the beds dip at angles of 40° or more. Generally the folds are smallest, most numerous, and most closely squeezed in thin-bedded rocks, such as shale and thin-bedded sandstone and chert.

Faults are numerous in Oklahoma, though they are not as numerous in Arkansas as might be expected in rocks that have been so intensely folded. Faulting in Arkansas has been limited by the presence of great thicknesses of shale distributed throughout the folded strata, which has permitted the beds to adjust themselves to the crustal shortening through shearing and crumpling of the thin-bedded rocks. Most of the faults are parallel with the folds and are thrust faults. Many of them were produced by the breaking of the strata in closely compressed anticlines. (See pl. 16 and fig. 6.) Some faults appear on the south side of anticlines and others on the north sides; consequently some of the fault planes dip to the north and others to the south. Of the several major faults in Oklahoma, the two longest, the Choctaw and Windingstair, reach into Arkansas. They are 125 and 110 miles in length, respectively. The discovery by Mr. Miser in 1927 of a window through an overthrust mass in the Potato Hills, west of Talihina, Okla., indicates the presence of folded thrust planes in the Ouachita Mountains. All the major faults in that State are interpreted as having low-angle thrust planes that have southerly dips.

GENERAL GEOGRAPHY AND GEOLOGY OF THE ARKANSAS VALLEY

The Arkansas Valley throughout most of its length is a synclinal trough from 30 to 40 miles wide, which extends nearly east and west,

[5] Griswold, L. S., Whetstones and the Novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, p. 210, 1892.

though its west end has a southwestward trend. On the west and southwest this valley blends with the Osage Plains, the Arbuckle Mountains, and the West Gulf Coastal Plain; on the east it passes into the Mississippi Alluvial Plain; on the south it merges into the Ouachita Mountains; and on the north it is joined by the foothills of the Boston Mountains, which form the southern limit of the Ozark Plateaus. This trough has been reduced by erosion to a plain having an average altitude of about 500 feet above sea level. Upon this plain stand Sansbois, Cavanal, Poteau, Sugarloaf, Magazine, Petit Jean, and Huckleberry Mountains, Mount Nebo, and other elevations of less prominence, besides a great number of ridges, hills, and nearly level highlands, most of which have an east-west trend. The highest of these mountains is Magazine Mountain, whose summit stands 2,823 feet above sea level. Many of the prominences, including those just named, present the appearance of buttes.

The principal stream is Arkansas River, which with its tributaries forms a network of broad alluvial valleys, whose general course is eastward, parallel with that of the trough. The rocks in this valley, practically all of which are of Pennsylvanian age, form a rather monotonous sequence of sandstone and shale that contain beds of coal over much of the area. As above stated, the strata have been folded, though less than those in the Ouachita area. The anticlines are generally narrower and steeper than the synclines; there is a tendency to overturning toward the north; and the folds decrease in intensity northward. In parts of Oklahoma, as the folds die out they blend into a slightly variable monoclinal structure, with a persistent though low inclination toward the northwest; whereas in Arkansas and the adjoining part of Oklahoma, as the local folding ceases the rocks rise toward the north in the southern monoclinal slope of the Boston Mountains. The structure bears a close relation to the topography, the long, narrow ridges indicating moderately to highly inclined rocks, and the buttelike mountains indicating practically horizontal rocks in synclinal basins.

GENERAL GEOGRAPHY AND GEOLOGY OF THE GULF COASTAL PLAIN

The Gulf Coastal Plain is continuous with the Atlantic Coastal Plain and comprises a great area of lowland, which borders the Gulf of Mexico from the Florida Peninsula west and south into Mexico and extends inland in the middle Mississippi Valley region to the uplands of the Ouachita, Arkansas Valley, Ozark, and Appalachian provinces, its northern limit in this region being approximately the mouth of Ohio River. This plain on the whole slopes regularly toward the Gulf from altitudes of more than 1,000 feet at its inner margin to sea level along the coast. It is dissected by shallow valleys having broad flood plains and commonly one or more low terraces.

The slope continues beneath the Gulf to the edge of the continental shelf, about 100 miles from shore and 200 to 400 feet below sea level. The Gulf Coastal Plain comprises several subdivisions, but only one of these—the West Gulf Coastal Plain—is adjacent to the Ouachita Mountain region.

The materials that underlie the Gulf Coastal Plain are chiefly gravel, sand, and clay of Cretaceous, Tertiary, and Quaternary age, deposited upon a submerged floor of Paleozoic and probably pre-Paleozoic rocks which had been deformed and rather uniformly reduced approximately to base-level. Most of these rocks are of marine origin and show that in comparatively recent geologic time the Gulf occupied this area and extended to the mouth of Ohio River. The post-Paleozoic strata now lie nearly parallel to the general surface, but have a somewhat greater slope Gulfward, so that the older formations crop out nearer the inner margin, and progressively younger ones appear in crescentic bands nearer the coast.

GEOGRAPHY

SURFACE FEATURES

The northern three-fourths of the Caddo Gap and De Queen quadrangles lies in the southern part of the Ouachita Mountain region, and the remainder, a narrow belt along their southern border, lies in the northern edge of the West Gulf Coastal Plain. The part of the quadrangles that is in the Ouachita Mountain region embraces much of the Athens Plateau, which is a piedmont belt extending westward completely across the middle of the quadrangles, and this part also includes some of the Ouachita Mountains proper, which are composed of groups of high ridges and intermontane basins. (See pl. 1.)

The high ridges are narrow and nearly parallel, trending in general east and south of east, and most of them are 1,500 to 2,000 feet above sea level. They are separated by narrow valleys that trend in most places parallel with the ridges but in others cut through them in gorges called water gaps. These ridges have steep rugged slopes and sharp even crests, above which rise a great many peaks a few hundred feet higher. The upland surface of the Athens Plateau and the intermontane basins lies mainly between 750 and 1,100 feet above sea level, but has been much dissected by V-shaped valleys. Many of the valleys are parallel and have a general east-west trend; others have crooked transverse courses; consequently the interstream areas consist of both parallel ridges and irregular-shaped hills. The part of the West Gulf Coastal Plain embraced in these quadrangles is extensively dissected, though most of its surface is very gently undulating. The surface of the quadrangles is therefore rough in most places and contains only small tracts of level land.

The highest point in the quadrangles is Raspberry Peak, in the De Queen quadrangle, which rises 2,360 feet above sea level. The lowest point is slightly less than 300 feet above sea level and is on Rolling Fork a few miles southwest of De Queen.

The Ouachita Mountains stand up in striking contrast with the remainder of the quadrangles and are thus their most conspicuous physiographic division. Though much of this area is a rugged mountainous country consisting of groups of high ridges, a considerable portion is occupied by intermontane basins. The groups of ridges that are partly or entirely embraced in the quadrangles are the Crystal, Caddo, Cossatot, and Cross Mountains, and the basins are the Caddo, Mazarn, and Cove. (See pl. 1.)

A small portion of the Crystal Mountains, a narrow chain of ridges extending from the west side of Montgomery County, Ark., north of east into Saline County, a distance of about 60 miles, is embraced in the northeast corner of the Caddo Gap quadrangle. They were named from the abundance of magnificent quartz crystals found in the hard sandstone that forms the ridges. (See pl. 17, *B*.) This part of the mountains consists of several short eastward-trending ridges with steep slopes, whose crests have numerous peaks. The highest of the peaks is High Peak, 1,834 feet above sea level. These mountains are traversed by the headwaters of Collier Creek, along which there is some of the most rugged topography in the Ouachita Mountains.

Lying south of the Caddo Basin and the Crystal Mountains and north of the Mazarn Basin is a narrow chain of ridges which form the west end of a group extending eastward to Ouachita River near Hawes post office, in Montgomery County, named by Griswold[6] the Caddo Range or Mountains. These mountains extend westward across the Caddo Gap quadrangle into the De Queen quadrangle, where they merge with a group on the south known as the Cossatot Mountains. The largest mountains of this chain are the Caddo Mountains proper and the Missouri Mountains. Much of the western part of the Missouri Mountains is a single ridge, but the eastern part is broken up into several rather distinct ridges, closely associated with which is Statehouse Mountain. The highest point in the Caddo Mountains is an unnamed peak, 2,212 feet above sea level, half a mile southwest of Slatington, and there are several other peaks of little less altitude, among which are Hurricane Knob and Round, Lost, and Fork Mountains. The western part of the Caddo Mountains proper is a ridge that is imperfectly divided into north and south ridges by longitudinal valleys; the middle part of these mountains takes a zigzag course; and the eastern part consists of five rather distinct ridges, upon which are several peaks, including Nel-

[6] Griswold, L. S., op. cit.

son, Strawn, White, and Sharptop Mountains. Fodderstack Mountain (one of the three of that name in these two quadrangles), an outlier of the Caddo Mountains, stands as a conspicuous feature in the southern part of the Caddo Basin.

The quadrangles embrace practically the entire group of ridges to which the name Cossatot Mountains is applied. This group extends south of east across the northeast corner of the De Queen quadrangle, where it joins the Caddo Mountains, and across the northern part of the Caddo Gap quadrangle, in which it contracts eastward and terminates near the east boundary. Many of the ridges slope down into the Cove Basin on the west, others into the Athens Plateau on the south, and still others into the Mazarn Basin on the north. The middle and western portions of the Cossatot Mountains are the highest and most rugged, consisting of a considerable number of ridges and several more or less isolated mountains, many of which rise more than 2,000 feet above sea level. Among the most prominent peaks that exceed this altitude are Eagle, Fodderstack, West Hanna, East Hanna, Nichols, Katy, and Buckeye Mountains and Tall Peak, in the De Queen quadrangle; Sugartree, Brushheap, and Fodderstack Mountains, in the Caddo Gap quadrangle; and McKinley Mountain and Raspberry Peak, lying partly in both quadrangles. Raspberry Peak, the highest of these, is 2,360 feet above sea level.

The ridges of the Caddo and Cossatot Mountains decrease in width and height toward the north in the De Queen quadrangle. This is due to the northward thinning of the basal, massive part of the Arkansas novaculite, which usually forms their crests.

The Cross Mountains, in the western part of the De Queen quadrangle, are the east end of a prominent group of mountains, the greater part of which is included within the Lukfata quadrangle. They consist of a few eastward-trending ridges, which in the De Queen quadrangle overlook the Cove Basin on the north and terminate on the east in the Athens Plateau. The northernmost ridges extend farthest east, whereas Sam Williams Mountain and other near-by mountains do not reach the Oklahoma-Arkansas line. Whisky Peak, their highest point, is 1,680 feet above sea level.

The topography of all parts of the Cross, Caddo, and Cossatot Mountains is of much the same type, but that of the Crystal Mountains is somewhat different, as the ridges of the Crystal Mountains are more massive, the slopes less uniform, and the crests not so sharp.

The greater portion of the Caddo Basin is in the Caddo Gap quadrangle and is limited on the east by the Crystal Mountains and on the south by the Caddo Mountains. Near the Caddo Mountains it exhibits a foothill topography consisting of low ridges upon which there are many dome-shaped knobs, the slopes of both knobs and ridges being steep and thickly covered with rock débris. Farther north the topography of the basin is gently rolling, the interstream areas are irregular, with the exception of a few short ridges, and the general surface ranges from 700 to 900 feet above sea level.

The comparatively wide valley between the Caddo and Cossatot Mountains in the Caddo Gap quadrangle is the west end of the Mazarn Basin, a large part of which is situated in Montgomery and Garland Counties, Ark., east of the quadrangle. With the exception of a single low ridge on the east border northeast of Glenwood, the topography of the part of the basin embraced in the quadrangle is gently rolling. The interstream areas are irregular in form, and the usual altitudes are between 500 and 1,000 feet above sea level, being highest to the west.

Much of the southeastern part of the Cove Basin lies in the northwest corner of the De Queen quadrangle, and in it are situated the villages of Hatfield, Cove, and Vandervoort. The basin takes its name from Cove. This part of the basin is bordered on the south by the Cross Mountains and on the east by the Cossatot Mountains and Athens Plateau. It is dissected by many valleys. The interstream areas consist in part of irregular hills but mainly of flat, low ridges with an eastward trend. The crests of the hills and ridges reach a common level, which ranges from 1,100 to 1,250 feet above sea level.

The Athens Plateau lies mostly in the quadrangles herein described. It is dissected by several narrow, crooked valleys of southward-flowing trunk streams and by numerous east-west valleys of small tributary streams. The interstream areas are eastward-trending ridges, of which the broadest and most prominent are in the Caddo Gap quadrangle. Water gaps are common, but they are less conspicuous than in the mountainous area because the ridges are not so high. The upland surface of this area ranges from 750 to 1,100 feet above sea level, being highest at the north, and the valleys of the larger streams that trench it are about 350 feet deep. The plateau is more fully described on pages 7–8.

The part of the West Gulf Coastal Plain that is included in the quadrangles extends along their southern boundary and ranges from 5 to 10 miles in width. The difference between the topography of this belt and that of the Athens Plateau is striking. This part of the quadrangles has a gently undulating surface consisting of shallow valleys, of rather wide alluvial bottoms bordered by remnants of terraces along the larger streams, and of hilly, irregular interstream areas. Most of this area is between 400 and 600 feet above sea level. In the Caddo Gap quadrangle there is a southward-sloping plateau-like area or cuesta, which is best preserved from erosion between Murfreesboro and the southwest corner of the quadrangle, where most of its surface is from 500 to 700 feet above sea level; but southeast of Murfreesboro the streams that formerly flowed down its southern slope have cut its surface into north-south ridges. This plateau extends westward across the extreme southeast corner of the De Queen quadrangle and continues farther west just south of that quadrangle. The plateau is formed by resistant southward-dipping gravel beds of Cretaceous age and is what Veatch[7] describes as the Lockesburg Wold.

The character of the surface differs greatly in the different parts of the quadrangles. The basin areas, the Athens Plateau, and the West Gulf Coastal Plain are nearly everywhere gently rolling, though there are many steep hill slopes, and a few low cliffs rise from the streams, most of them standing on the outside of the stream bends. The level tracts and the more gentle slopes are mantled with residual soil or wash from the higher ground. Rock outcrops are common and are especially abundant on the steeper slopes, in road cuts, and in stream beds.

In the mountainous areas the surface is very rough, the slopes are steep, and rock ledges are numerous. There are, however, no large surfaces of bare rock except along the crests of some of the higher ridges and in the water gaps, and there are not many cliffs. One of the best-known ledges of rock in west-central Arkansas is Standing Rock, which is on Board Camp Creek, in the De Queen quadrangle. This rock is formed by a vertical bed of the Arkansas novaculite 3 to 6 feet thick and rises like a wall of masonry to a height of 75 feet above the creek. (See pl. 2.) The slopes, where not occupied by bare ledges, are covered by talus, much of which consists of boulders. This material collects in large quantities on the slopes, but the most favorable places are the heads of steep-sided ravines, where the loose rock forms barren talus slopes.

DRAINAGE

Nearly all the drainage of the Caddo Gap and De Queen quadrangles flows southward into Ouachita and Little Rivers, which, in turn, empty into Red River, Little River entering it in Arkansas, and the Ouachita entering it near its mouth in Louisiana.

The principal streams in the Caddo Gap quadrangle are Caddo and Little Missouri Rivers, both of which join Ouachita River. Of these two Little Missouri River is the larger. It rises south of the Missouri Mountains, takes a southward course, and after passing through the Cossatot Mountains, across the Athens Plateau, and into the Coastal Plain leaves the quadrangle on the south side. It receives many small tributaries, among which are Long, Blaylock, and Hurricane Creeks and Muddy Fork, from the west; and Blocker,

[7] Veatch, A. C., Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas: U. S. Geol. Survey Prof. Paper 46, 1906.

Self, Bear, and Prairie Creeks, from the east. Caddo River rises north of the Missouri Mountains, runs eastward and southeastward, passing through the Caddo Basin, the Caddo Mountains, and Mazarn Basin, in the order named, and leaves the quadrangle at the east end of the Cossatot Mountains. Its principal western tributaries are Polk and Mill Creeks and South Fork and its eastern branches are Lick and Collier Creeks. The upper 12 miles of the stream runs parallel with the ridges, and the remainder runs transverse to them, but the only notable water gap formed is Caddo Gap, where the stream passes through Caddo Mountains. This is one of the most conspicuous and probably the best-known water gap in the Ouachita area, and from it the Caddo Gap quadrangle derives its name. Big Fork Creek, in the northwestern part of the quadrangle, flows northward into Ouachita River; Mazarn Creek, in the northeast corner, flows eastward and joins the same river; Antoine Creek, which heads in the eastern part of the quadrangle, receives the waters of Bigsby, Woodall, Caney, and Wolf Creeks and joins Little Missouri River south of the quadrangle; Simpkins, Saline, Vaughn, and Clear Creeks, in the southeast corner, also empty into Little Missouri River; and Brushy, Holly, Messer, and other small creeks in the western part of the quadrangle, as well as most of the southward-flowing streams that drain the plateau southwest of Murfreesboro, join Saline River.

The larger streams in the De Queen quadrangle are Saline River, Cossatot River, Rolling Fork, and Mountain Fork of Little River, which join Little River farther south. Saline River rises in the Cossatot Mountains and after flowing southward across the Athens Plateau and into the Coastal Plain leaves the quadrangle on the south side. Between 2 and 3 miles of its upper course lies in the Caddo Gap quadrangle. Among its tributaries are Brushy, Caney, Holly, and Messer Creeks from the east, and Camp, Snake, Panther, and Shepherd Creeks from the west. Cossatot River heads in the mountains in the northeast corner of the quadrangle, finds its way through the Cossatot Mountains by passing through several deep-cut water gaps, and flows southward across the Athens Plateau and into the Coastal Plain, receiving in its course Mine, Sugar, Caney, Harris, and Hale Creeks and other small streams from the east and Brushy, Flat, Cow, Opossum, Coon, and Buck Creeks and other small streams from the west. Rolling Fork rises in the east end of the Cross Mountains, flows southward, passing across the Athens Plateau and into the Coastal Plain, and leaves the quadrangle on the south side, after receiving Robinson Creek and smaller streams. It is joined outside the quadrangle by Bear and Rock Creeks, which drain a part of the southwest corner of the area. Mountain Fork of Little River runs south of west through the extreme northwest corner of the quadrangle. Its tributaries, whose courses lie partly i the quadrangle, are Twomile, Joshling, Sixmile, Dry, and Buffal Creeks. They drain most of the part of Cove Basin embraced in th area. Board Camp Creek, with its tributary, Macks Creek, drains small part of the mountainous region in the northeast corner of th quadrangle and enters Ouachita River on the north.

An interesting feature of the topography of the mountainous are is the great number of water gaps formed by Caddo, Little Missouri and Cossatot Rivers and smaller streams. The Little Missouri flows through no less than seven and the Cossatot no less than five; there are at least 17 in the Caddo Gap quadrangle and 20 in the De Queen quadrangle. Most of these gaps are rocky, narrow gorges through the ridges, with only room enough beside the streams for trails.

In much of the Athens Plateau and the Ouachita Mountains the streams might well be divided into two classes—those whose courses run parallel with the ridges and those that flow across the trend of the ridges. The latter class includes the trunk streams, which are joined almost at right angles by many of their tributaries. This arrangement of the streams, which is illustrated in Plate 1, is commonly known as the "trellis" system of drainage. This type of drainage is the result of the partial adjustment of an ancient drainage to the structure of the rocks, the trunk streams having intrenched their courses across the strike of the rocks, and many of their tributaries having cut their valleys wholly in the more easily eroded strata. The streams in the West Gulf Coastal Plain illustrate a consequent drainage, as they have a general southward course that is the same as the dip of the rock formations. (See pl. 1.)

Most of the streams are perennial and are supplied with water from springs in all parts of the area. They can be easily forded throughout much of the year but are subject to sudden rises after heavy rains.

In the Athens Plateau and the Ouachita Mountains the streams are rather swift, forming numerous riffles and rapids separated by quiet reaches, and flow in narrow valleys containing only small strips of flood-plain deposits; but on reaching the Coastal Plain the streams become sluggish and the valleys widen and contain considerable areas of alluvial deposits. The rapids are found in many of the water gaps. In some water gaps there are low waterfalls, noteworthy among which is that of Little Missouri River just north of the Montgomery-Pike County line, that of the same stream just west of Round Mountain, and that of Cossatot River about 2 miles northwest of Duckett post office. The north-south streams in the Athens Plateau, although their valleys are narrow, their currents swift, and their flood-plain deposits meager, have courses as crooked as those

STANDING ROCK, ON BOARD CAMP CREEK, ARK.

The rock, 75 feet high, is formed by a vertical bed of the Arkansas novaculite, 3 to 6 feet thick. Photograph by Bert Hiltebrand of the sluggish streams in the Coastal Plain, which flow through wide areas of alluvium. The meanders on the Athens Plateau are apparently intrenched, the streams having originally flowed in crooked channels on a cover of Cretaceous sediments, and later as they lowered their beds they incised their courses in the hard upturned Paleozoic strata. The size of the bends, however, is not wholly attributable to this cause. The surface on the inside of the bends slopes more or less gradually down to the present stream bed, whereas on the outside of the bends the descent to the stream is everywhere steep and in many places vertical. This indicates that the crookedness of the streams has increased as they have gradually deepened their valleys. The history of the streams is discussed more fully under "Geologic history" (pp. 143–146).

CULTURE

The area is not densely populated, but only the most mountainous parts are without houses. The rural population, most of which is engaged in agriculture, is sparse except in the level or gently rolling upland and valley areas where there is the greatest quantity of tillable land. The largest town is De Queen, the county seat of Sevier County. Among the villages and other towns of less size are Hatfield, Cove, Vandervoort, Wickes, Grannis, Gillham, and Dierks, in the De Queen quadrangle; and Murfreesboro, the county seat of Pike County, Center Point, Delight, Rosboro, Glenwood, Caddo Gap, and Womble, in the Caddo Gap quadrangle. All these places except Center Point are on railroads.

The main line of the Kansas City Southern Railway traverses from north to south the west half of the De Queen quadrangle. The Texas, Oklahoma & Eastern Railroad runs west from De Queen through Broken Bow to Valliant, Okla. The De Queen & Eastern Railroad extends from De Queen as far east as Dierks, though a few miles of its track lies south of the quadrangle. The railroad shown on the De Queen topographic map, running southeast from Dierks, and the line south of that place, which crosses Messer Creek and extends into Center Point Township, are merely lumber roads. Two branches of the Missouri Pacific Railroad enter the east side of the Caddo Gap quadrangle, one extending to Pike and the other to Womble. These two lines unite at Antoine, east of the quadrangle, and farther east, at Gurdon, Ark., join the main line of that railroad connecting St. Louis and Texarkana. The Caddo & Choctaw Railroad formerly extended from Rosboro westward to Cooper Junction, but its use has been discontinued. The Murfreesboro-Nashville Southwestern Railway, formerly the Memphis, Dallas & Gulf Railroad, traverses the southeastern part of the Caddo Gap quadrangle, entering at the south side near Tokio, Ark., and passing northeastward to Murfreesboro. This railroad formerly ran northeastward from Murfreesboro to the east border of the quadrangle. After leaving the quadrangle on the east side it joined the Missouri Pacific Railroad at Shawmut, Ark., used the track of that road from Shawmut to Glenwood and thence extended northeastward to Hot Springs. The part of the railroad between Murfreesboro and Hot Springs, however, is no longer used. The Prescott & Northwestern Railroad enters the Caddo Gap quadrangle at Tokio and runs as far as Highland.

Several main highways cross the quadrangles, and other roads that are less well maintained reach all parts of the area. On account of the character of the topography few of the roads follow section lines. In the mountainous districts they keep to the valleys and cross the mountains only where there are water gaps or saddles. Some main highways as well as trails penetrate the roughest, most scenic parts of the country, much of which is included in the Ouachita National Forest, formerly called the Arkansas National Forest.

Agriculture is the chief occupation in the quadrangles, the soil and climate of which are adapted to general farming, fruit growing, and grazing, but lumbering is carried on at many localities. Large lumber mills are now in operation at several towns, and small mills are located at numerous places. Very little mining is done, but the minerals mined include quartz crystals in the Crystal Mountains, antimony ore near Gillham, and diamonds near Murfreesboro.

DESCRIPTIVE GEOLOGY

STRATIGRAPHY

GENERAL FEATURES

The exposed rocks of the Caddo Gap and De Queen quadrangles are of sedimentary origin, though there are igneous rocks in four small areas near Murfreesboro. The igneous rocks are of the single kind known as peridotite and were probably intruded while the earliest Upper Cretaceous sediments exposed in the quadrangles were being laid down. The sedimentary rocks exhibit considerable diversity, consisting of clay, sand, marl, shale, slate, chert, gravel, limestone, sandstone, tuff, novaculite, and conglomerate. They are grouped into 16 formations, whose distribution is shown on Plate 3. The aggregate of the minimum thicknesses of the formations is 21,720 feet, and the aggregate of their maximum thicknesses is 26,875 feet. The sequence, thickness, and diverse character of the beds

Various classifications of formations of Paleozoic age exposed in the Ouachita Mountain region of Arkansas and Oklahoma

Caddo Gap and De Queen quadrangles, Ark.-Okla.	Ouachita geosyncline, Okla. and Ark. Ulrich, E. O., Fossiliferous boulders in the Ouachita "Caney" shale and the age of the shale containing them: Oklahoma Geol. Survey Bull. 45, 1927.	Ouachita Mountains, Okla. and Ark. Miser, H. D., and Honess, C. W., Age relations of the Carboniferous rocks of the Ouachita Mountains of Oklahoma and Arkansas: Oklahoma Geol. Survey Bull. 44, 1927.	Ouachita Mountains, Okla. Miser, H. D., Geologic map of Oklahoma, U. S. Geol. Survey, 1926.	Hot Springs district, Ark. Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Hot Springs folio (No. 215), 1923.	Southern Ouachita Mountains, Okla. Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey, Bull. 32, 1923.	Caddo Gap quadrangle, Ark. Purdue, A. H., The slates of Arkansas: Arkansas Geol. Survey, 1909.	Southeastern Oklahoma Taff, J. A., Grahamite deposits of southeastern Oklahoma: U. S. Geol. Survey Bull. 380, pp. 286-297, 1909.	Ouachita Mountains in Atoka quadrangle, Okla. Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (No. 79), 1902.	Southern Ouachita Mountains, Ark. Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, pp. 205-206, 1892.
Carboniferous. Pennsylvanian. Atoka formation.	Pennsylvanian. Atoka formation.	Carboniferous. Pennsylvanian. Atoka formation. Wapanucka limestone.	Carboniferous. Pennsylvanian. Atoka formation. Wapanucka limestone.			Carboniferous. Atoka formation.	Carboniferous. Atoka formation.		
[Not present.]	Johns Valley shale.	Caney shale.	Caney shale.			[Not present.]	Caney shale.		
Mississippian. Jackfork sandstone.	Jackfork sandstone.	Mississippian. Jackfork sandstone.	Mississippian. Jackfork sandstone.		Carboniferous. Penn. Jackfork sandstone.	Jackfork sandstone.	Jackfork sandstone.	Jackfork sandstone.	Lower Carboniferous. Sandstones and shales.
Stanley shale.	Mississippian. Stanley shale.	Stanley shale.	Stanley shale.	Carboniferous. Mississippian. Stanley shale.	Pennsylvanian? Stanley shale.	Stanley shale.	Standley shale.	Standley shale.	
[Not present.]		Hot Springs sandstone.	[Not present.]	Hot Springs sandstone.	[Not present.]	Age unknown. Fork Mountain slate. [Not present.]	[Not present.]	[Not present.]	
Dev.? Up. Dev.? Devonian. Up. Dev. Middle Devonian. Arkansas novaculite.	Upper Arkansas novaculite. Middle Arkansas novaculite. Devonian. Lower Arkansas novaculite.	[Not described].	Devonian? Devonian. Arkansas novaculite.	Devonian? Upper (?) Devonian. Devonian. Lower (?) Devonian. Arkansas novaculite.	Devonian. Arkansas novaculite.	Arkansas novaculite.	Ordovician. Talihina chert. Devonian and Silurian chert and black shale.	Ordovician. Talihina chert.	Lower Silurian. Novaculites.
Silurian. Missouri Mountain slate.	Silurian. Missouri Mountain slate.		Silurian. Missouri Mountain slate.	Silurian. Missouri Mountain shale.	Silurian. Missouri Mountain slate.	Missouri Mountain slate.			
Blaylock sandstone.	Blaylock sandstone.		Blaylock sandstone.	Blaylock sandstone.	Blaylock sandstone.	Ordovician. Blaylock sandstone.			"Shales, limestones, massive quartzose sandstones, cherty blue limestones, with gray, black, and yellow shales at the bottom."
Ordovician. Upper (?) Ordovician. Polk Creek shale.	Ordovician. Polk Creek shale.		Ordovician. Polk Creek shale.	Ordovician. Upper (?) Ordovician. Polk Creek shale.	Ordovician. Polk Creek shale.	Polk Creek shale.			
Middle Ordovician. Bigfork chert.	Bigfork chert.		Bigfork chert.	Middle Ordovician. Bigfork chert.	Bigfork chert.	Bigfork chert.			
Lower Ordovician. Womble shale.	Stringtown or Womble shale.		Womble schistose sandstone.	Lower Ordovician. Womble shale.	Womble schistose sandstone.	Stringtown shale.	Stringtown shale	Stringtown shale.	
Blakely sandstone.	Blakely sandstone.		Blakely sandstone.	Blakely sandstone.	Blakely sandstone.		?	?	
Mazarn shale.	(a) Mazarn shale.		Mazarn shale.	Mazarn shale.	Mazarn shale.	Ouachita shale.			
Ordovician? Crystal Mountain sandstone.	Cambrian. Crystal Mountain sandstone.		Ordovician? Crystal Mountain sandstone.	[Not exposed.]	Ordovician? Crystal Mountain sandstone.	Crystal Mountain sandstone.	[Not exposed in area of grahamite deposits.]	[Not exposed.]	
Cambrian. Collier shale.	Collier shale.		Cambrian. Collier shale.		Cambrian. Collier shale.	Age unknown. Collier shale.			

a Canadian.

of the formations are graphically represented in the columnar sections on Plates 4 and 5. From their fossil content, lithologic character, and stratigraphic position they are placed in the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Cretaceous, and Quaternary systems. The age assignments and formation names given to the Paleozoic rocks from time to time as knowledge of the Ouachita Mountain region has increased are shown in the accompanying correlation table.

CAMBRIAN SYSTEM

COLLIER SHALE

Definition.—The Collier shale received its name from Collier Creek, in the Crystal Mountains in the Caddo Gap quadrangle, along whose headwaters it was first observed by the authors. It is the lowest and consequently the oldest exposed formation, not only in these quadrangles but in the whole Ouachita Mountain region, and according to evidence stated on page 24 it is believed to belong to the Cambrian system. As the name implies, the formation consists principally of shale, but it contains some limestone and a meager amount of chert. The thickness that is exposed in the Caddo Gap quadrangle is 200 feet, but much more, probably several hundred feet, is exposed in the adjoining Mount Ida quadrangle, on the north.

Distribution.—The outcrops of the Collier shale in the Caddo Gap quadrangle occur in the Crystal Mountains, where they form narrow belts in valleys or on steep slopes.

Character.—The bulk of the formation is bluish-black soft graphitic clay shale. Owing to the severe squeezing and shearing that the shale has undergone, it is intensely crumpled, is full of glossy, slickensided surfaces, and has lost practically all traces of bedding. In places slaty cleavage may be observed. Thin and widely separated beds of black, dense, and much fractured chert are found in some exposures, and fragments from them are seen here and there on the surface. The upper 100 feet or more of the shale contains a considerable quantity of dark finely crystalline limestone, some of which occurs in lenses and layers half an inch or more thick distributed through the shale. In the lower parts of the shale the limestone is about 100 feet thick and occurs in much contorted layers from a few inches to more than 2 feet thick, interbedded with thin seams of graphitic shale. These layers are light steel-gray to bluish gray or black, the lighter colors predominating at the top and the darker at the base. All the limestone, however, is compact, much jointed, and brittle, contains many thin veins of white calcite, and becomes dark blue on weathered surfaces.

Age and stratigraphic relations.—The Collier shale is overlain by the Crystal Mountain sandstone, and this in turn by the Mazarn shale. The Mazarn shale is known from its fossils to belong to the Lower Ordovician series. The Crystal Mountain sandstone, on account of its lithology and stratigraphic relations, is referred to the same series, though the reference is doubtful, as no fossils have been found in the sandstone. The Collier shale has yielded no fossils, and it has no lithologic features that would give it claim to an age classification with the higher rocks. A conglomerate at the base of the overlying sandstone is of such a character that it establishes an unconformity at this horizon. The Collier shale is therefore classified as Cambrian.

ORDOVICIAN (?) SYSTEM

CRYSTAL MOUNTAIN SANDSTONE

Definition.—The Crystal Mountain sandstone received its name from the Crystal Mountains, most of which are formed by this sandstone. It is composed almost entirely of sandstone, is 850 feet thick, and is doubtfully referred to the Lower Ordovician series.

Distribution.—This formation is exposed only in the Crystal Mountains. Its exposures are narrow east-west belts, and they produce high rugged ridges on which many rock ledges protrude through a surficial mantle of huge boulders and finer material. The best exposures are on the headwaters of Collier Creek.

Character.—Besides sandstone the formation contains a thin basal conglomerate and a very subordinate quantity of shale. The sandstone is massive and coarse grained and is composed of well-rounded, translucent quartz grains, cemented together in some beds by calcium carbonate but in most beds by silica. The calcareous beds are brown and become rather friable on weathering, but the siliceous sandstone is light gray, is hard and dense, and breaks into large and small blocks that cover much of the surface. Joints in the sandstone are abundant, and they are so even and nearly parallel in many places that their surfaces may be mistaken for bedding planes.

Much of the sandstone is cut with a network of veins of white quartz from a fraction of an inch to several inches thick. In many places beautiful clusters of quartz crystals—both milky and transparent—line the walls of fissures, which range from several inches to several feet wide. (See pl. 17, *B*.) The Crystal Mountains received their name from the abundance of these crystals. The large number of quartz crystals that are sold at Hot Springs, Ark., for museums and private collections are obtained from this sandstone. The principal crystal mines in the Caddo Gap quadrangle are on Collier Creek.

The basal conglomerate reaches a thickness of 10 or 12 feet and has an earthy, calcareous matrix, in which there are rounded quartz grains reaching the size of peas and rounded and subangular pebbles and cobbles of bluish limestone and black chert as much as 6 inches in diameter. The limestone and chert pebbles are identical in character with the limestone and chert in the Collier shale, and for this reason there seems no doubt that they were derived from that formation. Where the more sandy parts of the conglomerate are weathered they resemble in places soft, coarse, brown, porous sandstone.

The small quantity of shale interbedded with the sandstone is a black clay shale, but in places there are thin alternating layers of a greenish color.

Age and stratigraphic relations.—The Crystal Mountain sandstone has not yielded any fossils. It is unconformably underlain by the Collier shale and is overlain by the Mazarn shale, of Lower Ordovician age, from which it is not separated by any indication of a stratigraphic break. The shale interbedded with the upper part of this sandstone closely resembles the basal portion of the Mazarn shale. This resemblance is so strong that to the observer in the field it appears to be conclusive evidence that the Crystal Mountain sandstone and Mazarn shale belong to the same series—Lower Ordovician—though the reference of the sandstone to this series can not be definitely made on account of the absence of fossils in the sandstone.

ORDOVICIAN SYSTEM

MAZARN SHALE

Definition.—The Mazarn shale is composed chiefly of shale with subordinate amounts of sandstone and limestone and is of Lower Ordovician age. It received its name from Mazarn Creek, whose headwaters are in the northeast corner of the Caddo Gap quadrangle. The shale to which this name is now applied was in 1909 regarded by Purdue as a part of his "Ouachita shale," which as defined comprised the rocks between the Crystal Mountain sandstone below and the Stringtown shale above. A sandstone now called the Blakely sandstone, which was in 1909 [8] regarded as the upper part of the Crystal Mountain sandstone, has since been determined by the authors to occur in the middle of the "Ouachita shale." The use of the name Stringtown has been discontinued in this area because the beds to which it was applied do not form a mappable unit distinct from the rest of the shale above the Blakely sandstone, and because the graptolites supposed to be characteristic of it have

[8] Purdue, A. H., The Slates of Arkansas, pp. 30, 33–35, Arkansas Geol. Survey, 1909; (abstract) U. S. Geol. Survey Bull. 430, pp. 321–325, 1910; (abstract) U. S. Geol. Survey Prof. Paper 71, pp. 160–162, 1912.

apparently been found well down in the underlying shale. The recognition of the Blakely sandstone as a distinct formation and the failure to separate the Stringtown made it necessary to give a new name (Womble shale) to the whole group between the Blakely sandstone and the Bigfork chert. It was also necessary to give a new name (Mazarn shale) to the shale between the Blakely and Crystal Mountain sandstones. The name "Ouachita shale" is abandoned because its limits are not the same as those of any one of the units now mapped and because Ouachita has the same pronunciation as Washita, the well-established name of the upper group of the Comanche series.

The Mazarn shale is apparently conformable with both the underlying Crystal Mountain sandstone and the overlying Blakely sandstone. The occurrence of a conglomerate in places at the base of the Blakely sandstone in Blakely Mountain, in the northwest corner of the Hot Springs district,[9] which is east of the area herein described, suggests the presence of an unconformity at this horizon in that district. No conglomerate was observed at the base of the sandstone in the Caddo Gap quadrangle.

Distribution and character.—The Mazarn shale is exposed in the Caddo Gap quadrangle but not in the De Queen quadrangle. It is the surface rock in the valley just north of the ridge running east from Womble and at places in the high ridges of the Crystal Mountains on the north. West of these mountains its exact areal extent is unknown, because the shale can not there be distinguished from the shale of the Blakely sandstone nor from the Womble shale. The sandstone in the Blakely thins out at Womble and is present at only one place west of that town.

The Mazarn consists predominantly of shale, although in places it contains small quantities of limestone and sandstone. The thickness is roughly estimated to be 1,000 feet. Much of the shale is black, clayey, and fissile, but other parts consist of alternating black and green layers, the latter commonly about 1 inch thick. Straight, well-defined joints dissect most of the shale, and slaty cleavage, at an angle to the bedding, is developed at many localities. In these places the differently colored layers produce ribboned slate, exposures and small blocks of which are especially numerous along the streams. (See pl. 6, *A*.) The limestone is apparently near the middle of the shale. It is dark blue on weathered surfaces and black on freshly fractured surfaces; it is compact, thin bedded, finely crystalline, and nonmagnesian; it occurs in beds probably not more than 10 or 15 feet thick; and it is interbedded with shale like that above and below.

[9] The Hot Springs district, described by the authors in U. S. Geol. Survey Geol. Atlas, Folio 215, comprises a part of the Hot Springs and Benton quadrangles and of two unnamed quadrangles.

Some of the limestone is a sandy conglomerate containing minute limestone pebbles. Sandstone, although in small quantity, is found in many places. It is gray, hard, laminated, fine grained, and quartzitic and occurs in thin layers some of which reach 2 feet in thickness.

Many thin veins of white quartz and some white calcite showing a comb structure at places cut the shale, sandstone, and limestone in all directions, and in some of the more level areas underlain by shale the residual quartz has collected in sufficient quantities to make the surface white. A boulder of folded laminated sandstone containing quartz veins that were broken by the shearing of the layers was observed loose on the surface, though probably not far from the parent ledge in the lower part of the formation. The shearing of the layers and the breaking of the quartz veins were caused by the folding of the sandstone. The folding of this sandstone and of the other rocks of the Ouachita Mountains took place near the middle or late in the Pennsylvanian epoch. From these facts the conclusion is drawn that at least some of the quartz veins of the Ouachita Mountains were formed before Pennsylvanian time. Evidence has been found in the fuller's earth mines at Klondike, in Saline County, Ark., east of these quadrangles, showing that some of the quartz veins of the Ouachita Mountains were formed after the folding of strata, but before the intrusion of the igneous rocks of these mountains in the Cretaceous period.

Fossils and correlation.—Fossils are rare in the Mazarn shale. Most of those that have been collected in the Mazarn as well as in younger formations of Ordovician age in this region are graptolites, which may as a rule be looked for only in black shale that splits into slabs with smooth surfaces parallel to the bedding. On such surfaces the graptolites appear like delicate white pencil markings, usually toothed like a saw on one or both sides.

Two collections have been made from the shale near Womble, in the Caddo Gap quadrangle, and another at a locality 12 miles west of Little Rock, Ark. The larger one of the collections near Womble was obtained in the N. ½ sec. 22, T. 3 S., R. 25 W., about 2 miles northeast of the town. It has furnished specimens which are recognized by Ulrich as follows: [10]

Didymograptus nitidus Hall.
Didymograptus extensus Hall.
Didymograptus similis Hall.
Didymograptus filiformis Tullberg.
Tetragraptus amii Lapworth.
Tetragraptus approximatus Nicholson.

[10] Ulrich, E. O., Revision of the Paleozoic Systems: Geol. Soc. America Bull., vol. 22, p. 677, 1911.

Tetragraptus clarkei Ruedemann.
Tetragraptus fruticosus Hall.
Tetragraptus cf. T. pendens Elles and Wood.
Tetragraptus quadribrachiatus Hall.
Tetragraptus serra Brongniart.
Tetragraptus similis Hall.

Ulrich points out that 8 of the 12 species just listed occur in the *Tetragraptus* zone and 4 in the *Didymograptus bifidus* zone in New York and Quebec, and that 10 are listed by British authorities from the Lower Arenig and Middle Skiddaw slates of Great Britain.

The collection from the locality 12 miles west of Little Rock is said by Ulrich to occur at a higher zone in the formation. It includes the following species which have been identified by him:[11]

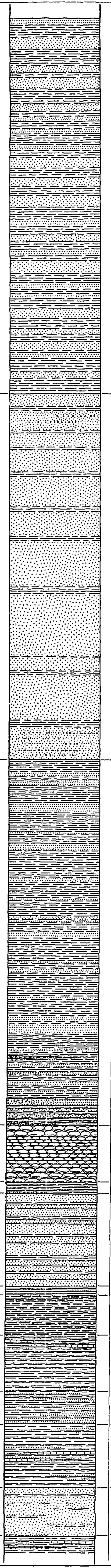
1. Didymograptus euodus Lapworth.
2. Didymograptus caduceus (Salter) Ruedemann.
3. Didymograptus caduceus nana Ruedemann.
4. Didymograptus n. sp. (near D. forcipiformis, but coarser).
5. Tetragraptus quadribrachiatus Hall.
6. Tetragraptus amii? Elles and Wood.
7. Tetragraptus pendens Elles and Wood.
8. Tetragraptus clarkei n. var. (larger).
9. Tetragraptus similis n. var.
10. Phyllograptus typus n. var.
11. Diplograptus sp. undet. cf. D. calcaratus priscus Elles and Wood.
12. Mesograptus sp. undet.
13. Cryptograptus antennarius Hall.
14. Cryptograptus tricornis? Carruthers.
15. Glossograptus hystrix Ruedemann.
16. Retiograptus tentaculatus? Hall.
17. Caryocaris wrighti Salter.

Of these Nos. 5 to 9 are found also in the lower zone, but in each case the later occurrence is a distinguishable mutation. The same species, also Nos. 2 and 10, occur in the *Didymograptus bifidus* zone in New York and Canada, and Nos. 2, 5, 6, 7, and 9 are found in the Skiddaw slates of Great Britain. Nos. 3, 4, 5, 13, 15, and 16—that is, most of the Axonophora—are found in and for the most part confined to the *Diplograptus dentatus* zone in Ruedemann's Deepkill section. However, on account of the strong development of *Tetragraptus* and the presence of *Didymograptus caduceus* in this Arkansas fauna I regard it as older than the *Diplograptus dentatus* zone and as approximately equivalent to the Ashhill Quarry zone, which Ruedemann places as a "transitional subzone" between the *Didymograptus bifidus* and the *Diplograptus dentatus* zones.

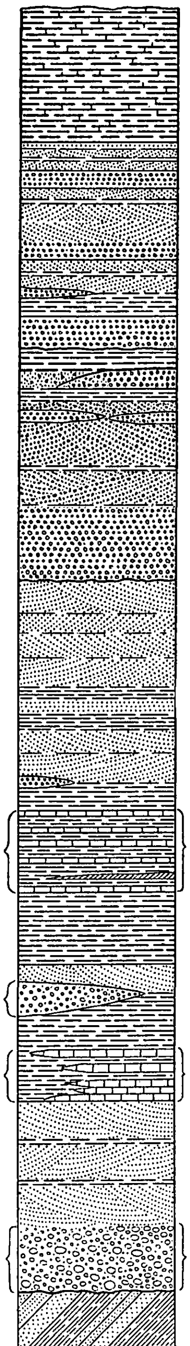
The Mazarn shale on the basis of the fossils discussed above is regarded by Ulrich as being of the same age as the lower part of the Beekmantown (Lower Ordovician) limestone of the Appalachian region.

[11] Ulrich, E. O., op. cit., p. 678.

System	Series	Formation	Symbol	Section	Thickness in feet	Character of rocks	Character of topography and soil
Carboniferous	Pennsylvanian	Atoka formation.	Ca		6,000	Sandstone and shale in nearly equal amounts. Sandstone hard, gray, massive, and thin bedded; some beds near base are coarse grained and contain some grit. Shale dark to coal-black; weathers to red clay.	Valleys and some ridges. Rocky soil suitable in most places for grazing and in others for general farming.
	Mississippian	Jackfork sandstone.	Cj		5,000–6,600	Sandstone, a little shale, and some millstone grit. Sandstone gray, fine to coarse grained; mostly quartzitic. Millstone grit containing quartz pebbles mostly in basal part of formation. Shale is green fissile clay shale.	Low ridges; cultivated in places. Rocky sandy soil, adapted in most places for grazing and in a few level areas for general farming.
		Stanley shale.	Cs		6,000	Mainly shale, with much sandstone and some tuff and conglomerate. Shale fissile, bluish black and black in fresh exposures along streams, green, yellow, or brown in more weathered exposures along roads. Sandstone hard, tough, compact, quartzitic, fine grained, greenish or bluish gray. Tuff massive, homogeneous, dark gray with a greenish tinge; contains large grains of feldspar. Conglomerate near base is composed of novaculite pebbles in dense siliceous matrix.	Low ridges and hills and narrow valleys; cultivated in places. Rocky soil, suitable for farming in the more level tracts, in others for grazing.
		Hatton tuff lentil.	Ch		(0–90)		
		-Unconformity.					
Dev.?	U.? Dev.						
Devonian	U. Dev.	Arkansas novaculite.	Da		300–950	Massive gray novaculite. Thin-bedded dark novaculite and black shale. Massive white novaculite.	High ridges with steep slopes; rock ledges abound. Scanty soil, suitable for grazing.
	M. Dev.						
Silurian		Missouri Mountain slate.	Sm		50±–300	Red and green slate.	Steep slopes or narrow valleys. Rocky soil, suitable for grazing.
		-Unconformity?					
		Blaylock sandstone.	Sb		0–1,500	Hard light to dark gray sandstone and dark shale.	Hilly valley areas and steep slopes. Rocky thin soil, suitable for grazing.
		-Unconformity?					
Ordovician	U.? Or.	Polk Creek shale.	Opc		0–175	Black fissile carbonaceous shale.	Rocky slopes and narrow valleys. Thin soil, suitable for grazing.
	Middle Ordovician	Bigfork chert.	Obf		700	Gray to black even-bedded, much fractured chert, some black shale, and a little black siliceous limestone.	Steep knobs and low ridges; little cultivated except in stream flats and on gentle slopes. Cultivated soil is stony and fertile.
	Lower Ordovician	Womble shale.	Ow		1,000	Shale in alternating black and green layers, some blue limestone, and a little sandstone.	Low hills and wide valleys. Rocky soil, cultivated in places but mostly suitable for grazing.
		Blakely sandstone.	Oby		0–400	Sandstone, mostly siliceous and gray, the rest calcareous and bluish black, interbedded with shale in black and green layers.	Sharp ridges; rock ledges abundant. Scanty rocky soil, suitable for grazing.
		Mazarn shale.	Om		1,000	Black and green banded shale, containing thin layers of gray sandstone and lenses of dark-blue limestone.	Low hills and wide valleys. Rocky soil, cultivated in places but mostly suitable for grazing.
Ordovician?		Crystal Mountain sandstone.	Oc		850	Massive coarse-grained sandstone; beds with calcareous cement become brown on weathering; beds with siliceous cement are gray.	High ridges with steep slopes; rock ledges abound. Scanty rocky soil, suitable for grazing.
		-Unconformity.					
Cambrian		Collier shale.	€c		200+	Bluish-black shale and some limestone.	Narrow valleys and steep slopes. Rocky soil, suitable for grazing.

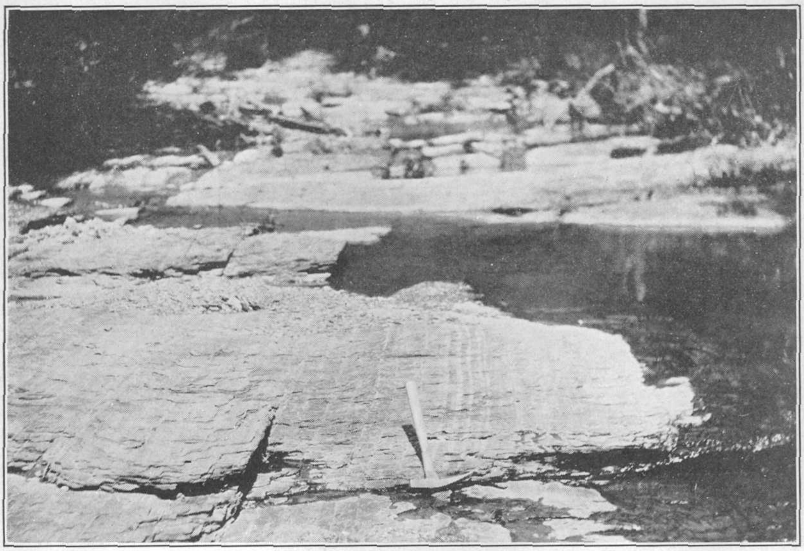


GENERALIZED SECTION OF THE PALEOZOIC ROCKS EXPOSED IN THE DE QUEEN AND CADDO GAP QUADRANGLES, ARKANSAS AND OKLAHOMA



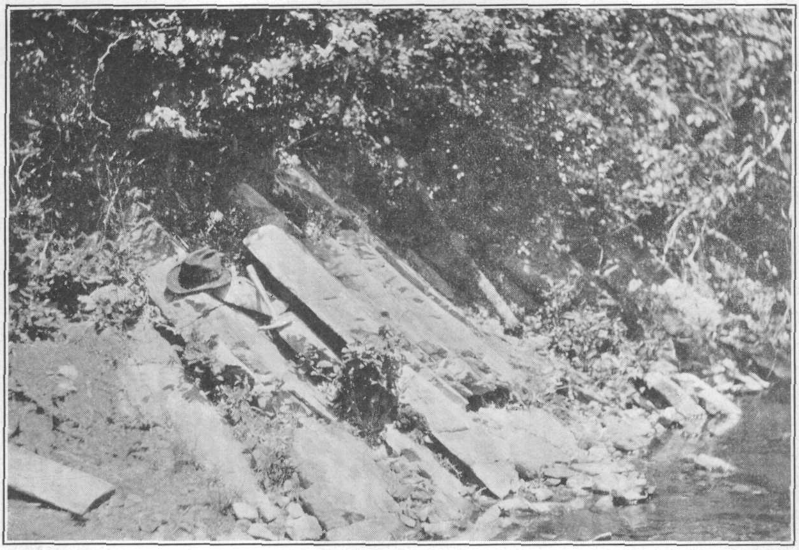
System	Series	Formation and member	Thickness in feet	Character of rocks	Character of topography and soil
Cretaceous	Gulf (Upper Cretaceous)	Brownstown marl.	100±	Fossiliferous blue or gray calcareous clay.	Gently rolling area. Fertile black waxy soil.
		Tokio formation (upper part of "Bingen sand" of Veatch).	(100-300+)	Gravel; gray cross-bedded quartz sand; lignitic material; volcanic ash, light-colored and dark clays, some of which contain fossil plants.	Hilly areas. Gray sandy and gravelly soil; suitable for general farming and fruit culture.
		Unconformity			
		Woodbine formation (lower part of "Bingen sand" of Veatch).	0-350	Gravel; greenish volcanic tuff; red clay; and dark plant-bearing clay.	Rolling southward-sloping plateau. Gravelly clay soil suitable for general farming and fruit culture.
		Unconformity			
	Comanche (Lower Cretaceous)				All soils mentioned below are suitable for general farming, if they are properly cared for.
				Gray cross-bedded sand in heavy beds; some clay.	Poor gray sandy soil.
		De Queen limestone member.	(0-72)	Fossiliferous limestone and an equal or greater amount of green clay. Gypsum and celestite near base.	Usually a yellowish-brown clay soil; in some areas fertile but in others poor.
		Trinity formation.	70-1,000+	Variegated clays.	
		Ultima Thule gravel lentil.	(0-40)	Pebbles less than an inch in diameter.	Dissected southward-sloping upland. Gravelly soil suitable for fruit culture.
				Variegated clays.	
		Dierks limestone lentil.	(0-40)	Fossiliferous limestone and a smaller amount of green clay.	Fertile black clay soil.
				Gray cross-bedded sand in heavy beds; some clay.	Sandy gray soil.
		Pike gravel member.	(0-100)	Irregularly bedded pebbles and cobbles as much as 10 inches in diameter.	Dissected southward-sloping upland. Gravelly soil suitable for fruit culture.
		Unconformity			
Carboniferous		Atoka formation, Jackfork sandstone, and Stanley shale.		Shale and sandstone.	

GENERALIZED SECTION OF CRETACEOUS ROCKS EXPOSED IN THE DE QUEEN AND CADDO GAP QUADRANGLES, ARKANSAS AND OKLAHOMA

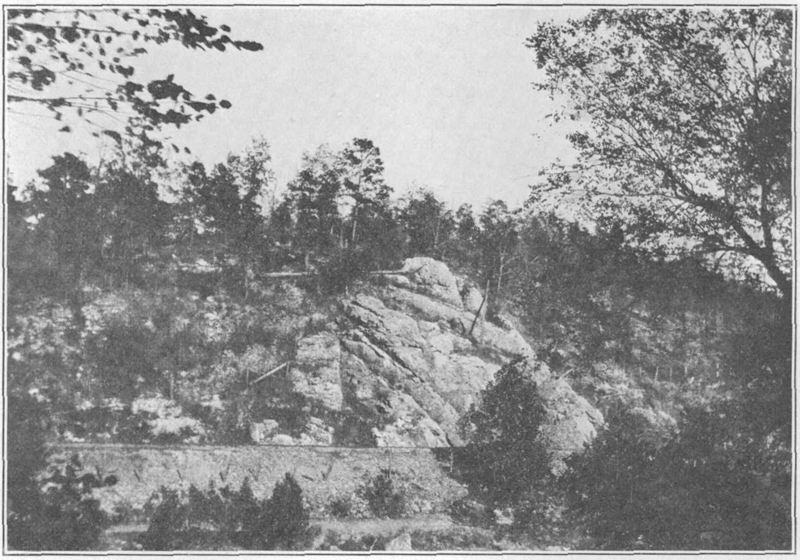


A. "RIBBONED" SHALE WITH HORIZONTAL CLEAVAGE THAT CUTS ACROSS BLACK AND GREEN LAYERS

The dip of the layers is high to the left. Such shale is common in the Mazarn shale, in the Blakely sandstone, and in the lower part of the Womble shale

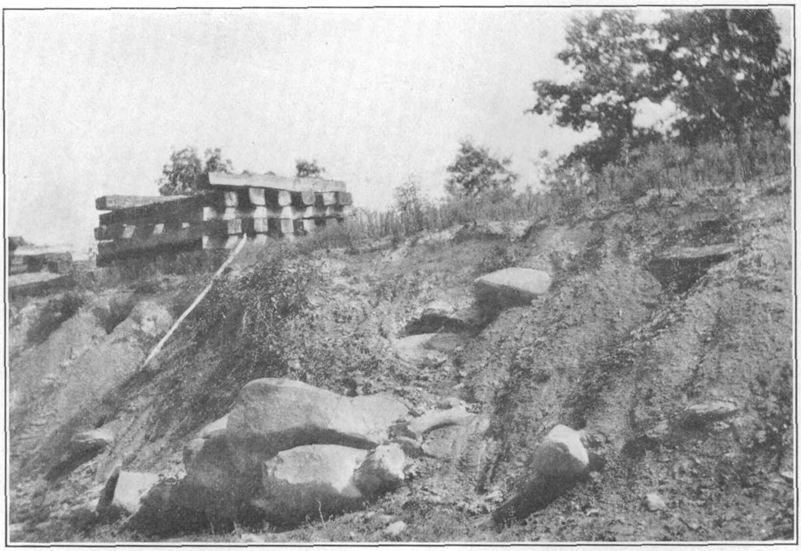


B. LIMESTONE IN WOMBLE SHALE, HALF A MILE SOUTHEAST OF PLATA, ARK.



A. LOWER DIVISION OF THE ARKANSAS NOVACULITE ON THE EAST SIDE OF CADDO RIVER AT CADDO GAP, ARK.

Shows an anticline that has been broken by two thrust faults. One fault with a dip of about 90° (shown by slickensides) separates the vertical ledge from the beds at the right that dip about 45° S. The other fault is in the middle division of the novaculite exposed on the slope at the left



B. SANDSTONE IN THE STANLEY SHALE IN A RAILROAD CUT AT VANDERVOORT, ARK.

Rounded boulders of hard, unweathered sandstone are embedded in weathered, friable sandstone or sand

BLAKELY SANDSTONE

Definition.—The Blakely sandstone was named from Blakely Mountain, in the northwest corner of the Hot Springs district, east of the area herein described. It was first studied by the authors in 1907–8 in the Caddo Gap quadrangle, where the principal outcrop forms a ridge extending from Womble to the east border of the quadrangle. It was then confused with and described as the upper part of the Crystal Mountain sandstone.[12] Its true stratigraphic place was not determined until 1909, when the field work in the Hot Springs district was begun. Earlier determination was prevented by the lithologic resemblance of the Blakely to the Crystal Mountain sandstone, the identical lithologic character of the underlying Mazarn shale and the base of the overlying Womble shale, and the misinterpretation of the structure of the ridge extending eastward from Womble—that is, the conclusion that the structure was a closely folded anticline instead of a monocline, which is its true structure.

The Blakely sandstone, as the name implies, contains sandstone, which, being very resistant, is the predominant surficial feature, but most of the formation is shale. The formation is known by its fossils to be of Lower Ordovician age. It is conformable with the Womble shale above, the two apparently grading into each other, and is apparently conformable with the underlying Mazarn shale. A conglomerate that is found at the base in Blakely Mountain, in the Hot Springs district suggests the presence of an unconformity at the base of the sandstone there. No conglomerate has, however, been observed at the base of the sandstone in the Caddo Gap quadrangle.

Distribution and character.—The principal occurrences of the sandstone in the Caddo Gap quadrangle are in the ridge extending from Womble eastward beyond the boundary of the quadrangle and in two low ridges between Womble and Caddo Gap. The sandstone in the small area at Black Springs is mapped as the Blakely, but it may be the Crystal Mountain sandstone. The sandstone of the Blakely thins out at Womble and is absent west of that place except for the possible occurrence at Black Springs. As the shale in the Blakely is similar to the Womble and Mazarn shales it can not be distinguished from these shales west of Womble. No exposures of the sandstone occur in the De Queen quadrangle.

The formation consists of about 400 feet of interbedded shale and sandstone, with the shale making probably 75 per cent of the whole. Although the sandstone occurs in less amount than the shale, it is so resistant that the formation produces ridges. Sandstone layers occur

[12] Purdue. A. H., The Slates of Arkansas, pp. 32–33, Arkansas Geol. Survey, 1909.

near the top of the underlying shale and also near the base of the overlying shale, and for this reason the upper and lower limits of the formation are arbitrarily fixed. The shale is black and argillaceous but contains green bands and is not unlike the Mazarn and Womble shales. (See pl. 6, *A*.) In some if not all places the green bands are due to weathering, the original color of the rock having been black. The sandstone is in beds, most of which are not more than 10 feet thick. It is made up of medium-sized, well-rounded. translucent quartz grains, firmly cemented together in most beds by silica but in the others by calcium carbonate. According to the character of the cementing material, there are thus two kinds of sandstone, one quartzitic and the other calcareous. The quartzitic variety is light to bluish gray, extremely hard, laminated, and much jointed, and disintegrates slowly on exposure to the weathering agencies. Owing to this character the crests of the ridges are usually covered with great heaps of angular boulders, seemingly broken from numerous massive beds of sandstone, although in fact the sandstone beds are thin and are separated by thick beds of shale. The calcareous sandstone is bluish black and on weathering loses its calcareous material and becomes friable, and gray to brown in color. The sandstone is intersected by many quartz veins, most of them less than half an inch thick, which are so abundant that some of them may be seen in most of the ledges and loose boulders.

Fossils and correlation.—No fossils have been procured from the Blakely sandstone in the Caddo Gap quadrangle, but the two following lists supplied by Ulrich show the graptolites that have been found in shale near the middle of the sandstone in Blakely Mountain, in the Hot Springs district.

Graptolites from shale in the Blakely sandstone in the NE.¼ sec. 29, T. 1 S., R. 20 W. in the Hot Springs district.

- Didymograptus sp. 1.
- Didymograptus sp. 2.
- Didymograptus sp. 3.
- Phyllograptus anna Hall.
- Phyllograptus cf. P. ilicifolius Hall.
- Phyllograptus cf. P. angustifolius Hall.
- Phyllograptus n. sp. (large theca).
- Glossograptus echinatus Ruedemann.
- Glossograptus horridus.
- Diplograptus sp.?
- Cryptograptus n. sp.?
- Climacograptus?

The following species are from the above locality but 1 foot lower in the shale:

- Tetragraptus n. sp. aff. T. quadribrachiatus (Hall).
- Tetragraptus cf. T. clarkei (? n. sp.).

Dichograptus n. sp.
Didymograptus manus.
Didymograptus euodes Lapworth.
Didymograptus spinosus Ruedemann.
Phyllograptus anna ultimus?
Diplograptus sp.?
Glossograptus cf. G. hystrix Ruedemann.
Glossograptus cf. G. echinatus Ruedemann.
Cryptograptus ? sp.

Ulrich states that the horizon yielding this and the preceding collections probably falls between Ruedemann's *Phyllograptus* zone and his next higher zone of *Diplograptus dentatus*, though doubtless nearer the latter than the former.

Other graptolites collected from the same locality as the two just mentioned but considerably higher in the Blakely are too poorly preserved for specific identification, though according to Ulrich they are evidently from a different zone from any of the underlying and overlying beds represented by collections. The presence of a small *Phyllograptus*, perhaps the same as *P. anna ultimus* Ruedemann, indicates, according to him, an alliance with the fauna of the Mazarn shale beneath. He therefore concludes that this zone is surely older than the Normanskill shale of New York, whose fauna is well represented in the Womble shale above.

The paleontologic evidence just cited indicates that at least the lower part of the Blakely sandstone is equivalent to the upper part of the Levis shale in Quebec, which is correlated by Ruedemann and Ulrich with the Beekmantown (Lower Ordovician) limestone of the northern Appalachian region.

WOMBLE SHALE

Definition.—The Womble shale is composed of shale and some thin beds of sandstone and limestone. It received its name from the town of Womble, part of which is on the base of the formation. The lower part of the shale to which the name Womble is now applied was in 1909 described by Purdue[13] as a part of the "Ouachita shale," and the upper part of the Womble shale was described by him as the Stringtown shale. The reasons for the discontinuance of these two names are given in the description of the Mazarn shale. The Womble shale lies conformably above the Blakely sandstone and below the Bigfork chert and belongs to the Lower Ordovician series, though a bed of Trenton (Middle Ordovician) age exposed at its top in the northwestern part of the Caddo Gap quadrangle and at Crystal Springs, Ark., has been provisionally included in it.

[13] Purdue, A. H., op. cit., pp. 30, 33–35.

Distribution and character.—The Womble shale is the surface rock over fairly large areas near Caddo Gap, Womble, Black Springs, and Big Fork, in the northern part of the Caddo Gap quadrangle, but it is nowhere exposed in the De Queen quadrangle. It forms valley areas in which there are low, irregular hills. Good rock exposures occur at many places, especially along the streams and roads.

The formation is probably about 1,000 feet thick; the thickness can not be determined exactly, as the beds are intensely crumpled. It consists of shale with some thin beds of sandstone and limestone, and much of it closely resembles the Mazarn shale. The shale is black, rather hard, and argillaceous and splits into thin pieces when struck with a hammer. The green bands are less numerous than they are in the Mazarn shale, and as a whole the Womble has a somewhat darker aspect than the Mazarn. The upper part is much darker than the lower part and contains much carbonaceous matter, which blackens the fingers when they are rubbed over freshly fractured surfaces. The upper part also contains graptolites in abundance. The shale is cut by numerous quartz veins at some places. The fragments of white quartz that are residual from these veins are so abundant in some areas that they whiten the surface.

Layers of black chert very similar to the Bigfork chert are found near the top of the formation at some places. Here and there the upper 50 to 75 feet of the formation consists of a porous, tough, fine-grained siliceous rock of low specific gravity, in layers from 2 to 4 inches thick. This variety of rock is dissected by numerous straight joints and ranges from gray to pink and bluish in color. Exposures of it occur in only a few places, but small blocks are common in the débris on the slopes. Its origin is not known, but it was probably formed by the weathering of a calcareous chert or siliceous shale, the calcareous material having been removed in solution.

Some sandstone is present in all parts of the formation. It is hard, compact, bluish green, quartzose, and fine grained and weathers gray or brown.

The limestone occurs as sporadic lenses in the upper 75 to 150 feet of the shale. It is not confined to any definite horizon but may be expected anywhere within this portion. It is a compact, brittle, fine-grained, nonmagnesian, even-bedded stone, is blue on weathered surfaces though black on fresh surfaces, and is closely set with veins of quartz and calcite half an inch or less thick. Some thin layers at or near the base contain sand and pebbles. The sand grains are well rounded and translucent; the pebbles are subangular, range from the size of peas to 2 inches in diameter, and consist of shale, fine-grained brown sandstone, and limestone like that of the adjacent beds. In some localities the limestone, like the beds both below and above, is greatly crumpled. Locally thin layers of black shale are interbedded with the limestone layers.

The limestone lenses, which have a maximum total observed thickness of about 85 feet, are made up of layers from a few inches to 2 feet thick, and they thin down to a few feet or entirely disappear within short distances. (See pl. 6, *B*.) This abrupt thickening and thinning of the limestone, its sporadic occurrence, and the conglomerate that it contains led formerly to the conclusion that there is an unconformity at the base of the limestone. This view seemed to be confirmed by the paleontologic evidence in hand at the time, and the limestone and overlying beds up to the Bigfork chert were called the Stringtown shale.[14] Subsequently graptolites from beds beneath the limestone were determined to be of the same age as those above, and this later evidence suggests that if any unconformity exists it is intraformational.

Fossils and correlation.—Graptolites belonging to two faunas are known. One of these faunas is represented in the Beekmantown of New York and in contemporaneous beds of the Levis shale in Quebec, and the other, the younger, in the Normanskill shale in New York. The younger fauna is commonly known as the *Nemagraptus gracilis* or Normanskill shale fauna.

The older fauna is represented in the Hot Springs district by a single collection obtained near the base of the Womble shale in the NW. ¼ sec. 39, T. 1 S., R. 20 W., and is said by Ulrich to be a Mazarn shale fauna, but the field relations apparently indicate that the shale yielding the fossils overlies the Blakely sandstone. The species were determined by Ulrich as follows:

Azygograptus sp.
Didymograptus sparsus.
Didymograptus cf. D. extensus.
Brygraptus.
Climacograptus.
Diplograptus (large).
Glossograptus horridus.
Phyllograptus sp.
Cryptograptus.

Several parts of the Womble shale in the Caddo Gap quadrangle have yielded graptolites belonging to the Normanskill shale fauna. Some of those collected in this area have been identified by Ulrich as follows:

Climacograptus bicornis Hall.
Dicranograptus parvangulus.
Dicellograptus sextans (Hall).

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[14] Purdue, A. H., op. cit.

Dicellograptus cf. D. sextans (Hall).
Dicellograptus cf. D. smithi Ruedemann.
Dicellograptus divaricatus (Hall).
Didymograptus superstes (Lapworth).
Didymograptus sagitticaulis Gurley.
Nemagraptus gracilis Hall.

The largest collection containing this fauna was obtained by Ulrich at Crystal Springs, Ark., east of the Caddo Gap quadrangle, where the entire formation is better exposed than at any other known locality. The species as identified by Ulrich follow:

Didymograptus sagitticaulis Gurley.
Didymograptus superstes Lapworth.
Didymograptus? n. sp.
Nemagraptus gracilis Hall.
Dicellograptus gurleyi Lapworth.
Dicellograptus rigidus Lapworth.
Dicellograptus sextans Hall.
Dicellograptus cf. D. intortus Lapworth.
Dicellograptus cf. D. divaricatus bicurvatus Ruedemann.
Dicranograptus rectus Hopkinson.
Dicranograptus parvangulus Gurley.
Dicranograptus diapason Gurley.
Climacograptus bicornis Hall.
Climacograptus pultifer Lapworth.
Climacograptus n. sp. (very small).
Diplograptus (vulgatus) acutus Lapworth.
Diplograptus incisus (Lapworth) Ruedemann.
Diplograptus incisus n. var.
Diplograptus basilicus Lapworth.
Glyptograptus englyphus Lapworth.
Glyptograptus angustifolius Hall.
Glyptograptus angustifolius var.
Glossograptus ciliatus var.
Glossograptus n. sp. (wide).
Glossograptus n. sp. (same at Summit, Nev.?).
Orthograptus whitfieldi? Hall.
Cryptograptus tricornis Carruthers.
Retiograptus geinitzianus Hall.
Lasiograptus mucronatus Hall.
Lasiograptus bimucronatus Nicholson.
Lasiograptus bimucronatus n. var.
Thamnograptus capillaris Hall.
Dictyonema n. sp.
Desmograptus (? obovatus).
Callograptus cf. C. salteri Hall.

Ulrich states that out of 33 species found in one exposure at Crystal Springs 23 are listed from the Normanskill shale of New York by Ruedemann and 15 from the Glenkiln shale of England by Wood, Elles, and Lapworth. This fauna is also represented in the Martinsburg shale in Virginia, the Athens shale of Tennessee, Virginia, and Alabama, and the Stringtown shale of Oklahoma. The Normanskill shale, according to Ulrich, is of upper Chazy age.

A fragment of a bryozoan belonging to the genus *Rhinidictya* was found in limestone in the Womble shale at Crystal Springs. Although the age indicated by it is indecisive, Ulrich states that it is not younger than Black River and might be lower to middle Chazy.

A younger fauna than that of the Normanskill shale has been obtained from a hard black shale that lies just beneath the lowest chert beds of the Bigfork chert and that is provisionally included in the Womble shale, with which this black shale has been mapped. This fauna is represented by two collections. One of the collections was made by L. S. Griswold and C. S. Prosser at the Texas tunnel mine, which is half a mile west of Crystal Springs, Ark.; it has furnished the following species which have been identified by Ulrich:

Dicranograptus arkansasensis Gurley.
Dicranograptus spinifer Elles and Wood.
Dicranograptus nicholsoni Hopkinson.
Climacograptus caudatus Lapworth.
Diplograptus calcaratus?
Diplograptus truncatus abbreviatus Elles and Wood.
Mesograptus sp. undet.
Retiograptus (Orthograptus) quadrimucronatus var. cornutus Ruedemann.
Cryptograptus insectiformis Ruedemann.
Lasiograptus bimucronatus n. var. near L. timidius Ruedemann.

The other collection containing the younger fauna was obtained by L. S. Griswold and J. P. Smith from a locality in the SW. ¼ SE. ¼ sec. 23, T. 3 S., R. 28 W., in the northwestern part of the Caddo Gap quadrangle. The species that have been identified by Ulrich are as follows:

Dicranograptus arkansasensis Gurley.
Dicranograptus spinifer Elles and Wood.
Diplograptus cf. D. acutus Elles and Wood.
Climacograptus cf. C. oligotheca Gurley.
Retiograptus? n. sp.

The local guide fossil of this younger fauna is stated by Ulrich to be *Dicranograptus arkansasensis* Gurley. The fauna according to him is the same as the faunas of the lower Hartfell shale of Scotland, of the Magog shale of Canada, and of the Snake Hill beds of the New York State survey. It is said by him to be of Trenton age and to be more closely allied to the fauna in the Bigfork chert than to the fauna in the Womble shale.

A collection of graptolites and other fossils which was obtained from black shale near the top of the Womble shale at a locality on a north hill slope one-eighth mile west of Buttermilk Springs has furnished the following species, which were identified by Ulrich:

Graptolites:

1. Leptograptus flaccidus spinifer Elles and Wood.
2. Dicellograptus patulosus Lapworth.
3. Azygograptus sp. undet.
4. Climacograptus bicornis Hall.
5. Climacograptus bicornis var.
6. Dicranograptus nicholsoni Hopkinson.
7. Dicranograptus spinifer (Lapworth) Elles and Wood.
8. Mesograptus near M. coelatus No. 1.
9. Mesograptus near M. coelatus No. 2.
10. Retiograptus (Orthograptus) cf. quadrimucronatus.
11. ?Diplograptus cf. D. acutus (Elles and Wood).
12. Cryptograptus cf. C. tricornis (Carruthers).
13. Retiolites? n. sp.?
14. Lasiograptus bimucronatus (Nicholson).

Various types of sponge spicules.

Leptobolus walcotti? Ruedemann.

Schizotreta minutula Winchell and Schuchert (cf. species in Maquoketa).

Concerning the above collection Ulrich says: "Most of the species are the same as or clearly allied to species characterizing the upper part of the *Nemagraptus gracilis* zone. Nos. 8, 9, 10, and 13 are more suggestive of the Bigfork chert and Polk Creek shale faunas. The graptolites indicate a horizon beneath the bed at the Texas tunnel mine."

BIGFORK CHERT

Definition.—The Bigfork chert received its name from the fact that it is typically developed over a large area around Big Fork post office, in the northwest corner of the Caddo Gap quadrangle. The formation is composed of chert interbedded with a small amount of shale and limestone and, as will be shown later, is known by its fossils to be of Middle Ordovician age. Its thickness can not be accurately measured owing to the intense crumpling of the beds, but it is estimated to be approximately 700 feet. In southeastern Oklahoma it is the basal part of the Talihina chert as defined by Taff.[15] The Bigfork in parts of the quadrangles under discussion was mapped by the Geological Survey of Arkansas as novaculite,[16] but it differs materially from the true novaculite of the quadrangles in being of coarser texture and darker color, in being older, thinner bedded, and nontranslucent and in having a much more complex structure.

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

[16] Griswold, L. S., Whetstones and the Novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, 1892.

The Bigfork chert is conformably underlain by the Womble shale and is conformably overlain by the Polk Creek shale, of Ordovician age, into which the Bigfork gradually passes by a thickening of its shale beds and a corresponding decrease in the number of its chert layers.

Distribution and character.—The Bigfork chert extends westward across the northern part of the Caddo Gap quadrangle, being exposed in narrow belts along the north base of the Missouri and Caddo Mountains and in the valleys of Long and Blaylock Creeks, farther south. These belts extend westward a short distance into the northeast corner of the De Queen quadrangle. They are all parallel with the adjacent high ridges, and their characteristic surface features are canyonlike valleys and low, steep-sided knobs, which are in reality foothills.

The formation, as previously defined, consists of chert interbedded with some shale and limestone. The chert is commonly in even-bedded layers having a thickness of 3 to 6 inches but at a few places thickening to 3 feet. It is very close textured and brittle and under the blows of a hammer flies into small pieces, most of which have an uneven but some a conchoidal fracture. Parts of it are finely laminated. It is black and dense when unweathered, but when weathered it ranges in color from slate to dark gray, the slate color occurring at most places. Some of the chert is rather porous and has the appearance of gray, soft, fine-grained sandstone. In some parts small quantities of calcite and pyrite are disseminated. Numerous joints, many of which are straight and have remarkably smooth glossy surfaces, form a network which cuts the layers in all directions. So numerous are the joints that it is difficult to obtain a hand specimen with fresh surfaces. In most parts the fractures along the joints are occupied by fine quartz veins containing a little calcite. The layers as a rule are greatly crumpled, and it probably was the strain accompanying the crumpling that formed the network of joints.

The shale is black, siliceous, and carbonaceous and forms even-bedded layers ranging from a fraction of an inch to several feet in thickness which are distributed throughout the formation, but it is meager or absent in places, particularly near the base. Black siliceous limestone in lenses and layers only a few inches thick occurs sporadically near the base and top.

Because of its minute jointing the formation rapidly breaks down under the action of weathering agents, and large quantities of finely broken material collect at the base of the knobs; but good rock exposures are numerous on the steeper slopes and in the stream beds.

Fossils and age.—Fossils are rare in the Bigfork chert and consist chiefly of graptolites, though other invertebrate remains, which are practically indeterminable, have been found at a few localities in the Ouachita Mountains. Sponge spicules occur in the chert in southeastern Oklahoma, but if such remains are present in Arkansas they have not been observed. The collections of graptolites have been obtained from the upper part of the Bigfork chert in the Caddo Gap quadrangle. Their localities together with their specific identifications by Ulrich follow:

SE. ¼ sec. 28, T. 3 S., R. 27 W.:
- Dicellograptus cf. D. anceps (n. sp. or var.).
- Retiograptus? (Orthograptus) quadrimucronatus.
- Mesograptus (small form).
- ?Climacograptus antiquus var.

SE. ¼ sec. 6, T. 4 S., R. 26 W.:
- Retiograptus? (Orthograptus) quadrimucronatus.
- Climacograptus antiquus (var. or young).

Northeast corner of SW. ¼ sec. 27, T. 4 S., R. 27 W.:
- Mesograptus (usual small form).
- Climacograptus antiquus.
- Retiograptus? (Orthograptus) quadrimucronatus.

Thus far the most extensive graptolite collection from the Bigfork chert in the Ouachita Mountain region has been obtained from the top 60 feet of the formation on Cedar Creek 6 miles northwest of Buckville, Montgomery County, Ark., about 12 miles north-northeast of the northeast corner of the Caddo Gap quadrangle. The species from this locality have been identified as follows by Ulrich:

- Climacograptus sp. undet.
- Dicellograptus divaricatus Hall.
- Dicellograptus cf. D. divaricatus Hall.
- Diplograptus trifidus (Gurley).
- Diplograptus vulgatus.
- Glyptograptus sp.
- Lasiograptus sp.
- Leptograptus flaccidus (Hall).
- Leptograptus sp.
- Mesograptus sp. undet.
- Mesograptus perexcavatus.
- Orthograptus sp.

Ulrich states that so far as these graptolites can be made out they suggest species found in the lower Hartfell shale of Scotland rather than any known in standard American sections. The well-marked graptolite *Orthograptus quadrimucronatus* is found in both the lower and upper parts of the Bigfork chert. In Great Britain it is confined to the upper (*Pleurograptus linearis*) graptolite zone of the lower Hartfell, and in Canada to shale that has been generally referred to the Utica. As stated by Ulrich the age of the Bigfork "according to the American standard may thus be anywhere between lower Trenton and Utica."

Other fossils, consisting of fragmentary shells, have been found in a chert layer and in associated limestone about 50 feet below the top of the formation on Blaylock Creek in the De Queen quadrangle. Concerning them Ulrich says:

Unfortunately these fragmentary remains are nearly ruined for purposes of identification by absorption and subsequent resilicification of the cavities. Possibly they represent a dozen species, but aside from a small *Hindia* it is difficult to be certain even of their respective genera. For the present it will suffice to say that the collection indicates definitely that the Bigfork chert is of Mohawkian [Middle Ordovician] age.

The fossil evidence, therefore, apparently indicates that the Bigfork chert is of Trenton age.

POLK CREEK SHALE

Definition.—The Polk Creek shale received its name from Polk Creek, in the Caddo Gap quadrangle, along the headwaters of which it is typically developed. It is a black shale of Upper (?) Ordovician age, containing a few thin, widely separated layers of chert and sandstone. Its thickness ranges from a feather edge to 175 feet, but the most common thickness is 100 feet. In southeastern Oklahoma this shale forms a minor portion of the Talihina chert.

The formation is underlain by the Bigfork chert, into which it passes by a somewhat gradual lithologic change. In the Cossatot Mountains and in a few places in the Caddo Mountains it is succeeded by the Blaylock sandstone of Silurian age; and in the Caddo and Missouri Mountains, where the Blaylock is usually absent, it is succeeded by the Missouri Mountain slate, also Silurian.

A stratigraphic break may exist between the Blaylock and the Polk Creek, but the only evidence for it is a conglomerate that has been found at the base of the Blaylock in the De Queen quadrangle. Such a break may occur also between the Polk Creek and Missouri Mountain formations in the areas where they are in contact; but the only evidence for this is the fact that the intervening Blaylock thins out to the north. An unconformity between the Polk Creek and Missouri Mountain formations in the Hot Springs district seems obvious from the character of a conglomerate that occurs at the base of the Missouri Mountain slate there.

Distribution and character.—The Polk Creek shale is exposed in the Caddo and Cossatot Mountains in both the Caddo Gap and De Queen quadrangles. In the Caddo Gap quadrangle it is present throughout the mountain belts, except in the vicinity of Prior and

Blaylock Mountains. The exposures are narrow strips which occur both on the mountain slopes and in the valleys and which are parallel with the trend of the mountain ridges. Their small width is due to the folded attitude and thinness of the formation. Although the shale is concealed by residual material from the shale itself and by débris from the adjacent strata that are exposed higher on the mountain slopes, rock outcrops are numerous, especially along ravines and stream beds.

The shale is black, fissile, and carbonaceous. In parts it is clayey, soft, and carbonaceous enough to soil the fingers in handling, but in others, especially in the lower part, it is a hard siliceous slate, sonorous when struck, and splitting with a cleavage that in places is at an angle with the bedding. On weathering it changes to a soft, gray, platy stone or disintegrates to clay. Thin layers of black dense chert like that of the Bigfork chert and thin layers of hard quartzitic sandstone are common in the formation, but they constitute a very small part of it. A lens of black oolitic limestone, which reaches 2 feet in thickness and contains many thin veins of calcite, occurs in the shale on Sugar Creek in the De Queen quadrangle.

This formation, like those below and above, has been intensely crumpled, so that in places it appears thicker than it actually is, and as a result of this crumpling it contains many slickensides and joints. Thin veins of white quartz are found along the joints and bedding planes, and small crystals of pyrite can be found disseminated through the shale in nearly all fresh exposures.

Fossils and age.—Fossils, nearly all of which are graptolites, are rather plentiful in the Polk Creek shale, especially in the basal part, and can be found in most good exposures. The following list of species, identified by Ulrich, contains most of those collected in the Caddo Gap and De Queen quadrangles:

Leptograptus? (?Dicellograptus) flaccidus trentonensis.
Dicellograptus morrisi?
Dicellograptus cf. D. complanatus Lapworth.
Dicellograptus complanatus, three new varieties.
Diplograptus (group of D. calcaratus) cf. D. incisus.
Diplograptus cf. D. acutus and Mesograptus foliaceus.
Mesograptus (?Amplexograptus), one or two species.
Mesograptus (?Amplexograptus) sp. No. 3.
Retiograptus? (Orthograptus) n. sp.
Retiolites? n. sp.

The largest graptolite collection from the Polk Creek shale in the Ouachita Mountains came from a locality on Cedar Creek 6 miles northwest of Buckville, Montgomery County, Ark., about 12 miles north-northeast of the Caddo Gap quadrangle—the same locality that yielded the large collection from the Bigfork chert (p. 38). The species as identified by Ulrich are as follows:

Amplexograptus sp. undet.
Climacograptus sp.
Diplograptus n. sp.
Glossograptus sp.
Dicellograptus aff. D. complanatus Lapworth.
Dicellograptus complanatus ornatus (Elles and Wood).
Dicellograptus cf. D. complanatus ornatus.
Dicellograptus cf. D. anceps Nicholson.
Dicellograptus forchammeri Geinitz.
Dicellograptus aff. D. forchammeri.
Dicellograptus forchammeri var. or n. sp.
Dicellograptus forchammeri var. flexuosus.
Dicellograptus elegans (Carruthers).
Dicellograptus n. sp.
Orthograptus quadrimucronatus Ami.
Orthograptus spinigerus.
Orthograptus cf. O. intermedius.
Lasiograptus.
Mesograptus sp. undet.
Nymphograptus velatus (Elles and Wood).
Retiograptus? or n. gen.

The Polk Creek shale graptolites are stated by Ulrich to be comparable with species occurring in Great Britain in the Hartfell shales, chiefly in the upper Hartfell, rather than with any species described from America. The correlation of the Polk Creek shale is further discussed in the following statements by Ulrich:[17]

In Scotland the Hartfell shales are placed at the top of the Ordovician. Lapworth divides this body of shale into two groups and recognizes three rich graptolite zones in the lower and two, separated by an unfossiliferous mudstone, in the upper. The lower group contains some species that have been identified also in America. Here most of them are confined to various horizons supposed to be of the age of the Trenton group. Others have been seen in this country as yet only in the older Normanskill shale, while the remaining two or three species are from shales now referred to the Utica. The lower Hartfell zones may thus be somewhat loosely correlated with our Trenton.

The graptolites of the upper Hartfell zones suggest two faunas in America In the Polk Creek shale we find *Dicellograptus complanatus*, which is characteristic of the lower of the two upper Hartfell zones. In America, however, this graptolite ranges with very slight modification through the whole of the Polk Creek shale. Apparently the same species is found also in the Sylvan shale of Oklahoma. Though the Sylvan shale seems to be much younger than the Polk Creek shale, a comparison of their respective faunas shows that besides *Dicellograptus complanatus*, also *Diplograptus crassitestus* and *Climacograptus ulrichi* are represented in both by indistinguishable species or close varieties.

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[17] Ulrich, E. O., The Ordovician-Silurian Boundary: Cong. géol. internat., 12^{e} sess., Compt. rend., pp. 620–621, 1914.

Perhaps the most important of the facts brought out by comparison of the British upper Hartfell graptolites with American species is the presence of *Dicellograptus complanatus* var. *ornatus* in the upper part of the Polk Creek shale in Arkansas. This well-marked variety is found in Scotland only in the upper part of the upper Hartfell—that is, in the *Dicellograptus anceps* zone. If this variety actually holds the same stratigraphic position in the two countries, and if *Dicellograptus complanatus* appeared about the same time in both places, then we might say that the essential equivalence of the Polk Creek shale and the upper Hartfell shale is assured. At the same time the upper limit of the Ordovician would be determined, in at least one American section, the same as it is in Britain.

Though the associated graptolites are perhaps less diagnostic than these dicellograptids, their evidence seems confirmatory. Compared with British species, the six or eight *Diplograptidae* of the Polk Creek shale, though perhaps in no case exactly identifiable with forms described by Elles and Wood, would yet seem not out of place in either a lower or an upper Hartfell zone. Some of them even suggest species from the younger Birkhill shale. Besides the *Diplograptidae* and the previously-mentioned dicellograptids the Polk Creek shale contains also a *Leptograptus* allied to the long-ranging *L. flaccidus*, a third *Dicellograptus*, reminding in this case of *D. morrisi*, and a *Retiolites*. The last three have been found only in the lower third of the formation.

Judging solely from internal faunal evidence, it would seem, therefore, that the base of the Polk Creek shale can not be older than lower Hartfell. That it is indeed younger and probably altogether upper Hartfell is indicated by the fact that the range of *Orthograptus quadrimucronatus* generally underlies the Polk Creek shale. In the Ouachita region this well-marked graptolite is found in the lower and upper parts of the Bigfork chert. In Britain *O. quadrimucronatus* is confined to the upper (*Pleurograptus linearis*) graptolite zone of the lower Hartfell and in Canada to shales that have been quite generally referred to the Utica.

Locally in Arkansas the upper 50 feet or more of the *O. quadrimucronatus* zone consists entirely of siliceous shale or slate. In such instances the lower boundary of the Polk Creek has been mapped so as to include a part of this zone. It seems well to add here that certain graptolite collections credited to the lower part of the Polk Creek shale remind of lower Hartfell rather than upper Hartfell zones. In fact the various local collections from shales 10 to 50 feet above the top of the Bigfork chert are often so different that it does not seem possible that they all represent the same zone. It may well turn out, therefore, that older graptolite zones than those of the upper Hartfell are locally represented in the siliceous black shales that it was found convenient to include in the Polk Creek shale rather than in the underlying Bigfork chert.

SILURIAN SYSTEM

BLAYLOCK SANDSTONE

Definition.—The Blaylock sandstone received its name from Blaylock Mountain, on Little Missouri River, in the Caddo Gap quadrangle, at the east end of which it is well exposed. It consists of sandstone and some shale, which are known by their fossils to be of Silurian age. The Talihina chert in southeastern Oklahoma, as defined by Taff,[18] does not include the Blaylock sandstone, for the

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

Blaylock is absent in that State except in McCurtain County, but the Talihina includes rocks that are both older and younger than the Blaylock. (See correlation chart opposite p. 22.)

Distribution and thickness.—The Blaylock has a smaller areal extent than most other formations of the Ouachita region. Although it occurs through the whole length of the region in Arkansas and in McCurtain County, Okla., it is limited to a narrow belt in the southern part of the region. In the quadrangles herein described its principal outcrops are in the Cross and Cossatot Mountains, though a few blocks of talus from beds probably not more than 10 feet thick are found on the Missouri Mountains in the De Queen quadrangle and on the north slope of the Caddo Mountains as far west as Statehouse Mountain in the Caddo Gap quadrangle. Its outcrops are rough, rocky strips with a nearly east-west trend and occur on mountain slopes and in narrow valleys. Rock ledges are common, but at most places the sandstone is concealed by débris. The thickness of the formation ranges from a feather edge to an estimated maximum of 1,500 feet; an accurate determination is impossible because of the close crumpling of the strata, which produces a repetition of beds in probably all places where any great thickness is exposed.

Character.—The formation consists of sandstone and shale, which differ in proportion both vertically and horizontally, though the sandstone usually occurs in greater amount. The sandstone is in remarkably even bedded layers from 1 to 6 inches thick, but in a few places the layers reach a thickness of 3 feet. It consists of fine angular quartz grains and a little mica with quartz as the cementing material, and in addition to these minerals microscopic examination of a thin section of a specimen from Bog Springs, in the De Queen quadrangle, reveals small quantities of plagioclase, orthoclase, zircon, tourmaline, pyrite, chlorite, and limonite. Most of the sandstone is hard, dense, light to dark gray, laminated, and quartzitic, but some is soft and has a yellow color and splits into more or less parallel plates when struck with a hammer. Flattened clay pellets and rather fine, crooked markings that are probably worm trails are common. Joints are numerous, and many of them are filled with thin veins of white quartz. On weathering the sandstone breaks up into angular fragments that lie scattered over the surface, and in places it turns brown but elsewhere it retains its gray color. The shale is interbedded with the sandstone and makes up a considerable part of the formation—fully 90 per cent of it in some localities in the northeast corner of the De Queen quadrangle—but in parts through 100 feet or more it is almost entirely absent, the sandstone layers coming together. It is micaceous, dark colored, argillaceous, and in many places black and fissile, but in others it is buff, thus closely resembling the Missouri

Mountain slate. In the places in the northeast corner of the De Queen quadrangle where shale constitutes the greater part of the formation most of the shale is buff, and in those areas as well as in some adjoining parts of the Caddo Gap quadrangle the contact between the Blaylock and Missouri Mountain formations is difficult to determine and can be mapped only arbitrarily.

A conglomerate, ranging from 2 to 4 feet in thickness and consisting of rounded chert pebbles in a dark-colored, siliceous, fine-grained matrix, was found at the base of the Blaylock on Sugar Creek, southeast of Shady post office, in the De Queen quadrangle. Some cavities that occur in this conglomerate were obviously once occupied by pebbles, probably of limestone, which have been removed by solution.

The Blaylock sandstone closely resembles much of the Stanley shale described below. Because of this resemblance, combined with the complexity of the structure over most of the quadranges, the authors have been temporarily at a loss to distinguish these formations in places.

Stratigraphic relations.—The Blaylock sandstone is apparently conformable with the underlying Polk Creek shale so far as concordance in the bedding of the two is concerned, but the conglomerate at the base of the Blaylock in the De Queen quadrangle, although it is of only local distribution, suggests a stratigraphic break at this horizon. The Blaylock is overlain by the Missouri Mountain slate, believed to be of Silurian age. Unfortunately contact exposures are so few as to make it difficult to determine definitely the relations of the top of the sandstone. Some features of the formation shown in this and other parts of the Ouachita region suggest an unconformity at its top. One of these features is the local occurrence of a conglomerate at the base of the Missouri Mountain slate, and another is the abrupt appearance of the Blaylock and rapid thickening from the north toward the south. Within a distance of 3 miles in the Caddo Gap quadrangle the formation increases in thickness from a feather edge to 1,500 feet. This difference may be due to an erosion interval during which the formation was removed from what was then the highest part of the region. The other feature that suggests an unconformity is the much crumpled condition of the Blaylock sandstone and underlying formations compared with those overlying it. On the other hand, little direct evidence of a stratigraphic break has been observed, and in the Caddo Gap quadrangle as well as in the De Queen the shale of the Blaylock sandstone appears to pass without lithologic change into the Missouri Mountain slate.

The alternative suggestion to account for the rapid thickening is that the formation was put down in a rapidly subsiding trough, whose northern border extended in an east-west direction across part of the Ouachita region. The suggestion to account for the intense folding is that the sandstone, because it is thin bedded, was not so competent as the overlying massive Arkansas novaculite and was crumpled by the horizontal compression movements, though beneath the great weight of overlying rocks, whereas the novaculite adjusted itself to the crustal shortening by shearing and thrust faulting. The novaculite also protected the immediately underlying Missouri Mountain slate from excessive crumpling.

Fossils and correlation.—The Blaylock sandstone is very sparingly fossiliferous. A few remains of Diplograptidae have been noted in sandstone layers at three or four localities in the Ouachita Mountain region, but these are too poorly preserved to be identified specifically. The interbedded shale on Little Missouri River at the south base of Blaylock Mountain, in the Caddo Gap quadrangle, has yielded a small collection of graptolites, which have been determined as follows by E. O. Ulrich:

Monograptus distans (Portlock).
Monograptus gregarius (Lapworth).
Monograptus argutus (Lapworth).
Monograptus aff. M. fimbriatus (Nicholson).
Dimorphograptus decussatus (Elles and Wood).
Gladiograptus perlatus (Nicholson).
Dictyonema sp. undet.

These species, as pointed out by Ulrich, are not comparable to any described forms from America but have all been described from specimens obtained in the Birkhill shales of Scotland, which are in Great Britain considered the base of the Silurian system. The Blaylock is therefore assigned by Ulrich to the early Silurian.

MISSOURI MOUNTAIN SLATE

Definition.—The Missouri Mountain slate was named from the Missouri Mountains in the De Queen and Caddo Gap quadrangles, in which it is well developed. The formation has been changed by regional metamorphism from shale to slate at most places in the quadrangles, but it is still shale at others. The Talihina chert in southeastern Oklahoma, as defined by Taff,[19] includes this slate. (See correlation chart opposite p. 22.) The Missouri Mountain slate is apparently of Silurian age, but this age assignment is based solely upon its lithologic character and stratigraphic relations, for no fossils have yet been found in it.

Distribution and thickness.—The slate is exposed in the Cross, Caddo, and Cossatot Mountains, in both of the quadrangles here

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

described. The outcrops are narrow belts which occur in some places on one side of the ridges, in others on both sides, and in still others near the crests, their position depending upon the structure—whether it is monoclinal, synclinal, or anticlinal. These three types of outcrop will be understood by reference to the structure sections of Plate 15. The surface in these belts is largely covered by residual material from the slate itself and by débris from other formations higher on the ridges, so that actual exposures are not common except on the steeper slopes and in or near stream beds. In places on the slopes of Missouri and Statehouse Mountains some of the exposures form low bluffs, most of which are even-faced, owing to the breaking off of the slate along joint planes.

The thickness ranges from 50 feet or less to 300 feet; the thinnest part occurs along the most southern outcrops, and the thickest in the Missouri Mountains.

Character.—The formation consists of shale in parts of the quadrangles, but the bulk of it is a soft clay slate that is hard enough in places to emit a clear ring when struck with a hammer. A conglomerate at the base and a few thin layers of sandstone and quartzite are present here and there. A few feet of slate at the base is green at some places, is locally somewhat sandy, and contains small crystals of iron pyrites. The slate above the basal portion ranges from blood-red to dark brownish red, but has patches and streaks of green. The green patches may be seen in stream beds and in quarries and other exposures, and the streaks, which are as much as 2 inches wide, may be seen along joints. Green may have been the original color of the slate at the base, but the color of the green patches and streaks higher in the formation is secondary, the original color being red. Some parts of the slate have weathered to a buff color. The red color is due to the presence of the red iron oxide hematite; the green color is due to chlorite.

The red and green slates are remarkably homogeneous, are in most parts dissected by joints in two or more sets running in different directions, and have well-developed slaty cleavage, which in places is parallel with and elsewhere is oblique to the bedding, permitting it to be split into thin pieces, most of which have even and glossy surfaces. The joints may be seen in all exposures. Their closeness depends upon the amount of close folding that the slate has undergone at any particular place. Where the folding has been least intense the joints are a few inches to 10 or 12 feet apart, but where it has been most intense they are a quarter of an inch or less apart, and here the slate on weathering breaks up into small prisms resembling shoe pegs.

The top 10 feet of the slate on Statehouse Mountain and the upper 50 or 60 feet on Sugartree Mountain, in the Caddo Gap quadrangle, and probably some in other parts of the quadrangles is black, but in the Hot Springs district this color is common throughout the formation. The exposed ledges and surface fragments of the slate are generally buff, black, green, yellow, or reddish brown. In weathered outcrops in the Hot Springs district the black shale is shown to pass gradually through green to buff and yellow; the last three colors are secondary.

The sandstone and quartzite are in layers from 3 to 5 inches thick and occur in places near the base and top of the formation. They are gray and hard and are composed of rounded, translucent quartz grains. On Missouri Mountain, in the De Queen quadrangle, a layer of conglomerate 15 inches thick and also thinner ones, all made up of chert pebbles in a siliceous matrix resembling novaculite. occur in the upper part of the slate. A conglomerate 1 to 4 inches thick, consisting of rounded chert pebbles in a shale matrix, was observed at the base of the slate in the water gap west of Hightop Mountain, in the Caddo Gap quadrangle. Fragments of conglomerate near the base were found in other parts of the quadrangles, but none were seen in place. Farther east, in much of the Hot Springs district, there is a basal conglomerate of rather wide distribution.

The following microscopic analyses of the red and green varieties of the Missouri Mountain slate were made by Dale:[20]

Dark reddish slate, from Mena, near Big Fork: In color this slate is somewhat darker than the "red" slate of New York. To the unaided eye it has a minutely granular texture and a roughish, speckled, almost lusterless surface. Contains very little magnetite, does not effervesce with cold dilute hydrochloric acid, is sonorous, splits readily, and has some argillaceous odor. Under the microscope it shows a matrix of muscovite (sericite), with brilliant aggregate polarization, quartz grains ranging up to 0.025 millimeter, muscovite and chlorite scales, and abundant hematite in minute dots. There are also rhombs, from 0.1 to 0.2 millimeter, of chlorite and rhodochrosite, probably pseudomorphs. No other carbonate. The constituents, arranged in descending order of abundance, appear to be muscovite, hematite, kaolin, quartz, chlorite, rhodochrosite (?), and magnetite. This slate compares favorably in texture with the "red" slate of New York.

Light-greenish slate, from the Missouri Mountain slate, locality not designated: This * * * to the unaided eye has an exceedingly fine texture and a very fine, almost lusterless cleavage surface; shows pyrite on sawn edge; contains a little magnetite; does not effervesce with cold dilute hydrochloric acid, is sonorous, very fissile, and has a slight argillaceous odor. Under the microscope it shows a matrix of muscovite (sericite), with a brilliant aggregate polarization and great evenness of texture. A very minute bed of quartz grains, chlorite, and muscovite lies in the cleavage, which is therefore the bedding also. The grain is indicated by the transverse position of some of the muscovite scales. Quartz not very abundant, but occurs in grains up to 0.037 millimeter. Rutile needles abound from 0.0028 by 0.0009 up to 0.014 by 0.0014 millimeter.

[20] Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, pp. 63–64, 1914.

Muscovite and chlorite scales occur, the latter producing the green color. There are some opaque granules (limonite? and pyrite), occasional lenses, 0.14 millimeter long, of a central mass (probably rhodochrosite), with secondary muscovite at both ends. No other carbonate. Shows a number of tourmaline prisms up to 0.025 by 0.008 millimeter. The chief constituents, arranged in descending order of abundance, appear to be muscovite, quartz, kaolin, chlorite, rutile, pyrite, magnetite, and tourmaline. This mica slate probably possesses more petrographic interest than economic value. Its fissility, freedom from carbonate, and color are very favorable, but it will probably be found too delicate for use on a roof.

Stratigraphic relations and age.—In the Cross and Cossatot Mountains and in a few localities farther north the Missouri Mountain slate succeeds the Blaylock sandstone of Silurian age. Northward in the quadrangles under discussion it overlaps that sandstone and rests upon the Polk Creek shale, of Ordovician age, at most localities in the Caddo Mountains. This overlap and a conglomerate found at the base strongly suggest a stratigraphic break at the base of the Missouri Mountain slate. The possible relations of the formation to the Blaylock sandstone are rather fully discussed in the description of the Blaylock.

The Missouri Mountain slate is apparently conformable with the succeeding Arkansas novaculite, into which it seems to grade lithologically, as indicated by the presence of thin shale beds like the Missouri Mountain slate in the lower part of the novaculite, but a conglomerate separates the two formations at Hot Springs, Ark., and in southeastern Oklahoma. This conglomerate is not known to have a general distribution in Arkansas, and its local occurrence there may not indicate an unconformity at the top of the slate.

No fossils have been found in the Missouri Mountain slate. Its correlation is therefore based upon its stratigraphic relations and lithologic character. The position of the slate between the Blaylock sandstone, of early Silurian age, and the Arkansas novaculite, the lower part of which is of Onondaga (Middle Devonian) age, indicates that this slate is Silurian or Devonian. The nearest exposures of Silurian and Devonian rocks outside the Ouachita Mountains are in the Ozark region in northern Arkansas and northeastern Oklahoma, in the Arbuckle Mountains in southern Oklahoma, and on the southwest flank of the Nashville dome in Tennessee. The rocks of these systems are poorly represented in the Ozark region and the Arbuckle Mountains, and no part of them resembles in lithology the Missouri Mountain slate. They are, however, well developed on the southwestern flank of the Nashville dome, where strata of Silurian age are succeeded by strata of Helderberg, Oriskany, Onondaga, and later age, in the order named. Although the Silurian rocks of Tennessee consist mainly of limestone, they contain considerable thicknesses of earthy and shaly limestone, which, in the basal part of the strata of Niagara age, changes in color from gray to red as the Mississippi embayment is approached. The rocks of Devonian age earlier than the Onondaga in Tennessee contain no beds with a red color. It seems reasonable, therefore, to assume that the Missouri Mountain slate is equivalent to at least a part of the Silurian rocks in Tennessee. If this supposition is true, the absence of calcareous deposits of this age in the Ouachita Mountains and their presence in the Arbuckle Mountains, the Ozark region, and the Nashville dome may be accounted for by the varying topographic features on the land area that supplied the clastic material and by variations in the character of the material and in the conditions of its deposition. The authors believe that the low-lying, deeply weathered land mass that supplied the red mud for the Missouri Mountain slate existed in northern Louisiana and eastern Texas, where it is now concealed by Cretaceous and younger sediments.

If the reference of the Missouri Mountain slate to the Silurian system is correct, it follows that strata of Helderberg and Oriskany age are not present in the quadrangles under discussion. Their absence may be attributed to an unconformity at the top of the slate, for which there is some evidence, though not enough to be conclusive.

DEVONIAN SYSTEM

ARKANSAS NOVACULITE

Definition.—The Arkansas novaculite consists predominantly of novaculite with subordinate though considerable amounts of shale and conglomerate.

Novaculite as it is found in the Ouachita Mountains of Arkansas and Oklahoma is a gritty, fine-grained, homogeneous, highly siliceous rock, possessing a conchoidal or subconchoidal fracture and being translucent on thin edges. The name novaculite was first applied to the rock by Henry R. Schoolcraft in 1819. The authors regard it as belonging to the class of cherts.

The occurrences of novaculite are not as common as the occurrences of other sedimentary rocks, such as shale, sandstone, and ordinary chert, but it is widely distributed in the quadrangles herein described and in other parts of the Ouachita Mountains. Although the novaculite is exposed throughout much of the length of these mountains, a distance of about 200 miles, it is thickest and best developed and has its largest areal extent in Arkansas. Hence the formation has been appropriately named the Arkansas novaculite. The novaculite corresponds to the upper part of the Talihina chert of southeastern Oklahoma.

Distribution and surface form.—Within these quadrangles the Arkansas novaculite is exposed in the Cross, Caddo, and Cossatot

Mountains. Here, as in other parts of the Ouachita Mountains, the outcrops are narrow, more or less parallel, nearly east-west belts, whose small width is due to the steep dip of the formation. Owing to the narrowness of the belts and to the greater resistance of the novaculite to weathering than that of the adjacent strata above and below, its outcrops stand up as sharp ridges, whereas the older and younger rocks form intervening valleys. Consequently the mountainous districts of the quadrangles present a corrugated surface when viewed from any of their highest elevations.

The crests of the ridges attain a common elevation, but rising above them are low peaks whose existence is due to local synclinal or anticlinal folds in the novaculite. Prominent among these peaks are Tall Peak, Raspberry Peak, East Hanna Mountain, West Hanna Mountain, Eagle Mountain, High Point, and Whisky Peak, in the De Queen quadrangle; and Brushheap, Hogpen, Hightop, Tweedle, Wilson, and Strawn Mountains, in the Caddo gap quadrangle.

The brittleness of the novaculite and its many joints cause it to break down into angular blocks and fragments which cover the ridges in most places, but in others, particularly along the crests and in the water gaps, the edges of the beds project through the débris as rough bare ledges, some of which are several feet high. (See pl. 7, *A*.) On the west side of Board Camp Creek in the De Queen quadrangle, a single bare ledge of novaculite 3 to 6 feet thick juts out on a hill slope and rises vertically above the creek to a height of about 75 feet. It is known as Standing Rock. (See pl. 2.) About one-tenth of a mile north of this ledge, on the east side of the same stream, is a similar though lower projecting ledge known as Devil's Pulpit.

Thickness.—The Arkansas novaculite is thickest in the Caddo, Missouri, and Cossatot Mountains, where, in many places, if not in most, it is about 900 feet thick. The greatest known thickness is 950 feet and was measured 1 mile west of West Hanna Mountain. At Caddo Gap the formation is about 890 feet thick. It decreases in thickness both northward and westward. Along the northern border of the De Queen quadrangle it is in places only about 250 feet thick, and on account of this northward thinning the ridges composed of it become lower in this direction. In the Cross Mountains the formation ranges in thickness from 300 to 550 feet.

Character.—The formation, as developed in these quadrangles and in many other parts of the Ouachita Mountains, consists of three lithologic divisions—a lower one, made up almost entirely of massive, white novaculite; a middle one, consisting mainly of thin layers of dense, dark-colored novaculite interbedded with shale; and an upper one, consisting chiefly of massive, highly calcareous novaculite. These divisions differ in thickness and character from place to place.

The lowest part commonly ranges in thickness from 150 to 300 feet, but reaches a maximum of 410 feet at Caddo Gap and a minimum of 10 feet in the extreme northeast corner of the De Queen quadrangle. This division is made up almost wholly of typical novaculite, whose color and massiveness make it the most conspicuous part of the formation. In fact, it is this part that occupies the crests of the ridges. The beds range from 2 to 10 feet in thickness and are generally uniform, though in places thin lenses wedge in between them. Some of the exposed bedding planes show large, uneven ripple marks. At a number of places beds of red and buff and less commonly black and green shale reaching 15 feet in thickness are interbedded with the basal layers of this division of the formation.

The massive novaculite is fine grained, homogenous, highly siliceous, translucent on thin edges, and white with a bluish tint, but where unweathered it is bluish gray. It possesses an uneven to conchoidal fracture and a waxy luster like that of chalcedony. Though the bulk of the novaculite is white, much of it is colored in various shades of red, gray, green, yellow, brown, and in many places black; the darker colors are prevalent in the lower 50 to 75 feet. These colors are produced by iron and manganese oxides and possibly in some places by carbonaceous matter. In parts, especially near the base, the novaculite has fine parallel laminations, and much of it contains a few cavities that are oval in cross section and half an inch in their longest dimension. The fresh unweathered novaculite contains a little calcite in particles of microscopic size uniformly disseminated through it, but exposures of the calcareous stone are few and have been found only in stream beds and in road cuttings through water gaps. Much of the white novaculite, as pointed out by Owen,[21] is "equal in whiteness, closeness of texture, and subdued waxy luster, to the most compact forms and white varieties of Carrara marble; and, though of an entirely different composition, it resembles this in external physical appearance so closely that, looking at specimens of these two rocks together, it is difficult to distinguish them apart." Joints in several sets are numerous and run in all directions, but the most prominent are those normal to the bedding. Many of them are occupied by white quartz veins, which are usually so thin as to be inconspicuous. Slickensides along both joints and bedding planes are common.

The middle part of the formation ranges in thickness from a minimum of probably 75 feet in the vicinity of East Hanna Mountain to a maximum of 525 feet near West Hanna Mountain. It consists

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[21] Owen, D. D., Second Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas, p. 23, Philadelphia, 1860.

chiefly of interbedded shale and novaculite. The novaculite is similar to that in the lower, massive part of the formation, except that the common color is dark gray to black and that the beds are much thinner, usually ranging from 1 to 6 inches in thickness. Moreover, some thin layers are argillaceous and possess a fairly good cleavage, resembling in these respects a highly siliceous shale. The whole division is cut by many joints, some of whose faces are so smooth that they look as if they had been polished. In some places the novaculite layers are partly and in others wholly replaced by beds of conglomerate from 1 inch to 2 feet thick. The matrix of this conglomerate is very compact novaculite; its pebbles are small and well rounded to subangular, and the larger percentage are composed of novaculite, though some are of sandstone or other hard rock. Where these beds are present, fragments from them form conspicuous débris, attracting attention because of their smooth, spotted joint surfaces, which are at right angles to the bedding and are straight and even, irrespective of the hard pebbles.

The shale ordinarily observed is black, weathering to a buff or brown color, and it occurs in beds of uniform thickness, ranging from a fraction of an inch to 70 feet. It is usually fissile argillaceous shale, but in places has been hardened to slate. Much of it is notably like the lower part of the Stanley shale. On Shields Creek, in the Caddo Gap quadrangle, 20 feet of the shale and in other places a smaller part of it is red. Although the red shale resembles the Missouri Mountain slate, it differs in having dull cleavage surfaces and in exhibiting on the cleavage surfaces faint elongated markings parallel with the bedding.

The upper part of the formation, though of considerable east-west extent in the Ouachita Mountains, is present, so far as known, only along their southern border, having been planed off on the north during the post-Devonian erosion interval that followed the deposition of the materials forming the novaculite. It is believed to be present everywhere in the two quadrangles. Its thickness ranges from about 20 to 125 feet, and the thickest parts are along the most southern exposures of the formation. So resistant is this part of the formation that in some places where it and the underlying beds of the formation are not overturned it produces low ridges and knobs on the slopes of the higher ridges. The best example of such ridges and knobs is along the south side of the first ridge north of Dog Mountain, in the De Queen quadrangle. This part of the formation consists chiefly of massive, highly calcareous light-gray to bluish-black novaculite with some thin beds of ordinary dense chalcedonic novaculite like that characteristic of the middle and lower parts of the formation. Some of the calcite apparently contains manganese and is hence a manganiferous calcite. Honess[22] has found manganese carbonate to be abundant in the upper division of the formation in McCurtain County, Okla. Fine lamination parallel with the bedding is common. On weathering, the more calcareous rock loses its calcium carbonate, becomes white or cream-colored, porous, and soft enough to receive impressions from the hammer without breaking, and shows a great many oval and irregular-shaped cavities like those in the basal division of the formation. These cavities are due to the removal of calcium carbonate through solution. The shape of some of the cavities suggests that they may be casts of poorly preserved shells.

Near the Arkansas-Oklahoma line a few lenses of dark-gray, finely crystalline nonmagnesian limestone as much as 15 inches thick are interbedded with the calcareous novaculite in the upper part of the formation. The limestone, as well as the associated novaculite, contains well-rounded grains of translucent detrital quartz, which are visible with the aid of a pocket lens. Although some dense, hard novaculite is present in most if not all places, this part of the formation becomes less calcareous and more siliceous northward in the quadrangles, and in some localities it consists entirely of novaculite like that in the basal division of the formation.

The microscopic study of thin sections of the novaculite shows that the calcite occurs as small rhombohedra and irregular-shaped aggregates, which are embedded in what may be considered a fine-grained groundmass consisting entirely of cryptocrystalline quartz. The calcite contains a trace of magnesium, and some of it has been replaced by secondary quartz. The rhombohedra are usually 0.05 to 0.08 millimeter across and are bounded by straight walls in which the quartz granules are packed like a course of masonry, none being included in the calcite. Away from the walls of the rhombohedra, the small quartz grains are arranged irregularly but without any pore space between them. They are angular and generally average less than 0.1 millimeter across, though a few widely separated grains are much larger and have rounded outlines. The fine grains are not cemented but, as Griswold states, seem merely to be jammed together, the tenacity of the stone apparently being due to the interlocking of the irregular edges of the grains.

The Indians used the novaculite extensively for their stone implements. Many tools made of this rock are found in these quadrangles as well as in adjoining areas, and the old workshops along the streams where they were fashioned can still be identified. Most of the material used was quarried from the massive novaculite at the

[22] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 113–114, 137, 1923.

base of the formation, but some implements were made from the well-rounded novaculite pebbles found in the Cretaceous and later deposits of the Coastal Plain.

The following section of the Arkansas novaculite was measured in Caddo Gap, where the strata dip 80° S.:

Section of Arkansas novaculite on east side of Caddo River at Caddo Gap

	Ft.	in.
Stanley shale: Buff shale with subordinate amount of dense, fine-grained siliceous yellow stone in thin layers. Fragments of novaculite conglomerate were observed several feet south of this outcrop. On the slope on the west side of Caddo River boulders of this conglomerate are thick on the slope, their parent bed being in buff-colored shale	40	
Arkansas novaculite:		
Upper division—		
Dark-colored dense novaculite in two layers	1	10
Concealed	1	
Massive white novaculite in beds ranging in thickness from a few inches to 3 feet. Much of it is dense and hard, though most of it is porous and soft, crumbling into a white powder when struck with a hammer. Slickensides were observed near the middle of the bed	115	
Middle division—		
Buff to red, though at the top somewhat greenish shale containing minute yellow specks and many thin layers of dense light-colored novaculite, which is in part laminated	11	
Thin-bedded, dense, black novaculite. Interbedded shale is in subordinate amount at base, but nearer the top it predominates	14	
Layer of black, dense novaculite, the lower half of which is a minutely pebbled conglomerate and contains numerous conodonts		6
Black, dense, thin-bedded, laminated novaculite with subordinate amount of drab, interbedded shale	21	
Black, minutely pebbled novaculite conglomerate containing numerous conodonts		1
Black, dense novaculite and dark-colored shale	2	
Concealed	65	
Black and greenish-gray clay shale with a few thin layers of dense novaculite. Conodonts, linguloids, and sporangites were collected from thin layers in this bed	19	
Dense black novaculite in thin layers, some 1 foot thick. Some of the layers have poor cleavage and others are finely laminated with parallel black and white bands; a few contain sand. Black shale in thin layers alternating with those of the novaculite makes up half or nearly half of this bed. The strata are intensely jointed and are somewhat contorted, so the actual thickness would be less than here indicated	230	
Concealed	1	

Arkansas novaculite—Continued.

	Ft.	In.
Lower division—		
Much jointed, white, dense, novaculite. Bedding can not be detected because of joints. An exposure of 40 to 45 feet at one place is apparently an exposure of a single massive bed. Slickensides are common in places. At the top, which is toward the south, the novaculite is brecciated, the fragments being cemented together and partly replaced by limonite. A coating of manganese oxide is common along the joints	115	
White dense novaculite in massive beds, some about 10 feet thick. In places thin lenses wedge in between the thicker beds. The whole is much jointed. Small oval cavities and fine laminations are present in some layers. At the top there are thin coatings of manganese oxide along the joints. Some of these coatings are small concentric rings	215	
Yellow hard shale interbedded with probably an equal amount of dense, white to yellow novaculite in thin layers	29	
Dense white novaculite, most of whose beds are less than a foot thick. The top bed is 3 feet thick and in its upper 2 or 3 inches are subangular to angular pebbles or fragments of novaculite	35	
Black and buff shale interbedded with thin layers of dense novaculite	16	
Missouri Mountain slate: Red and buff slate.		
	891	5

Origin of the novaculite.—The following summary, partly taken from Branner,[23] is sufficient to show the various theories advanced to explain the origin of the novaculite. The most comprehensive papers are those by Griswold, Rutley, and Honess, which are cited below.

Owen[24] considered the novaculite a metamorphosed sandstone. Branner[25] suggested that the compact novaculite may be metamorphosed chert. Comstock[26] regarded many of these rocks as hot-water deposits. Griswold[27] regarded the novaculite as a sandstone of extremely fine grain and maintained that the very argillaceous shale associated with the novaculite grades into siliceous shale and then into transparent novaculite, and that it is therefore shale minus the argillaceous component. Rutley,[28] in a review of the subject, reached the conclusion that the novaculite has resulted from the replacement

[23] Branner, J. C., On the Origin of Novaculites and Related Rocks: Jour. Geology, vol. 6, pp. 368–371, 1898.

[24] Owen, D. D., Second Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas, pp. 23–25, 1860.

[25] Branner, J. C., Arkansas Geol. Survey Ann. Rept. for 1888, vol. 1, p. 49 [footnote], 1888.

[26] Comstock, T. B., Report upon Preliminary Examination of the Geology of Western-Central Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 1, pp. 95 and 129, 1888.

[27] Griswold, L. S., Whetstones and the Novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, 1892.

[28] Rutley, Frank, On the Origin of Certain Novaculites and Quartzites: Geol. Soc. London Quart. Jour., vol. 50, pp. 377–392, 1894.

by silica of dolomite or dolomitic limestone. Hinde,[29] on hearing Rutley's paper, expressed the opinion that the rock is of organic origin. Derby [30] held the view that it is the product of a replacement of limestone by silica. Weed [31] expressed the opinion that it was formed as a chemical precipitate in a deep sea and that although it has been hardened it has otherwise been very little altered. Van Hise [32] was inclined to believe that it may be largely an organic precipitate, although now completely recrystallized so as to be composed of perfectly fitting granules of quartz. C. L. Baker,[33] who has studied the Arkansas novaculite and the Caballos novaculite of the trans-Pecos region of Texas, which is regarded by E. O. Ulrich as of Onondaga age and therefore equivalent to the lower division of the Arkansas novaculite, says: "In the field, in the hand specimen, and under the microscope I found nothing that I could consider as doing anything but support Branner's view that the novaculites are simply metamorphosed cherts." Honess,[34] who has made a thorough study of the Arkansas novaculite in McCurtain County, Okla., found volcanic ash in the formation in exposures near Wright City. From the occurrence of the ash he suggests that at least some of the novaculite is silicified and devitrified volcanic ash, but in the absence of positive evidence for proving the suggestion he believes that the novaculite was formed by chemical precipitation, without the aid of organisms.

The opinion held by the authors of this report and the basis for it may be stated as follows: The rounded, translucent grains of quartz that may be seen with the aid of a pocket lens in about equal numbers in both the highly calcareous novaculite and in the interbedded nonmagnesian limestone found in the upper division of the formation near the Arkansas-Oklahoma line west of Grannis, Polk County, Ark., are obviously detrital. Such grains make up the small amount of sandstone found in the novaculite, and the microscope shows that they are also sparsely disseminated through the chalcedonylike novaculite that constitutes the bulk of the formation. But the close-fitting arrangement of the grains of cryptocrystalline quartz in the highly calcareous and the chalcedonylike novaculite, which grade into each other, and the absence of any cementing material in

[29] Hinde, G. J. (discussion of Rutley's paper): Geol. Soc. London Quart. Jour., vol. 50, pp. 391–392, 1894.

[30] Derby, O. A., Notes on Arkansas Novaculite: Jour. Geology, vol. 6, pp. 366–368, 1898.

[31] Weed, W. H., Geological Sketch of the Hot Springs District, Ark.: 57th Cong., 1st sess., S. Doc. 282, p. 84, 1902.

[32] Van Hise, C. R., A Treatise on Metamorphism: U. S. Geol. Survey Mon. 47, p. 853, 1904.

[33] Davis, E. F., The Radiolarian Cherts of the Franciscan Group: California Univ. Dept. Geology Bull., vol. 11, No. 3, p. 334, 1918.

[34] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 138–139, 1923.

these rocks indicate that the fine-grained quartz in them is not of detrital origin. In other words, the novaculite is not a fine-grained quartzite but a chert. The absence of indications of any such pronounced regional metamorphism in the Ouachita region as would be necessary to have produced quartzite of a texture like the novaculite further supports this view, because if such metamorphism had occurred surely much of the sandstone of the region would also have been changed to a quartzite as dense as the novaculite.

That the silica which formed this quartz was deposited in the sea simultaneously with the other material of the formation seems evident, because the novaculite is overlain, underlain, and in part interbedded with beds of clay shale so impervious that they would have prevented the free circulation of the underground water necessary to introduce from other sources the large amount of silica required as replacement material. To be sure, the extensive jointing of the shales has made them somewhat pervious, so that in places the underground water circulates in them freely, but the usual even distribution of the silica everywhere in any particular layer or bed of the novaculite precludes the possibility that it was introduced subsequent to the jointing. Besides, the jointing of the novaculite beds themselves shows that these beds were siliceous when the jointing took place.

The silica may have been derived from siliceous organisms, or from chemical precipitates, or from both. No remains of organisms, such as those that have contributed their silica to the formation of certain cherts in other parts of the world, have been found in the novaculite. Their apparent absence would seem greatly to reduce the possibility of such a source for the silica, for if the remains of such organisms were ever present it does not seem probable that the solution and recrystallization of the silica and calcite would have destroyed them everywhere in an area so large as that occupied by the novaculite. The authors therefore believe that the silica for the novaculite was deposited in the sea by chemical precipitation.

Age and stratigraphic relations.—The Arkansas novaculite conformably succeeds the Missouri Mountain slate, but a conglomerate of local distribution at its base in Arkansas and Oklahoma indicates emergence in at least a small area before or during the early part of Arkansas novaculite time. The formation is unconformably succeeded by rocks of Carboniferous age—in the quadrangles herein described by the Stanley shale, but in much of the Hot Springs district and in adjoining areas by the Hot Springs sandstone, which is a lenticular formation underlying the Stanley. This unconformity is shown by the apparent thinning out of the beds at the top of the novaculite near Hot Springs and by a heavy conglomerate of wide though not general distribution at the base of the Carboniferous rocks at and near Hot Springs.

The only fossils thus far found in the formation in Arkansas comprise silicified wood and a single collection of many conodonts from a minutely pebbled novaculite conglomerate and of conodonts, small linguloids, and sporangites in associated shale. These have been obtained from the middle division of the formation. The wood was found at two localities near Glenwood. The other fossils were procured at Caddo Gap, and upon them Ulrich bases the opinion that the middle and perhaps also the upper division are to be correlated with the Woodford chert in the Arbuckle Mountains and with the Chattanooga shale. He believes, however, that a small part of the middle division is of the same age as the Genesee shale of the Appalachian region. He assigns the Woodford and the Chattanooga to the Mississippian series, and he accordingly assigns to this series these two divisions of the Arkansas novaculite, with the exception of the part of Genesee age; but the United States Geological Survey classifies the Woodford chert and the Chattanooga shale as Devonian (?). As the whole of the Arkansas novaculite is still treated as a unit the lower part of which is Devonian, its middle and upper divsions are also tentatively assigned to that age. Ulrich[35] stated in 1911 that the Arkansas novaculite "can not be younger than the Waverlyan and is most probably much older—that is, Oriskanian." From a study of fossils collected by him from novaculite beds resembling the Arkansas novaculite near Ti, Okla., he now holds that only the lower division, which he regarded as Oriskany in 1911, is of Onondaga (Middle Devonian) age. The novaculite beds near Ti underlie a bed of chert, which not only holds the same stratigraphic position as the Woodford chert of the Arbuckle region but has precisely the same lithologic character.

Ashley[36] has expressed the view "that the novaculite of Arkansas was deposited at the same time as the Camden chert of Tennessee and the Clear Creek chert of Illinois, and is of the same age." The authors of this report have also held this view, because the Camden chert in its color, hardness, luster, density, fracture, and fineness of grain resembles to a marked degree some of the more calcareous stone of the Arkansas novaculite, especially that in the upper division. Moreover, this opinion is apparently supported by the facts that novaculite is not a common rock and that the Arkansas novaculite and Camden chert are not distantly separated. No stratigraphic or other evidence is known which militates against this view except that of the above-mentioned fossils from the middle and upper divisions of the formation. If these fossils indicate Upper Devonian

[35] Ulrich, E. O., Revision of the Paleozoic Systems: Geol. Soc. America Bull., vol. 22, p. 477, 1911.

[36] Ashley, G. H., The Camden Chert—An Ideal Road Material: Resources of Tennessee, vol. 1, pp. 42–43, 1911.

age for the middle and upper divisions of the formation, it follows that only the lower division, which contains the greatest amount of typical novaculite and which at least locally has an unconformity at its top, is of the same age as the Camden chert. This conclusion is thus the same as that of Ulrich.

Schuchert[37] in 1908 regarded the Camden chert as being of Oriskany age and the same opinion has been held by Ulrich[38] and by Pate and Bassler;[39] but Dunbar,[40] who has recently studied the Devonian rocks, including their faunas, in western Tennessee, concludes that the typical Camden chert is of Onondaga and not of Oriskany age. Furthermore, Dunbar[41] has differentiated and named as formations certain rocks that formerly have been included in the lower part of the Camden chert. The oldest of these formations (named by him the Decaturville chert) he regards as being of Helderberg age; the next (his Quall limestone), as of Oriskany age; and the youngest (his Harriman chert), as of Oriskany age. The Camden chert as restricted by Dunbar and the chert he designates the Harriman chert are described by him as really being novaculite, and it is these two formations that the authors observed at various places in Tennessee and regarded as having much the same lithologic character as the Arkansas novaculite. Ulrich concurs in Dunbar's conclusions regarding the age of these cherts and thus correlates the lower part of the Arkansas novaculite with the Camden chert as restricted by Dunbar.

A single fragmentary specimen of *Leptocoelia flabellites* has been found by Honess at the top of the lower division of the novaculite formation on Bog Springs Mountains, 150 paces north of the south quarter corner of sec. 5, T. 3 S., R. 27 E., Oklahoma.[42] The locality is on the west border of the De Queen quadrangle. This species is a characteristic Devonian form and is stated by Dunbar to be very common in the Camden chert.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES

STANLEY SHALE

Definition.—The Stanley shale took its name from the village of Stanley (formerly spelled Standley), in Pushmataha County,

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[37] Schuchert, Charles: The Paleogeography of North America: Geol. Soc. America Bull., vol. 20, p. 544, 1910.

[38] Ulrich, E. O., op. cit., pl. 28.

[39] Pate, W. F., and Bassler, R. S., The Late Niagaran Strata of West Tennessee: U. S. Nat. Mus. Proc., vol. 34, p. 427, 1908.

[40] Dunbar, C. O., Stratigraphy and Correlation of the Devonian of Western Tennessee; Tennessee Geol. Survey Bull. 21, pp. 88–90, 1919.

[41] Idem, p. 33.

[42] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 117, 1923.

Okla. It consists mainly of shale, though it contains much sandstone and a little tuff and conglomerate. The thickest bed of tuff, which is near the base, has been mapped and is herein described as the Hatton tuff lentil, taking its name from the village of Hatton, in the De Queen quadrangle, where it is excellently exposed. In places shale at the base has been changed to a slate that was formerly called the "Fork Mountain slate," from Fork Mountain, where it is well developed.[44] The Stanley belongs to the Carboniferous system, and represents a part of the Mississippian series. Except the tuff and conglomerate none of the beds have distinguishable characteristics. On this account and because the formation is much folded, the exact determination of the thickness is impossible, but an approximate thickness of 6,000 feet was measured from 1 to 2 miles southwest of Glenwood, in the Caddo Gap quadrangle.

Distribution.—The Stanley shale is the surface rock in the Mazarn and Cove Basins, over most of the Athens Plateau, and in the narrow valleys in the mountainous districts—an area of outcrop much larger than that of any other formation. The sandstone of the Stanley weathers so easily that it nowhere produces prominent ridges. In fact, the formation is exposed only in valleys, basins, or low plateaus.

Character.—The shale that constitutes the greater part of the formation is argillaceous, though much is sandy; it breaks into thin, hard plates with smooth glossy surfaces showing small mica flakes, and in most places it is bluish black but in others black. Here and there at the base it is carbonaceous enough to blacken the fingers when they are rubbed over fresh surfaces. The dark colors prevail along most of the streams and in the deeper artificial exposures where the shale is not weathered, but the colors usually seen along the roads and in other exposures away from the streams are green, yellow, or brown, the shale in such places having been weathered. The shale is much crumpled—in fact, the crumpling is so great in places that the bedding can not be made out except where sandstone layers are exposed. Joints cut the shale in all directions, and many of them are occupied by quartz veins. Residual quartz from these veins occurs in sufficient quantity to whiten the surface in some of the more level parts of the country, as around Blanchard, Grannis, Wickes, and Vandervoort. Most of the veins are a fraction of an inch thick, but some are more than 1 foot thick; a few that have the same strike as the folded strata can be traced for a mile or more. Quartz is usually the sole mineral occupying these veins, though other minerals, among which are lead, zinc, and antimony minerals, occur at a number of places in the De Queen quadrangle. The metallic minerals just mentioned have been mined from time to time near Gillham.

[44] Purdue, A. H., The Slates of Arkansas: Arkansas Geol. Survey, 1909.

The final product of weathering of the shale is a yellow or red clay that is only a few inches thick in most places.

In parts of the northeast corner of the De Queen quadrangle and in the adjoining part of the Caddo Gap quadrangle shale at the base of the formation as much as 150 feet thick has been changed to a slate, to which, as previously stated, the name "Fork Mountain slate" has been applied. In some places the fresh part of this slate is dark gray, with here and there a thin black layer, and in others it is black throughout, whereas the exposed portion, which usually forms small bluffs, is reddish and yellow. The parts so altered are similar to weathered parts of the Missouri Mountain slate. Slaty cleavage is so well developed that the slate easily splits in thin sheets, and slate quarries have been opened in it, but much crumpling and the abundance of joints, including both dip and strike joints, render most of the bed worthless for commercial slate. In some localities thin flinty layers, many of which resemble novaculite, and a few layers of quartzite are present. These layers occur in greatest numbers at the base of the formation, not only where the shale has been altered to slate but elsewhere. They reach a thickness of 15 inches, but the most common thickness is 2 to 3 inches.

Sandstone constitutes about one-fourth of the formation and although it occurs throughout the formation, there is more in the lower and upper parts of the formation than in the middle. The fresh rock is hard, tough, compact, quartzitic, rather fine grained, and greenish or bluish gray and occurs in layers as much as 18 feet thick, most of which are interbedded with some shale, though numerous successive layers aggregating several hundred feet in thickness are interbedded with little shale. Only a few beds have a light-gray color. At places near the top and base of the formation some of the quartz grains of which the sandstone chiefly consists are larger than usual, and therefore some of the sandstone is coarse grained, and some is even millstone grit. The grains are mainly angular, though some are rounded. Besides quartz the minerals that are present, as determined through microscopic examination of thin sections, are orthoclase, plagioclase, microcline, tourmaline, calcite, pyrite, magnetite, zircon, and chlorite. Chemical tests show that a phosphate, probably apatite, is also present but in small amount. Some of the feldspar grains are fresh, but the others are altered to kaolin. Quartz is the cementing material, and some grains of that mineral are enlarged by secondary quartz. The sandstone, like the associated shale, contains thin quartz veins, a few of which carry calcite.

So readily does the sandstone break down on weathering that it forms few prominent ridges, and very little shows on the surface except along the roads and streams. The altered sandstone is soft, porous, more or less earthy, and green, yellow, or brown. Weathering has reached to the greatest depths in the more level areas, but even there the hard, unaltered rock is usually only a few feet below the surface. Besides soil, the material above the hard rock in those areas consists mainly of white or cream-colored sandstone that is soft enough to crumble between the fingers, though such sandstone contains a few unaltered boulders and some thin streaks of limonite. (See pl. 7, *B*.) Most of the sandstone boulders found on the surface have weathered by exfoliation like igneous rocks and have become rounded. If such boulders are broken open the weathered portion of many of them is found to be merely a thin though sharply defined surficial zone inclosing unaltered rock.

In some parts of the quadrangles a bed of conglomerate ranging in thickness from a feather edge to 15 feet rests upon the Arkansas novaculite, and in places there is a similar conglomerate that is separated from that formation by 20 to 75 feet or more of shale. These conglomerates consist of dark and light colored angular to subangular pebbles of novaculite embedded in a matrix of dense siliceous material resembling novaculite.

A bed of dense black chert 2 to 6 inches thick occurs in the formation, probably near the middle.

Widely separated layers, lenses, and nodules of phosphate rock, whose greatest observed thickness is 1½ inches, occur in shale in the basal part of the formation, both above and below the Hatton tuff lentil, in the vicinity of the Cross Mountains. A few small nodules of phosphate were seen near Gillham, but these are probably near the middle of the formation. This rock is black, has a rather high specific gravity, and weathers to a white or yellow color on exposed surfaces. Its fracture ranges from platy and uneven to conchoidal. Chemical analyses of two samples show that they contain 6.08 and 10.56 per cent of phosphorus pentoxide, which is equivalent to 13.28 and 23.07 per cent of tricalcium phosphate, respectively.

A number of beds of tuff, all of which are very similar in lithologic character, occur near the base of the formation in the northern and western parts of the De Queen quadrangle. The chief difference between them and the sandstone of the Stanley is that they contain much feldspar in large grains and the sandstone only a small quantity of this mineral. According to Williams[45] these beds were first observed and noted by J. Perrin Smith and were afterwards examined by R. A. F. Penrose, jr. Williams, who studied hand specimens and thin sections, states in his brief description of the rock that it contains much detrital igneous material, and he called it the "Polk County

[45] Williams, J. F., The Igneous Rocks of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 2, pp. 375–376, 1891.

ash bed." The tuff has been observed by other geologists, who have applied the names "igneous rock," "tuff," "basic igneous dikes," and "graywacke" to it. The tuff is here described only briefly. A full description of the tuff in McCurtain County, Okla., is given by Honess[46] in a report which was published after the present report was written.

The lowest and thickest of the tuff beds is the Hatton tuff lentil. The distribution of this lentil and the partial distribution of the thinner beds are represented on Plate 3. The Hatton tuff is exposed in or near the Cross Mountains and within a small area at the west end of the ridges in the northeastern part of the De Queen quadrangle. Farther east and north it loses its distinguishing characteristics and changes to a sandstone not unlike other sandstones in the Stanley shale. A change of the tuff to sandstone may be seen in a hand specimen, even where the tuff is typically developed. The exposures are narrow bands, which are marked in many places by low ridges but in others by no distinctive topographic feature. Although rock ledges are numerous, only a row of large, exfoliated, spherical boulders indicates the existence of the underlying tuff at many places. Notwithstanding this the tracing of the bed across the country is rather difficult on account of the dense undergrowth of young timber usually found in this region. The best outcrop is in the railroad cut half a mile south of Hatton, where the lentil was first observed by the authors. (See pl. 8, *B*.)

The Hatton tuff in and near the Cross Mountains is usually 90 feet thick, but at the west end of the mountains, in the northeast corner of the De Queen quadrangle, it is much thinner and probably does not exceed 30 feet, which is the thickness at Gillham Springs. At Hatton it is separated from the Arkansas novaculite by about 140 feet of shale containing some argillaceous sandstone. Farther northeast the beds between the Hatton tuff and Arkansas novaculite are much the same in thickness and character as they are at Hatton, but southwest of Hatton they are thicker, probably 300 or 400 feet, and contain a larger proportion of sandstone. They contain the previously described beds of conglomerate that are near the base of the Stanley, and they are of the same age as the slate of the Stanley that has been called the "Fork Mountain slate."

There are two and possibly three or four of the thinner beds, which range in thickness from 6 to 40 feet. They all dip at high angles and crop out as east-west bands only a few paces wide. None of them can be followed more than a few miles, owing to the thinning out of the beds, to the lack of continuous exposures, and to their changing

[46] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 139–202, 1923.

to sandstone, with which they are usually associated. The two belts that were traced the greatest distance are exposed in and near the village of Cove. They are the outcropping edges of the same bed, 30 to 40 feet thick, and are exposed in a closely compressed anticline. The northern belt, which extends through the village, is the northern limb of the anticline, and the southern belt, which passes a little less than a quarter of a mile to the south, is the southern limb. About 500 feet of shale and sandstone beneath the tuff is exposed at Cove without revealing the Hatton tuff below.

All the tuffs, including the Hatton tuff, are similar in lithologic features. They are so massive and homogeneous and their joints are so well developed that if bedding planes exist they are, in most if not all places, confused with the joints, but the bedding can be determined by the parallel arrangement of numerous green, flattened pellets of chloritic material that are usually present in some parts of the beds. The color of the unweathered rock is dark gray with a greenish tinge, but that of the weathered rock, which consists of a layer usually less than an inch thick over the surface of the exposed parts, ranges from light greenish gray on the surface to brown next to the fresh portion. The rock is tough and compact and like other beds in the Stanley contains quartz veins, but the veins seem more numerous in the Hatton lentil than elsewhere in the Stanley. In its macroscopic character it strikingly resembles a porphyritic igneous rock. The largest conspicuous grains are feldspars, which are usually 2 millimeters or less in diameter, but some are as much as 5 to 7 millimeters. (See pl. 8, *A*.) On weathering, the grains of feldspar kaolinize and become white, giving the rock a spotted appearance. Other minerals that occur in various amounts and mostly in grains of microscopic size are quartz, muscovite, magnetite, pyrite, zircon, apatite, chlorite, calcite, and kaolin. E. S. Larsen, who has studied thin sections of the tuffs, states that they are composed largely of devitrified and silicified volcanic glass, of which a large part is ordinary volcanic ash consisting of fragments of the walls of bubbles, though some of the larger fragments of glass are fluidal. The original rock from which the tuff was derived, Larsen states, was probably near a rhyolite or quartz latite.

Stratigraphic relations.—In the Caddo Gap and De Queen quadrangles the Stanley shale succeeds the Arkansas novaculite, whose upper part is tentatively assigned to the Devonian system, but in parts of the Hot Springs district it conformably succeeds the Hot Springs sandstone, which is there a lenticular formation resting upon the novaculite and forming the base of the Carboniferous system. An unconformity at the base of the Carboniferous rocks is indicated (1) by the occurrence of a conglomerate as much as 35 feet thick at the base of the Hot Springs sandstone, (2) by the occurrence of a conglomerate beneath the Stanley shale at places in the De Queen and Caddo Gap quadrangles, and (3) by the fact that the Stanley rests upon the Bigfork chert, of Ordovician age, at places in the Mount Ida quadrangle, which adjoins the Caddo Gap quadrangle on the north. Although an unconformity occurs at the base of the Carboniferous rocks, the erosion surface over which the sea of that period transgressed was very even to judge from the rather uniform thickness of the top strata of the novaculite in the quadrangles here described.

The Stanley is conformably overlain by the Jackfork sandstone, which is in turn overlain in these quadrangles and other parts of the Ouachita Mountain region of Arkansas by the Atoka formation. However, in parts of the Ouachita region of Oklahoma the Caney shale, which in places is overlain by the Wapanucka limestone and this in turn by the Atoka formation, rests upon the Jackfork sandstone. In the Arbuckle Mountain region of Oklahoma both the Stanley and the Jackfork are absent, and the Caney shale usually rests upon the Woodford chert, with which the middle and upper divisions of the Arkansas novaculite are herein correlated, but over part of the Arbuckle region the Sycamore limestone intervenes between the Woodford and the Caney, being thickest in the west and dying out entirely in the east. The few known localities in the Ouachita region where the Caney does not rest upon the Jackfork are near Ti, in the southern part of the McAlester quadrangle. There the Sycamore, the Stanley, and the Jackfork are all absent, and the Caney rests directly upon the Talihina chert, whose uppermost beds correspond in age and lithology to the Woodford chert and also to the middle and upper parts of the Arkansas novaculite.

Fossils and correlation.—Although the Stanley shale attains a thickness of 6,000 feet and is widely distributed in the Ouachita Mountain region, it has so far yielded only a few fossil plants and invertebrates. The overlying Jackfork sandstone, of equal extent and thickness, has yielded no determinable invertebrate fossils, but the Caney shale, which rests upon the Jackfork in parts of Oklahoma, has supplied a rather large invertebrate fauna, some fish remains, and a few plants. The Jackfork sandstone, the Stanley shale, and the lower part of the Caney shale are classed as Mississippian and the upper part of the Caney shale as Pennsylvanian, by the United States Geological Survey. Differences of opinion have, however, existed and still exist among geologists concerning the age of these formations. When the Jackfork sandstone and Stanley shale were first described[47] they were classed as Ordovician. Now they and

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

the Caney shale are placed in the Carboniferous system by all geologists, but are believed by some to belong to the Mississippian series and by others to the Pennsylvanian series. The opinions of different geologists who have studied fossils from the Caney, Jackfork, and Stanley formations are presented in the next few pages.

David White furnishes for this report the following statements concerning a number of plant collections from the Caney, Jackfork, and Stanley formations in Oklahoma:

Most of the collections are designated by the lot numbers used in the paleobotanic work of the Geological Survey at the National Museum.

3911. Impure limestone fragments collected by Taff and others from Caney shale:

Lepidodendron sp. suggestive of L. brownii.

3952. Caney shale:

Vermicular traces of algae or borings, probably of no present value.

3910. Ramentum, possibly of Psaronius, associated with very small seeds, probably Trigonocarpum.

3911. SW. ¼ sec. 2, T. 1 S., R. 16 E., Antlers quadrangle. Black shale in valley of Caney Creek:

Calamitean stem base of pre-Pottsville aspect.

3912. Tributary of Ellen Creek, just north of Ti post office, northeast corner of sec. 20, T. 3 N., R. 16 E.:

Asterocalamites, probably A. radiatus.

6240. Eight miles east of Atoka. Collected by White. Jackfork? (probably Stanley):

Asterocalamites, probably A. radiatus.
Stigmaria with small scars.
Lepidophloios? decorticated, indeterminable twigs.

These fragments have a lower Carboniferous aspect, but the evidence is inconclusive.

5669. East-northeast of Tuskahoma, foot of Kiamichi Mountain:

Lepidodendron sp., indeterminable.
Lepidodendron veltheimianum, as described from the Carboniferous limestone by earlier authors.
Sphenophyllum sp. (probably), indeterminable.
Sphenopteris sp., indeterminable.
Asterocalamites scrobiculatus (equals radiatus).

5508. NE. ¼ NE. ¼ sec. 32, T. 2 N., R. 20 E., lower part of heavy black shale, in creek bed. Stanley (?):

Asterocalamites scrobiculatus.
Asterophyllites?
Sphenopteris cf. S. larischii.
Fern stem (Aneimites?).
Lygenopteris sp.?
Trigonocarpum sp.
Sphenopteris sp., Mississippian aspect, indeterminable.

A collection of plants was obtained by Mr. Miser in 1914 and 1923 from the top of the Stanley shale in the Whitley railroad cut 2½ miles by road south of Gillham and 1 mile southwest of King. (See pl. 9, *A*.) This collection was also examined by David

White and is said by him to contain the best fossil plants that have come to his attention from the Stanley and Jackfork formations. He has supplied the following statement and list of species:

Sphenopteris cf. S. schimperiana.
Sphenopteris cf. S. quercifolia.
Sphenopteris cf. S. goepperti.
Sphenopteris cf. S. sphyropteris.
Sphenopteris cf. S. vespertinus or bifida.
Aneimites?, stem.
Neuropteris antecedens?
Asterocalamites scrobiculatus.
Calamites sp. with wide ribs.
Sphenophyllum cf. S. tenerrimum, with very small leaves.
Lycopod stem, obscure, phyllotaxy verticillate in aspect.
Carpolithes, very small, species probably new.
Carpolithes cf. C. siliqua.
Trigonocarpum, small, coronate, same as at other localities.
Trigonocarpum cf. T. parkinsoni?
Rhacopteris? sp., fragment possibly from the basal portion of a leaf of this genus.

The fossils in this collection have been subjected to wave attrition and have been reduced to very small fragments, most of which are somewhat macerated as well as torn.

Asterocalamites scrobiculatus and another calamarian stem comparable to *Calamites roemeri* are most numerous in the collection. With these are plant fragments, better described as ragged scraps, including *Sphenopteris*, probably *S. goepperti* or possibly *S. refracta* (which may be identical with *goepperti*); *Rhacopteris?* or *Adiantites;* a *Rhodea* or *Rhacopteris*, probably identical with *R. moravica; Sphenopteris* cf. *S. schimperiana* and *Sphenopteris* cf. *S. quercifolia*, together with another *Sphenopteris*, possibly *S. bifida.* The Trigonocarpums are comparable to *T. conchaeforme* and a new species found in the Floyd shale of Alabama. *Carpolithes siliqua* is of doubtful systemic value and is best known from the Pocono. *Neuropteris antecedens* is probably present. *Sphenophyllum* cf. *S. tenerrimum* as here identified is a more rigid and simpler type than that in the Pottsville.

On the whole the plant material, consisting mainly of minute fragments, though in part closely related to species known from the Pottsville, appears to find a closer relation and some specific identities in the floras described from the Carboniferous limestone, probably of Chester age, in the Old World. The *Lepidodendron* quoted as *L. veltheimianum* is identical with one from the Chester of Alabama, in which it is associated with a similar phase of *Asterocalamites scrobiculatus.*

The discovery of better material will doubtless necessitate a revision of some of the tentative [specific] identifications. Possibly such material will show that the beds are Pennsylvanian, but the aspect of the plant fragments and the apparent relations of the beds strongly suggest that they are Mississippian. Accordingly, I am inclined to regard them as Mississippian and to suggest that they are of Chester age, but the paleobotanic data available are insufficient to justify their conclusive reference to the Mississippian.

The examination suggests the possibility of the deposition of a great thickness of sandstone and shale derived from the north Texas land mass on the south during the period of Mississippian uplift and deformation and the concomitant early stages of Pennsylvanian subsidence. Further, it is to be noted that marine conditions appear to have been absent in the Stanley-Jackfork region during most if not all of the time of deposition of this great thickness of beds.

Prosser, who collected some fragments of fossil plants from the Stanley shale in Hot Springs, made the following statement [48] concerning them:

On one of the olive pieces of shale is a fern pinnule, which is similar to those of *Sphenopteris*. It resembles somewhat the pinnules of *Sphenopteris decomposita* Kidston, from the calciferous sandstone (lower Carboniferous) of Scotland, but nothing could be stated positively of such a fragment. Other fragments resemble *Cordaites*.

A few invertebrate fossils have been found in the Stanley shale by Honess in McCurtain County, Okla. The following statement from his report [49] gives the opinion of Charles Schuchert concerning them:

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

"It seems to me fairly certain that these specimens can not be other than Mississippian or Pennsylvanian. As you got an undoubted Lepidodendron even beneath lots 943 and 944 and as the specimen appears to me like a Pennsylvanian form, it seems that the whole of the Stanley and Jackfork may be Pennsylvanian in age rather than Mississippian. The marine fossils do not indicate anything to the contrary. Your marine fossils are as follows:

Orbiculoidea nitida Phillips. Loc. 1015 and 1016. I can not distinguish the specimens from Coal Measures forms.
Crinoid columnals. Loc. 943 and 944. Common. At least two species.
Cystodictya, sp. undet. Loc. 943 and 944.
Rhombopora, sp. undet. Loc. 944.
Fenestella, sp. undet. Loc. 944.
Bryozoa. Undet. Common. Loc. 944.
Productus suggesting Pustula nebraskensis. Loc. 943 and 944.
Chonetes, sp. undet. Loc. 943.
Very fragmentary. Finely striate form.
Fish bone. Loc. 943."

The same fossils as those submitted to Schuchert were also submitted to E. O. Ulrich, who reports in part as follows: [50]

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

The fossils observed by me in the Jackfork, seemed decidedly corroborative of my convictions respecting the post-Chester age of the Stanley. So far as

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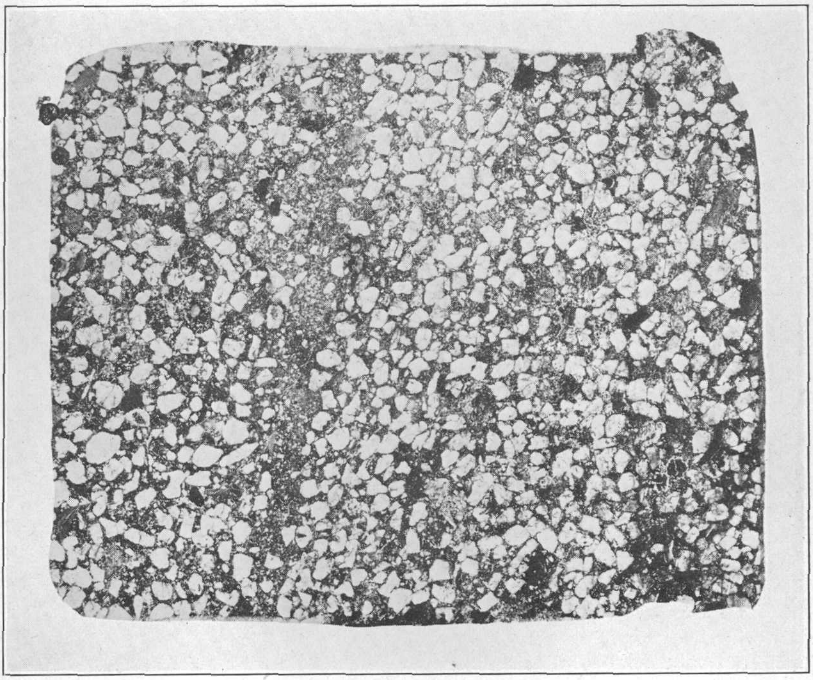
[48] Prosser, C. S., Notes on Lower Carboniferous Plants from the Ouachita Uplift: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, pp. 423–424, 1892.

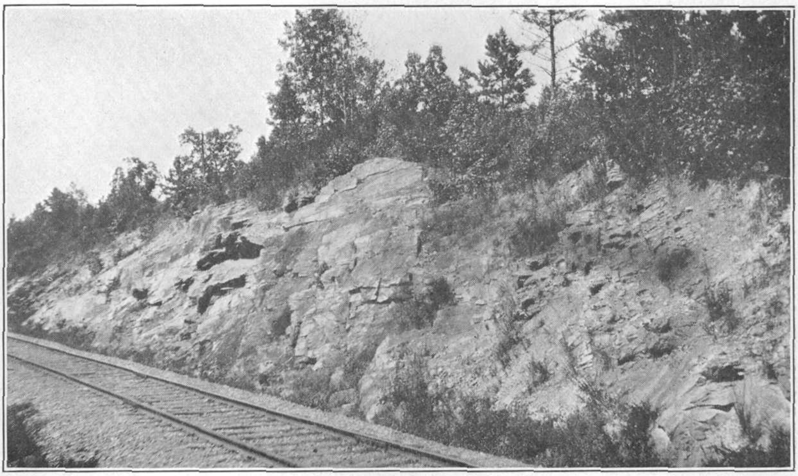
[49] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 177–178, 1923.

[50] Idem, p. 178.

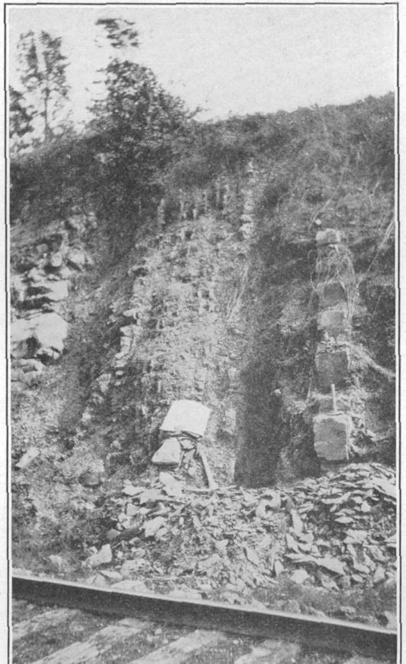


A. POLISHED SURFACE OF SPECIMEN OF TUFF FROM THE STANLEY SHALE IN THE DE QUEEN QUADRANGLE

Shows the numerous fragments of feldspar (light and dark gray) and the few fragments of other rocks (black), embedded in a matrix of fine-grained material. Natural size

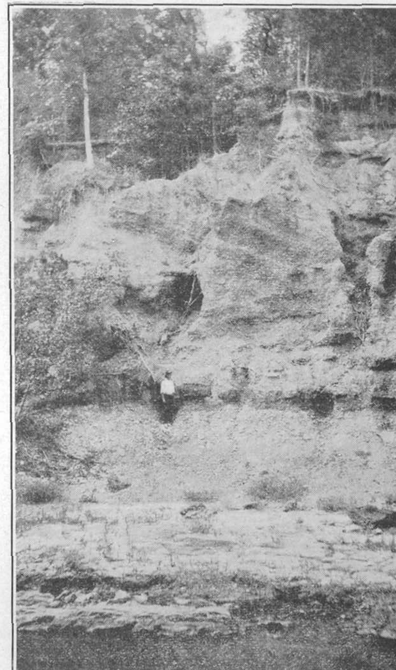


B. HATTON TUFF LENTIL OF STANLEY SHALE, HALF A MILE SOUTH OF HATTON, ARK.



A. STANLEY SHALE IN WHITLEY RAILROAD CUT, 2½ MILES SOUTH OF GILLHAM, ARK.

Fossil plants were obtained from the shale at this locality



B. PIKE GRAVEL MEMBER OF THE TRINITY FORMATION AT BLUFF FORD ON MUDDY FORK, 1 MILE WEST OF NATHAN, ARK.

The feet of the man shown in the picture are level with the contact of the gravel with the steeply dipping sandstone of the Atoka formation, which is well exposed in the bed of Muddy Fork in the foreground. Note the cross-bedding in the gravel

I can see, your new evidence leaves the problem just about where I left it in 1911—that is, with the probabilities favoring assignment of the Stanley to the earlier Pennsylvanian.

Morgan [51] has recently made a study of the Caney shale including its fauna in the northern part of the Arbuckle Mountains of Oklahoma. He says:

From the evidence afforded by the fossils the conclusion is here drawn that the upper part of the Caney is of Pennsylvanian age and partially equivalent to the Morrow formation, and that the lower part is late Mississippian, approximately equivalent to the Moorefield, Fayetteville, and Batesville formations of Arkansas.

Eastman,[52] who studied fish remains from the Caney shale in Oklahoma, stated that the character of such remains tends to support the upper Mississippian age of the Caney.

Some fragmentary casts of shells were found in the De Queen quadrangle in a bed of dark greenish-gray millstone grit at the base of the Jackfork sandstone, about one-eighth of a mile south of an abandoned sawmill site, which is near the north line of sec. 34, T. 7 S., R. 30 W. A collection from the locality was submitted for examination to G. H. Girty, whose report follows:

The material contains little besides crinoid segments, which are in considerable abundance. Mr. Frank Springer has kindly examined some of these crinoid fragments for me and writes as follows regarding them: "It is impossible even to guess at the geologic age of the crinoid-stem fragments you have sent me. I have seen some joints in somewhat similar condition in highly metamorphic Carboniferous material in New Mexico, but so far as the crinoid fragments show it might belong anywhere from the Silurian to the Trias or Jura."

Among the other forms are fragments of a finely costate shell, which is probably some species of *Productus*. Another fragment suggests a species of *Myalina*, but it may not belong to that genus. A third and last type is a tiny fragment of some lunarium-bearing bryozoan suggesting *Fistulipora*, *Meekopora*, or less probably *Cystodictya*. The age of this collection is probably Carboniferous, but more than this it is impossible to say.

A large fauna has recently been obtained by Honess from two localities in the northwest corner of McCurtain County, Okla., from a thick succession of sandstone which he calls the Jackfork sandstone. The fauna is described [53] by him as a Morrow fauna and is composed of the following species as identified by him:

Zaphrentis gibsoni.
Aulopora angularis, n. sp.
Aulopora magna, n. sp.
Aulopora gracilis.

[51] Morgan, G. D., Geology of the Stonewall Quadrangle, Oklahoma: Bur. Geology Bull. 2, p. 56, Norman, Okla., 1924.

[52] Eastman, C. R., Brain Structures of Fossil Fishes from the Caney Shales: Geol. Soc. America Bull., vol. 24, pp. 119–120, 1913.

[53] Honess, C. W., Geology of Southern Leflore and Northwestern McCurtain Counties, Okla.: Bur. Geology Circ. 3, Norman, Okla., 192[illegible]

Polypora sp.
Rhombopora sp.
Many undeterminable forms.
Chonetes arkansanus.
Chonetes sp.
Productus cf. P. gallatinensis.
Productus sp. (1).
Productus sp. (2).
Productus sp. (3).
Pustula punctata.
Pustula moorei, n. sp.
Avonia sp.
Marginifera splendens.
Squamularia transversa.
Rhipidomella pecosi.
Rhipidomella sp.
Schizophoria resupinoides?
Rhynchopora minuta, n. sp.
Girtyella cf. G. emarginata.
Spiriferina transversa.
Spiriferina spinosa.
Spirifer rockymontanus.
Reticularia cf. R. setigera.
Brachythyris laticosta.
Hustedia brentwoodensis.
Hustedia miseri.
Composita subtilita.
Composita wasatchensis.
Composita cf. C. gibbosa.
Edmondia sp.
Nucula anadontoides.
Nucula parva.
Nucula sp.
Leda bellistriata.
Leda rugosa, n. sp.
Parallelodon obsoletus.
Parallelodon tenuistriatus.
Leiopteria jackforkensis, n. sp.
Leiopteria sp.
Conocardium parrishi.
Myalina orthonota.
Schizodus wheeleri.
Aviculopecten cf. A. hertzi.
Aviculopecten halensis.
Aviculopecten sp. 1.
Aviculopecten sp. 2.
Allorisma cf. geinitzi.
Pleurophorus oblongus.
Cypricardella oblonga.
Cypricardella, n. sp.
Astartella n. sp. 1.
Astartella n. sp. 2.
Plagioglypta annulistriata.

Pharkidonotus percarinatus.
Euphemus carbonarius.
Phanerotrema grayvillense.
Worthenia? tabulata.
Worthenia sp.
Euconospira arkansana.
Trepospira depressa.
Euomphalus catilloides.
Strophostylus cf. S. subovatus.
Platyceras parvum.
Zygopleura rugosa.
Meekospira peracuta var. choctawensis.
Meekospira sp.
Sphaerodoma intercalaris.
Sphaerodoma primigenia.
Orestes nodosus.
Conularia crustula.
Orthoceras sp.
Metacoceras cornutum.
Gastrioceras excelsum.
Gastrioceras sp.
Griffithides sp.
Eupachycrinus cf. E. magister.
Eupachycrinus sp.
Crinoid stems and plates of doubtful genus.
Fragments of wood.
Shark spine.

Concerning the above-listed fauna Honess comments in part as follows:

The fauna is regarded as definitely Morrow and equivalent to the Wapanucka. The Morrow fauna * * * occurs about midway in the sandstone series which forms Boktukola syncline. The sandstone series overlies the Stanley shale in normal sequence and is 13,618 feet thick. * * * The questions arising are: (1) Is the whole section Jackfork sandstone, or is only the lower portion Jackfork and the upper part something else? (2) How much of the sandstone series may be regarded as Morrow? (3) Where is the Caney shale? From the point of view of the lithology there is no difference between that part of the formation which lies below the fauna and that part which lies above it. There is no large body of shales intervening any place in the section to form a basis of division, and no part of this vast series looks like or resembles in any way the Caney shale or the Atoka formation. The Wapanucka limestone is wanting, and in its stead there are fine-grained ferruginous sandstones. The entire series (13,618 feet thick) is one continuous and uniform whole, and this being a fact, the writer does not see fit to do otherwise than to speak of a Lower Jackfork (that portion which lies below the Morrow fauna) and an Upper Jackfork (that part which lies above it). * * *
The question of the exact limits of the true Morrow is one which can not be answered at the present time. We shall have to await the discovery of other fossiliferous horizons, lower in the series. As to the Upper Jackfork, it is all Pennsylvanian, of course, by the law of superposition, and is, apparently, a sandy shoreward phase of the Atoka formation of more northerly latitudes.

Not having discovered the Caney shale in the Jackfork sandstone series, it must be much thinner in its southerly development, or possibly wanting entirely in the Boktukola syncline. Whether its position is represented by some one or more of the thin shaly bands in the Lower Jackfork or to some part of the Stanley, if it may be permitted to go that far, is also an unsolved problem. It is hoped that some time, somewhere, the Caney fauna may be discovered in the section beneath the Morrow horizon.

Correlating, then, the Wapanucka of the Arbuckle region with the Morrow of the Ouachita region, a portion, at least, of the Upper Jackfork should be equivalent to the Atoka formation; and the Caney of the Arbuckles either pinches out to eastward and southward or wedges into the Lower Jackfork or older sediments somewhere beneath the Morrow. The Woodford of the Arbuckle region is regarded as pre-Stanley and probably equivalent to the middle division of the Arkansas novaculite, as Doctor Ulrich has pointed out.

The Caney shale, as pointed out by Honess, is possibly absent in the localities where he obtained the above-listed fossils, but several unpublished maps by J. A. Taff show it to be present farther north and west in the Ouachita Mountains of Oklahoma. There it rests upon the Jackfork sandstone in large areas, but it rests upon chert beds of the same age as the Woodford chert at a few places along the north edge of the mountains in Oklahoma. It is succeeded in places by the Wapanucka limestone and this in turn by the Atoka formation; in other places it is succeeded directly by the Atoka formation. At all places in the Ouachita Mountains of Arkansas the Atoka rests upon the Jackfork sandstone; the Caney shale and Wapanucka limestone appear to be absent there.

As Honess applies the name Morrow to the fossil-bearing beds of his Jackfork sandstone and correlates the beds with the Wapanucka limestone, the sandstone (Upper Jackfork sandstone of Honess) above the fossiliferous bed is, as pointed out by him, a probable phase of the Atoka formation. The question then arises, shall we follow time equivalency or lithologic character in the use of formation names? If we are to follow time equivalency, the Upper Jackfork sandstone of Honess could be called Atoka formation and his Lower Jackfork sandstone would be the true Jackfork sandstone. The Upper and Lower Jackfork sandstones of Honess are designated Atoka and Jackfork, respectively, by Mr. Miser on the geologic map of Oklahoma recently published by the United States Geological Survey. If Mr. Miser is correct in his conclusions concerning the Jackfork sandstone of Honess it follows that the so-called Jackfork fauna obtained by Honess overlies the true Jackfork sandstone.

The following statement with reference to the age of the Caney, Jackfork, and Stanley formations has been written by G. H. Girty for this report:

The Stanley shale and Jackfork sandstone have thus far furnished few invertebrate fossils, or none at all, and consequently the evidence as to their geologic age furnished by the formations that inclose them—rarely a factor that can safely be neglected—here takes a place of prime importance. The Stanley shale is succeeded in the geologic section by the Jackfork sandstone, and that in turn by the Caney shale. If this succession is established, as it seems to be, if the two formations themselves furnish only dubious evidence, and if the Caney shale is of Mississippian age, as the invertebrate fossils seem to indicate, the conclusion is ineluctable that the Stanley and Jackfork are Mississippian or older.

The Caney shale contains two very unlike faunas, of which the upper is Pottsville in age, and the lower, it is believed, Mississippian. The lower fauna, which is the only one that at present concerns this discussion, ranges through about 500 feet, beginning at the basal contact with the Jackfork sandstone. It is abundant in individuals, especially those belonging to a few species, and presents a fair variety of forms, of which 42 were recognized when the fauna was originally described. Though in these respects the evidence is favorable for purposes of correlation, it is rendered somewhat ambiguous by the fact that the Caney fauna is peculiar and very unlike any of the well-known faunas of Carboniferous age, Mississippian as well as Pennsylvanian. The faunas of northern Arkansas and northeastern Oklahoma are, however, intermediate in character, as they are intermediate in position between the region which saw the development of the typical Mississippian faunas and that in which the Caney fauna lived. In this intermediate region are found many species that are identical with or closely related to those of the Caney shale, and at the same time others that are characteristic of the Chester faunas of the upper Mississippi Valley, the two groups of species occurring either directly associated or in distinct but interfingering beds. The rocks in Arkansas containing such intermediate faunas have been classified as the Moorefield shale, the Batesville sandstone, and the Fayetteville shale and are recognized by all as of Mississippian age. These facts are not open to dispute—the three formations of northern Arkansas are of Chester age, or possibly in part of pre-Chester Mississippian age, and the Caney fauna is more or less closely related to those Mississippian faunas, but is not at all closely related to any American fauna of known Pennsylvanian age. On these grounds the Caney shale was in 1909 correlated with the Moorefield-Fayetteville interval in the geologic sequence of northern Arkansas and identified as Mississippian.

In the intervening years much evidence has accumulated bearing upon this question, and it has accumulated all upon one pan of the balance. Faunas in a general way related to the Caney fauna prove to have had a wide dispersion on the North American continent and to have been confined to Mississippian time wherever the facts of paleontology and stratigraphy permitted this to be determined. On the other hand, or perhaps in other words, no fauna whose age could be determined as Pennsylvanian has been found that is in any sense comparable to the fauna of the Caney shale. As a more confined statement, many hundred collections of invertebrate fossils have been examined from areas in Oklahoma and Arkansas continuous with that in which the Caney shale occurs. In these collections a profound faunal change is shown between those that came from the Morrow group, which is of Pennsylvanian (Pottsville) age, and those that came from the underlying Mississippian formations. Without exception, wherever faunas of the Mississippian type were obtained, they occurred stratigraphically below faunas of the Morrow type.

In this region, then, where the evidence is so pertinent and so abundant, its bearing is perfectly plain. The faunal succession is the same in the region where the Caney, Jackfork, and Stanley are developed. The higher fauna of the Caney shale is entirely different from the lower fauna and is closely related to that of the overlying Wapanucka limestone, the upper part of the

Caney shale and the Wapanucka limestone being without much question of Pottsville age and belonging in the general horizon of the Morrow group.

If the Wapanucka and the upper part of the Caney correlate with the Morrow group, the lower part of the Caney occupies the same position in the geologic sequence as the Mississippian beds that underlie the Morrow. Not only so, but its fauna, as already pointed out, is rather closely related to the faunas of those Mississippian formations, whereas no rocks belonging to the Morrow, much less any of those that overlie the Morrow, have furnished anything even remotely comparable to it.

E. O. Ulrich presented at Tulsa, Okla., in March, 1927, a paper that was based on extensive field investigations by him in 1908 and previous years and also on recent office studies of fossils. In this paper, which was published in 1927 as Bulletin 45 of the Oklahoma Geological Survey, he expresses the opinion that the Stanley shale is of Mississippian age and that the Jackfork sandstone and the overlying Caney shale (called by him the Johns Valley shale) are of Pennsylvanian age. He holds that the fauna in this shale is not in place, but has been transported from exposures of Mississippian Caney shale and that the fauna is now really embedded in a black shale of Pennsylvania age. After the presentation of Mr. Ulrich's paper Mr. Miser spent three months making a special field study of the age relations of the Carboniferous rocks in the Ouachita Mountains of Oklahoma. Among the things Mr. Miser did was to examine carefully the Caney shale at its type locality, which is now known as Johns Valley. This locality is also the type locality of the Johns Valley shale of Mr. Ulrich.

The shale in Johns Valley lies on top of the Jackfork sandstone in a broad, long synclinal basin. In the lower 50 to 100 feet of the shale there are numerous ice-borne boulders and blocks of many kinds of rock, including limestone, flint, and sandstone. The limestone masses, which are more numerous than the other kinds, range in size from small particles an inch or less in diameter to blocks measuring 30 feet across, though Mr. Miser observed one block measuring 200 feet in length, another measuring 100 by 195 feet, and a third about 50 by 369 feet. Fossils obtained from many of the masses have been studied by Mr. Ulrich, who concludes that the faunas represented range in age from that of the Arbuckle limestone (Lower Ordovician part) to that of the Sycamore limestone (Kinderhook).

The boulder bed just mentioned is overlain by a black platy hard shale perhaps several hundred feet in thickness. In several fresh, clean exposures of the shale there are hundreds of small phosphate nodules—most of them nearly spherical—and many concretionary masses of limestone. The limestone concretions all lie parallel with the bedding of the shale, and the phosphate nodules are rather uniformly disseminated through portions of the shale. The nodules and the limestone concretions contain fossils, all of which belong to the fauna of the Mississippian Caney shale. Every feature of the shale as revealed in the exposures can be matched with exposures of the Caney shale in the areas where it rests upon the Woodford chert. The lithology of the shales in the two different stratigraphic positions—one on the Jackfork and the other on the Woodford—is the same. The character and arrangement of the limestone concretions are the same, and also the character and distribution of the phosphate marbles are the same. To Mr. Miser, as well as to several other geologists who accompanied him to Johns Valley in June, 1927, the conclusion which they reached while looking at the field relations was obvious that the fauna as represented in the phosphate nodules and limestone concretions lived, died, and was buried where it is now found. If the fauna had been transported by floating ice, as is believed by Mr. Ulrich, there would surely have been some admixture of the Caney fossils with those of pre-Caney age, and also there would surely have been an admixture of rocks of pre-Caney age. The excellent exposures of the Caney that were examined by Mr. Miser and his geologist companions do not reveal a single pre-Caney fossil nor a single specimen of rock of pre-Caney age.

The available evidence on the age of the Caney, Jackfork, Stanley, and Hot Springs formations is fully reviewed by C. W. Honess and Mr. Miser in Bulletin 44 of the Oklahoma Geological Survey, which was published in 1927. Their conclusions as expressed in that report are that the Caney shale of the Ouachita Mountains contains beds of both Pennsylvanian and Mississippian age, and that the Jackfork, Stanley, and Hot Springs formations are of Mississippian age.

JACKFORK SANDSTONE

Definition.—The Jackfork sandstone took its name from Jackfork Mountain, in the McAlester and Tuskahoma quadrangles, Oklahoma. As the name implies, the formation consists chiefly of sandstone, but it contains a little shale and millstone grit. It is underlain by the Stanley shale and overlain by the Atoka formation. In much of the southern part of the quadrangles herein described the truncated edges of these three formations, which dip at high angles, are covered by nearly flat-lying strata of Cretaceous age. The Jackfork is of Carboniferous age and, like the Stanley shale below it, is believed to represent a part of the Mississippian series. In the Caddo Gap quadrangle it ranges in thickness from about 5,000 to 6,600 feet; in the De Queen quadrangle not all of the formation is exposed.

Distribution.—In the Caddo Gap quadrangle the Jackfork sandstone occurs in six belts having a general south of west trend and from half a mile to 3 miles wide on the Athens Plateau and in one small belt a few miles northeast of Glenwood, and in the De Queen quadrangle it occupies three belts with a like trend and range of width along the southern border of the Athens Plateau. In these belts the formation produces low ridges, rising but little above those in the areas of the Stanley shale and Atoka formation, but farther north, outside the quadrangles, it forms many of the highest ridges of the Ouachita Mountains.

The formation is best exposed along the streams. Although it is fairly conspicuous in the areas away from the streams—in places standing in vertical ledges that resemble gigantic masonry—the amount of sandstone that is exposed is small in comparison with the enormous thickness and areal extent of the formation. In those areas it is largely concealed by sand that has been derived from it by weathering, and a person may travel over it for considerable distances without seeing any exposures of sandstone.

Character.—Although the formation consists almost entirely of sandstone, there are some beds of green, finely fissile clay shale. The shale in the upper part aggregates on Little Missouri River possibly 400 feet, and that in the lower part in the same locality comprises two or three beds from 6 to 10 feet thick, but it constitutes a larger portion of the formation in probably most other parts of the quadrangles.

The sandstone is in beds, most of which are from 6 inches to 10 feet thick, but many are much thicker, the thickest observed bed measuring 84 feet.

The sandstone is compact and ranges from fine to coarse grained; most of it is quartzitic. On talus slopes it occurs in hard, angular blocks, and when long exposed forms rounded gray boulders, some of which weather by exfoliation. The prevailing and characteristic color of the unweathered sandstone is light gray, though some is bluish gray, greenish gray, or even white, and the color of weathered portions is light gray, yellow, or brown, the gray color being the most common. Altered feldspar grains occur in much of the formation, and mica flakes are common, especially in the greenish beds. Other minerals which have been observed in thin sections are zircon, tourmaline, titanite, chlorite, pyrite, and magnetite.

Some of the sandstone, especially in the basal part, contains large quantities of rounded pebbles of milky quartz, which are usually the size of peas or smaller. Such sandstone, which is really a millstone grit, closely resembles that at the base of the Winslow formation in the Boston Mountains of Arkansas and Oklahoma. The beds containing this grit are more resistant to weathering agencies than the other beds, and when the Cretaceous sea formerly occupied the southern part of the quadrangles they withstood the attack of the waves, and in places in the Caddo Gap quadrangle formed low islands and promontories along the shore of that sea. Residual quartz pebbles from the basal part are abundant on the first ridge of Jackfork sandstone south of Glenwood, and some of them reach half an inch in diameter.

The sandy soil from the Jackfork sandstone is very poor. Few farms have been made on it, and most of those have been soon abandoned. The prevailing timber of the Jackfork is yellow pine, and that of the Stanley shale is pine mixed with hardwood trees. This fact is of great assistance in tracing the contact between the two formations.

Stratigraphic relations and age.—The stratigraphic relations and age of the Jackfork sandstone are fully discussed in connection with the Stanley shale.

PENNSYLVANIAN SERIES

ATOKA FORMATION

Definition.—The Atoka formation received its name from Atoka, Okla. It consists of shale and sandstone and is considered to be of early Pennsylvanian (Pottsville) age. Not all the formation is present in the quadrangles, the upper part having been removed by erosion, but the remaining part is fully 6,000 feet thick.

Distribution.—In the Caddo Gap quadrangle the Atoka formation crops out in two east-west belts in the southern part of the Athens Plateau. One of these belts is less than half a mile and the other somewhat more than 2 miles wide. The formation is not exposed in the De Queen quadrangle and if present there is concealed beneath Cretaceous sediments along the southern border.

Character.—The sandstone and shale in the formation occur in nearly equal amounts. In some parts the formation is all sandstone through a thickness of 75 to 100 feet, but more commonly the shale and sandstone are about equally interbedded. The sandstone is hard, micaceous, ripple marked, and light to greenish gray, contains quartz grains of medium size, and occurs in beds from a few inches to 12 feet thick. In some beds near the base it is coarse grained and contains a small quantity of grit. The usual color of the exposed sandstone is brown. This color, together with the large content of shale, makes the formation easily distinguishable from the Jackfork sandstone. Most of the sandstone after weathering is readily eroded, so that the formation generally forms valleys between the ridges of Jackfork sandstone, though some beds of it stand up in rather prominent ridges.

Small quantities of asphalt are found here and there in the sandstone, and fragments of plants and fossil wood are common. In an abandoned railroad cut, known as Dead Man's Cut, on the west bank of Antoine Creek, east of the Caddo Gap quadrangle, 2 feet of the formation bears thin veins of carbonaceous material that resembles coal. Similar veins are reported from other places but were not observed in the course of field work.

The shale is sandy and micaceous and is dark to coal-black, but weathers to a rusty color, then turns darker, and next becomes pea-green before finally changing to a red plastic clay. It differs from the shale of the formations beneath in being exposed in fewer places, in having a more basic appearance, and in breaking down into small splinters and granular fragments instead of flakes.

Black compact chert in a layer reaching a thickness of several inches was observed in the formation at a few places.

Stratigraphic relations and age.—In the Caddo Gap quadrangle and to the north and east of it in Arkansas and also in parts of Oklahoma the Atoka formation rests upon the Jackfork sandstone, but in other parts of Oklahoma it rests upon the Wapanucka limestone, of Pennsylvanian age, and in still others, where this limestone is wanting, upon the underlying Caney shale, of early Pennsylvanian and late Mississippian age. The Caney shale in turn rests upon the Jackfork sandstone in most of the Ouachita area of Oklahoma, but in parts of the Arbuckle area it succeeds the Sycamore limestone, of Mississippian age, and in others the Woodford chert classified by the United States Geological Survey as of Devonian (?) age, with which the middle and upper divisions of the Arkansas novaculite are herein correlated. Although the Caney shale and Wapanucka limestone have not been recognized in Arkansas, no unconformity has been detected in that State between the Jackfork sandstone and the Atoka formation. Whether an unconformity exists or whether the Caney and Wapanucka are only apparently absent and are represented in the upper part of the Jackfork or the lower part of the Atoka, or both, is not known; but the lithologic character of the upper part of the Jackfork is such as to lead to the conclusion that it does not represent either of the formations named. The lower part of the Atoka may possibly represent one or both of them, with such a difference in lithologic character as might come about in widely separated parts of the same formation.

The Atoka formation is overlain by the Hartshorne sandstone in the Arkansas Valley of Oklahoma and Arkansas, north of the Caddo Gap and De Queen quadrangles, and the Hartshorne is in turn overlain by the McAlester shale.

The Wapanucka limestone, which underlies the Atoka formation in parts of Oklahoma, is probably the equivalent, in part at least, of the Morrow group of the Boston Mountains in northern Arkansas and northeastern Oklahoma.[54] The Atoka, Hartshorne, and McAlester formations are all the equivalent of the Winslow formation of the Muskogee and Tahlequah quadrangles[54] situated partly in those mountains, but only the first two and the base of the McAlester are the equivalent of the Winslow as mapped in the Winslow quadrangle, and probably only the Atoka is the equivalent of the basal uneroded portion of the Winslow capping the mountains in the Fayetteville, Eureka Springs, and Harrison quadrangles. The Winslow, which overlies the Morrow group (known by its flora to be of Pottsville age), has not yielded fossils for accurate correlation, though its partial equivalent, the Atoka formation, on the south has yielded a few collections of invertebrate fossils.[55] Mather, in commenting on one of the collections, says the deposition of the Atoka sediments must have begun in early Pottsville time.

The McAlester formation is known from its flora to correspond in age to the lower portion of the Allegheny formation in the Appalachian trough.[56]

Concerning the flora associated with the Coal Hill coal, which lies in the rocks immediately above the Hartshorne sandstone and at the base of the McAlester shale and which is commonly called the Hartshorne coal, David White[56] states that it indicates basal Allegheny age but contains a few traces of Pottsville development, illustrated particularly in *Mariopteris* and *Neuropteris*. It thus seems probable that the Atoka formation, which reaches an estimated thickness of 7,000 to 8,000 feet in the Arkansas Valley in Arkansas, 6,000 to 7,000 feet in this valley in Oklahoma, and 6,000 feet in the Caddo Gap quadrangle, and the part of the Winslow lying below the horizon of the Hartshorne sandstone are of Pottsville age, and they are so classified by White.

CRETACEOUS SYSTEM

COMANCHE SERIES (LOWER CRETACEOUS)

TRINITY FORMATION

Definition.—The Trinity formation was so named because of its extensive development around the headwaters of Trinity River in Texas, whence its outcrop extends as a continuous belt northward

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[54] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Tahlequah folio (No. 122), 1905; Muskogee folio (No. 132), 1906.

[55] Mather, K. F., Pottsville Formations and Faunas of Arkansas and Oklahoma: Am. Jour. Sci., 4th ser., vol. 43, p. 137, 1917.

Morgan, G. D., Geology of the Stonewall Quadrangle, Oklahoma: Bur. Geology Bull. 2, pp. 64–65, Norman, Okla., 1924.

[56] White, David, Report on Fossil Plants from the Coal Measures of Arkansas: U. S. Geol. Survey Bull. 326, pp. 24–31, 1907.

into southern Oklahoma, and thence eastward into southwestern Arkansas. In the quadrangles herein described it consists of clay, sand, gravel, limestone, gypsum, and celestite, the most abundant named first and the least abundant last. The limestone occurs in two beds, the Dierks limestone lentil, the older, near the base, and the De Queen limestone member, the younger, near the middle of the formation. The first was named from Dierks, in the De Queen quadrangle, near which it is exposed, and the second was named from De Queen, where it is exposed. The gravel also occurs as two beds, the Pike gravel member at the base, and the Ultima Thule gravel lentil, which is above the Dierks limestone. The Pike gravel was named from the village of Pike, in the Caddo Gap quadrangle, and the Ultima Thule gravel was named from the village of Ultima Thule, in the De Queen quadrangle. These four lentils and members and the interbedded sand and clay of the Trinity dip about 100 feet to the mile toward the south. Although the Trinity lies nearly horizontal, it rests upon the truncated upturned edges of steeply dipping shale and sandstone of Carboniferous age, which however, form a floor that has only minor irregularities and undulations. A pronounced unconformity, therefore, occurs at the base of the Trinity. A notable though less striking unconformity exists at the top of the formation, as shown by the eastward truncation of its beds, and the resulting overlap of the Woodbine formation and the overlying Tokio formation, both of Upper Cretaceous age.

Distribution and thickness.—The Trinity formation is exposed in a belt which trends eastward along the southern boundary of the De Queen and Caddo Gap quadrangles and hence lies within the northern border of the Gulf Coastal Plain. This belt has irregular north and south boundaries, is narrowest on the east, and is continuous except where the formation is concealed by surficial deposits of alluvium and terrace remnants along the streams that cross the belt.

The formation ranges in thickness from about 70 feet at the east line of the Caddo Gap quadrangle to more than 600 feet farther west. This maximum is indicated by a well 2 miles north of Center Point, which entered the formation 100 feet or more below its top and which reached a depth of 500 feet without striking Carboniferous rocks. Its thickness at Nashville, Ark., about 3 miles south of the Caddo Gap quadrangle, where a well passed through it, is about 750 feet. The approximate depth to the base of the Trinity at any locality within the De Queen and Caddo Gap quadrangles may be obtained by multiplying the number of miles from the locality to the north boundary of the Trinity by 100, the approximate average southward dip in feet per mile of the base or floor of the Trinity. To make this calculation as accurate as possible the difference in altitude of the locality above or below that of the Trinity boundary due north of the locality should, as the case demands, be added to or subtracted from the figure obtained by the above method. The altitude of the base of the Trinity in the southern parts of the quadrangle is shown by contours in Figures 8 and 9. (See pp. 184–185.)

Owing to the southward dip of the formation its younger beds are exposed south of the older ones.

Character.—The Pike gravel member is the thickest and most persistent gravel bed in the quadrangles and has a larger surface distribution than any other. In much of its belt of outcrop it forms an even though dissected southward-dipping upland. This form is due to the resistant nature of the gravel and the ease with which the overlying unconsolidated clay and sand have been eroded. Some of the larger areas of outcrop are at or near Pike, Nathan, Muddy Fork, Dierks, Lebanon, and King. The thickness of the gravel is rather uniform, being in most places between 20 and 50 feet, but it apparently attains 100 feet near Pike. The gravel thins out at a few isolated places within its belt, as near Murfreesboro and Lebanon, where rocky headlands and islands of Carboniferous sandstone along the old Cretaceous shore were not completely buried by the gravel, though they were by higher beds. The sand and clay separating the Ultima Thule and Pike gravels thin to the west and are absent just west of the Arkansas-Oklahoma line, in consequence of which the Ultima Thule gravel either rests upon the Pike gravel or upon Carboniferous rocks. If the Pike gravel is present there it can not be distinguished from the overlying gravel.

This gravel consists mainly of pebbles less than half an inch in diameter, but it contains many larger ones and some cobbles as much as 10 inches in diameter. These larger pebbles and cobbles are at most places especially abundant in a thickness of several feet at the base. All the pebbles and cobbles are partly to thoroughly rounded. Most of them are dense white, gray, brown, red, or black novaculite, unquestionably derived from the Arkansas novaculite, which is exposed in the Ouachita Mountains. A small number, however, are quartz, quartzite, and sandstone. Those of quartzite and sandstone are most abundant in the cobble bed, but they constitute a minor portion of it. The proportion of quartz pebbles in the Pike gravel and the Ultima Thule gravel increases westward from the longitude of De Queen. They are derived from quartz veins in McCurtain County, Okla., which are largest and most numerous in the Ordovician shale in the central part of the county. The proportion of pebbles derived from the novaculite in that county likewise increases westward from the longitude of De Queen. Some of the gravel is conspicuously cross-bedded. Most of it is loose and contains some sand or clay as lenses in the upper part and as a filling in the interstices between the pebbles. Nearly horizontal beds of gravel are in places cemented by brown iron oxide and are thus converted into hard conglomerate. The source of the iron oxide was probably iron pyrites, which was once disseminated through the gravel and adjacent beds and was later taken into solution by ground water and deposited in its present form at or near the surface. Much of the gravel in the vicinity of Nathan is firmly cemented with a small percentage of silica. Three exposures of gravel thus cemented were observed along the wagon road leading south of east from Nathan to Murfreesboro; the one farthest east is at the ford across Bacon Creek, 2½ miles from Nathan. The best exposed section of the Pike gravel in the quadrangles is at Bluff Ford, 1 mile west of Nathan. (See pl. 9, *B*.)

The Ultima Thule gravel lentil is exposed in a discontinuous crooked belt extending from a point near Ultima Thule eastward as far as Cossatot River, beyond which it is represented here and there by lenses a few feet thick. The lentil itself is only a few feet thick just west of the Cossatot and is not far above the Dierks limestone and about 100 feet above the Pike gravel. It thickens toward the west and reaches a maximum of 40 feet near the State line. Just west of the State line it rests upon the Pike gravel or upon Carboniferous rocks. It resembles the Pike gravel except that most of the pebbles are smaller, only a few exceeding 1 inch in diameter.

Lenses of gravel as much as 25 feet thick occur above the De Queen limestone northwest of Provo. They resemble the two gravel beds just described.

In addition to the bedded deposits much gravel occurs scattered over the surface as residual material from the erosion of beds that now crop out and of others that have entirely disappeared.

The beds of gravel of the Trinity formation, as well as the later beds of gravel in the quadrangles, have been held by some geologists to be surficial deposits of post-Tertiary age. The opinions of the different geologists have been diverse, however, and are briefly given on pages 97–99.

The Dierks limestone lentil is exposed in an irregular belt extending from the vicinity of Delight westward to Cossatot River. It is cut out on the east, owing to an overlap of the Woodbine formation upon lower beds of the Trinity; on the west it thins out and seems to give way horizontally to clay which occupies a part of the interval between the Pike and Ultima Thule gravels. The westernmost outcrop that was observed is just northwest of Moody Shoal Ford. The limestone lies about 50 feet above the base of the Trinity formation along the western part of its outcrop and probably 200 feet above the base north of Delight. Northwest of Murfreesboro it laps up against rocky headlands of Carboniferous sandstone which jutted out into the old Cretaceous sea. The lentil approximates 40 feet in thickness at most places but at some is only 10 feet thick. It is composed of alternating beds of limestone and green clay, but the limestone usually predominates. Much of the limestone is compact, gray, and hard and occurs in even-bedded layers attaining the thickness of one foot, but a considerable portion is earthy and shaly. The limestone weathers to thin slabs and nodular masses and usually produces a black soil, which gives the belt of country underlain by this limestone the popular name "black-land belt."

The De Queen limestone member is exposed in a narrow, somewhat sinuous band which extends north of west and west from Plaster Bluff, 3 miles south-southwest of Murfreesboro, passing north of Corinth and Center Point, and thence passing through De Queen and into Oklahoma. The member is about 60 feet thick at most places but is a little more than 70 feet thick along Messer Creek and 72 feet thick at De Queen. It consists of limestone with an equal or greater quantity of tough green clay and some gypsum and celestite. Most of the limestone is gray, hard, and compact and is in layers 10 inches or less thick; but much of it is earthy, platy, and yellowish gray and contains small lenses of clay. Ripple marks, sun cracks, and worm trails are found on the surface of some layers, and disseminated crystals of pyrite are common. The gypsum occurs in the lower part of the member. The thickest exposure is in Plaster Bluff, where the gypsum is found in a single bed ranging from 10 to 14 feet in thickness. This bed consists of pure saccharoidal gypsum, though there are some thin seams of satin spar and as much as 3 feet of interbedded clay in its lower part. The thickest layer of gypsum is at the top and is four feet thick. There are a few outcrops and reported occurrences of gypsum as far west as Messer Creek, but there it is not everywhere pure and at no place does its reported or observed thickness exceed three feet. Coarsely granular white to pink celestite occurs in clay in the lower part of the member, in some places as short lenses and in others as a single layer from 1 to 6 inches thick. The thicker layers and lenses contain vugs which are lined with large tabular crystals. Only a few exposures of this mineral have been observed, the westernmost one near Provo and the easternmost at Plaster Bluff. The most extensive exposures are near Martha post office, where the mineral occurs on the surface as friable residual masses.

The De Queen member usually forms a poor yellowish-brown clay soil. Throughout much of its belt of outcrop ledges and boulders are found at the surface, but in places the limestone is entirely concealed by surface material; in some such places its presence may be detected from the growth of hawthorn thickets over it.

Clay occurs in all parts of the Trinity formation, but constitutes a greater proportion of the middle than of the lower and upper parts.

It is interbedded with sand, gravel, and limestone, and in places contains sand, pyrite, novaculite pebbles, lenses of impure limestone, pieces of carbonized fossil wood, and pot-shaped concretions of iron oxide. The fresh clay is white, blue, green, purple, or red, and all these colors may be seen in different layers in a single exposure.

Sand occurs mostly in two beds. The lower lies between the Pike gravel and the Dierks limestone. It is thickest on the east and thinnest on the west, and at a few localities near Pike, Delight, Murfreesboro, and Lebanon it is impregnated with asphalt. The higher sand is at the top of the formation and does not extend east of the longitude of Center Point, beyond which it is overlapped by the Woodbine formation. The sand is cross-bedded and fine grained, is interbedded with some clay, and is usually compact, but a small quantity is firmly cemented by iron oxide. It is gray where unweathered, but is red or yellow in most exposures, and it produces a gray soil.

A number of deep wells have been drilled in the Trinity formation in the quadrangles, most of them at and near De Queen. The log of one of them is given below to show the character of the Trinity in that vicinity.

Log of ice-factory well near the Kansas City Southern Railway station at De Queen

[Altitude of top of well about 375 feet above sea level. Depth of well as given in the log is 244 feet; the actual depth is 249 feet]

	Thickness	Depth
Quaternary system (stream deposits):	*Feet*	*Feet*
Surface earth	12	12
Gravel	6	18
Cretaceous system (Trinity formation):		
De Queen limestone member—		
Limestone	4	22
Red clay	8	30
Limestone	7?	37
Blue clay	9?	46
Limestone	3	49
Blue clay and lignite coal	11	60
Limestone	7	67
Yellow clay	14	81
Limestone	9	90
Ultima Thule gravel lentil: Red clay and gravel	18	108
Limestone	5?	113?
Blue clay	7	120
Blue slate	30	150
Blue clay	10	160
Dierks limestone lentil—		
Limestone	7	167
Blue slate	12	179
Limestone	4	183
Blue clay	9	192
Sandstone	10	202
Calico clay	12	214
Sandstone	7	221
Pike gravel member: Gravel; base not reached	23	244

A recent report by Honess [57] describes occurrences of "fine yellow sand with locally a little small gravel showing" on the higher ridges

[57] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, 1923.

west of Blanchard post office in the De Queen quadrangle. He expressed the opinion in the report that the deposits are Cretaceous; but at the end of a visit to the localities in October, 1923, in company with Mr. Miser, he and also Mr. Miser concluded that most if not all the material there is deep residual sand from the underlying thick beds of sandstone in the Stanley shale.

Fossils and correlation.—Invertebrate fossils in the Trinity formation occur only in the Dierks limestone lentil and the De Queen limestone member, and they represent a brackish-water molluscan fauna with some purely marine elements. There is, however, a small quantity of carbonized wood in different parts of the formation and some vertebrate fossils, a few of which have been found in beds not far below the De Queen limestone, at the base of Plaster Bluff. Concerning the vertebrate fossils R. T. Hill [58] says that they "have the appearance of being saurian remains, except what is probably the palatal bone of a fish, resembling the *Lepidotus mantelli* Agassiz." The Dierks limestone contains great numbers of small oysters (*Ostrea franklini*) and other shells, most of which are more or less comminuted. The oyster shells are more numerous than the others and in places make up beds several feet thick. The De Queen limestone is less fossiliferous than the Dierks, but fossils consisting mainly of *Ostrea franklini* and other pelecypods are numerous in many layers.

T. W. Stanton, to whom the fossils collected from these limestones were transmitted for identification, states that they belong to the fauna of the Trinity group of Texas and show a rather definite relationship to the fauna of the Glen Rose limestone of that State.

A collection from the Dierks limestone in the northeast corner of sec. 3, T. 8 S., R. 27 W., 3 miles west-southwest of Nathan, contains the following species:

Ostrea franklini Coquand.
Anomia texana Hill.
Modiola branneri Hill.
Astarte? sp.
Glauconia sp.

Another collection from this limestone in the northeast corner of sec. 9, T. 8 S., R. 25 W., about 2 miles northeast of Murfreesboro contains the following species:

Serpula paluxiensis Hill.
Ostrea franklini Coquand.
Exogyra sp.
Anomia texana Hill.

[58] Hill, R. T., The Neozoic Geology of Southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, p. 152, 1888.

Modiola branneri Hill?
Nucula sp.
Barbatia parva missouriensis Hill?
Cucullaea sp.
Eriphyla pikensis Hill.
Astarte sp.
Corbicula arkansaensis Hill.
Cardium? sevierense Hill.

Specimens of ammonites and of *Nautilus* have been collected by T. W. Stanton in the Dierks limestone near Murfreesboro.

The combined faunas of three collections made from the De Queen limestone between Fairview Church and Cossatot River, a few miles east of De Queen, contain the following species:

Serpula paluxiensis Hill.
Membranipora sp.
Ostrea franklini Coquand.
Anomia texana Hill.
Barbatia parva missouriensis Hill?
Mytilus tenuitesta Roemer?
Astarte? sp.
Avicula sp.
Eriphyla pikensis Hill.
Cyprina? sp.
Glauconia branneri Hill.
Glauconia? sp.

Many specimens of *Ostrea franklini* var. *camelina* Cragin, a much larger species than *Ostrea franklini*, were found near the base of the De Queen limestone by the roadside, 2 miles north of Provo.

GULF SERIES (UPPER CRETACEOUS)

WOODBINE FORMATION

Definition.—The Woodbine formation of the Gulf series (Upper Cretaceous) received its name from the village of Woodbine, in Cooke County, Tex. The formation consists mainly of quartz sand in northeastern Texas and in Bryan and Choctaw Counties, Okla., where it is appropriately called the Woodbine sand. Water-laid volcanic material is present in the Woodbine but increases in quantity toward the east in Texas, Oklahoma, and Arkansas and makes up a large part of the formation in McCurtain County, Okla., and in southwestern Arkansas, where the term formation is more suitable than the term sand. In Arkansas the Woodbine comprises the lower part of the "Bingen sand" of Veatch and later authors.

Distribution and character.—The area of outcrop of the Woodbine formation is a belt extending from the valley of Little Missouri River near Murfreesboro, in the Caddo Gap quadrangle, in a west by south direction across this quadrangle and the southeast corner of the De Queen quadrangle. The Woodbine and also the gravel and sand of the younger Tokio formation produce the southward-sloping Lockesburg cuesta on which the villages of Centerpoint, Corinth, and Highland are located. A description of the cuesta is given on pages 17–18.

The thickness of the formation in the Caddo Gap quadrangle is not definitely known but appears to be as much as 200 feet. It thins eastward and is not present east of the valley of Little Missouri River in this quadrangle. The thickness of the formation as revealed in a well at Nashville, 4 miles south of the Caddo Gap quadrangle, is apparently 350 feet. Only the lower part of the formation—the basal gravel, some 60 feet thick—is present in the De Queen quadrangle. The beds above this gravel crop out farther south.

Besides the gravel at the base of the formation there are thinner beds and lenses of gravel that occur here and there in water-laid volcanic tuff that overlies the basal gravel. These several gravel deposits resemble one another as well as those of the Trinity formation. Like the gravel beds in the Trinity and in the terrace deposits, they have all been held by some geologists to be of post-Tertiary age. This and other views concerning the gravel beds are briefly discussed on pages 97–99.

The gravel deposits in the Woodbine formation are cross-bedded and are composed of partly rounded to well-rounded pebbles, most of which are less than 1 inch in diameter, although many reach a diameter of 6 inches. Some beds 12 to 15 feet thick, as well as thinner ones, have been converted into hard conglomerate by the infiltration of iron oxide, which has cemented the pebbles together. Most of the pebbles are novaculite; the rest are quartz, quartzite, and sandstone. The novaculite pebbles are commonly white, but various shades of red, blue, gray, green, brown, and yellow are common. It is obvious from the nature of these pebbles that they were derived from the rocks of the Ouachita Mountain region, but many doubtless came directly from partly eroded gravel beds of the Trinity.

In addition to the kinds of pebbles just mentioned there are rather extensive deposits of pebbles of igneous rocks. Most of the larger igneous pebbles that have been observed do not occur in the thicker beds of gravel but in thin beds and lenses of gravel interbedded in the volcanic tuff, though numerous small pebbles are disseminated through the tuff.

Clay is found at some places in beds many feet thick interbedded with the volcanic tuff. It is gray to brown, is laminated, and contains at places fossil leaves, some of which were collected at a locality on Mine Creek, 4 miles north of Nashville, Ark., half a mile south of the southern border of the Caddo Gap quadrangle.

The volcanic tuff in the Woodbine occurs in widespread beds that attain a thickness of 125 feet or more. The tuff is mostly cross-bedded, soft, grayish and olive-gray, is composed of coarse and fine grains of volcanic rocks and is for the most part unconsolidated but is in a few places cemented by calcite. The calcite-cemented masses are lenticular and spherical. The best exposures of tuff in the Caddo Gap quadrangle are on and near Mine Creek, Blue Bayou, and other streams near Centerpoint.

The tuff deposits vary greatly in texture and in mineral composition, and the various materials are commonly more or less mixed, but two main types of pyroclastic deposits can usually be recognized. One may be called a lithic tuff[59]—that is, one composed predominantly of fragments of rocks that were originaly crystalline, or almost completely crystalline. The second is vitric tuff,[59] composed largely of glassy pumice, or more commonly of alteration products derived from glassy volcanic fragments. Both types contain variable amounts of crystal grains that represent phenocryts set free from their matrix by the explosive eruptions that pulverized and scattered the rock. They also contain more or less water-laid débris derived from pre-Upper Cretaceous sedimentary rocks.

The unweathered lithic tuff is greenish gray and is formed of rather well-sized rock pellets and mineral fragments, commonly 2 to 4 millimeters in diameter. The rock grains are rounded to subrounded, and the mineral grains are euhedral or angular and are usually without signs of attrition. These crystal grains are orthoclase, pale-green augite, brown hornblende, black spinel, magnetite, titanite, and apatite. The orthoclase and augite are most abundant. The augite is commonly euhedral with very delicate multiple-terminating pyramids that give a cockscomb-like habit. The titanite, spinel, and magnetite have very perfect euhedral crystal faces. Some of the small rock fragments came from an older tuff bed of a type that was clearly deposited directly from the air, and such fragments have been reworked.

The lithic tuff was produced in large measure by the explosive pulverization of material that had previously crystallized in the throat of a volcano, or it was produced by an eruption breaking through previously formed igneous rock masses. However, the presence of euhedral crystals indicates that molten material contributed to the lithic tuff. Such crystals must have been set free from a liquid or pasty matrix before they were blown into the air. The shattering of a solid rock mass would give only crystal fragments.

The vitric tuff is light colored, being blue-gray or cream-colored to almost white. The most abundant phenocrysts are angular or euhe-

[59] Pirsson, L. V., Am. Jour. Sci., 4th ser., vol. 40, p. 193, 1915.

dral orthoclase. Dark minerals occur in smaller quanitity than in the lithic tuff and are entirely absent at some horizons. Where present they include biotite, augite, hornblende, titanite, apatite, and magnetite. The pumice fragments, which reach a maximum diameter of an inch or more, usually have elongated bubble walls, giving a fibrous structure which closely resembles that of rotten wood. Some of the fragments have very thin bubble walls and a structure so delicate that they go to pieces at a touch.

The rock types represented in the two varieties of volcanic material do not differ greatly and are similar to the fresh igneous rock pebbles and cobbles that are sparingly found in the gravel beds and lenses associated with the tuff. The predominant rock type is dark gray or dark greenish gray, with few phenocrysts reaching a maximum diameter of 5 millimeters and usually a very fine grained groundmass. The microscope shows a trachytic structure characterized by rudely parallel plagioclase crystals, 0.1 millimeter in length in the coarser types and 0.02 in the finer-grained ones. The mineral composition is about as follows:

Mode of the predominant volcanic rock in the Woodbine formation

Plagioclase	50–65
Orthoclase	20–40
Nephelite	15–20
Pyroxene or hornblende	2–15

The rocks are porphyritic, orthoclase and augite or hornblende phenocrysts forming 1 or 2 per cent of the rock. Plagioclase with a composition near oligoclase is the most abundant mineral and occurs in very slender prisms which give the rocks a trachytic structure. Orthoclase occurs as rare phenocrysts and as groundmass material less abundant than plagioclase. Nephelite occurs in very small euhedral crystals inclosed in feldspar and also as interstitial material between feldspar grains. Pyroxene is rare, and instead of it brown hornblende is found in a few specimens. The predominant type of volcanic rock is best described as a phonolite. Other identified types include nephelite syenite, a haüyne phonolite, and fourchite similar to but more feldspathic than that from the Hot Springs region.

The vitric tuff contains a large proportion of glass that is usually completely altered to clay minerals. For this reason the rock types represented by the glass can not be exactly determined. It is probable that in part they represent glassy phases of the phonolite. However, the larger proportions of orthoclase, the smaller proportions of ferromagnesian minerals, and the fact that the glassy material is commonly rather silicic indicate that the pumice tuffs are derived largely from syenitic rocks. On Mine Creek occur tuff masses that are composed entirely of altered glass and orthoclase with no dark minerals whatever, and it is probable that these represent a normal syenite.

The deposits of tuff when fresh are greenish gray, bluish gray, and cream-colored to almost white, but on weathering they become a yellow, mealy earth that still retains the texture of the fresh rock, and that finally changes to red plastic clay at and near the surface. Comparatively unoxidized bentonitic tuff is found only in wells and a few exposures.

The volcanic material in the Woodbine formation in the Caddo Gap quadrangle and also in adjoining areas in Arkansas, Oklahoma, and Texas is fully described in Professional Paper 154–F, by C. S. Ross, H. D. Miser, and L. W. Stephenson.

Age and stratigraphic relations.—The Woodbine formation rests upon the truncated edges of different parts of the Trinity formation of the Comanche series in the De Queen and Caddo Gap quadrangles, the youngest subjacent beds being to the west and the oldest to the east. A marked angular unconformity therefore separates the Gulf series from the Comanche series. The table on page 94 shows the stratigraphic relations of the Woodbine in the De Queen and Caddo Gap quadrangles and also in southeastern Oklahoma and northeastern Texas.

The fossils and correlation of the Woodbine are discussed under the Tokio formation on pages 92–94.

TOKIO FORMATION

Definition.—The Tokio formation received its name from the village of Tokio, at the southern edge of the Caddo Gap quadrangle. The formation when first defined by Miser and Purdue was described as the "Tokio sand member of the Bingen formation." Recent field work by Stephenson and Dane, in which Miser cooperated for short periods of time, has shown that an unconformity occurs at the base of a gravel bed immediately underneath the "Tokio sand member of the Bingen." It has also shown that the part of the "Bingen" below this gravel bed is equivalent to the Wodbine sand of Texas. As a result of this work, and also as a result of study of the fossils by Stephenson, the following changes in names have been made: (1) The name "Bingen" has been discontinued in Arkansas and Oklahoma; (2) the "lower Bingen"—the part below the unconformity—is called the Woodbine formation; (3) the "Tokio sand member of the Bingen" is now called the Tokio formation, though the lower limit of the new formation is extended so as to include the heavy gravel at whose base there is an unconformity. The Tokio formation as thus defined has a basal gravel like the Woodbine, and each formation has an unconformity at its base. The formation in the Caddo Gap quadrangle rests upon lower and lower rocks toward the east, first upon the truncated edge of the Woodbine formation, then upon successive parts of the Trinity formation.

Distribution and character.—The Tokio formation is exposed in a belt which extends in a west by south direction across the Caddo Gap quadrangle and which passes south of the De Queen quadrangle. The belt of exposure is not continuous but is broken by bands of alluvium and terrace gravel along several streams that cross it. The formation appears to range from 100 to 150 feet in thickness. It is composed largely of sand and gravel with some clay. The gravel bed at the base is as much as 25 feet thick, but there are three other beds higher in the formation, the thickest of which is 50 feet thick. The gravel deposits are composed of well-rounded pebbles consisting of quartz and novaculite of many colors and ranging in size from that of a pea to a diameter of about 6 inches. Parts of some beds are cemented together with iron oxide and are thus hard conglomerate.

The exposures of sand and clay in the Caddo Gap quadrangle are mostly confined to the vicinity of Tokio and the region east of Little Missouri River. The sand is an incoherent though firmly packed gray quartz sand in beds, some of which are more than 30 feet thick. It is conspicuously cross-bedded, contains disseminated particles of kaolin and a few scattered pebbles, becomes red on weathering, and produces a gray sandy soil. Light and dark clays are interbedded with the sand. Some of them contain fossil plants, and some contain small quantities of pyrite and lignitiferous matter. The light-colored clays are in beds that reach a thickness of 5 to 6 feet, and they consist of plastic ball clay and kaolin. The kaolin is chalky white to creamy in color, but the lowest layer of one bed has a lavender color. It is nonplastic, is very fine grained, and breaks with a conchoidal fracture. It has been prospected, and samples have been tested and found to be fuller's earth. Also many experiments have been made to determine its fitness in the manufacture of china ware, but thus far the bed has not been worked.

The kaolin is very pure clay and has little resemblance to the tuff of the Woodbine formation, but microscopic studies by C. S. Ross apparently show that the beds were originally beds of volcanic dust. The largest dust fragments are less than 1 millimeter in diameter, and most of the individual fragments are so small that the original rock structure is evident only in the rock pellets of the coarse-grained parts of the beds. In the pellets the crystalline rock structure is retained and shows that the rock was a phonolite. The heavy minerals, augite, hornblende, zircon, and tourmaline, are present in very small amount, but the rock contained little besides feldspar and nephelite.

The lower beds of the Tokio formation on the Riley place and on the Twin Knobs, near Murfreesboro, consist in large part of altered serpentine grains and peridotite fragments. Although the beds are water-laid, showing lamination and pronounced cross-bedding, the igneous material may have been ejected into the air from the nearby vents at the diamond mines and then fallen to or near its present position. There is, however, no evidence known as yet against the derivation of the material from adjacent peridotite exposures by means of erosion.

Age and correlation.—The Woodbine and Tokio formations have yielded fossils from which the age of the formations may be determined. Fossil plants have been obtained from the Woodbine formation on Mine Creek 4 miles north of Nashville, Ark., and from the Tokio formation in the big railroad cut 2½ miles east of Tokio, Ark., and in the Adams kaolin pits in sec. 24, T. 8 S., R. 25 W., 5 miles east-southeast of Murfreesboro, Ark. The plants at the Adams pits occur in a 5-foot bed of kaolin which is probably altered volcanic material; the plants on Mine Creek are from a lens of clay in a thick bed of tuff; and the plants at the railroad cut are from a dark gumbo clay that is overlain by sand and light-colored clay.

No fossil invertebrates have been found in the Woodbine formation in Arkansas, but the Tokio formation has yielded small collections,[60] mostly of poorly preserved prints and molds from five or six localities south of the De Queen and Caddo Gap quadrangles.

The fossil plants from the Woodbine and Tokio formations have been studied by Berry,[61] who has also studied a fossil flora of 43 species from the Woodbine sand at Arthurs Bluff, on Red River in Lamar County, Tex.,[62] where the fossil plants occur both associated with coarse sandstone containing a considerable percentage of tuffaceous material and in more or less sandy cross-bedded clay interbedded with and overlying the standstone. Berry says:

> I can therefore only state the well-known fact that the Woodbine and Bingen formations are at least partly contemporaneous. I am of the opinion, which is based on the range of the Woodbine plants in other formations, that Arthurs Bluff is approximately on the boundary between the lower and upper members of the Bingen as recognized by Miser in Arkansas in the specific area where he collected the plants.

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[60] The collections were made by C. H. Dane, L. W. Stephenson, and H. D. Miser.

[61] Berry, E. W., Contributions to the Mesozoic Flora of the Atlantic Coastal Plain, XII—Arkansas: Torrey Bot. Club Bull. 44, pp. 167–190, 1927.

[62] Berry, E. W. The Flora of the Woodbine Sand at Arthurs Bluff, Tex.: U. S. Geol. Survey Prof. Paper 129, pp. 153–181, 1922.

Since the publication of Berry's papers on the fossil floras of the Bingen formation of Arkansas and the Woodbine sand at Arthurs Bluff, in Texas, much has been learned in regard to the age and stratigraphic relations of these and other formations of the Gulf series in Arkansas and northeastern Texas. Miser and Purdue[63] in 1919 divided the Bingen sand of Veatch, in Howard and Pike Counties, Ark., into the lower or main part of the formation and an upper or Tokio sand member. The distribution of the Tokio sand member, as represented on the map accompanying the paper cited, shows that it overlaps the main part of the Bingen and finally conceals completely the Bingen from west to east. The unconformity beneath the gravel bed at the base of the Tokio formation of the present report has since been traced by C. H. Dane to the southwest as far as Little River, where it is concealed by the river alluvium. From northeast to southwest the Tokio, according to Dane,[64] becomes interstratified with beds of clay of increasing thickness, until in Sevier County the clay predominates over the sand.

The lower part of the Bingen sand of Veatch contains the thickest beds of volcanic tuff already mentioned, and thin beds of volcanic material are present in the overlying Tokio formation. The beds of volcanic tuff of the lower part of the Bingen sand have been traced by Miser westward from Arkansas through McCurtain, Choctaw, and Bryan Counties, Okla., and by L. W. Stephenson through the northern parts of Red River, Lamar, and Fannin Counties, Tex. In all these areas the beds of volcanic material form a continuous and characteristic deposit connecting directly with the upper part of the Woodbine sand. The tuffaceous beds are interbedded with the fossil plant-bearing beds at Arthurs Bluff. In Lamar and Fannin Counties the volcanic tuffs have been identified by Stephenson beneath the Eagle Ford clay, showing that the lower part of the Bingen is in reality the eastward extension of the upper part of the Woodbine sand.

The Tokio in Arkansas has been found by Dane to contain fossils at several stratigraphic positions, the lowest within 70 feet of the base, which, according to Stephenson, indicate with reasonable certainty that this division is younger than the Eagle Ford clay. Inasmuch as the lower part of the Bingen—that is, the Woodbine sand—passes beneath the Eagle Ford in Texas, and the upper part of the Bingen—that is, the Tokio formation—is younger than the Eagle Ford, it follows, according to Stephenson, that the Eagle Ford is represented in Arkansas by the unconformity between the Woodbine

[63] Miser, H. D., and Purdue, A. H., Gravel Deposits of the Caddo Gap and De Queen Quadrangles, Arkansas: U. S. Geol. Survey Bull. 690, pp. 22–24, 1918.
[64] Dane, C. H., U. S. Geol. Survey Mem. for the Press, Sept. 10, 1926.

and Tokio. The stratigraphic relations of the Woodbine and Tokio formations are shown in the table below.

Stratigraphic relations of Cretaceous rocks of the De Queen and Caddo Gap quadrangles

Northeastern Texas	Southeastern Oklahoma		De Queen and Caddo Gap quadrangles
Brownstown marl.	Brownstown marl. Present in McCurtain County but not exposed.		Brownstown marl (restricted).
Blossom sand.	Tokio formation. Present in McCurtain County.		Tokio formation.
Bonham clay.			
	Unconformity?		Unconformity
Ector tongue of Austin chalk; basal part is shaly clay and sand with "fish bed conglomerate" at base. Thins out toward northeast in Fannin County.	Not present.		Not present.
Eagle Ford clay. Thins out toward east in Lamar County.	Eagle Ford shale. Present only in Bryan County.	Not present in McCurtain County.	Not present.
Woodbine sand.	Woodbine sand in Bryan and Choctaw Counties.	Woodbine formation in McCurtain County.	Woodbine formation. Thins out toward east in Caddo Gap quadrangle.
Unconformity	Unconformity		Unconformity
Washita group.	Washita group. Thins toward east.		Not present.
Fredericksburg group.	Goodland limestone.		Not present.
Trinity sand.	Trinity sand. Thins toward west by overlap of younger beds of formation over older beds of beds of formation.		Trinity formation. Thins out toward east beyond east border of Caddo Gap quadrangle. The eastward thinning is due to unconformity at base of Woodbine and Tokio formations.

BROWNSTOWN MARL

The lower part, probably 100 feet or more, of the Brownstown marl occupies about 5 square miles in the southeast corner of the Caddo Gap quadrangle. Veatch[65] who has studied the formation over a much larger area than the authors of this paper, describes it as follows:

> The Brownstown formation, into which the Bingen sand gradually grades, is well developed in the southern part of Sevier County, Ark., about Brownstown, from which place it takes its name. It is a blue or gray calcareous clay containing many fossil oysters and is characterized by the presence of the large oyster *Exogyra ponderosa*, whence it has sometimes been called the *Exogyra ponderosa* marl. The soil derived from the formation, when not mixed with surficial deposits, is black and waxy, but the subsoil is yellow, and in most of its outcrops the bed is a yellow clay marl.

A collection of fossils from the Brownstown marl was obtained by R. D. Mesler at an exposure along a wagon road half a mile southeast

[65] Veatch, A. C., Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 25, 1906.

of Delight. The following identifications of the forms in the collection have been made by L. W. Stephenson:

Foraminifers.
Nucula sp.
Cucullaea sp.
Leda sp.
Nemodon sp.
Ostrea mesenterica Morton?
Exogyra ponderosa Roemer.
Pecten sp.
Anomia argentaria Morton.
Liopistha (Cymella) bella (Conrad)?
Crassatellites? conradi (Whitfield)?
Lucina sp.
Cardium (Criocardium) dumosum (Conrad)?
Cardium sp.
Cyprimeria depressa Conrad.
Cymbophora sp.
Dentalium sp.
Turritella quadrilira Johnson?
Cerithium sp.

Concerning the age of the bed from which the fossils were obtained Stephenson says:

Compared with the standard Gulf series (Upper Cretaceous) section in the vicinity of Austin, Tex., the containing stratum corresponds in age to the lower part of the Taylor marl. There is nothing in the collection to indicate that the containing bed is as old as the Austin chalk of the type region.

TERTIARY (?) SYSTEM

Several small areas of gravel occur on the upland surface of the Athens Plateau between Athens and the headwaters of Holly Creek, in the Caddo Gap quadrangle. The hills capped by them range from about 850 feet above sea level at the south to about 1,000 feet at the north, and they represent remnants of the Hot Springs peneplain, which was produced about the beginning of the Tertiary period or sometime during that period. The position of the gravel on the crests of the hills shows that it was laid down by streams on this peneplain before the dissection of the peneplain was begun late in the Tertiary period or soon thereafter. They are therefore tentatively assigned to the Tertiary system. There is no evidence that the Tertiary sea ever extended far enough northwest of the present limit of Tertiary sediments, near Hope, Ark., about 45 miles distant, to lay down the gravel under discussion. The gravel was probably deposited by streams whose courses were markedly different from the present courses of Little Missouri and Saline Rivers, which now drain this part of the Athens Plateau. The deposits were formerly more extensive than they now are, and doubtless most of the original gravel beds have been carried away by streams during the dissection of the peneplain.

The gravel nowhere appears to exceed 15 or 20 feet in thickness. It consists of subangular to well-rounded pebbles and cobbles as much as 10 inches in their longest dimension. Most of the pebbles are novaculite; the rest are sandstone. Owing to long exposure to weathering the novaculite pebbles have become somewhat porous and have lost the dense chalcedonic appearance that is usually shown by the novaculite.

QUATERNARY SYSTEM

TERRACE DEPOSITS

The terrace deposits are found chiefly along Little Missouri, Saline, and Cossatot Rivers and Rolling and Muddy Forks, in the Coastal Plain along the southern borders of the quadrangles. Only small patches occur along these and other streams farther north.

Most of the terrace deposits in the Athens Plateau and the Ouachita Mountains form "second bottom" land and have been mapped with the alluvium where they have been mapped at all. In a few places terrace gravel a few feet thick occurs at a considerable height above the streams. The gravel caps a hill just north of the village of Caddo Gap and two hills just east of the village. It occurs 60 to 70 feet higher than the water above the dam on Caddo River at that place and about 680 feet above sea level. The gravel at Glenwood caps the small knob on which the high school is located and another about 1,000 feet northeast of the high school. The first of these occurrences is 115 feet above Caddo River at the ford south of the town, or about 627 feet above sea level, and the second appears to be 15 or 20 feet higher. The highest observed deposit of the gravel above the streams in the northern parts of the quadrangles caps a low hill a little more than 2 miles west of Langley. This hill slightly exceeds 850 feet above sea level and rises about 150 feet above Little Missouri River at the ford on the west.

The terrace deposits in the southern parts of the quadrangles occupy benches that range from 35 to 150 feet above mean water level, and some deposits are strewn along the slopes between the different benches.

The deposits are in general unassorted mixtures of small and large pebbles and sand and are in most places overlain by a good soil. The gravel is of local origin, having been derived directly from the rocks of the Ouachita Mountains and indirectly from the same source through the gravel beds of Cretaceous age in these quadrangles. It is made up mostly of novaculite pebbles, which are partly rounded to well rounded and range in size from minute pebbles to cobbles a foot in diameter. A few pebbles are sandstone and quartz. The terrace gravel in the Coastal Plain so closely resembles the gravel of Cretaceous age that in places it is difficult and in some places apparently impossible to distinguish them. In such places the altitude of the gravel deposit, the character of the surface, and the assortment and size of the pebbles have to be considered in determining the age. These deposits range in thickness from a thin mantle to 50 feet or more, but most of them are 15 to 20 feet thick. As a rule the largest patches contain pebbles and cobbles at the base and sand or loam at the top, whereas the smallest patches contain only pebbles and cobbles.

VARIOUS AGE DESIGNATIONS OF GRAVEL DEPOSITS

The several beds of gravel in the quadrangles that are older than the gravel of the alluvial deposits have been held by some geologists to be superficial and to be of post-Tertiary age, though other opinions have been held concerning them. The beds about which there has been much diversity of opinion include all those of the Trinity, Woodbine, and Tokio formations, the gravel of possible Tertiary age near Athens in the Caddo Gap quadrangle, and the gravel of the terrace deposits. The diversity of opinion has been due largely to the regional reconnaissance character of the studies of the deposits by the different geologists and also to the lack of topographic maps such as those that are now available.

Hill[66] in 1888 regarded the outcropping edges of the gravel beds in the Trinity, Woodbine, and Tokio formations as superficial deposits of post-Tertiary age and assigned to them the name "Plateau gravel."

Hay,[67] who traced the northern border of the Cretaceous rocks of southwestern Arkansas, stated in his report of 1888 that the gravel deposits along this border are surficial deposits of post-Tertiary age laid down by "strong currents of water." The gravel deposits described by him occur in the Trinity, Woodbine, and Tokio formations.

McGee[68] in 1891 referred to the Lafayette formation the beds of gravel in southwestern Arkansas that are now classified as Lower Cretaceous, Upper Cretaceous, and Quaternary in age. Concerning the age of the Lafayette formation he says, "Its position in the biotic

[66] Hill, R. T., The Neozoic Geology of Southwestern Arkansas; Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, pp. 28–42, 1888.

[67] Hay, O. P., The Northern Limit of the Mesozoic Rocks in Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, pp. 263 et seq., 1888.

[68] McGee, W J, The Lafayette Formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 470–471, 1891.

scale is unknown, its meager flora combining Laramie (Cretaceous) and Pleistocene or modern features, and its still more meager fauna representing the entire Neocene."

Harris[69] in 1894 regarded the gravel beds of Cretaceous and Tertiary age of southwestern Arkansas as shore deposits "laid down under similar conditions, though by no means in the same geological epoch," and he thinks their "rearrangement presumably took place before the close of the epoch represented by the underlying stratified beds."

Ashley[70] in 1897 described as "overwash gravels," the gravel of possible Tertiary age near Athens, Ark., and also the gravel beds of Cretaceous age along the border of the Coastal Plain in southwestern Arkansas. He assigned them a post-Tertiary age.

Taff[71] in a report published in 1902 also regarded the out-cropping edges of the gravels in the Woodbine and Tokio, and a few areas of outcrop of those in the Trinity as surficial deposits and referred them and the terrace gravels to the Neocene (?), though he mapped as Trinity large areas of gravel that are assigned to that formation by the present writers.

Hayes[72] in 1903, after making a brief statement concerning the Trinity formation and its relations to the Paleozoic rocks in southwestern Arkansas, said, "Both Trinity and Paleozoic were * * * covered by a thin and irregular deposit of coarse sand and gravel called the Lafayette."

Veatch[73] in 1906 made the statement that remnants or the redeposited remnants of the Lafayette formation are very common throughout the Coastal Plain in Arkansas and Louisiana, but he did not refer specifically to the gravel deposits of the De Queen and Caddo Gap quadrangles. He did say, however, that "Portions of the weathered outcrops of the Bingen and Nacatoch sands have been mistaken[74] for these surficial [Lafayette] beds."

Branner[75] in 1908 in his description of kaolin deposits between Murfreesboro and Delight called the gravel there the Lafayette gravel and assigned it a Pleistocene age. These gravels are now

[69] Harris, G. D., The Tertiary Geology of Southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 7–9, 1894.

[70] Ashley, G. H., Geology of the Paleozoic Area of Arkansas South of the Novaculite Region: Am. Philos. Soc. Proc., vol. 37, pp. 303–306, 1897.

[71] Taff, J. A., Chalk of Southwestern Arkansas with Notes on Its Adaptability to the Manufacture of Hydraulic Cements: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 3, pp. 694–696, 1902.

[72] Hayes, C. W., Asphalt Deposits of Pike County, Ark.: U. S. Geol. Survey Bull. 213, p. 353, 1903.

[73] Veatch, A. C., Geology and Underground Waters of Northern Louisiana and Southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 44–46, 1906.

[74] Veatch cites the above-mentioned reports by Hill and Taff.

[75] Branner, J. C., The Clays of Arkansas: U. S. Geol. Survey Bull. 351, pp. 148–153, 1908.

regarded by the present authors as being a part of the Tokio formation.

Purdue[76] in 1908, in describing the geology of the peridotite area at the American diamond mine near Murfreesboro, Ark., says, "The top of the ridge [at the mine] is covered to a depth of 10 to 12 feet with 'plateau gravel' (Lafayette formation) cemented into a conglomerate." This gravel is now classified as the lowest bed of gravel of the Tokio formation.

ALLUVIUM

Most of the streams in the Athens Plateau and Ouachita Mountains flow on bedrock and are bordered by cliffs and steep slopes or by only small patches and belts of alluvium, but most of the streams in the Coastal Plain flow in flat-bottomed valleys and are bordered by flood plains, some of which are 2 to 3 miles wide. Although fine and coarse gravel makes up a large part of the valley filling, the surface is usually covered with rich loam and sand, and most of it makes good farm land. These gravel deposits in the Coastal Plain have been derived from erosion of the outcropping edges of older gravel deposits of the region, though some of them have been carried by the streams from the Ouachita Mountain region. They thus do not differ from the gravel of Cretaceous age already described, except in their distribution and lack of assortment. Little is known of the thickness of the alluvium, but it is probably less than 25 feet at most places.

IGNEOUS ROCKS[77]

GENERAL FEATURES

Peridotite, the only igneous rock observed by the authors in the quadrangles here described, is exposed in four places near Murfreesboro in the Caddo Gap quadrangle, and three of these exposures have yielded diamonds. The exposure that was first discovered and that has been known to geologists since 1842 is 2½ miles south-southeast of Murfreesboro, near the confluence of Prairie Creek with Little Missouri River, and is hence named the Prairie Creek peridotite area. (See pl. 10.) Diamonds were discovered on it in 1906, and since then more than 10,000 diamonds, ranging in weight from a small fraction of a carat to 40.23 carats, have been taken out. The mines that are operated on it are the Ozark, Mauney, and Arkansas.

[76] Purdue, A. H., A New Discovery of Peridotite in Arkansas: Economic Geology, vol. 3, No. 6, p. 526, 1908.

[77] Much of this section has been written by C. S. Ross, to whom the specimens of the rocks were submitted for microscopic study. Other descriptions of the peridotite by Messrs. Ross and Miser have been given in the following recent articles: Diamond-Bearing Peridotite in Pike County Ark.: Econ. Geology, vol. 17, pp. 662–674, 1922; U. S. Geol. Survey Bull. 735, pp. 279–322, 1923; Smithsonian Inst. Ann. Rept. for 1923, pp. 261–272, 1925.

The other exposures of peridotite are all within an area of 1 square mile about 2 miles northeast of the Prairie Creek area and 3 miles east-southeast of Murfreesboro. Two of these, the Kimberlite and American areas, are so named from the mines located on them, and the third, the Black Lick area, is at and near a locality known as the Black Lick. (See pl. 14.) The Kimberlite and American areas have been prospected on a small scale, and each has yielded a small number of diamonds. The Black Lick area has been prospected less than any of the others and has thus far produced no diamonds.

A 5-foot dike of ouachitite was discovered a few years ago by Mitchell[78] at a locality 7 miles east of Gillham in the southeast part of sec. 9, T. 7 S., R. 30 W. Weathered boulders on a hill slope attracted his attention and led to the discovery. The rock, according to him, is a black, heavy material, with biotite, augite, and pyrite recognizable in hand specimens.

PRAIRIE CREEK PERIDOTITE AREA

LOCATION AND TOPOGRAPHY

The Prairie Creek peridotite area is roughly triangular and comprises about 73 acres. (See pl. 10.) The surface is gently rolling and has an altitude of 340 to 380 feet, except along its northwest margin, where there are three knobs or hills, known as West, Middle, and East Hills, that rise to altitudes of 401, 415 to 420, and 441 feet, respectively. This area is joined on the southeast by rolling country, but along other parts of its boundary it is joined by the low, nearly level valley floor of Little Missouri River and some of its tributaries. The surface of most of the valley floor is between 315 and 340 feet above sea level, though near the Ozark mine it attains an altitude of a little over 355 feet.

ROCKS ASSOCIATED WITH THE PERIDOTITE

The peridotite area is adjoined along most of its east side by clay and sand of the Trinity formation and on its north and west sides and much of its south side by alluvium. (See pl. 10.) The alluvium conceals not only the Trinity formation, but also parts of the margin of the peridotite body and possibly many dikes that radiate from the exposure. On Prairie Creek, near its mouth, erosion of the alluvium has revealed sand of the Trinity formation at three places and a peridotite dike at one place.

Many boulders of Carboniferous sandstone are in the bank of Little Missouri River just below the mouth of Prairie Creek, and although they are not in place they are probably near the parent ledges.

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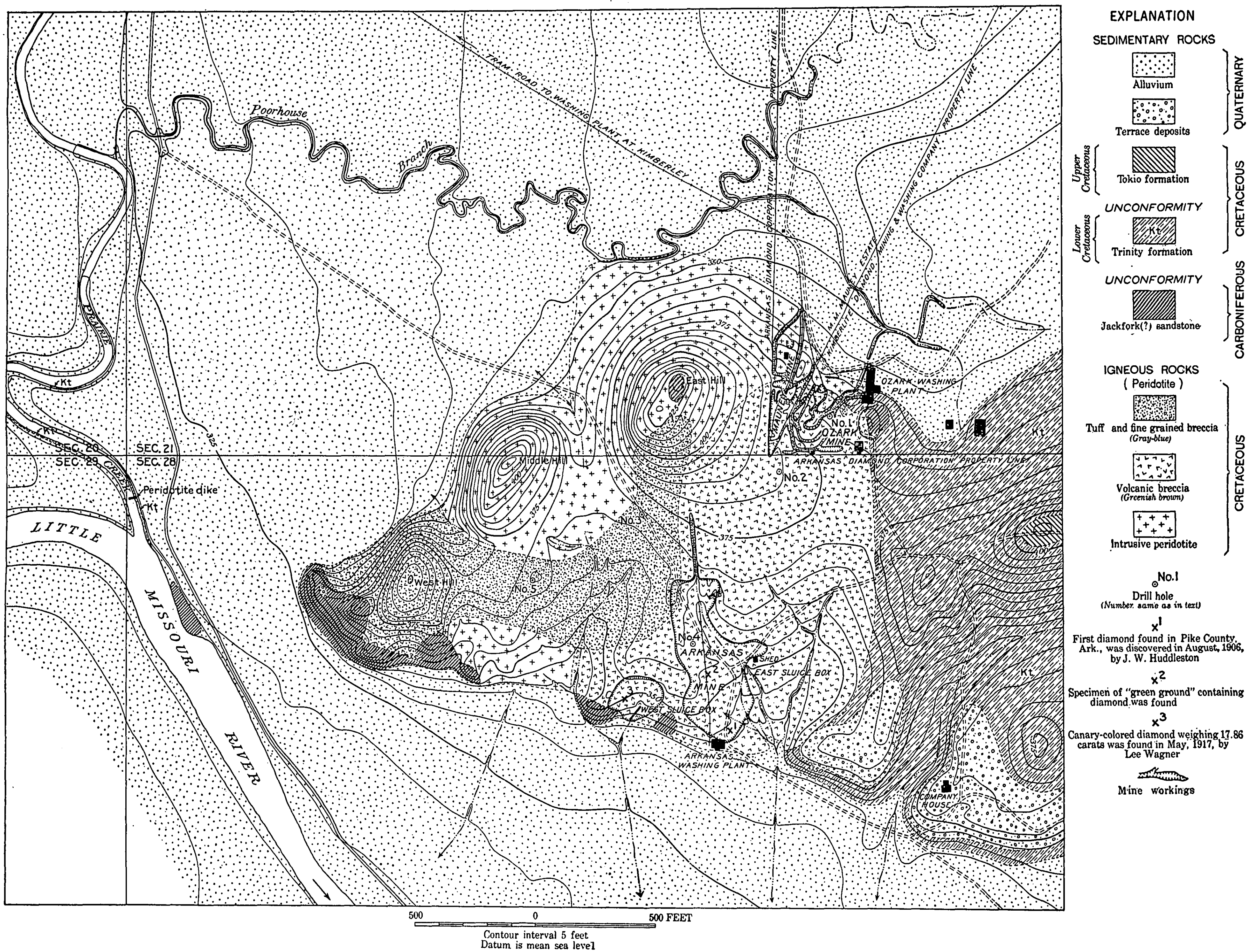
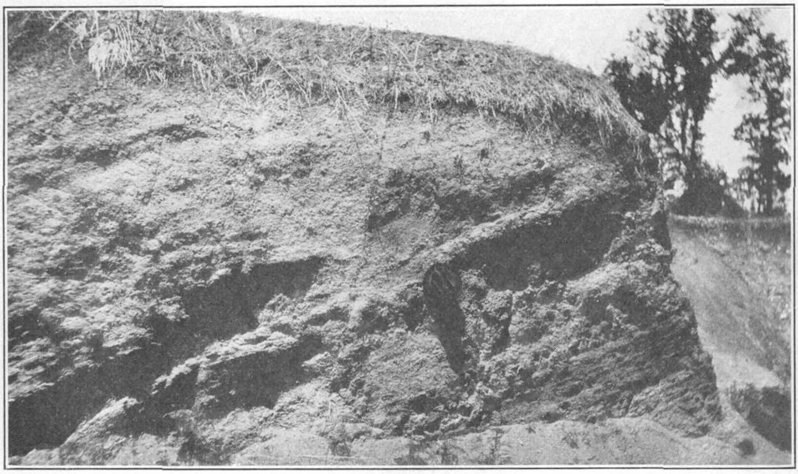
[78] Mitchell, G. J., Antimony in Southwestern Arkansas: Eng. and Min. Jour.-Press, vol. 114, p. 455, 1922. Also map accompanied by letter dated Sept. 7, 1923.



GEOLOGIC MAP OF THE PRAIRIE CREEK AREA OF PERIDOTITE IN T. 8 S., R. 25 W., 2½ MILES SOUTH-SOUTHEAST OF MURFREESBORO, PIKE COUNTY, ARK.

Surveyed with plane table in 1916 by H. D. Miser

A. INTRUSIVE PERIDOTITE ("HARDEBANK") IN THE NORTHERN PART OF THE MAUNEY MINE, NEAR MURFREESBORO, ARK.



B. ALTERED VOLCANIC BRECCIA ("BLUE GROUND") IN CUT OF OZARK MINE NEAR MURFREESBORO, ARK.

The bedding dips about 30° W.

Boulders of peridotite also occur at the same locality. Their source is not known, but they were probably derived from one or more dikes that are now concealed.

A small part of the east side of the peridotite exposure and a greater part of its south and southwest sides are adjoined by exposures of sandstone of Carboniferous age, which may be the Jackfork sandstone. The sandstone is massive and gray, greenish gray, and brown, and some of it has been changed to a hard compact quartzite. A mass of fine-grained gray quartzite about 100 feet long and 50 feet wide occurs on the crest of East Hill. It was perhaps derived from the Jackfork sandstone and included in the peridotite magma during the upward movement of the magma toward the surface.

Terrace gravel, as much as 10 feet thick, rests upon the Carboniferous sandstone in a very small area on the west point of West Hill, and similar gravel overlain by clay rests upon the Trinity formation southeast of the Arkansas mine. These terrace deposits are from 350 to 370 feet above sea level and have the same altitude as the long north-south terrace on which the town of Murfreesboro stands. The gravel consists of well-rounded pebbles and cobbles of variegated novaculite.

The black soil overlying the peridotite at the Ozark, Mauney, and Arkansas mines contains numerous pebbles of novaculite to a depth of 1 or 2 feet. The greatest altitude at which the pebbles in the soil occur is nearly the same as that of the above-mentioned terrace gravel, and this fact suggests that they have been derived from a terrace deposit that was laid down on the peridotite. If such a deposit was laid down, Little Missouri River must have once flowed across the southeastern part of the peridotite exposure.

CHARACTER OF THE PERIDOTITE

General features.—Although the Prairie Creek peridotite area comprises 73 acres, the exposures of the hard, unweathered rock do not exceed 12 acres. The depth of the weathered material has not been determined, though it has been shown by pits and drill holes to be at least 205 feet.

The weathered peridotite is a soft earth or a fairly soft rock. It shows many shades of green, blue, and yellow, and the rocks of these colors are known by the miners as "green ground," "blue ground," and "yellow ground." The soft earth at the surface is black from the presence of organic matter and is known as "black ground." It is waxy like gumbo and is as much as 4½ feet thick here and there, though it is usually only about 1 foot thick. At places fully half of the black ground is composed of well-rounded novaculite pebbles and angular fragments of sandstone and quartzite.

The peridotite appears to be divisible into three rather distinct types. One is a massive intrusive rock; another is a volcanic breccia, which is almost identical with the first in mineral composition and is probably the pyroclastic equivalent of that rock; and the third comprises volcanic tuff and fine-grained breccia. The distribution of these types is shown in Plate 10.

The first two types are nearly black when fresh and weather to dingy olive-green; the third type is light blue.

Intrusive peridotite.—The intrusive peridotite is the surface rock in two areas. One area extends from the northern part of the Ozark mine across the northern part of the Mauney mine and thence westward and southwestward beyond Middle Hill. (See pl. 11, *A*.) The other area lies between the Arkansas mine and West Hill.

The intrusive peridotite is very similar in appearance to the associated volcanic breccia and is no doubt its hypabyssal equivalent. Different occurrences of the intrusive type differ very little in color and mineral composition. Where unaltered it is a very dense porphyritic rock, which is dull black, greenish black, or brownish black. The fresh rock is hard and exceedingly tough and for this reason is called "hardebank" by the miners. Olivine forms the only phenocrysts of appreciable size occurring in the rock. Their color is nearly white when the olivine is unaltered, but many of the aggregates of secondary minerals derived from them are nearly black. The greenish or brownish black groundmass is fine grained and has a dull surface on fresh fracture. A very few grains of chromite have been observed with the unaided eye.

The microscope shows that the rocks are composed essentially of olivine phenocrysts in a groundmass of pale red-brown mica. (See pl. 12.) The mineral composition of a typical specimen is as follows:

Mode of intrusive peridotite

Augite	6
Olivine	11
Serpentine (derived from olivine)	24
Phlogopite	56
Perovskite	1
Magnetite	2
	100

In some specimens the alteration of the olivine to serpentine is almost complete, but in many of the larger phenocrysts alteration has occurred only along the borders and cracks. Many of the phenocrysts have a fine euhedral outline, even though completely altered to serpentine, but others have a rounded outline. Most of the olivine-serpentine areas are surrounded by a narrow reaction rim of the brown mica phlogopite, which, unlike the other phlogopite, contains no poikilitic inclusions. In thin sections the serpentine is colorless or pale yellow, and much of it contains minute inclusions of secondary magnetite, which developed during the alteration of the olivine.

The most abundant mineral of the groundmass is phlogopite, which occurs in fine-grained aggregates, in large anhedral crystals, and as narrow reaction rims around olivine grains. Most of the phlogopite is poikilitic and incloses all the other minerals of the groundmass. Its color in thin sections is usually very pale yellow to reddish brown, but some grains are rose-pink in the direction of maximum absorption. Most of the phlogopite is unaltered, but some of the fine-grained groundmass aggregate of mica is pale green through partial alteration of the mica to chlorite.

Light-colored augite is found in most of the rocks of this type, and where best developed it occurs in euhedral needles from 0.05 to 0.15 millimeter in length. (See pl. 12, *B*.) In other specimens it forms very small irregular grains. Small black crystals of magnetite and rounded or octahedral crystals of yellow perovskite are abundant accessories.

Inclusions of several kinds have been noted in the intrusive peridotite. One kind, which may represent altered limestone inclusions, forms subangular areas as much as 3 inches in their longest dimension composed mostly of very fine grained serpentine, which is greenish brown to nearly black in the hand specimen and is surrounded by thin layers of light-green coarser-grained serpentine.

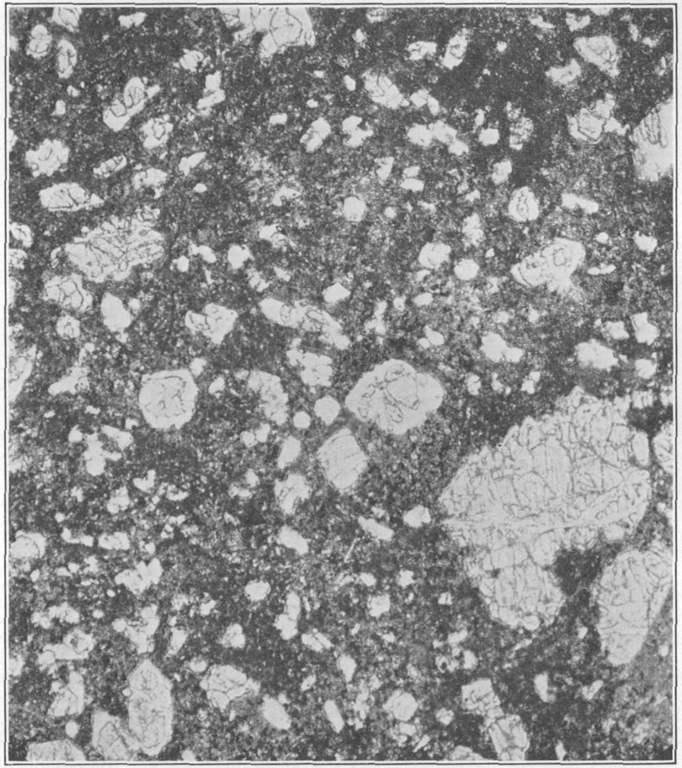
Small shale fragments are present in much of the rock, and they have become dull green through the development of minute crystals of chlorite. No large fragments of black shale like those in the breccia were observed. Another kind of inclusion appears to have been originally a very coarse grained igneous rock composed largely of hypersthene. The original minerals have been completely altered, and the rock is now composed of serpentine and secondary amphibole and pyroxene. The amphibole is rose-purple, pleochroic, manganese-bearing tremolite, and the green pleochroic pyroxene is intermediate between aegirite-augite and diopside.

The diamonds that have been recovered from the soft decomposed material derived from the intrusive type of peridotite are said to be few and small.

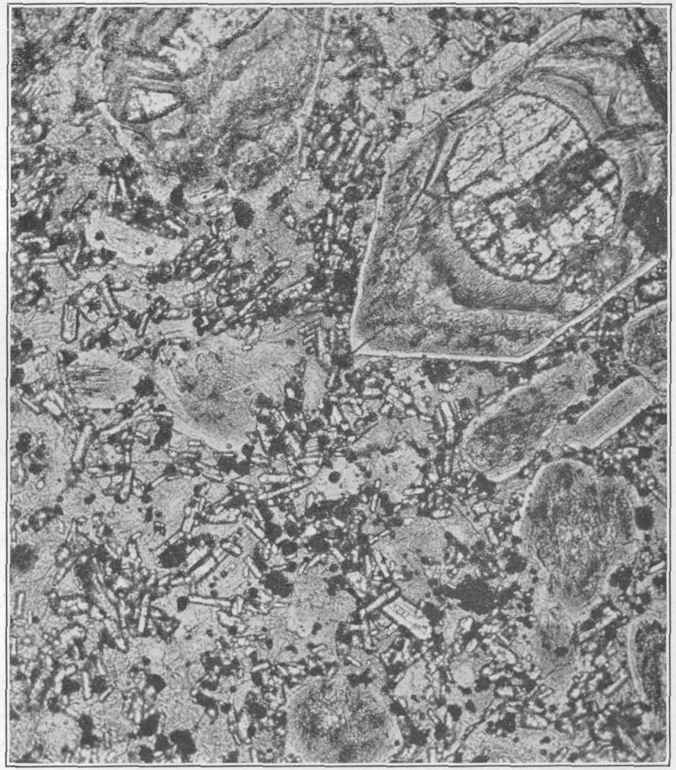
PLATE 12

A. Nearly fresh rock. Large phenocrysts of olivine show partial alteration to serpentine. Dark-gray groundmass is fine-grained aggregate of phlogopite, augite, and magnetite. Enlarged 15 diameters.

B. Rock from summit of Middle Hill. Phenocrysts of olivine partly altered to serpentine. Groundmass is phlogopite containing small prisms of augite and black grains of magnetite and perovskite. Enlarged 50 diameters.

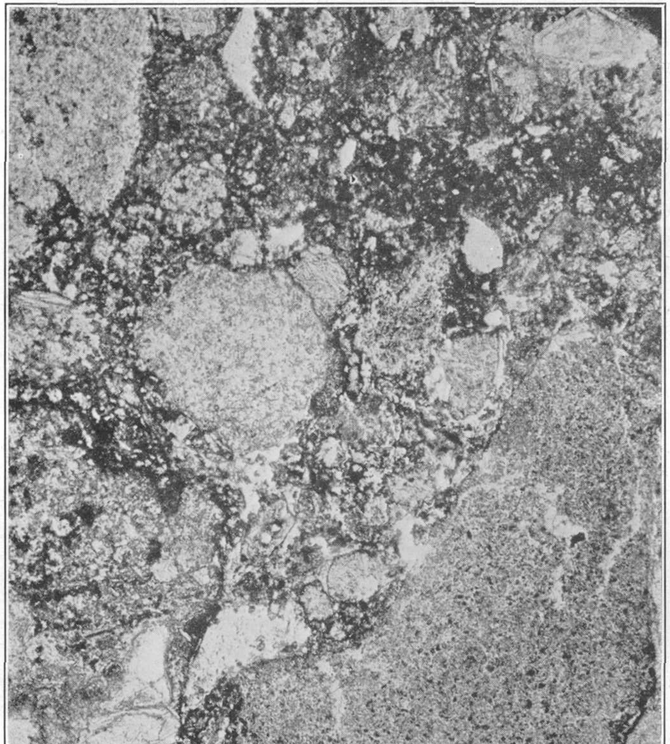


A



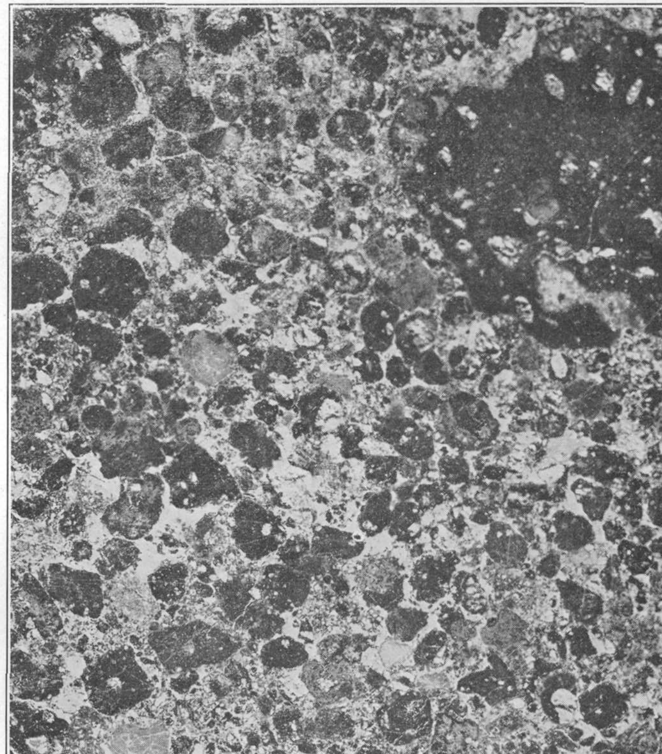
B

PHOTOMICROGRAPHS OF INTRUSIVE PERIDOTITE ("HARDEBANK") FROM PRAIRIE CREEK AREA, NEAR MURFREESBORO, ARK.



A. PHOTOMICROGRAPH OF BLUE-GRAY TUFF FROM DRILL HOLE NO. 3 NEAR ARKANSAS MINE, NEAR MURFREESBORO, ARK.

Large fragments are metamorphosed shale. Crystal in upper right corner is phlogopite. Groundmass is an aggregation of alteration minerals. Enlarged 15 diameters



B. POLISHED SURFACE OF VOLCANIC BRECCIA (" BLUE GROUND ") FROM SOUTHERN PART OF MAUNEY MINE, NEAR MURFREESBORO, ARK.

Composed of angular fragments of altered peridotite. Large dark fragment contains phenocrysts of altered olivine in serpentine groundmass. Natural size

Volcanic breccia.—The volcanic breccia is a pyroclastic rock similar to and closely associated with the porphyritic intrusive peridotite. It is the surface rock over a fairly large area extending from the southern parts of the Ozark and Mauney mines southward to and beyond the Arkansas mine. It has yielded most of the diamonds taken from these three mines. Although the distribution of the breccia is shown on the accompanying map (pl. 10), the boundary line that represents the contact between it and the intrusive peridotite is not accurately drawn, because there are comparatively few exposures of unaltered rock.

The breccia as it is revealed at the surface is weathered and has changed to clay or soft rock except in three or four small areas near the shed on the Arkansas mine, where there are exposures of rock that is weathered very little. In these areas it is a very firmly cemented, tough pyroclastic rock. An examination of the least-weathered specimens of it show them to be composed of rock fragments that differ greatly in texture, some of the fragments being porphyritic peridotite and others being completely aphanitic. The original olivine phenocrysts are now light-colored aggregates of serpentine, some containing cores of fresh olivine. A few flakes of dark mica can usually be recognized in the hand specimen. The microscope shows that the rock differs little from the porphyritic intrusive phases. Olivine phenocrysts partly altered to serpentine are abundant, and a few small phenocrysts of phlogopite are present. The groundmass is composed of a fine-grained aggregate of phlogopite, augite, magnetite, and perovskite. The shale inclusions are much altered and are now composed largely of very small quartz and augite or chlorite grains.

Some of the altered breccia is clay, but some is fairly hard rock. A small quantity of the clay is yellow and is known as "yellow ground," but the soft rock and most of the clay have a dirty-green color and are known as "blue ground" or "green ground." Most of the "blue ground" or "green ground" as revealed in gullies is a breccia (pl. 13, *B*) and is fairly hard, though the hard rock softens on long exposure so that it can be washed for the recovery of the diamonds. The "blue ground" shows bedding at a few places; the best exposure is near the southwest end of the large northeastward-trending cut of the Ozark mine. There the bedding dips about 30° W., and the several layers show not only a difference in color but also a difference in the size of the rock fragments composing the breccia. (See pl. 11, *B*.)

The "blue ground" is composed largely of angular and subangular fragments of igneous rock but contains many irregular fragments of shale, clay, and sandstone. Most of the fragments of sedimentary rocks are less than 1 inch in their longest dimension, though some 15 inches long were seen. The fragments of shale and sandstone have been derived from rocks of Carboniferous or earlier age, and most or all of them have probably been carried upward hundreds or thousands of feet from their source.

The fragments of igneous rock in the "blue ground" reach a maximum size of about 6 centimeters and average less than 2 centimeters in diameter, but some layers consist entirely of fine material a few millimeters in diameter. (See pl. 13, *B*.) The olivine in the "blue ground" has completely disappeared but is represented by light-colored areas 1 centimeter or less in diameter. The individual rock fragments and their difference in texture can be easily recognized. The fine-grained layers are now a friable granular rock, in which weathered serpentine is the only recognizable mineral.

A number of minerals that are rarely observed in hand specimens or in thin sections of the volcanic breccia are obtained as concentrates by washing the soft, decomposed rock for the recovery of the diamonds. The minerals, not including the diamonds, are hematite, limonite, barite, colorless quartz, amethyst quartz, magnetite, schorlomite (or melanite), chromite, almandite, pyrope, pyrite, diopside, and epidote. The proportions of these minerals differ somewhat from place to place, but in general those named first are the most abundant and the last the least abundant. All the minerals here mentioned, except possibly the diopside and epidote, occur in larger quantities than the diamonds. An assay of a sample of the concentrates from the Arkansas mine revealed a small quantity of platinum $0.40 per ton (platinum at the time of assay was worth $150 to $160 per ounce).[79] The assay was made several years ago by a reliable firm for the Arkansas Diamond Corporation. The platinum presumably occurs in the chromite; no flakes of it have ever, so far as known, been observed in the concentrates from the mines. It therefore does not occur in workable quantity.

The barite, colorless quartz, and amethyst quartz are described under the heading "Veins in the peridotite," on page 109. The magnetite occurs as irregular and octahedral grains as much as 10 millimeters in their longest dimension, and part of it, like the barite and quartz, is present in veins in the peridotite. The hematite and limonite occur as irregular and rounded grains as much as 10 millimeters in their longest dimension, but some grains have the forms of pyrite crystals, from which they have been derived. Some of the hematite and limonite have, however, been derived from magnetite. The chromite is present as irregular black grains 8 millimeters

[79] Information furnished by John C. Peay, manager of the Arkansas Diamond Corporation.

or less in their longest dimension. A mineral that is either melanite or schorlomite is apparently more abundant than the chromite; the grains are also irregular in shape and are as much as 7 millimeters in their longest dimension. The almandite is dark red and occurs in irregular grains, the largest 6 millimeters long. Crystals of this mineral are very rare. The pyrope is present in about the same quantity as the almandite; its grains are pale red to hyacinth-red, irregular, and as much as 4 millimeters in length. The epidote and diopside occur as brown and green prismatic grains, and their maximum length is about 3 millimeters.

The diamonds from the volcanic breccia as well as the few diamonds from the intrusive peridotite are described in the section on economic geology, on pages 147–150.

Tuff and fine-grained breccia.—The tuff and fine-grained breccia are exposed in a large area, which extends from West Hill eastward to the Arkansas mine and thence northward nearly to the crest of East Hill, and in two small areas, one in the Ozark mine and the other in a gully in the northeastern part of the Arkansas mine. The boundaries of the areas of exposure as represented on Plate 10 are somewhat indefinite on account of the small number of rock outcrops.

The only locality that reveals these rocks in contact with the volcanic breccia is in the large northeastward-trending cut of the Ozark mine. There the northernmost exposures of a blue rock (tuff or fine-grained breccia) show it to be in contact with "yellow ground," which is probably derived from intrusive peridotite. The contact is distinct and dips about 70° NW.

These rocks as they are revealed at the surface are light bluish gray and are fairly hard, though at most places the hard rock has been concealed by soft blue earth. The black soil ("black ground") which is so characteristic of the areas of the intrusive peridotite and volcanic breccia is present in parts only of the areas of the tuffs.

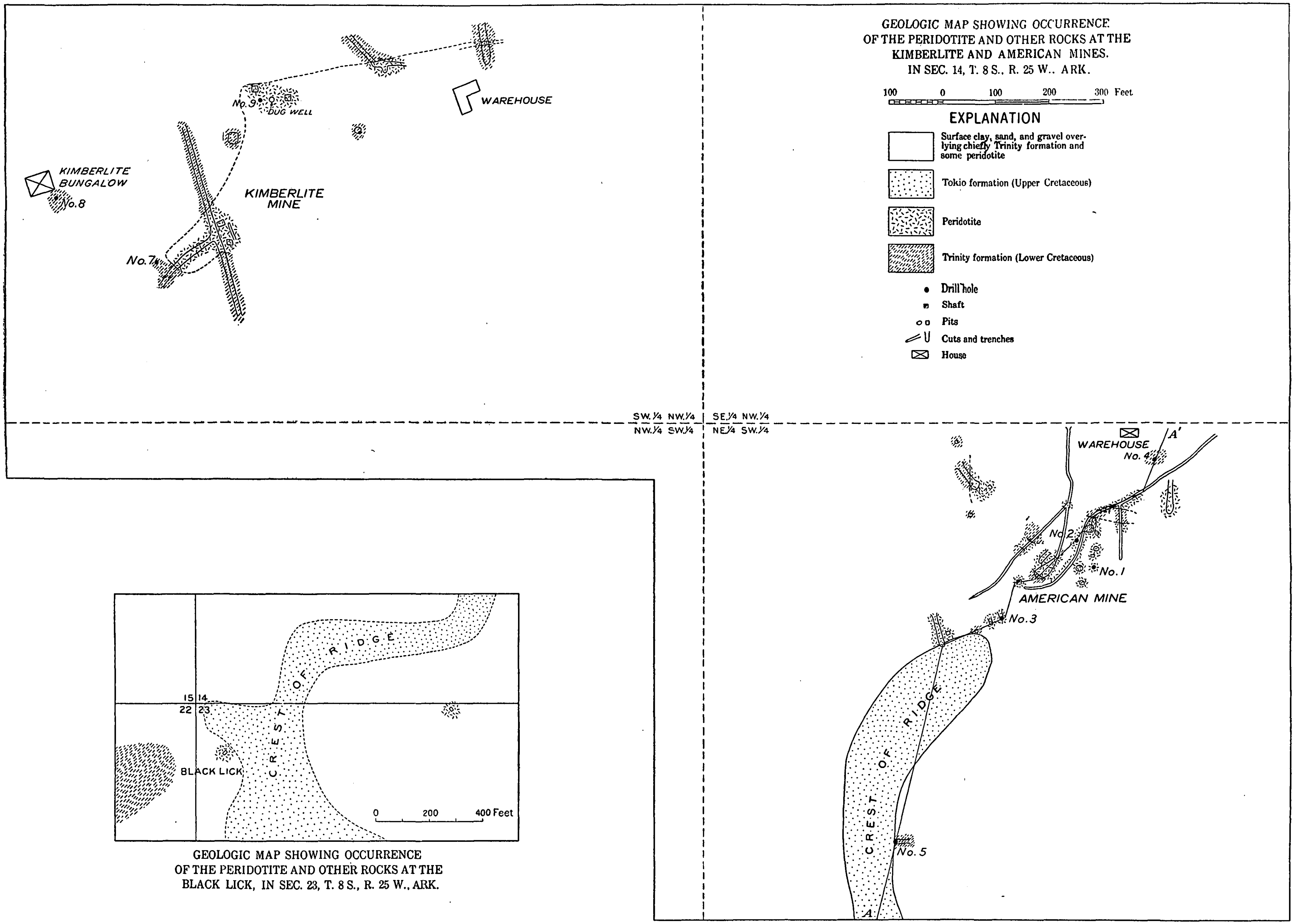
The blue-gray tuff varies greatly in texture. Some specimens are composed of fragments that average less than 1 millimeter in diameter and have an even-grained lithoidal appearance. Others contain similar material inclosing fragments as much as 10 millimeters in diameter, and still others are made up largely of such fragments with only a little fine-grained matrix between them. Reddish-brown phlogopite occurs in fine fresh flakes commonly 1 millimeter or less in diameter, but some of them reach 3 millimeters. Many small white or pale-yellow grains are serpentine, probably derived from olivine.

The microscope shows that the most abundant mineral of the rock is a pale blue-green chlorite, which is secondary to an older mineral or more probably to the very fine grained aggregate that formed the groundmass of the original rock. In some specimens these chloritic grains are angular in outline and are formed of radial aggregates with a small amount of fine-grained phlogopite remaining unaltered. This fact leads to the conclusion that the original rock was an olivine-mica peridotite like the intrusive rock and the volcanic breccia. Accessory minerals in the tuff are magnetite, secondary calcite, and fine-grained opaque aggregates. Shale fragments are abundant in the tuff in many places, and fine-grained sandstone fragments are less abundant. (See pl. 13, *A*.) The smaller inclusions have developed various amounts of chorite, but the larger ones are not greatly metamorphosed, and most of them are only slightly indurated.

Alteration is much more complete in the light blue-gray volcanic tuff than in the intrusive rocks and the volcanic breccia, and so the original composition of the tuff is very much more problematic, but there is no reason to suspect any great difference in the mineral composition of the original forms of these three classes of rocks. It is evident, however, that the later history of the tuff is different from that of the other rocks of igneous origin. The tuff contains much chlorite, whereas the other rocks contain little or none of that mineral. It is very probable that the different types of alteration shown by the igneous rocks resulted from different conditions at the time of extrusion.

The dikelike injection breccia is similar in all ways to the tuff and in the hand specimen is almost indistinguishable from it. Breccia of this sort is exposed as a dike in a gully in the northern part of the Arkansas mine. The dike is about 10 feet wide and trends northeast. The contacts with the volcanic breccia ("blue ground") on each side of the dike are concealed by loose surficial material, and the dike can not be followed more than 25 or 30 feet.

Associated with and grading into the purely pyroclastic tuff are green-gray rocks which resemble it and can not be sharply delimited from it. These rocks contain various proportions of material that is not derived from the peridotite. Quartz is by far the most abundant foreign mineral, but alkalic feldspar is not uncommon. The quartz shows enlargement, but the presence of well-rounded cores in many of the grains leaves no doubt that the quartz had a sedimentary origin. It seems clear, therefore, that the parts of the tuff beds were reworked and received an admixture of quartz derived from near-by sand and sandstone. Quartz-bearing tuff is exposed on the crest and north end of West Hill, where it protrudes as hard, rough boulders, whose distribution and shape suggest that the rock is in beds



MAPS SHOWING THE DISTRIBUTION OF THE PERIDOTITE AT THE AMERICAN AND KIMBERLITE MINES AND AT THE BLACK LICK, IN T. 8 S., R. 25 W., PIKE COUNTY, ARK.

with a northerly strike and a dip of 90°. Numerous claylike inclusions, as much as half an inch in their longest dimensions, are present.

Few or no diamonds have been obtained so far as known from the tuff and fine-grained breccia.

VEINS IN THE PERIDOTITE

Veins composed of quartz and barite cut the volcanic breccia in the Ozark mine, and the occurrence of fragments of quartz on the surface at the Arkansas mine indicates that such veins are present there also. These veins are rare and attain a thickness of not more than 2 inches. The barite occurs as crystals next to the breccia, and the quartz surrounds and incloses the crystals, showing that the barite was deposited in fissures in the peridotite and was followed by the quartz. Some of the quartz, especially that next to the breccia, is chalcedony, but much of it is massive and some occurs as crystals lining cavities in the veins. These crystals range from a small fraction of an inch to 2 inches in their longest dimensions and many are clear and transparent, though most of them are milky. Much of the massive quartz and many of the crystals have a pale amethyst color. On the Arkansas mine the amethyst has been found most abundant near the west sluice trough.

Veins consisting of barite, altered serpentine, and small crystals of magnetite were observed in the intrusive peridotite at the Mauney mine. Some are as much as 2 inches thick. One vein of barite a quarter of an inch thick was observed in the altered volcanic breccia in the Arkansas mine. The barite in these veins and the loose fragments of it observed at different places in the mines is blue, white, and colorless. Some of it occurs in tabular crystals and sheaflike aggregates of crystals.

A pocket of vein material is present at the contact of the weathered intrusive peridotite and the tuff in the north side of the large northeastward-trending cut of the Ozark mine. The pocket has a maximum dimension of 2 feet and consists of white coarse-grained calcite and a tough cream-colored mineral known as paligorskite, which is a hydrous silicate of aluminum and magnesium.

A few veins of paligorskite less than half an inch thick occur in the altered volcanic breccia in the Arkansas mine. A small quantity of calcium, which may be due to the presence of tremolite, is present in the mineral.

DIKE NEAR MOUTH OF PRAIRIE CREEK

The peridotite dike represented on Plate 10 near the mouth of Prairie Creek was exposed during the late eighties on the left bank of Little Missouri River just below the mouth of this creek, but since then the Little Missouri has shifted its channel to the south so that the exposure is now in the bed of the creek. A pit was dug by Mr. Miser at the water's edge until the dike was reached. It is there about 8 inches wide, and the rock has altered to a soft yellow earth in which yellow mica and many inclusions are conspicuous.

Specimens of the fairly hard rock collected in 1900 by J. A. Taff were examined by the writers. The igneous portion that cements the inclusions is yellowish brown and is composed of a groundmass weathered to yellow compact clay and of brown phlogopite in crystals, the largest 2 millimeters in their longest dimension. Owing to the advanced stage of weathering no other minerals can be recognized.

KIMBERLITE PERIDOTITE AREA

The Kimberlite peridotite area is in a cleared tract on the crest of a low hill in the SW. ¼ NW. ¼ sec. 14, T. 8 S., R. 25 W. The map of this area (pl. 14) shows by patterns only the observed and reported occurrences of the rocks. The peridotite is not revealed in natural exposures. It is covered with yellow to red surficial clay, a few inches to a few feet thick, derived largely from the weathering of the Trinity formation, which at the surface at this locality consists of yellow, red, and brown clay. The dike that is exposed in the trench farthest east at the Kimberlite mine (fig. 4) is probably an eastward continuation of the larger mass of peridotite in this area. The form of the intrusion, to judge from present exposures, is that of a crescent-shaped dike which strikes northeast and has a length of at least 700 feet and a width of possibly 100 feet at the surface.

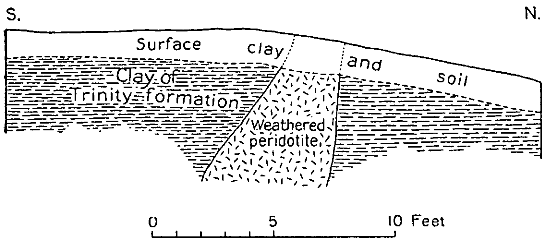


FIGURE 4.—Section of dike of weathered peridotite cutting the clay of the Trinity formation at the Kimberlite mine, Pike County, Ark. This dike is revealed in the exposure that is farthest east at this mine

Exposures indicate that the clay of the Trinity in contact with the peridotite was metamorphosed into a vitrified clay for a few feet, at least, away from the contact when the peridotite was intruded, but since then the clay has weathered so much that it is now only a little harder and lighter in color than the clay that was not metamorphosed. Many inclusions of black shale, derived from the Paleozoic shale beneath, occur in both the fresh and the disintegrated peridotite, and some of them reach 2 inches in diameter. They are baked by heat from the intruding peridotite, and although they are much weathered near the surface they remain harder than the ordinary black shale, which is widely exposed in the Ouachita Mountains on the north. Veins of white barite and of yellow paligorskite with the fibers parallel to the walls of the veins cut both the fresh and the altered peridotite.

The hard, unaltered peridotite, known locally as "hardebank," occurs as two small patches a few feet across in the southwestward-trending trench at the west boundary of the mass. Elsewhere it has disintegrated to a soft green and yellow earth. The unaltered rock is dense, tough, porphyritic, and greenish black and is similar to the intrusive peridotite found in a part of the Prairie Creek area.

AMERICAN PERIDOTITE AREA

The American peridotite area lies on a steep wooded north slope at the northeast end of a ridge in the NE. 1/4 SW. 1/4 sec. 14, T. 8 S., R. 25 W. The ridge at this locality is between 550 and 600 feet above sea level and rises about 100 feet above a wet-weather branch that is just east of the house shown on Plate 14. It is capped by the Tokio formation, which consists of about 15 feet of interbedded clay and gravel and of a basal layer of conglomerate 12 to 15 inches thick, composed of novaculite pebbles cemented together by brown iron oxide. The Tokio is underlain by the Trinity formation, represented here by clay, and by the peridotite that has been intruded upward into the Trinity.

Most of the peridotite has been deeply weathered, and only a few small fragments of it were found at the surface. The Trinity and the peridotite are concealed by red and yellow surficial clay in which there are many pebbles and some fragments of conglomerate. The surficial clay on the lower half of the hill slope is black and is called "black ground."

The peridotite at the time of examination was exposed in shallow pits, trenches, and cuts not more than a few feet deep and in a shaft and a tunnel. Its superficial portion has decomposed to a soft greenish earth, locally known as "green ground," the more weathered portions of which have changed further to a yellowish earth called "yellow ground."

The relation of the peridotite to the sedimentary rocks is represented in the accompanying section (fig. 5), which shows that the peridotite penetrates the Trinity formation, but does not penetrate the Tokio formation. The only noticeable effect of metamorphism is that the clay of the Trinity has in places been baked to a hard gray stone for a distance of 2 feet away from its contact with the peridotite.

The shape and full extent of the peridotite mass are not known, because of the small number of exposures. The weathered rock

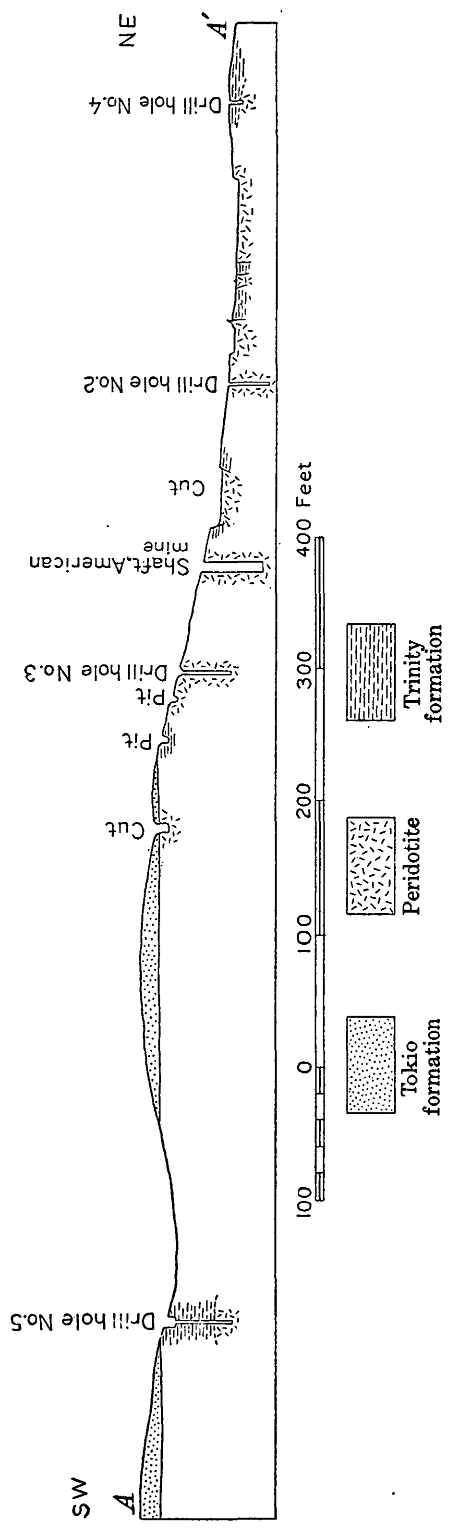


FIGURE 5.—Structure section through the American mine, Pike County, Ark., along the line A—A' in Plate 14, illustrating the relations of the peridotite to the Trinity and Tokio formations

exposed at the surface at the time of examination occurs within an area of 2½ acres, but including that penetrated by drill holes Nos. 4 and 5 it occurs at and near the surface of a much larger area.

The hard peridotite and most of the altered peridotite contain many small angular inclusions of black shale, which were derived from the Paleozoic shale through which the igneous rock was intruded. These shale inclusions are present in most of the altered rock. Some pieces of clay from the Trinity, the largest 6 inches in diameter, a few fragments of sandstone, and some well-rounded pebbles of quartz also were observed in the altered rock.

The peridotite even where hard is so much altered that a microscopic study of it is not very satisfactory, but it is apparently the same rock as the volcanic breccia of the Prairie Creek area.

BLACK LICK PERIDOTITE AREA

The Black Lick peridotite area is near the crest of a crooked ridge that stands about 550 feet above sea level, in sec. 23, T. 8 S., R. 25 W. The ridge is capped by the basal part of the Tokio formation, which here consists of 30 feet of gravel and a basal layer of conglomerate composed of novaculite pebbles cemented together by brown iron oxide. The Trinity formation and the peridotite which has penetrated the Trinity underlie the Tokio.

The peridotite lies on the upper part of the gentle west slope of the ridge. The occurrence of a black soil at this locality led someone to make a very small opening in search of peridotite where a yellowish-green earth was poorly exposed. This pit was deepened to 7 feet in 1912 by Mr. Miser, who also made another pit 6 feet deep 900 feet farther east. Since 1912 the first pit has been enlarged and other shallow pits have been made near it and also near the one farthest east. All of the pits reveal altered peridotite, and they comprise the only exposures of this rock in the vicinity. The only exposures of the Trinity, which is represented here by clay, are farther down the slope from the pits of the Black Lick. The peridotite exposed in the pits at the Black Lick has weathered to a soft yellowish-green earth which still retains structural features indicating that the unweathered rock was a volcanic breccia composed of fragments of porphyritic peridotite and some fragments of clay.

The pits that are 900 feet east of the Black Lick are in a timbered area which is comparatively level over several acres. The surface material consists of a black gumbo soil mixed with some water-worn gravel and is 2½ feet thick. Below this black soil yellowish green earth derived from peridotite was penetrated in all the pits. Although the material has disintegrated so much that microscopic study is impossible, the texture is clearly porphyritic, the phenocrysts being serpentinous pseudomorphs after olivine, whose outlines are in many places sharply defined and well preserved.

The extent of the peridotite in the vicinity of the Black Lick is not known, but the altered rock exposed in the pits is probably all within a single area. If this is true, it will be readily understood from the relations of the peridotite to the Tokio stated above that pits or drill holes on the crest of the ridge must pass through the Tokio before the peridotite is reached.

RELATION OF THE PERIDOTITE TO THE OTHER IGNEOUS ROCKS OF ARKANSAS

The peridotite in the Caddo Gap quadrangle is, as has been pointed out by Williams,[80] related in age to the other igneous rocks of Arkansas. The igneous rocks in other parts of the State consist of nephelite syenite, pulaskite, and related intrusive rocks and occur in four small areas in the eastern part of the Ouachita Mountain region

[80] Williams, J. F., The Igneous Rocks of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 2, p. 391, 1891.

and in the northwest border of the Gulf Coastal Plain. One of these areas is in the Fourche Mountain region, near Little Rock, Pulaski County; a second is near Bauxite, Saline County; a third is at Magnet Cove, Hot Spring County; and the fourth is at Potash Sulphur Springs, Garland County. In addition there are hundreds of dikes of igneous rock scattered here and there over much of the east half of the Ouachita Mountain region. Concerning these dikes Williams [81] says:

> Outside of these four typical regions there are many dikes of igneous rock which as far as their petrographic characteristics are concerned might be associated as well with one group [region] as with another and which are, as a matter of fact, probably directly connected with none of them, although formed from the same magma from which they all derived their material.

The rocks in the dikes include tinguaite, fourchite, ouachitite, and monchiquite. Of these the monchiquite is more closely related in composition to the peridotite in the Caddo Gap quadrangle than any other, for it is composed mainly of altered olivine and augite and at some places contains much biotite.

AGE OF THE PERIDOTITE

The peridotite of each of the several occurrences is similar to that of the others, and although there is no surface connection between these occurrences, the similarity of the rocks makes it seem very probable that the rocks are of common origin and are connected beneath the surface.

The three types of peridotite were apparently formed by three distinct volcanic outbursts, but they are so closely related that they probably represent successive stages in a single period of volcanic activity. Present evidence indicates the igneous history of the region set forth below.

First the intrusive peridotite was injected upward into the Carboniferous and Lower Cretaceous rocks. Then volcanic explosions broke up into small fragments not only much of the intrusive peridotite but also some of the shale and sandstone of Carboniferous age. In the Prairie Creek peridotite area the fragments were apparently ejected into the air and then deposited in inclined layers, which have since been hardened, becoming a breccia.

A second group of explosions probably took place, forming the tuff and closely associated fine-grained breccia of the Prairie Creek area. The distribution of these rocks and their relation to the intrusive peridotite and to the volcanic breccia apparently indicate that they are the younger.

[81] Op. cit., pp. 2–3.

The peridotite is younger than the Trinity formation, of Lower Cretaceous age, as is shown (1) by the high dip of the contacts between the peridotite and the nearly horizontal beds of the Trinity, (2) by the metamorphism of the clay of the Trinity adjacent to its contact with the peridotite, and (3) by the occurrence in the peridotite of fragments of clay and pebbles derived from the Trinity.

The peridotite is of the same age as or older than the Tokio formation of Upper Cretaceous age. This is shown by the fact that the lower beds of the Tokio on the Riley place and on the Twin Knobs, near Murfreesboro, contain altered serpentine grains and fragments of peridotite. Although these grains and fragments were water-laid, there is a probability that they were ejected as fragmental material from one or more near-by vents rather than washed by streams from peridotite exposures. The belief that the peridotite is not younger than the Tokio is supported by the fact that the Tokio rests upon the peridotite at the American mine and at the Black Lick.

From the foregoing facts it must be concluded that the peridotite is younger than the Trinity formation, of Lower Cretaceous age, and is not younger than the Tokio formation, of Upper Cretaceous age. The volcanic activity that produced the peridotite probably accompanied the down warping of the Mississippi embayment early in the Upper Cretaceous epoch.

COMPARISON OF ARKANSAS AND SOUTH AFRICAN ROCKS

The peridotite of Arkansas is generally believed to be similar in character and mode of occurrence to that of South Africa, and the exact points of similarity are here recorded. Wagner,[82] who has carefully studied the South African diamond deposits, says of them:

> The pipes represent deeply eroded, funnel-shaped volcanic necks of the Maar type, which appear to have been formed by the violent explosive liberation at the earth's surface of highly compressed vapors and gases, emanating from a deep-seated, ultrabasic magma. They are occupied, as a rule, by nonvolcanic detritus derived from the shattering and comminution of the rocks pierced by the explosions, by fragmentary material derived from trituration of kimberlite [peridotite], and at greater depths by solid plugs of the later rock.
>
> Dealing first with the relationship of pipes to fissures, we have learned that the magma in its ascent appears invariably to have been guided to within a greater or less distance of the original surface by planes of structural weakness in the earth's crust. * * * The earliest eruptions appear to have been in the nature of mighty explosions, which resulted in blowing out of funnel-shaped apertures. The bulk of the material forcibly ejected during these outbursts no doubt fell back into the vents, which at one stage of their history may thus have been more or less completely occupied by nonvolcanic detritus.

[82] Wagner, P. A., The Diamond Fields of Southern Africa, 1914.

The relief of pressure occasioned by these earlier explosions must be assumed to have led to the ascent of the magma into the pipes, where it appears, as a rule, to have given rise, by successive eruptions, to a number of distinct columns of kimberlite [peridotite] and kimberlite tuff.

The material that occupies the vents Wagner describes as follows:

It has been pointed out that in so far as the pipe filling is concerned, the rocks pierced by the explosions, the kimberlite magma, and the atmosphere have all contributed.

We may divide * * * the foreign matter of the pipes into three principal groups—rock fragments derived from the adjacent pipe walls; xenoliths [included fragments] of rock which have been brought up from below; masses of rock which, to attain the position in which we now find them, must have fallen into the pipes from above.

The pipe rock proper consists of kimberlite and of material derived from its brecciation, comminution, and decomposition.

The microscope reveals the fact that among the products comprehended under the general term of blue ground three main varieties may be distinguished. These are the true kimberlite tuff or kimberlite breccia, injection breccia, and decomposed kimberlite. * * * As greater depths are attained in the mines the products we have hitherto been dealing with, as one would naturally expect, are replaced in increasing measure by "hardebank," or kimberlite, the parent rock, to the trituration and decomposition of which they owe their origin.

Wagner divides the diamond-bearing rocks of South Africa into two types, both of which occur as intrusives and as volcanic breccias. One of these is a "basaltic kimberlite," rich in olivine and poor in mica, and the other is a "mica peridotite." Both types are diamond bearing in South Africa, but the first has produced most of the diamonds.

The quotations and abstracts given above, which outline very briefly the type of eruption and describe the diamond-bearing rocks of South Africa, serve as a basis for comparison with the diamond-bearing rocks of Arkansas. In South Africa work has proceeded to great depths—3,601 feet in the Kimberley mine—and the geologic relations are known in considerable detail, whereas in Arkansas only the surface of the ground has been scratched. Nevertheless rather striking points of similarity between the diamond-bearing rocks of South Africa and of Arkansas are evident.

The violence of the volcanic explosions by which the South African vents were produced and the extent to which the kimberlite and country rock were shattered and mixed together in the vents have been emphasized. In Arkansas the peridotite was evidently much shattered and the explosive violence brought to the surface Paleozoic rocks that lay far beneath the surface. Injection breccias that are composed of shattered country rock mixed with a small proportion of volcanic material and that have the characteristics of dikes have been identified in both areas.

In many of the South African vents recurring volcanic activity produced compound pipes that are formed of slightly different rocks and that even bear diamonds of dissimilar character. Petrographic studies have shown that in Arkansas there are at least three types of rock, only one of which carries diamonds in considerable quantity.

STRUCTURE

GENERAL FEATURES

The sedimentary rocks of the Caddo Gap and De Queen quadrangles originally lay nearly horizontal. The Cretaceous strata are still nearly horizontal, but they have been tilted so that they have a low southward dip, and the Paleozoic strata are inclined at high angles, so that their edges appear at the surface.

When the Paleozoic rocks are crossed from north to south they are found to lie in a series of anticlines and synclines, and in a few places they have suffered displacement by faults. The greater part of their folding and faulting took place near the middle of the Pennsylvanian epoch, although slight warping occurred at a much earlier time.

To aid in understanding the structure of the quadrangle the structure sections in Plate 15 are introduced. These sections represent the structure as it is inferred from the position of the beds observed at the surface, but they are on too small a scale to show all the minute structural details.

STRUCTURE OF THE PALEOZOIC ROCKS

FOLDING

The Caddo Gap and De Queen quadrangles contain two areas where the oldest rocks have been uplifted through folding and now stand as high as the youngest. One of these areas includes the mountainous portions of the Caddo Gap quadrangle and the northeast corner of the De Queen quadrangle. It is a part of the west end of the Ouachita anticline, which is the most prominent fold of the Ouachita region in Arkansas. The other area includes the Cross Mountains, in the western part of the De Queen quadrangle. It is the east end of the Cross Mountains anticline, which is one of the most prominent folds of the Ouachita region in Oklahoma.

The large composite folds are essentially anticlinoria, and some of their larger subdivisions can be followed for long distances; but the single folds, which are narrow and overlap one another lengthwise, can be traced only a few miles along their axes. They all have the same direction as that of the ridges and therefore bear a close relation to the topography, for outcropping edges of the hard strata upturned on the folds have formed the ridges and the softer intervening strata underlie the valleys. Their general trend does not depart far from west, but it is north of west in the Ouachita anticline, west in the Cross Mountains anticline, and south of west in the Athens Plateau. The westward divergence of the folds of the Athens Plateau from those of the Ouachita anticline is attributed to the eastward plunging of the Cross Mountains anticline in the De Queen quadrangle. Many adjacent folds are of nearly the same height, and the same beds are repeated many times at the surface. The dip gradually changes in steepness from place to place along the strike, and on some of the folds it even changes in direction within a mile. These changes may take place where a single fold breaks up into two folds, or where a symmetrical fold is closely compressed so that the strata are parallel. Two structure sections of the same mountain or valley only a mile apart might therefore be very different. Scarcely any two ridges are alike in structure, and some of them, especially many high peaks, are composed of two or three anticlines with their intervening synclines. The sides of most folds have been compressed until they are parallel, the rocks on one side having been turned through an angle exceeding 90°, so that the beds on both sides of the crest dip in the same direction. The dips of the overturned rocks are in places as low as 40°. This shows that the rocks in those places have been turned through an angle of 140°. The rocks have been overturned toward the north in some folds and toward the south in others. (See pls. 15 and 16.) This overturning of the rocks in two directions has produced fan-shaped folds at a few places. A compound fan-shaped fold in the De Queen quadrangle is illustrated by Plate 16, *F*, and a number of folds with a fan-shaped arrangement are illustrated by Figure 6. In most places the folds are smallest, most numerous, and most closely squeezed in the shale and thin-bedded sandstone and chert. Joints in several sets and slickensides are common in all the rocks but are most numerous in those just named.

OUACHITA ANTICLINE

The part of the Ouachita anticline that is situated in the Caddo Gap and De Queen quadrangles includes the Caddo, Crystal, and Cossatot Mountains and the Caddo and Mazarn Basins. In these quadrangles it is divided longitudinally into two anticlines by the Mazarn syncline, much of which extends in a general north of west direction along the valley of South Fork in the Caddo Gap quadrangle and along Mine Creek in the De Queen quadrangle. The anticline lying north of this syncline is the Crystal Mountain anticline, and that on the south is the Cossatot anticline.

Crystal Mountain anticline.—The Crystal Mountain anticline contains the area of greatest uplift in the quadrangles. The highest part lies along the northern edge of the Caddo Gap quadrangle, where the following formations not elsewhere revealed are exposed: Collier shale, Crystal Mountain sandstone, Mazarn shale, Blakely sandstone, and Womble shale. These shales and the Bigfork chert are so intensely crumpled that the details of their structure can not be determined, so that it has been necessary to generalize their structure as shown on Plate 15, but many of the smaller as well as all the larger folds of the other formations are determinable. The strata in most places are inclined at angles of 40° or more from the horizontal. Most of the folds are parallel and straight, trend north of west, and overlap one another lengthwise. The folds are rarely symmetrical; as a rule either one limb is much steeper than the other or both limbs, being closely compressed, dip in the same direction. The axial planes of most of the folds dip to the north, and therefore the south limbs of those anticlines that are not overturned have steeper dips than the north limbs, and both limbs of the overturned folds dip to the north. In some places, especially in the vicinity of High Point, in the De Queen quadrangle, the reverse relation is noted. (See pl. 16, *E*, and fig. 6.) On account of this overturning in two directions a fan-shaped fold has been formed at one place in the De Queen quadrangle. (See pl. 16, *F*.) The overthrusting in the process of folding was therefore mainly from the north but partly from the south. Some of the anticlines are broken by thrust faults.

The Crystal Mountains comprise an area of short branching and interlocking anticlines and synclines. The ridges, most of which are produced by the hard Crystal Mountain sandstone, show from place to place an anticlinal, a synclinal, or a monoclinal structure, and the valleys, which are occupied by the Collier and Mazarn shales, reveal much the same variety. The ridge of Blakely sandstone that runs east from Womble to the east border of the Caddo Gap quadrangle is a monocline, and much of it is fairly straight, but its structure near Plata is affected by short wrinkles that have made the ridge crooked and produced small projecting spurs.

The part of the Crystal Mountain anticline that lies in the northeast corner of the De Queen quadrangle and the adjoining part of the Caddo Gap quadrangle is a closely corrugated belt composed of folds of nearly equal size, and in most of the folds the outcrops of the same formations are repeated. The Missouri Mountain slate and Arkansas novaculite are commonly exposed in the anticlines, most of which are ridges, and the Stanley shale is exposed in the synclines, most of which are valleys. The structure of the ridges varies from

PLATE 16

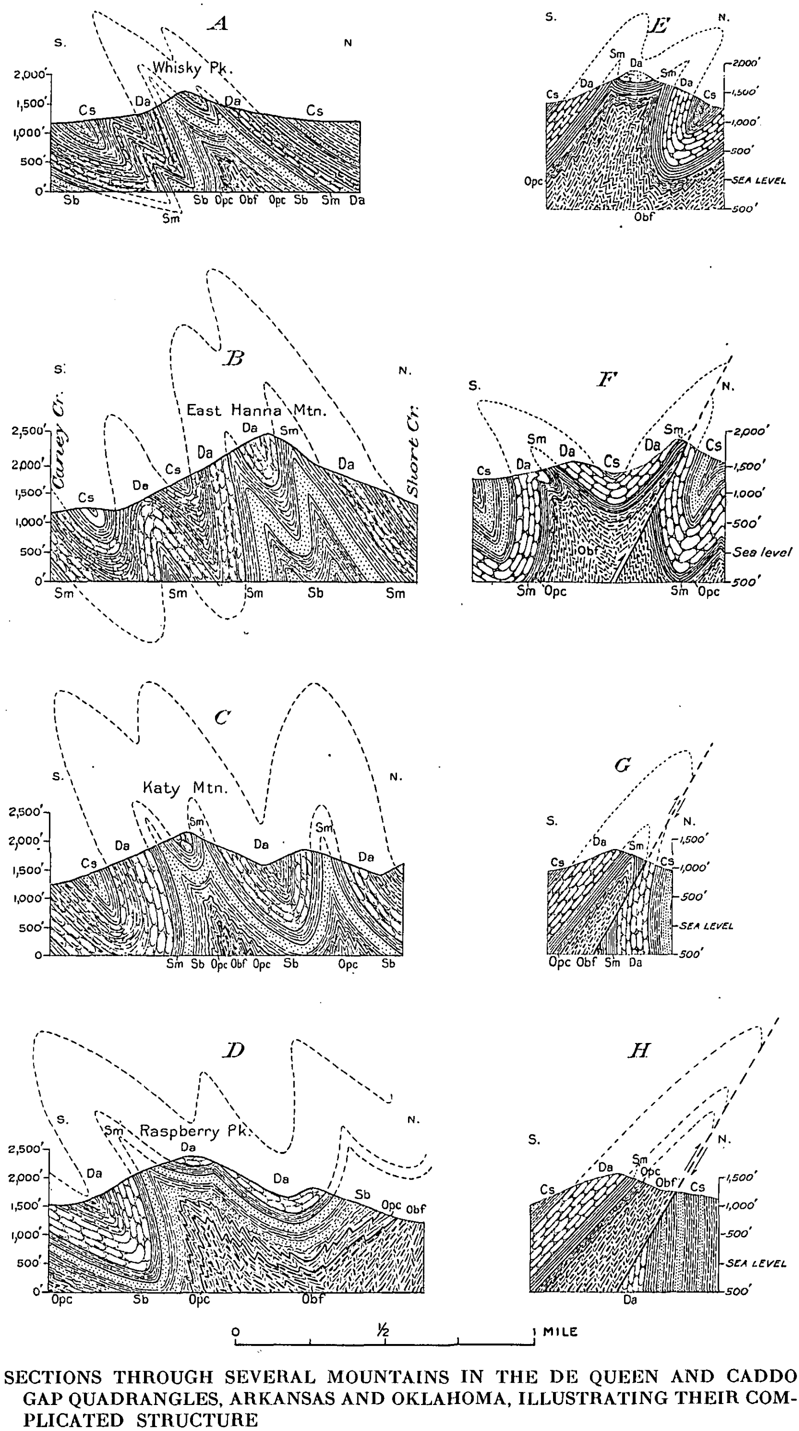
A, *B*, *C*, and *D*. Sections through Whiskey Peak, East Hanna Mountain, Katy Mountain, and Raspberry Peak, illustrating closely compressed folds overturned toward the south.

E. Section through High Point, illustrating closely compressed folds overturned toward the north.

F. Section through two ridges 1 mile east of Spring Valley School and north of Mine Creek, in the De Queen quadrangle, illustrating a fan-shaped double anticline, which is broken at the right by a thrust fault.

G. Section through Brier Creek Mountain, half a mile west of Little Missouri River, showing the formation of a thrust fault by the breaking of an overturned anticline.

H. Section through Brier Creek Mountain 1½ miles west of Little Missouri River, showing displacement along the fault greater than that in section G.



SECTIONS THROUGH SEVERAL MOUNTAINS IN THE DE QUEEN AND CADDO GAP QUADRANGLES, ARKANSAS AND OKLAHOMA, ILLUSTRATING THEIR COMPLICATED STRUCTURE

Cs, Stanley shale; Da, Arkansas novaculite; Sm, Missouri Mountain slate; Sb, Blaylock sandstone; Opc, Polk Creek shale; Obf, Bigfork chert place to place. Some ridges or parts of ridges are composed of single anticlines, but others—for example, High Point (pl. 16, *E*), in the De Queen quadrangle, and the east end of Statehouse Mountain, in the Caddo Gap quadrangle—are made up of two anticlines with the intervening syncline. The east end of Fork Mountain, in the Caddo Gap quadrangle, is composed of two synclines and the intervening anticline. Not all parts of the ridges, however, are anticlinal; some are monoclinal, such as the Missouri Mountains between Slatington and Fork Mountain, and others are synclinal.

In the vicinity of Caddo Gap the folds along the south side of the Crystal Mountain anticline plunge toward the east at comparatively high angles, so that the oldest rocks are exposed on the north and west and the youngest on the south and east. Here the plunging anticlines and synclines interlock in such a way that the truncated upturned edges of the strata zigzag across the country. The best example of this type of structure in the Ouachita Mountain region is in the Zigzag Mountains at and near Hot Springs, Ark.

Cossatot anticline.—The Cossatot anticline consists of a large number of minor anticlines with their complementary synclines and lies almost entirely in these two quadrangles. The axis of greatest uplift passes just north of Prior, Blaylock, Brushheap, and Raspberry Mountains, in the Caddo Gap quandrangle, and along the valley of Sugar Creek and by Shady post office, in the De Queen quadrangle, and hence runs along or near the central part of the anticline. The oldest formations exposed along this axis are the Bigfork chert and the Polk Creek shale, and the other formations, owing to their close folding, are repeatedly exposed in narrow bands on the north and south. The single folds, as well as the major fold which they compose, trend north of west, parallel with the Crystal Mountain anticline. The single folds are of about equal height, are only a few miles long, and are all less than a mile wide. They overlap one another lengthwise and plunge at their ends, some to the east and some to the west. Reference to Plates 15 and 16 will show that most of the folds are not symmetrical, but that many of them are overturned, some to the north and some to the south, and that others, although not overturned, have steeper dips on one side than on the other.

The overturning to the north prevails near the east and west ends of the anticline, and the overturning to the south in the middle portion. A structure section (fig. 6) through the western part of the Cossatot anticline and the adjoining part of the Crystal Mountain anticline shows a fan-shaped arrangement of the folds. The strata in most places in the Cossatot anticline stand nearly on edge, dipping 50° or more from the horizontal. A line of faulting runs along the north side of the anticline. The ridges are all produced by the Arkansas novaculite, and the structure of many of them is simple—that is, a ridge or some part of one may be monoclinal, synclinal, or anticlinal. Many others, however, consist of two or more folds and therefore have a complex structure. A north-south section (fig. 6) passing through the summit of West Hanna Mountain shows that this mountain is composed of three anticlines and that one of the intervening synclines forms its summit. A similar section through East Hanna Mountain (pl. 16, *B*) shows three anticlines and the two intervening synclines. A northeast section through the highest part of Eagle Mountain (fig. 6) reveals a syncline at the summit and a faulted anticline on the northeast slope. Katy Mountain (pl. 16, *C*) and Tall Peak are each composed of two anticlines and the intervening syncline; Nichols Mountain is made up of a syncline and an anticline; and Raspberry Peak (pl. 16, *D*) of two anticlines and two synclines. The summits of these mountains and many others have a synclinal structure, and because of this they form some of the highest points in the quadrangles.

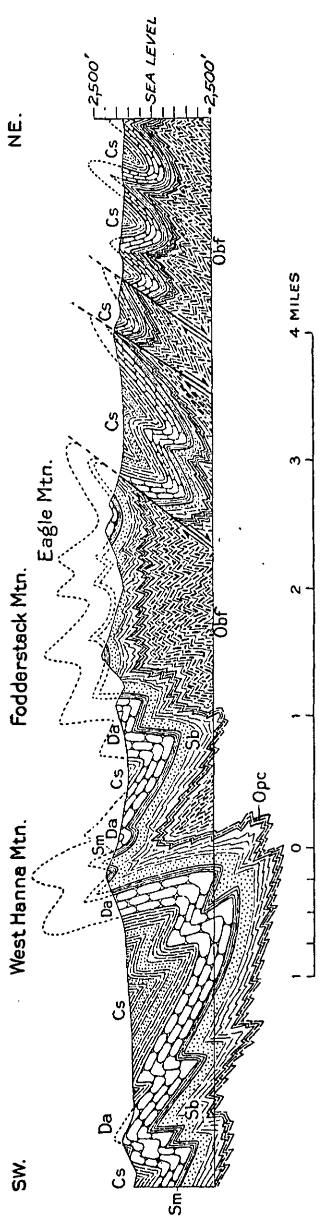


FIGURE 6.—Section along line X—X, Plate 3, in the De Queen quadrangle, illustrating the fan-shaped arrangement of the folds. Cs, Stanley shale; Da, Arkansas novaculite; Sm, Missouri Mountain slate; Sb, Blaylock sandstone; Opc, Polk Creek shale; Obf, Bigfork chert

Mazarn syncline.—The Mazarn syncline extends in a north of west direction along the valley of South Fork in the Caddo Gap quadrangle and that of Mine Creek in the De Queen quadrangle. It is widest on the east border of the Caddo Gap quadrangle and is narrowest in the vicinity of McKinley and Lost Mountains, where it is no wider than the single synclines in the anticlinal areas on either side and where it is crossed by the faulted anticline passing through Lost Mountain and Hurricane Knob, but farther west along Mine

Creek and the head of Cossatot River, in the De Queen quadrangle, it is fairly distinct. Along its edges are narrow synclines which reach into the anticlinal areas on each side and interlock with the numerous anticlines that plunge beneath the Mazarn syncline. A narrow syncline which is occupied by the Jackfork sandstone lies on the east boundary of the Caddo Gap quadrangle. In most parts of the Mazarn syncline the detailed structure could be worked out with extreme difficulty, if at all, because there are here no distinctive beds in the Stanley shale, which is the surface formation over most of the syncline, and because the Stanley, having relatively low rigidity, has been thrown into small, closely compressed folds or wrinkles instead of the larger ones found in the more competent formations such as the Arkansas novaculite.

CROSS MOUNTAINS ANTICLINE

The Cross Mountains anticline, which is one of the major folds of the Ouachita region of Oklahoma,[83] extends eastward to the middle of the De Queen quadrangle. This composite anticline finds expression in the Cross Mountains, whose easternmost anticlinal ridges are separated from the Cossatot Mountains by a narrow synclinal trough, which connects the Athens Plateau with the Cove Basin. The single folds have a general eastward trend. All are of nearly the same height and reveal the same formations—the Stanley shale and Arkansas novaculite—but in addition to these rocks the anticlines near Bog Springs and Hatton bring to the surface the Blaylock sandstone and the Missouri Mountain slate. As a rule, the folds are asymmetric. Those anticlines that are not overturned have steeper dips on the south limb than on the north and those that are overturned have northward dips on both the north and south limbs. Whisky Peak, the principal mountain of the group in the De Queen quadrangle, consists of three anticlines with the intervening synclines, one of which occupies the summit. (See pl. 16, *A*.)

ATHENS PLATEAU

The general structure of the Athens Plateau is that of a southward-sloping monocline corrugated with many minor folds. These folds are nearly parallel and have a general south of west trend. Toward the west their trend and that of the Ouachita anticline diverge and they pass on both sides of the eastward-plunging Cross Mountains anticline. The most conspicuous and easily distinguishable folds are formed by the Jackfork sandstone and the Atoka formation. Although each of these formations is about 6,000 feet

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[83] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 236–240, 1923.

thick, the beds stand at steep angles, having dips that commonly exceed 50°, and in some places they are overturned. The usual direction of the overturning is from the south.

Although the Stanley shale, which is also exposed on this plateau, has a thickness of 6,000 feet, it is folded many times and doubtless much faulted and overturned in its wide belts of outcrop, but the lack of distinctive beds, except the Hatton tuff lentil and the associated beds of tuff, makes the determination of the folds nearly impossible. Although the dips and strikes differ somewhat, most of the strikes have an eastward trend, and most of the dips are 40° or more.

COVE BASIN

The Stanley shale, which is the prevailing surface formation of the Cove Basin, is compressed into many narrow, steep-sided folds, but in most localities in this basin, as on the Athens Plateau, only the general structural features can be determined. The folds trend in general eastward, but next to the Cossatot Mountains they trend south of east. The principal feature is an anticline, whose axis passes eastward one-tenth of a mile south of the depot at Cove. Two or more beds of tuff that occur near the base of the Stanley are exposed on the anticline.

FAULTING

Faults are common, though less numerous than might be expected in strata that have been so closely compressed as these. The number of the faults has been limited by the great predominance of thin-bedded strata over massive, rigid beds like the Crystal Mountain sandstone, Arkansas novaculite, and Jackfork sandstone, in consequence of which the beds as a whole bent instead of breaking under stress. About 30 faults have been mapped in the two quadrangles, and others may be detected in future work. The faults were produced by the breaking and overthrusting of strata in closely compressed anticlines. (See pl. 16, *G* and *H*.) An anticline at Caddo Gap has been broken by two thrust faults. (See pl. 7, *A*.) So far as observed all the faults are thrust faults except one small normal fault in the SW. ¼ sec. 31, T. 3 S., R. 26 W. The direction of the faults, therefore, is in the main east, or parallel with the ridges. The longest ones do not exceed 12 miles in length and most of them are much shorter. The dip of all the fault planes is high; some of them dip south and some north. The dislocation ranges, even along a single fault, from a few feet to a few thousand feet or more, but only a minimum measure is obtainable anywhere.

As may be seen by reference to Plate 3, many of the faults occur near the boundary between the Mazarn syncline and the Cossatot anticline. These faults, in fact, form the principal line of faulting in the quadrangles, and the line extends from the valley of Sugar Creek in the De Queen quadrangle approximately eastward, passing south of Fancy Hill and along the valley of South Fork in the Caddo Gap quadrangle, and apparently terminates near Caddo River. From Little Missouri River westward the line consists of a single fault, but in the eastern part of range 27 it comprises three and along the base of Bearden, Tweedle, and Reynolds Mountains there are two long and two short, nearly parallel faults. The overthrust of these faults is from the south. Their planes as well as those of most other faults in the quadrangles dip in the same direction as the broken strata.

A cross fault, having a northwesterly trend and with its upthrow on the northeast side, is situated on the border of the Caddo Gap quadrangle east of Kirby. It truncates the east end of a syncline containing the Jackfork sandstone and the overlying Atoka formation, and the Stanley shale is brought up even with the Atoka, making a vertical dislocation of at least 5,000 to 6,600 feet, which is the range of thickness of the Jackfork in the Caddo Gap quadrangle. How much greater the displacement is can not be determined, but it may amount to fully 10,000 feet. Although the hade was not observed, the fault is thought to belong to the thrust variety because of the almost exclusive occurrence of this type in most of the Ouachita region. Much of the displacement may have been horizontal—that is, in a southeastward direction on the northeast side of the fault and in a northwestward direction on the southwest side. Detailed mapping in the adjoining area on the east will doubtless yield further information concerning this peculiar fault.

METAMORPHISM

Mechanical and chemical action which accompanied the folding of the beds in this region has produced changes in many rocks. The alteration by these two agencies has perhaps been most effective upon the shale, changing some of it to slate. The beds that have been most affected are the Mazarn, Womble, and Polk Creek shales, the Missouri Mountain slate, the shaly part of the Arkansas novaculite, and the base of the Stanley shale, although at most places these have been only slightly altered. This production of slate has consisted in the flattening of the mineral particles of the shale, the rotation of their axes to a position at right angles to the pressure, and the formation of new minerals with their major axes lying in the same direction, thereby producing slaty cleavage. This cleavage is usually at an angle to the bedding. The sandstone that is not calcareous has become more or less quartzitic. Examples of this alteration occur in the Crystal Mountain and Blakely sandstones. The Jackfork sandstone and the sandstone of the Stanley shale are quartzitic, but on long exposure to weathering they lose much of their siliceous cement.

STRUCTURE OF THE CRETACEOUS ROCKS

The Trinity and succeeding formations probably have the same attitude now as when they were deposited, except that they have been slightly tilted toward the south, the oldest formations having been tilted most. (See pl. 15 and figs. 8 and 9.) The strike of the Trinity and Woodbine formations is east or nearly east, but that of the Brownstown marl, Tokio formation, and other formations that are exposed east and south of the quadrangles is north of east.

The southward dip of the floor or base of the Cretaceous just north of Center Point is more than 100 feet to the mile, as is shown by a well 2 miles north of that place, which did not reach the base of the Cretaceous at a depth of 500 feet. A southward dip of more than 100 feet to the mile also is shown near De Queen, as the ice-factory well 249 feet deep at that place did not reach the base of the Cretaceous. The dip of the base of the Cretaceous is about 100 feet to the mile from the north edge of the Gulf Coastal Plain southward to Nashville, Ark., a distance of 15 miles. A well at that city reached the Cretaceous floor at a depth of about 1,250 feet.

On the north edge of the Gulf Coastal Plain in the Caddo Gap and De Queen quadrangles the Cretaceous floor emerges from beneath the Cretaceous cover at about 350 feet above sea level along the principal streams, and it gradually rises toward the north, the highest remnants still capped by the Cretaceous attaining an altitude of 800 feet above sea level. The dip of the floor where the Cretaceous cover is thus partly removed ranges from about 60 to 100 feet to the mile, but the usual dip is about 80 feet to the mile.

The Cretaceous strata, as noted in the foregoing paragraphs, do not everywhere have a uniform dip to the south. Although from this fact they are seen to be slightly warped, no folds in the Caddo Gap and De Queen quadrangles are known to be developed sufficiently to be called anticlines or synclines.

GEOLOGIC HISTORY

The geologic history of the Caddo Gap and De Queen quadrangles is recorded in their surface features and in the underlying rocks. The history interpreted from the topographic features probably is the less complete, because its records have been largely destroyed by erosion. Although the succession of events as recorded in the quadrangles is imperfect, many facts may be inferred from studies in other parts of the Ouachita Mountain region and in adjoining provinces, for the same processes that operated in the area comprised in the quadrangles also affected similarly an extensive region around it.

CAMBRIAN PERIOD

Collier deposition.—The thickness of the Collier shale is not known, for its base is nowhere exposed, but at least a few hundred feet of it is visible between the north line of the Caddo Gap quadrangle and Mount Ida, in Montgomery County. Its black color and argillaceous nature show that it was derived from mud containing carbonaceous matter, and the limestone beds within it indicate that it was laid down close to a shore and consequently is a shallow-water formation. If it was thus laid down, the land area that supplied it was low, and the streams of the area were unable to carry coarse material. The purity of the limestone beds indicates that there were times in which sedimentation almost ceased and in consequence the sea cleared, so that the calcareous material was deposited without much mud. Marine life at this time was meager, if we may judge from the apparent absence of fossils from both the shale and the limestone.

Deposition was halted by an emergence in the present Crystal Mountain area, and also in McCurtain County, Okla.,[84] and a period of erosion was the result. The known extent of the stratigraphic break caused by this emergence is thus considerable. This together with the fact that it occurs in rocks many hundred feet below those known by their fossils to be of Lower Ordovician age, is apparently sufficient reason for believing that the Collier shale belongs to the Cambrian system.

ORDOVICIAN (?) PERIOD

Crystal Mountain deposition.—After erosion had attacked the Collier shale for a period which may have been long or short the area included in west-central Arkansas and southeastern Oklahoma was again covered by the sea, and the material of the Crystal Mountain sandstone was spread upon it. Quartz, chert, and limestone pebbles, which were obviously derived from beds in the Collier, were deposited along the shore as the sea crept upon the land, and these pebbles, with other material, formed conglomerate. As the water deepened deposition became restricted to sand, which in places accumulated to a depth of 850 feet. This is rather coarse quartz sand, much of which is well rounded, and at the time of its

[84] Honess, C. W., Geology of the Southern Ouachita Mountains, Okla.: Oklahoma Geol. Survey Bull. 32, pp. 46–47, 1923.

deposition it formed a clean sandy beach and ocean bed. It contains no fossils, probably because the rapid piling up and shifting of the sand prevented colonies of marine life from becoming established. As time went on the material brought into the sea became gradually finer, and eventually the sea floor and probably the beach became muddy, thus bringing in Mazarn deposition.

ORDOVICIAN PERIOD

Mazarn, Blakely, and Womble deposition.—The sea, which gradually became muddy at the end of Crystal Mountain time, continued so throughout most of Mazarn, Blakely, and Womble time, when mud was widely distributed in the present Ouachita Mountain region both in Oklahoma and Arkansas. The land area was probably low; it was also presumably wet in parts, and this condition permitted a reduction of the iron oxide in the residual mantle. Greenish mud derived from this mantle was laid down in thin layers alternating with layers that had been blackened by carbonaceous matter. These conditions prevailed until 1,000 feet of mud, which later formed the Mazarn shale, had accumulated, and some sand had been intermittently brought to the sea and put down in thin layers. Next at least a part of the region was uplifted and eroded.

Blakely time began with an advance of the sea over the eroded areas. Pebbles were laid down here and there in the Hot Springs district, but later sand and mud were deposited in alternate layers until in places a thickness of 400 feet accumulated. This sedimentation in the Hot Springs district was twice interrupted by extreme shallowing of the water if not by changes of the area to land, as is shown by beds of conglomerate above the base of the sandstone. None of these conglomerates were observed in the Caddo Gap quadrangle. The distribution of the sand was not general, for west of Womble it is only locally represented, and it is absent in the vicinity of Mount Ida, on the north side of the Ouachita anticline. During Womble time mud and a very small quantity of sand accumulated until a thickness ranging from 250 to 1,000 feet was put down. This increase of mud and decrease of sand after Blakely time may have resulted from a subsidence of the supplying land area.

The sea was probably shallow during the deposition of the 2,400 feet of mud and sand composing the three formations just described. There must have been, therefore, a practically continuous subsidence of the sea bottom while these sediments were accumulating.

Marine life was meager during Mazarn and Blakely time but was more abundant during Womble time. It consisted chiefly of graptolites, an extinct order of Hydrozoa, which while alive floated in the water. After they died their delicate remains sank to the bottom of the sea and were there buried in the mud that was being brought from the land. They have doubtless supplied some of the carbonaceous matter of the black shale to which the mud has since hardened.

Although the water was muddy and received some sand during Mazarn, Blakely, and Womble time, it became clear enough now and then to permit limestone to be formed. But during a large part of this time limestone was being formed on the north in the Ozark region, on the west in the Arbuckle Mountains of Oklahoma, and on the east in the southern Appalachian region. This difference in the character of the sediments on these three sides and the small distribution of the Blakely sandstone, which is exposed only in the southern part of the Ouachita Mountains, strongly indicate that the clastic materials of these formations came from the south.

Bigfork deposition.—After the Womble deposition was completed, layers of silica and thinner layers of mud, aggregating 700 feet in thickness, were put down in probably all the Ouachita Mountain region and later formed chert and shale, respectively. To the formation thus produced the name Bigfork chert has been applied. The deposition of chert and shale in alternating layers during Bigfork time and that of limestone and shale of the Hermitage formation of Tennessee suggest that the Bigfork and the Hermitage, both of Trenton (Middle Ordovician) age, were formed contemporaneously. The water, to judge from the small amount of shale in the formation, was at first relatively clear, but late in Bigfork time much mud brought from the land area was intermittently deposited with the silica forming the chert. Furthermore, the water was not of great depth, as is indicated by the ripple-marked surface of the sandstone. In the Bigfork, as in the Womble shale beneath, great numbers of graptolite remains were buried in the mud layers and are now well preserved in the shale. Evidently conditions at this time were not favorable for other kinds of marine life, as only a few brachiopods, bryozoans, and trilobites have been found in the Bigfork chert of Arkansas and a few sponge species in this formation in Oklahoma. The presence of the spicules suggests that at least a part of the silica which produced the chert was derived from such remains, but whether it was largely deposited by organic means or by chemical precipitation alone or by both processes is not known.

Polk Creek deposition.—Bigfork time was ended and Polk Creek time was begun by an increased muddiness of the sea. Black mud was rather uniformly spread over much if not all of the Ouachita Mountain region. Great numbers of graptolite remains were embedded in the soft mud, and many of them have been well preserved, though the mud has been changed to shale and in places to slate.

SILURIAN PERIOD

Blaylock deposition.—After Polk Creek time the land area which, it is believed, existed on the south was probably elevated sufficiently to invigorate the streams, so that in addition to a good deal of mud they now carried to the sea large quantities of sand. Later the sand and mud hardened into sandstone and shale, respectively, and to these beds the name Blaylock sandstone is applied. Graptolites comparable to species found in Great Britain rather than any now known elsewhere in America lived at this time, but their remains are scarce, only a single collection having been made.

A conglomerate of local distribution in the De Queen quadrangle indicates that land was not far distant, if indeed it did not exist in the quadrangle prior to Blaylock time. That sediment at this time was put down in a rapidly subsiding trough is suggested by the pronounced thickening of the formation southward, the increase amounting to at least 550 feet within a few miles from the thin edge of the formation, in the Hot Springs district, and reaching 1,500 feet within a like distance, in the Caddo Gap quadrangle. This depositional trough, though it exists only on the south side of the Ouachita Mountain region, has a considerable length extending from a point near Malvern, in central Arkansas, westward nearly to Wright City, in southeastern Oklahoma. The northward thinning of the sandstone may be due partly to erosion, as is indicated by the local occurrence of a conglomerate at the base of the overlapping Missouri Mountain slate. If the thinning out of the sandstone is due entirely to erosion at least 1,500 feet of material has been removed from the northern part of the present Ouachita region, and it would be expected that the underlying Polk Creek shale would also have been removed from large areas at the same time the Blaylock was being removed. But the Polk Creek shale is generally present in the region north of that in which the Blaylock sandstone occurs, and its thickness there is much the same as it is in places where it underlies the Blaylock. The conclusions regarding the Blaylock are that it was deposited in a minor east-west trough on the south side of the Ouachita geosyncline, that the northward thinning of the formation can be attributed in only a very small part to erosion, and that the land-derived sediments for it came from the south.

Blaylock sand deposition was ended by an emergence of parts of the region, including at least parts of the quadrangles herein described, but this emergence probably was not general, else more than local evidences of an erosion period would be present. The succeeding Missouri Mountain slate is in places like some of the shale in the Blaylock, and the apparent absence of any distinct boundary between the two shows that sedimentation in such places may not have been interrupted by land conditions.

Missouri Mountain deposition.—After Blaylock time the sea deepened, trangressed over those parts of the area that had been dry land, and in places put down a layer of coarse conglomerate that constitutes the initial deposit of the Missouri Mountain slate. Next fine red clay and in some places black clay were laid down throughout the Ouachita region. The prevailing absence of coarse material, such as subsequently becomes sandstone or conglomerate, suggests that the bordering land was low. The common red color of the shale indicates that the surface of this land had been deeply weathered after long exposure and that the mantle of soil had been colored red by the long-continued oxidation of its iron content. The removal of this material from the land area was probably the result of invigorated erosion.

DEVONIAN PERIOD

Arkansas novaculite deposition.—The next epoch, which was one of sedimentation throughout the Ouachita region, was characterized by the deposition, through organisms or chemical precipitation or both, of silica and a little calcareous material. The first deposit in a few places is a conglomerate, consisting of rounded quartz and novaculite pebbles embedded in a novaculite matrix. The local occurrence of the conglomerate suggests that little of the region was above water. As the water deepened silica and very meager amounts of other materials, later forming massive white novaculite, accumulated and in places reached a thickness of 425 feet. That the land during the accumulation of this vast amount of siliceous material was low or possibly remote is attested by the delivery of only a very small quantity of detrital material, which consisted wholly of rounded quartz grains and mica; and that the sea was relatively shallow is shown by the presence of ripple marks in the heavy bedded novaculite.

This part of the novaculite is of Middle Devonian age. Next mud, usually black, was put down in thin layers intermittently with those of the siliceous material, but later the silceous material, some calcium carbonate, and a very small quantity of mud were deposited. The middle and upper divisions of the Arkansas novaculite, which are considered to be chiefly of the same age as the Woodford chert in the Arbuckle Mountains and the Chattanooga shale, were thus formed. Some of the mud laid down at this time was red, as shown by the red color of the shale that it formed. This points to local conditions similar to those under which the mud during the Missouri Mountain epoch was deposited—that is, a near-by, long-exposed, and deeply weathered land surface, upon which there was a revival of erosion.

Sedimentation during the Arkansas novaculite epoch was not continuous; after Middle Devonian time it was interrupted by emergence and erosion, as shown by the presence and character of a conglomerate at the base of the middle division of the formation in the northern part of the Hot Springs district. The absence of this conglomerate in much of the De Queen and Caddo Gap quadrangles and in the Trap Mountains in the Hot Springs district suggests that the land area over which this part of the formation suffered erosion at this time may not have been of wide extent, but a conglomerate at this horizon was observed in the Potato Hills, near Talihina, Okla. Other conglomerates higher in the formation and similarly confined to the northern part of the Hot Springs district likewise indicate that land at different times was near by.

Life was meager during the Arkansas novaculite epoch. The only remains found thus far in Arkansas are a single collection of conodonts from a minutely pebbled conglomerate and conodonts, small linguloids, and sporangites from associated shale. This collection was made from the middle division of the formation at Caddo Gap. Pieces of silicified wood found in a conglomerate in this part of the formation near Glenwood, Pike County, Ark., and a piece of silicified tree trunk at least 2 feet in diameter, found at the top of the formation near Rosboro, Pike County, indicate the existence of trees of fair size on the land. Similar fossil wood occurs in the Woodford chert of Oklahoma.

This epoch was ended by an emergence from the sea over much of the Ouachita Mountain region. While this area was land much erosion took place on it and planed off the novaculite strata north of the quadrangles under discussion and in the northern part of the Hot Springs district. Many of the rounded novaculite pebbles from the eroded strata are found in the overlying conglomerate at the base of the Carboniferous rocks. But in the Caddo Gap and De Queen quadrangles, as in many other parts of the Ouachita region, so uniform is the character of the beds at the top of the Arkansas novaculite that, with the exception of thin, locally distributed conglomerates, there is no apparent evidence of an unconformity at this horizon.

CARBONIFEROUS PERIOD

After the period of erosion at the end of Arkansas novaculite time a bed of pebbles was laid down here and there in the Caddo Gap and De Queen quadrangles and now constitutes the only visible evidence in the quadrangles for a stratigraphic break at the base of the Carboniferous. In the northern part of the Hot Springs district the pebbles were spread out in a continuous bed and were followed by a bed of gray sand, later to form the Hot Springs sandstone; but this sandstone does not extend into the southern part of that district, nor into the Caddo Gap, De Queen, Mount Ida, and Lukfata quadrangles and other areas on the west. The distribution, character, and stratigraphic relations of this sandstone and its basal conglomerate suggest that the materials composing them came from a near-by northern source.

The deposition of the Hot Springs sand was followed throughout the Ouachita region by the Stanley epoch, during which mud and sand were alternately deposited to a depth of 6,000 feet.

Stanley deposition was in turn followed by Jackfork time, during which fully 6,000 feet of sand accumulated over much if not most of the Ouachita area.

The Stanley shale and Jackfork sandstone are exposed through the entire length of the Ouachita region, and the Jackfork sandstone is exposed at places in the Arkansas Valley in Arkansas, but both formations thin out to the north and west. They are absent in the Arbuckle Mountains and at a locality on the north border of the Ouachita region near McAlester, Okla., and also in the Ozark region. Not only do the formations themselves become thinner toward the north, but sandstone beds that form about one-fourth of the Stanley shale along the southern border of the Ouachita region become thinner or thin out completely before they reach the north side of the region, and the Jackfork sandstone changes toward the north from a formation composed almost entirely of sandstone with very little shale to a formation composed largely of shale. This northward thinning of the sandstone beds of the Stanley shale and the dovetailing of thick beds of shale in the Jackfork sandstone to the north imply a southern source for the sand and mud that later made up these formations. Many small quartz pebbles, one-fourth of an inch or less in diameter, occur in the Jackfork sandstone, particularly in its lower part, on the southern border of the Ouachita Mountains. They become less abundant toward the north. The enormous thickness and comparatively large areal extent of the Stanley and Jackfork indicate that the land mass to the south suffered great erosion.

The black color of the shale in the Stanley and the presence in it of many plant fragments, which are usually indeterminable, indicate the existence of plant life on the land. Marine fossils have not been found in the Stanley except at a few localities in McCurtain County, Okla.,[85] and none have been found in the Jackfork sandstone except at one locality in the De Queen quadrangle. The practical absence of marine fossils in these formations, combined with

[85] Honess, C. W., Geology of the Southern Ouachita Mountains, Okla.: Oklahoma Geol. Survey Bull. 32, pp. 177–178, 1923.

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the wide distribution and shallow-water character of the deposits, suggests that the formations are for the most part of fresh-water origin and that the materials composing them were deposited in a great delta formed at the mouths of rivers running north and draining the land area on the south. Any land area that could have supplied so much sediment in so short a time must have been extensive and must have been rapidly eroded, and it therefore probably included mountains.

Volcanic material that later formed tuff was deposited in the southern part of the Ouachita Mountain region early in Stanley time. The absence of bedding and of sorting of the rock and mineral fragments forming the tuff suggest that they were laid down on land, but the roundness of some of these fragments at some places shows that in those places they were deposited in water. As the tuff occurs only on the south side of the Ouachita region and thins out toward the north and as the size of the fragments of its component materials apparently decreases toward the north, it would seem that the volcanic materials which it contains were ejected from some vent or vents on or near the old land area at the south. The southern land area was low and was eroded very little during Devonian and possibly during early Mississippian time, but diastrophic movements produced mountains on the land during the Stanley and Jackfork epochs. The occurrence of the tuff near the base of the Stanley shale and the probability that the fragmental materials composing the tuff had a southern source strongly suggest that the mountain-making movements were accompanied by volcanic activity during which the materials for the tuff were ejected.

In parts of Oklahoma the Caney shale, containing in its lower part an upper Mississippian marine invertebrate fauna and in its upper part a fauna and flora of Pottsville (early Pennsylvanian) age, overlies the Jackfork standstone, and in places the Caney is succeeded by the Wapanucka limestone, of Pottsville age. The next formation in order in that State is the Atoka, also of Pottsville age, but in Arkansas and parts of Oklahoma the Atoka rests upon the Jackfork. Although the Caney and the Wapanucka have not been recognized in Arkansas, no unconformity has been detected in this State between the Jackfork and the Atoka. Whether an unconformity exists or whether the Caney and the Wapanucka are only apparently absent and are represented in the upper part of the Jackfork or lower part of the Atoka or both is not known, but the lithologic character of the Jackfork indicates that it does not represent either of the formations named. The lower part of the Atoka may possibly represent one or both of them with such a difference in lithologic character as might come about in widely separated parts of the same formation.

At least 6,000 feet of interbedded sand and mud containing some plant remains were laid down during Atoka time in the Caddo Gap quadrangle, and there was probably more, because the Atoka, being the youngest Paleozoic formation, has doubtless suffered some erosion. Great thicknesses of shale and sandstone younger than the Atoka are widely exposed in the Arkansas Valley, and the youngest of these rocks are of the same age as the Allegheny formation in the Appalachian region, which forms a part of the Pennsylvanian series. The sediments for the Atoka formation and the younger shale and sandstone apparently came from the south, like the sediments for most of the older rocks in the Ouachita Mountain region. Geologists believe that the clastic materials for the lower Pennsylvanian rocks of northern Texas were derived largely from an extensive old land area on the east and northeast, now covered by later formations. It appears fairly certain, therefore, that at least a part of the land area which supplied most of the material for the enormous thicknesses of Carboniferous rocks exposed in the Ouachita Mountains and Arkansas Valley was situated in Louisiana and eastern Texas. The location of this old land area may have roughly coincided with that of the Sabine uplift.

FOLDING AND UPLIFT

The area occupied by the Ouachita Mountain region and the Arkansas Valley was, taken as a whole, a geosyncline or subsiding synclinal trough, not only in Carboniferous time but throughout most of the Paleozoic era. Its subsidence began with or before the deposition of the mud that formed the Collier shale, of Cambrian age, and continued at least through the Allegheny epoch of Pennsylvanian time. During this long period there accumulated in this trough an enormous amount of sediment, which produced rocks whose exposed thickness aggregates a maximum of 41,000 feet and a minimum of 23,000 feet. At times, however, oscillations in the outer part of the earth produced low land areas of greater or less extent, and these caused irregularities in the deposition of different beds or formations that amounted in some places to their extreme thinning or absence. Near the end of the Paleozoic era this subsiding trough was converted into land, and its rocks were folded and faulted. The uplift, folding, and faulting in the Ouachita Mountain and Arkansas Valley regions were probably contemporaneous at least in part with extensive movements of a like nature in the Arbuckle Mountains, in southern Oklahoma, which, according to Morgan,[86] took place at four

[86] Morgan, G. D., Geology of the Stonewall Quadrangle, Okla.: Bur. Geology Bull. 2, pp. 19–21, Norman, Okla., 1924.

different times during the Pennsylvanian epoch—namely, near the end of Atoka deposition and thus near the end of the Pottsville time; near the end of the deposition of the sediments of the Savanna sandstone of Allegheny age; a little before the end of the deposition of the sediments of the Wewoka formation of middle Pennsylvanian age; near the end of the deposition of the sediments of the Vamoosa formation of late Pennsylvanian age.

The writers are inclined to agree with Morgan[86] and Honess[87] that the close folding and extensive faulting of the rocks of the Ouachita Mountains took place near the middle of the Pennsylvanian.

The folding and faulting were produced by horizontal compression movements acting in a nearly north-south direction. That the active force affecting the region came from the south is shown by the flattening of the folds northward from the axis of the Ouachita anticline toward Arkansas River and by their final dying out in the Ozark region. This force from the south corresponds with the northwestward movement that produced the Appalachian folds, to which the folds of the Ouachita region are similar. Many of the folds are overturned, some from the south—that is, in the same direction as that of the active force affecting the region—and others from the north, in an opposite direction to that of the active force. The amount of horizontal compression of the strata in the quadrangles has been about half their original extent. The mud, sand, and other materials had become indurated probably to a large extent by their own weight, but the force that effected the folding further consolidated them into firm rocks, and the permeating waters in places produced new minerals and cemented the particles firmly together. The shearing force and pressure further modified the deposits by the formation of cleavage and joint planes.

LATE PENNSYLVANIAN, PERMIAN, AND MESOZOIC TIME

OUACHITA PENEPLAIN

The De Queen and Caddo Gap quadrangles, as well as the rest of the Ouachita Mountain region, have, so far as known, been only partly submerged since their emergence near the middle of the Pennsylvanian epoch. Much of the area has remained land and has consequently undergone erosion from this emergence until now. The highest ridges in the Ouachita Mountains stand more than 2,000 feet above sea level, but the rocks composing some of the ridges have had at least 18,000 feet of strata removed from above them. Had this material not been removed a few of these mountains would now have

[86] Morgan, G. D., op. cit., pp. 19–21.
[87] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 259, 1923.

altitudes of more than 20,000 feet above sea level. They never attained such altitudes, however, because erosion progressed with elevation and may have worn away the rocks nearly as fast as the region was raised.

Erosion has not continued at a uniform rate up to the present time; there have been intervals when the region was reduced to a low-lying one of low or moderate relief, on which erosion was at a minimum. Such a low-lying area that has a nearly level surface is known as a peneplain. The evidence available indicates the successive formation of two peneplains—the Ouachita and the Hot Springs. The Hot Springs peneplain is described in the account of the Cenozoic era. Both peneplains have been largely destroyed by subsequent erosion, the Ouachita being now marked merely by the sharp, even crests of the Ouachita Mountains and the Hot Springs by low, greatly eroded upland surfaces on which there are only small tracts of level country.

The Ouachita peneplain was produced by a long period of erosion, which began near the middle of the Pennsylvanian epoch and continued through the Permian epoch and Triassic and Jurassic periods to the Lower Cretaceous epoch. If any part or parts of the present Ouachita Mountain region and Gulf Coastal Plain were submerged during Permian, Triassic, and Jurassic time, evidence of such submergence has not thus far been discovered. The Ouachita peneplain has undergone uplifts and tilting probably three or more times. At the beginning of the Cretaceous period this peneplain and a large area on the south, including the old land mass in Louisiana and northeastern Texas, were depressed and permitted the Gulf waters to extend northward until the shore line passed eastward several miles at least north of the south line of the De Queen and Caddo Gap quadrangles. How much farther the sea extended is not known, but it probably did not completely cover the quadrangles. During the northward advance of the sea the peneplain was doubtless slightly lowered by wave erosion.

The Ouachita peneplain forms the floor upon which the sediments of Lower Cretaceous age were deposited in the southern parts of the quadrangles and farther south, east, and west. The floor is smooth except for minor irregularities and south of the Ouachita region has a low dip (about 80 feet to more than 100 feet to the mile) to the south. (See fig. 7.)

If this plain were projected northward with a slope of 80 feet to the mile its altitude would be found to coincide or nearly coincide with that of many of the higher ridges in the northeastern part of the De Queen quadrangle and the northern part of the Caddo Gap quadrangle. (See fig. 7.) The altitude would be about 2,000 feet

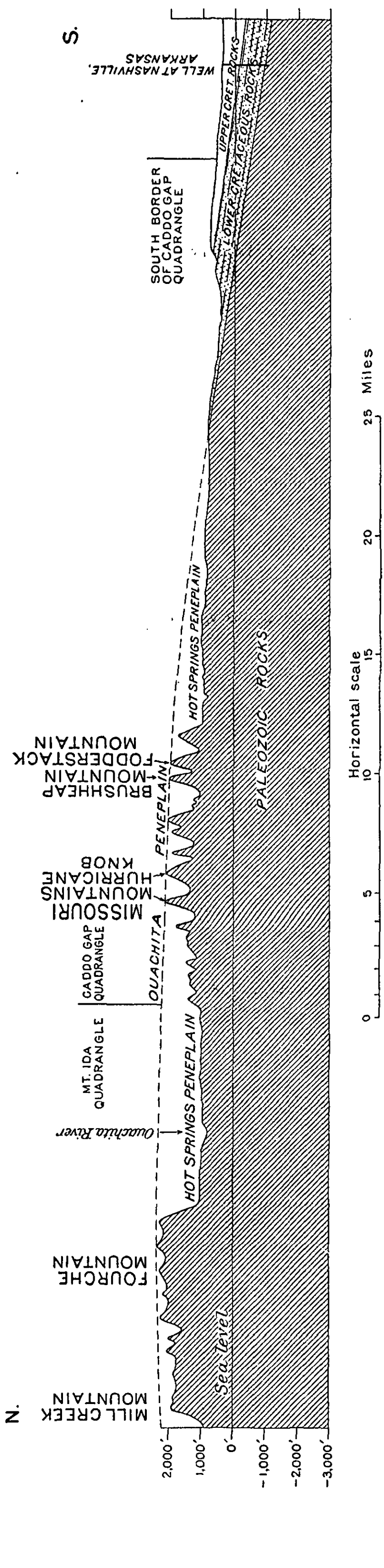

FIGURE 7.—North-south section through the Caddo Gap quadrangle and areas north and south of it, showing the relations of the Hot Springs and Ouachita peneplains

above sea level in the vicinity of Porter Mountain, Tall Peak, and Raspberry Peak, in the De Queen quadrangle, and about 1,900 feet at Blaylock Mountain and 1,650 feet at Redland Mountain, in the Caddo Gap quadrangle. The altitudes just given accord fairly well with those of the crests of these and near-by mountains and the crests of the high ridges above which Tall and Raspberry Peaks rise, but the projected plain would be higher than most of the mountains farther north and east in the quadrangles and higher than all the crests north of the quadrangles. The level attained by the crests north of the quadrangles, therefore, has a lower dip toward the south than 80 feet to the mile. The projected level would also be higher than the Cross Mountains, in the De Queen quadrangle.

In Arkansas the high ridges of the Ouachita Mountains are separated from the Gulf Coastal Plain by the Athens Plateau, but in McCurtain County, Okla., a short distance west of the De Queen quadrangle, they extend southward clear to the Coastal Plain. In that county they gradually increase in elevation northward from the north edge of the Coastal Plain, where the steeply dipping hard rocks that produce the ridges farther north have at most places been eroded down level with the softer rocks.

The foregoing data show that the southward dip of the Ouachita peneplain increases to the south not only in the southern part of the Ouachita region but also along the northern edge of the Coastal Plain, where it forms the floor for the rocks of Lower Cretaceous age.

The peneplain in Arkansas has also a very low dip toward the east. It is about 2,000 feet above sea level in the northeast corner of the De Queen quadrangle and the northwest corner of the Caddo Gap quadrangle, 1,100 to 1,300 feet above sea level at and near Hot Springs, and 500 to 600 feet above sea level at and near Butterfield, Hot Spring County, at the east end of the Ouachita Mountains. This eastward dip is apparently due to an eastward tilting of the part of the Ouachita Mountain region in Arkansas during the down warpings of the Mississippi embayment in Upper Cretaceous and Tertiary time.

In the De Queen and Caddo Gap quadrangles, as in other parts of the Ouachita Mountains, the only remnants of the Ouachita peneplain are the even-crested higher ridges, composed of the hardest rocks, the intervening softer portions of its surface having been entirely removed and some of the hardest parts having been reduced below the level attained by the higher ridges. The ridges have sharp crests, and no level tracts are preserved on them. Many or all of the crests may, in fact, have been slightly reduced below the level of the original peneplain, and some of the low peaks on the ridges, such as Tall and Raspberry Peaks, may have stood above the level of the peneplain.

DEPOSITION IN LOWER CRETACEOUS TIME

During the northward advance of the Lower Cretaceous sea across the Ouachita peneplain into the De Queen and Caddo Gap quadrangles pebbles of sandstone and novaculite were deposited on the beach, upon the beveled edges of the steeply dipping beds of sandstone and shale of Carboniferous age. The gravel bed thus formed is the lowest bed of the Trinity formation and to it the name Pike gravel member has been applied. Later in Trinity time there was an alternation of conditions that brought about the deposition of sand, clay, calcareous material, and gravel to a depth of 600 feet or more. The gravel was probably laid down on beaches, and the sand and clay were deposited on beaches and in deltas at the mouths of streams that flowed from the north. The only fossils in these deposits are fragments of wood and the bones of vertebrate animals. But the calcareous material, most of which was deposited at two times, forming the Dierks and De Queen limestones, was laid down in brackish water, as is shown by the molluscan faunas of the limestones. The faunas consist chiefly of fossil oysters. During the deposition of the beds of the De Queen limestone strontium sulphate and calcium sulphate were precipitated from the sea water and formed celestite and gypsum, respectively. The comparatively clear water in which the oysters and other marine forms lived and contributed their remains for the Dierks limestone gave way toward the west, in the De Queen quadrangle, to muddy water in which very little or no limestone was formed. In consequence of this the limestone merges into clay toward the west. The hard sandstone of Carboniferous age formed rocky headlands and islands at some places, as northwest of Murfreesboro, but many or all of these were later buried by sediments as the sea gradually encroached toward the north upon the land.

No Lower Cretaceous rocks younger than the Trinity crop out in the quadrangles herein described, but there are exposures of them near Cerrogordo, Ark., only a few miles south of the southwest corner of the De Queen quadrangle. These rocks there consist of the Goodland limestone and overlying beds of marl and limestone, all of which represent the Fredericksburg and Washita groups of the Lower Cretaceous series. Whether a part or all of the sediments of these two groups were laid down anywhere in the De Queen and Caddo Gap quadrangles and later removed through erosion is not known.

Deposition during Lower Cretaceous time was ended, in these quadrangles, by an uplift that brought the submerged parts of the quadrangles above water. After this uplift much of the Trinity was eroded from the quadrangles. The erosion was least on the west and greatest on the east, where, as near Delight, it removed all the higher beds of the formation down to and including the Dierks limestone lentil. The amount of erosion at this time in the Ouachita Mountains is not known, but the Ouachita peneplain was probably not reduced to any great extent.

INTRUSION OF IGNEOUS ROCKS

The peridotite that occurs near Murfreesboro, in the Caddo Gap quadrangle, appears to be the result of three distinct but closely related outbursts of igneous activity.

First, a magma was intruded upward into the Carboniferous and Lower Cretaceous rocks, and on cooling and solidifying it became a hard rock that is now called intrusive peridotite.

This was followed by exceedingly violent volcanic explosions, which blasted a conduit through the older rocks and shattered into fragments some of the intrusive peridotite, also some of the Carboniferous shale and sandstone, and other sedimentary rocks that formed the walls of the vents. Explosive craters were no doubt formed at the surface outlet of these volcanic vents. At the Prairie

Creek peridotite locality and possibly elsewhere large quantities of fragments were ejected into the air and on falling back accumulated within the crater in layers dipping toward its center. The fragmental material thus accumulated and some that probably did not reach the surface was consolidated to the hard rock now called volcanic breccia.

The peridotite fragments and altered olivine grains in the lower part of the Tokio formation (Upper Cretaceous) on the Riley place, near Murfreesboro, and the altered serpentine grains in the lower part of the Tokio formation on the Twin Knobs, also near Murfreesboro, were apparently water-laid like the associated sand, gravel, and clay. They may have been derived from outcrops of peridotite, but they were probably fragmental material that was ejected during volcanic eruptions.

Slightly later occurred another time of explosive volcanic activity, during which fragmental volcanic material very similar to that of the previous eruption accumulated and subsequently consolidated into the hard rocks that are now called tuff and fine-grained breccia. These rocks are, so far as known, present only in the Prairie Creek peridotite area.

That the several phases of volcanic activity took place after Trinity (Lower Cretaceous) time and during or before Tokio (Upper Cretaceous) time is shown by the facts (1) that the peridotite has penetrated and cut across the nearly flat-lying beds of the Trinity formation (figs. 4 and 5), (2) that it is overlain at places by the Tokio formation (fig. 5), and (3) that pebbles of it occur in the lower part of the Tokio. The pebbles of the peridotite in the Tokio were probably ejected as fragmental material during the volcanic eruptions, and if so the eruptions took place during the time when the Tokio was being deposited. The several phases of volcanic activity probably accompanied the diastrophic movements that produced the downwarping of the Mississippi embayment early in Upper Cretaceous time.

DEPOSITION IN UPPER CRETACEOUS TIME

The beginning of Woodbine time in the Upper Cretaceous epoch was marked by a northward advance of the Gulf waters into the southern parts of the De Queen and Caddo Gap quadrangles. During and after this advance thick beds of gravel, sand, and clay were laid down in shallow waters, probably on deltas, along beaches, and in stream channels. The only fossils that have been found in the beds thus laid down are those of land plants. Most of the pebbles in the gravel beds are novaculite and were derived by erosion from the gravel beds in the Trinity and from the outcrops of the novaculite on the north.

A thick bed of water-laid volcanic tuff in the Woodbine indicates extensive volcanic activity during Woodbine time. This activity doubtless took place at or near the same time as that in the areas of the peridotite near Murfreesboro. The source of the bulk of the volcanic material is, however, not known, though a minor part was doubtless contributed by the volcanic explosions near Murfreesboro which brought the peridotite to the earth's surface. Most of the materials in the tuff and ash are, as shown by previous discussion, not related to peridotite. Instead they are similar to but not identical with the syenites and related types of igneous rocks near central Arkansas.

The thickest known deposits of tuff in Arkansas and Oklahoma lie in Pike County, Ark., and the adjoining counties of Howard and Sevier in that State. This, combined with the known occurrence of volcanic activity at Murfreesboro, Pike County, suggests that the vent or vents, through which the enormous quantity of tuff and ash in southwestern Arkansas and southeastern Oklahoma were ejected, were located in these three counties. The areas of Lower Cretaceous and older rocks in these and adjoining areas have been carefully studied by numerous geologists, but thus far no evidence of volcanic vents except the peridotite vents near Murfreesboro has been discovered. The inference follows that the vents supplying the other kinds of volcanic material were perhaps in the southern parts of Pike, Howard, and Sevier Counties, south of the De Queen and Caddo Gap quadrangles, where they are concealed by beds of Upper Cretaceous and Quaternary age.

Woodbine time was ended by uplift and a consequent period of erosion. Tokio deposition then followed and was apparently accompanied by volcanic activity at the areas of peridotite near Murfreesboro. A bed of water-laid material, possibly peridotite tuff, is found at the base of the formation near that place. Also the kaolin deposits of the Tokio are of such a character as to indicate volcanic activity that resulted in the ejection of fine dust, which was deposited in thin beds in the Caddo Gap quadrangle. The kaolin of the Tokio formation has been derived by alteration from the beds of volcanic dust. Marine fossils have not been found in the Tokio formation in the Caddo Gap quadrangle, but they have been obtained at localities only a few miles south of the quadrangle.

Deeper water deposits succeeded the near-shore deposits of the Tokio formation. Those in the southeast corner of the Caddo Gap quadrangle consisted of marl filled with marine shells, to which the name Brownstown marl is applied, but still younger beds of sand, clay, and chalk of Upper Cretaceous age were laid down south and southeast of the De Queen and Caddo Gap quadrangles. The

Ouachita region and the near-by portion of the Gulf Coastal Plain were uplifted at the end of the Upper Cretaceous epoch, and there was a consequent withdrawal of the Gulf waters toward the south. The De Queen and Caddo Gap quadrangles have so far as known remained dry land since then.

The several oscillations of Upper Cretaceous time are briefly discussed as follows by Veatch:[88]

> As a result of this submergence [Upper Cretaceous] the low-lying area in western North America became a great mediterranean sea, which connected the Gulf of Mexico and the Arctic Ocean. In the Texas-Arkansas area the depression was at first greatest to the southwest, but during the latter part of the Cretaceous the movement was reversed and the western region was gradually elevated as the area near the Mississippi was depressed. This resulted finally in the development of the Mississippi embayment and in the severing of the connection between the Gulf and the interior sea, which was thus converted into a series of great inland lakes which persisted through much of the Tertiary. Because of this east-west and then west-east tilting the lower portion of the Upper Cretaceous, which in central Texas is characterized by thick limestone and light-colored marl beds, is in Arkansas and Indian Territory composed entirely of near-shore sands with no marine fossils; while the upper portions, which in Texas are dark-colored calcareous clays, contain in Arkansas, Mississippi, and Alabama a large percentage of chalk and chalk marls.

DRAINAGE DURING CRETACEOUS TIME

The drainage of the present Ouachita Mountain region during Lower Cretaceous time, when the region was presumably a low southward-sloping peneplain (the Ouachita peneplain), must have been toward the south into the sea. The present Ouachita Mountain region was in fact probably reduced so nearly to a plain that the courses of the streams were largely independent of the structure of the rocks. After the region was elevated at the end of Lower Cretaceous time the streams continued to flow southward but across the area of newly formed unconsolidated sediments. These sediments doubtless overlapped the Ouachita region for some distance beyond their present margin, and upon them the southward-flowing streams along the south side of the region were superimposed. When their channels were later cut down to the beveled upturned edges of the hard Paleozoic rocks below, they were incised therein regardless of the structure of the rocks.

But the southward-flowing streams in most of the Ouachita Mountain region have apparently had a different history, for there is little or no evidence that Cretaceous or later deposits ever covered more than a small part of the region. Their history is complicated,

[88] Veatch, A. C., Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 22, 1906.

and probably no single explanation can account for their courses across the edges of the rocks and through the ridges. An explanation here offered is that the streams may have flowed toward the south, away from the axis of the Ouachita anticline, during the gradual emergence of the Ouachita Mountain region from the sea. This emergence was so slow and much of the 18,000 feet of Carboniferous rocks removed by erosion was so soft at that time that the most vigorous streams easily kept their courses across the folds as the folds increased in height or as the streams worked down to them, so that, when the edges of the Arkansas novaculite and other hard strata were reached, the courses had become so well established that they were maintained across these strata.

The downwarping of the Mississippi embayment during Upper Cretaceous and Tertiary time was accompanied by an eastward tilting of much of the southward-sloping Ouachita region, so that the region now slopes to the southeast. Much of the southward drainage was therefore diverted toward the southeast. The southeastward courses of Saline, Ouachita, Caddo, and Little Missouri Rivers may thus be explained. The similar course of Arkansas River may also be explained in this way, though, as believed by Branner,[89] the drainage in the Arkansas Valley flowed westward during Permian, Triassic, and Jurassic time. If this is true there has been a reversal of the Arkansas drainage.

The parts of the courses of the streams that are in the east end of the Ouachita Mountain region may have been superimposed upon Upper Cretaceous sediments, though it appears that the east end of the region was not covered by sediments of this age.

TERTIARY AND QUATERNARY TIME

Erosion was accelerated by uplift at the end of Upper Cretaceous time, and it lowered the surface rapidly along the belts of rock of least resistance, leaving the edges of some of the more resistant rocks standing up as mountain ridges. In this way the Hot Springs peneplain was produced in parts of the Ouachita Mountain region, including the De Queen and Caddo Gap quadrangles. In these quadrangles the peneplain stood at the same level as the present dissected plateau surfaces of the Mazarn and Cove basins and much of the Athens Plateau. During the lowering of the region by erosion which produced the peneplain the edges of the steeply dipping Arkansas novaculite withstood erosion and persisted as ridges. The edges of the Jackfork sandstone in the Athens Plateau in the Caddo Gap quadrangle also produced low ridges upon the peneplain.

[89] Branner, J. C., The Former Extension of the Appalachians across Mississippi, Louisiana, and Texas: Am. Jour. Sci., 4th ser., vol. 4, pp. 358–360, 1897.

Owing to the various hardnesses of the rocks, the part of the Caddo Basin in the Caddo Gap quadrangle was apparently not reduced to a peneplain at this time.

The part of the peneplain in the Ouachita region in Arkansas has a general southward and southeastward dip toward the Gulf Coastal Plain. Its gradient is much less than that of the Ouachita peneplain, which shows that the post-Ouachita uplift that resulted in the tilting of the surface toward the south and east was greater in the interior than near the coast. The highest part of the Hot Springs peneplain is in and north of the northwest corner of the De Queen quadrangle, where it attains an altitude of about 1,250 feet above sea level, and the lowest part is along the eastern edge of the Ouachita region, where its altitude is about 400 feet. (See fig. 7.) The peneplain along its southern border in the quadrangles under discussion stands 750 feet above sea level. The relation of the peneplain to the Tertiary deposits in Arkansas has not been fully worked out, but at the few places where the authors have studied it, along the eastern margin of the Ouachita Mountain region, it appears to pass beneath the Eocene (early Tertiary) strata of the Coastal Plain. If this is its position, the peneplain is of early Tertiary age.

The streams on the Hot Springs peneplain were graded and built up wide flood plains, over which they meandered regardless of the structure of the rock strata, though the outcropping edges of the Arkansas novaculite and those of the Jackfork sandstone in many places were not reduced to the level of the peneplain. The edges of these formations produced ridges which still persist. Some of the streams were able to maintain their courses across the edges of these hard strata while the region was being reduced to form the peneplain. In this way water gaps were cut in the ridges.

Beginning with the Eocene epoch of the Tertiary period, the Mississippi embayment was again submerged by a northward extension of the Gulf of Mexico. The sea did not reach the quadrangles under discussion, and the thin deposits of water-worn gravel found here and there on the Athens Plateau near Athens, in the Caddo Gap quadrangle, and similar deposits over the higher parts of the east end of the Athens Plateau east of this quadrangle, were probably laid down by streams as flood-plain deposits during the Tertiary period.

Later a succession of uplifts halted by periods of stability and depression elevated the region about 500 feet to its present altitude and forced the Gulf waters back to their present position. This elevation rejuvenated the streams and enabled them to carry away in a short time most of their former flood-plain deposits and to dissect the Hot Springs peneplain so completely that little comparatively level upland is left on the present plateau surface. The larger streams, such as Little Missouri, Cossatot, and Saline Rivers and Rolling

Fork, have gradually incised their channels to a depth of as much as 350 feet in the hard Paleozoic rocks. These streams probably inherited their crooked courses from their predecessors, which ran in similar courses across the Hot Springs peneplain. Many of the smaller streams have partly or wholly eroded their valleys in the soft shale between the nearly east-west ridges of hard sandstone. Such streams flow toward the west or toward the east, whereas the larger streams usually have southward courses. A trellised arrangement of the streams has thus been produced in the Athens Plateau in these quadrangles. (See pl. 1.)

The cutting of the stream valleys from the Hot Springs peneplain down to their present level in the De Queen and Caddo Gap quadrangles has not been continuous. There have been times, as shown by terrace deposits, when the streams reached grade. These deposits are few, and their areal distribution is small along the streams in the Athens Plateau and farther north. This is due to the great hardness of the rocks there, which prevented the streams from cutting wide, flat-bottomed valleys. These streams have considerable fall, though in some stretches their currents are comparatively slow and their valleys are widened somewhat. In such places the streams have deposited some alluvium.

The larger streams and many of the smaller ones in the Coastal Plain in the southern parts of the quadrangles, where the rocks are mostly unindurated sand, clay, and gravel, have cut their channels down to base level, and the larger ones have cut wide, flat-bottomed valleys in which extensive flood-plain deposits have been laid down. These deposits occur at various altitudes, the highest being as much as 150 feet above the streams.

ECONOMIC GEOLOGY

The principal mineral resources of the Caddo Gap and De Queen quadrangles are clay, diamonds, and road material, all of which have been mined. Lead, zinc, and antimony minerals, quartz crystals, slate, asphalt, building stone, and limestone for lime have been mined at times, and deposits of tripoli, pyrite, marcasite, iron ore, manganese ore, and gypsum have been explored.

The soils of the quadrangles are a source of considerable wealth, though they are for the most part not naturally so fertile as soils that are underlain by rocks of other sorts. The water resources are valuable for both water supplies and the development of power. Timber is one of the most valuable natural resources and will continue to be one for an indefinite period, if proper care is given to the forests.

DIAMONDS

HISTORY AND OCCURRENCE

The first diamonds found near Murfreesboro, which were the first found in Arkansas, were picked up on the Prairie Creek peridotite area (pl. 10) on August 1, 1906, by John W. Huddleston. Diamond mining has continued intermittently at several mines from the date of Huddleston's discovery to the present time.

Nearly all the diamonds have been found within the exposures of the peridotite at the Prairie Creek, Kimberlite, and American peridotite areas, though a very few have been found along streams where they have been washed from these areas, and the finding of several small diamonds has been reported from areas of the Woodbine formation, 3 to 4 miles south of Corinth. The mines that have produced diamonds are the American, Kimberlite, Mauney, Ozark, and Arkansas. (See pls. 10 and 14.) The diamonds at these mines have been found not only on and near the surface but also at depths of 20 feet. How much deeper the diamonds extend is not known, but they probably occur at a depth much greater than that to which mining can be carried.

The yield of diamonds in carats per load of diamond-bearing material differs from place to place in the mines and with depth. This yield as it has been determined from the great amount of work at one mine, is 1 carat for 8 loads (16 cubic feet each) of diamond-bearing material.

Most of the diamonds from the Arkansas, Ozark, and Mauney mines have been obtained within the area or areas in which the volcanic breccia is exposed. The areal distribution of the breccia at the surface of these mines is shown on Plate 10.

On the Riley place, half a mile northeast of the Ozark mine, the Tokio formation contains pebbles of peridotite and grains of altered serpentine. The material is possibly peridotite tuff. The Ozark Diamond Mines Corporation washed 1,000 loads (16 cubic feet each) of material from the Tokio at that locality but found no diamonds.

PRODUCTION AND CHARACTER

The number of diamonds that have been found near Murfreesboro, Ark., since their discovery in 1906 is only partly known, for the mining companies have withheld from publication the complete figures of production. The production so far as known to the authors includes at least 10,000 diamonds up to the end of 1923.

The bulk of the diamonds from the mines have been held by the mining companies, though some uncut stones have been given away or sold, and some cut stones have been sold. Cut stones were first offered to the public in 1921 by Tiffany & Co., of New York, and by the Charles S. Stifft Co., of Little Rock, Ark.

The diamonds that have been found range in weight from a very small fraction of a carat to many carats. Some are so small that 250 diamonds would be required to weigh 1 carat. The largest diamond, which was found in the Arkansas mine, weighed 40.23 carats; another from the same mine found in September, 1921, weighed 20.25 carats; and a third stone weighing 17.86 carats was found in the Arkansas mine in May, 1917. Pictures of the last-mentioned diamond and nine others from the Arkansas mine are shown in Plate 17, *A*. The average weight of the 3,000 diamonds produced from the Arkansas mine to the end of 1920 was about 0.4 carat,[90] but the average weight of the entire production of all the mines is probably between 0.3 and 0.4 carat.

Most of the diamonds are white, brown, or yellow. There is, according to Kunz and Washington,[91] a large proportion of white stones, most of them of high grade in color, brilliancy, and freedom from flaws. They also say that many stones are as fine as any that have ever been found and that some of the yellow ones are of exceptional quality and color. Kunz[92] also makes the following statement in describing several yellow, brown, and white stones from the Arkansas mine: "These are absolutely perfect and are equal to the finest stones found at the Jagersfontein mine, or that were ever found in India."

The following statement regarding the diamonds from the Mauney and Ozark mines was supplied in 1921 by Austin Q. Millar, of the Kimberlite Diamond Mining & Washing Co.:

From a careful examination of several thousand diamonds the percentages of yield of the various grades of the mine run are: White stones, 40; yellow, 22; brown, 37; true bort, 1. The gem material of the yellow, the deep canary, is most magnificent, and the mahogany shade of the brown is equally desirable. The white gem material is matchless for purity, and about 10 per cent of the stones classed as white are of this grade. * * *

Their crystallographic characteristics are distinct. As the larger proportion of the recoveries belong to the more complex forms of the isometric system, the trisoctahedron and hexoctahedron predominate more than the octahedron or dodecahedron. Rarely are crystals recovered that present sharp angular faces, the characteristic rounded (convexed) surfaces greatly predominating. The true bort is translucent with a radial structure and occurs in rounded forms.

Stones have been found with a blue or pink tinge, and occasionally a "frosted" or etched white is noticeable in the recoveries.

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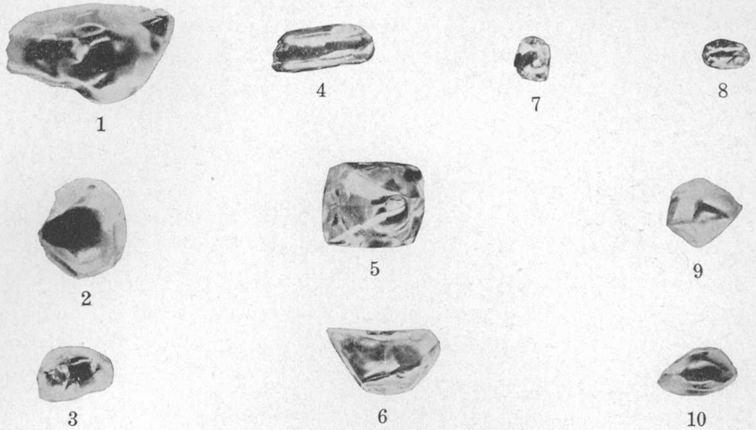
[90] Kunz, G. F., Eng. and Min. Jour., vol. 103, p. 160, 1921.

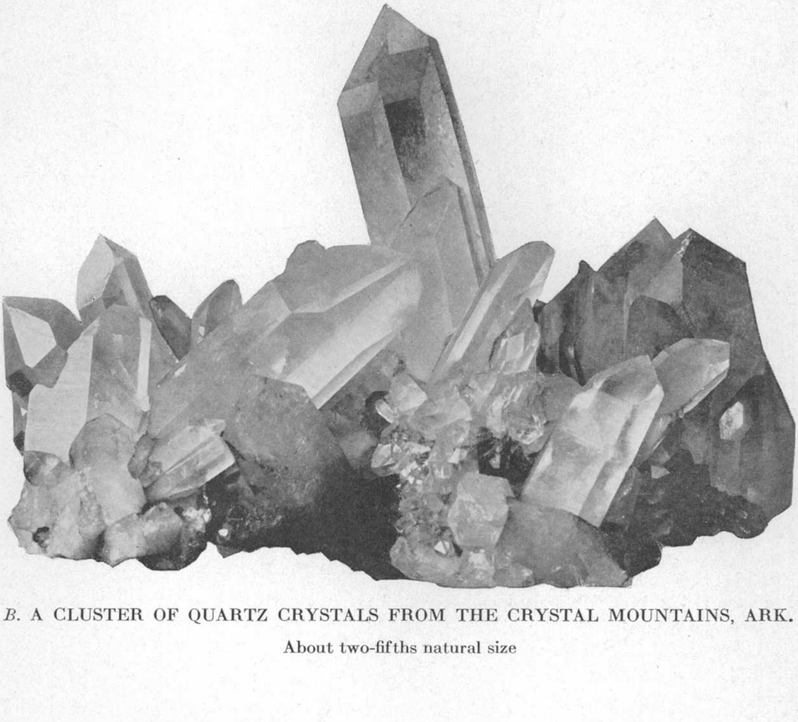
[91] Kunz, G. F., and Washington, H. S., Diamonds in Arkansas: Am. Inst. Min. Eng. Trans., vol. 39, pp. 173–174, 1909.

[92] Kunz, G. F., Precious Stones: Mineral Industry, vol. 27, pp. 621–622, 1919.



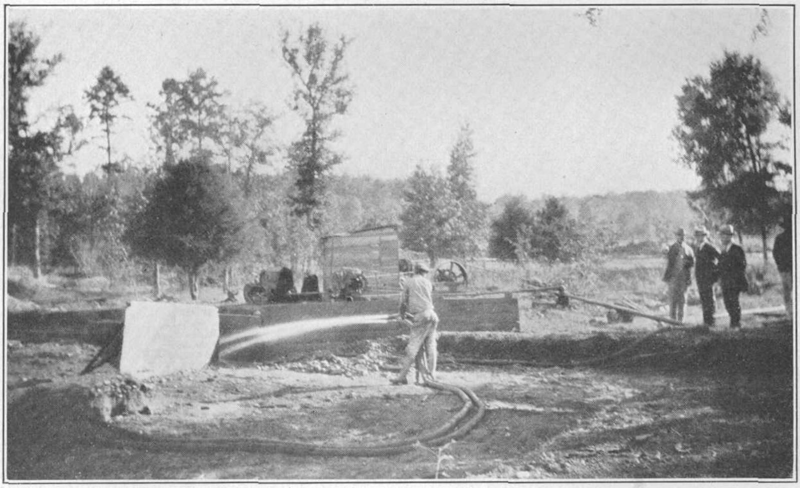
A. DIAMONDS FROM THE ARKANSAS MINE, NEAR MURFREESBORO, ARK.

These diamonds are in the Col. Washington A. Roebling collection in the U. S. National Museum. Their weights in carats are as follows: 1, 11.21; 2, 6.83; 3, 3.30; 4, 2.77; 5, 17.86; 6, 4.40; 7, 1.19; 8, 0.91; 9, 2.50; 10, 1.40. Four-sevenths natural size



B. A CLUSTER OF QUARTZ CRYSTALS FROM THE CRYSTAL MOUNTAINS, ARK.

About two-fifths natural size



A. DIAMONDS BEING MINED AT THE ARKANSAS MINE BY MEANS OF A JET OF WATER AND THEN CARRIED THROUGH A SLUICE TO THE PLANT

B. DIAMOND PLANT AT THE ARKANSAS MINE

Here the sluiced material is sized and jigged. Then the concentrates, after being placed on smooth sheets of metal, are carefully searched for stones

Fragments and fractures were much more noticeable when mining was being done in surface material; but at slight depth in the undisturbed volcanic ground these features were almost entirely absent.

MINING AND TREATMENT OF DIAMOND-BEARING MATERIAL

Many diamonds, probably several hundred, have been picked up by miners from the surface of the peridotite areas, especially the Prairie Creek area, but most of the diamonds that have been produced have been obtained by washing the diamond-bearing material. Different methods of mining and washing have been employed, as required by the character of the diamond-bearing material, which varies not only from one locality to another but also with depth.

Much of the decomposed peridotite, including the surficial black soil called "black ground" and the underlying "blue ground," "yellow ground," and "green ground," is soft enough to be washed for the recovery of the diamonds without being first crushed or weathered. Most of the "black ground" is very sticky, like gumbo, when it is wet, so that it disintegrates with some difficulty in the washing plants.

All the mining has been done in shallow open cuts. Hydraulic mining has been used to some extent, but most of the work has been done by hand and by means of plows and scrapers. Whenever the hydraulic method is employed, the water carries the soft weathered diamond-bearing material through a sluice trough. The concentrates from the sluice trough are then jigged by hand in small sieves or run through a small plant equipped with screens and jigs. (See pl. 18.) Then the jigged concentrates are placed on smooth sheets of metal where they are carefully searched for diamonds.

Much of the material that has been mined, however, has been hauled in tramcars with a capacity of 16 cubic feet each to the washing plants. A log washer was used for a short time in the Ozark washing plant, but its use was not a success on account of the sticky nature of the "black ground" that was washed in it.

Washing pans of the type common in the South African diamond fields have been used successfully. A pan of this type is circular, has a flat bottom, and rests in a horizontal position. At its center is a vertical revolving shaft to which radiating arms are attached. On these arms are metal teeth that revolve and stir the diamond-bearing material that is fed into the pan. During this stirring the diamonds and associated heavy minerals gradually settle to the bottom of the pan, and the clay and other light minerals rise to the surface and flow out of the pan near its center. The concentrates thus obtained in the bottom of the pan are next sized and then jigged. The jigged concentrates are carefully searched for diamonds on metal-covered tables or are washed with water over a greased table. This table is covered with a thick coat of grease and is shaken rapidly from side to side by an eccentric. When the concentrates are washed across the table the grease sticks to and holds the diamonds, whereas it does not stick to the other minerals, most of which are therefore washed off the table. The grease with its included diamonds and other minerals is removed from the tables from time to time. The diamonds are then freed from the grease by converting it into soap or by putting it into boiling water.

CONCENTRATE MINERALS ASSOCIATED WITH THE DIAMONDS

A number of minerals besides diamonds are concentrated during the treatment of the diamond-bearing material. They are hematite, limonite, barite, colorless quartz, amethyst quartz, magnetite, pyrope, almandite, schorlomite (or melanite), chromite, pyrite, diopside, and epidote. The quantity of each mineral varies somewhat from place to place, but in general the most abundant have been named first and the least abundant last. A few specimens of amethyst quartz of gem quality have been found, and some of them have been cut for use in jewelry. A small number of pebbles of the dense chalcedonic varicolored novaculite that are found on the surface at the diamond mines have also been cut for this use.

ANTIMONY

The antimony deposits of the De Queen quadrangle have been described in a number of reports, the most important of which are the following:

Wait, C. E., The antimony deposits of Arkansas: Am. Inst. Min. Eng. Trans., vol. 8, pp. 42–52, 1880.

Comstock, T. B., A preliminary examination of the geology of western central Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 1, pp. 136–147, 1888.

Jenney, W. P., The lead and zinc deposits of the Mississippi Valley: Am. Inst. Min. Eng. Trans., vol. 22, pp. 206–208, 1894.

Ashley, G. H., Geology of the Paleozoic area of Arkansas south of the novaculite region: Am. Philos. Soc. Proc., vol. 36, No. 155, pp. 217–318, 1897. Reprinted in Contributions to Biology from the Hopkins Seaside Laboratory, Stanford Univ., No. 12, pp. 306–308, 1897.

Hess, F. L., The Arkansas antimony deposits: U. S. Geol. Survey Bull. 340, pp. 241–252, 1908.

Shriver, E. H., Antimony deposits of Arkansas; Min. and Sci. Press, vol. 114, No. 26, pp. 920–922, June 30, 1917.

Mitchell, G. J., Antimony in southwestern Arkansas: Eng. and Min. Jour.-Press, vol. 114, pp. 455–456, 1922.

The deposits were examined by Mr. Miser in July, 1916, when practically all the mines were in operation, but the description of their general features which is given below is taken in large measure from the above-listed reports.

The deposits occupy a narrow belt about 8 miles long lying along the northern edge of Sevier County, near Antimôny post office and the village of Gillham. The location of the mines is shown on Plate 3. The exact date of discovery of the deposits is not positively known, but it seems to have been in the winter of 1873–74. Mining operations were begun immediately and have been carried on from time to time whenever high prices for antimony permitted its economic recovery. The last mining was done in 1917, though no ore has been marketed since 1916.

The country rock is the Stanley shale, which has high dips, reaching in places 90°, and a strike of N. 70°–80° E. Owing to the absence of distinctive beds the determination of the structure here, as in most other places where the Stanley is the surface formation, is practically impossible. Although fissure veins of massive and comby quartz are common in this and older formations over much of the Ouachita area of Arkansas and Oklahoma, it is only in the vicinity of Gillham and Antimony that they are known to carry antimony minerals. An interesting exception is the reported occurrence of crystalline native antimony near Kirby, in the Caddo Gap quadrangle. While the authors were in that locality they were shown a piece of this mineral weighing a pound or more, but they were informed that it was the only piece that had been found. Also a second specimen of this native metal that is stated to have been found at a locality near Kirby was shown to Mr. Miser by J. N. Garner, of Nashville, Ark. The veins that carry the antimony minerals follow the bedding planes of the sandstone and shale in which they are found, but some small veins and a few larger ones cut across the bedding. The principal veins are therefore vertical or nearly so. They are slickensided, showing both horizontal and vertical striations, and the black shale on either side has been disturbed somewhat by the movements which produced the striations. The thickness ranges from a feather edge to 4 feet but is commonly about 1 foot. Although quartz constitutes most of the gangue, some angular fragments of shale are included in the vein. The country rock was not affected during the introduction of the quartz, and even the included fragments remain unaltered. In some places the surface outcrop is marked by protruding ledges of quartz; in others by loose fragments.

The ore bodies occur in lenticular masses ranging in thickness from a feather edge to 2½ feet. Besides quartz they contain as original minerals stibnite (Sb_2S_3), jamesonite ($2PbS.Sb_2S_3$), zinkenite

($PbS.Sb_2S_3$), galena (PbS), sphalerite (ZnS), pyrite (FeS_2), chalcopyrite ($Cu_2S.Fe_2S_3$), siderite ($FeCO_3$), and calcite ($CaCO_3$). Traces of arsenic, bismuth, cadmium, cobalt(?), silver, and rarely gold are found. Cervantite ($Sb_2O_3.Sb_2O_5$) and bindheimite ($PbO.Sb_2O_5.H_2O$) occur as oxidation products of stibnite and jamesonite, respectively. The commercial ores are antimony oxide and sulphide and lead minerals, which in places are silver bearing. At depths of 40 to 115 feet from the surface these ores contain admixtures of sphalerite and other impurities, which have been removed through solution from the upper parts of the veins. The following analyses reveal the purity of the stibnite, which is the chief ore mineral, and of the cervantite:

Analysis of stibnite from Stewart mine

Antimony	69.87
Sulphur	27.91
Iron	.02
Zinc	.01
Silica	2.69
Silver	None.
	100.50

Analysis of ore from Antimony Bluff shaft

[C. E. Wait, analyst]

Stibnite	99.711
Chalcopyrite	.055
Bismuthinite	.005
Gangue	.229
Silver	None.
	100.000

Analysis of cervantite from Antimony Bluff shaft

[C. E. Wait, analyst]

Antimony	76.38
Oxygen	20.03
Sulphur	.01
Oxide of iron	.12
Silica	1.19
Water	2.23
Silver	None.
	99.96

The paragenesis of the vein minerals is not known except that most of the quartz preceded the metallic minerals, as shown by their occurrence on the crystal faces of the comby quartz, and that some of the quartz was deposited with the metallic minerals. Their origin also is not clear. Many of the quartz veins in McCurtain County, Okla., contain orthoclase and are regarded by Honess[93] as quartz-orthoclase

[93] Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pp. 39–40, 48–49, 64–66, 1923.

pegmatites. The metallic minerals near Gillham and some or all of the quartz associated with them were probably derived from an igneous magma. The nature of the minerals, as pointed out by F. L. Hess and G. J. Mitchell, suggests this origin.

For an igneous origin it is necessary to assume the existence of concealed masses of intrusive rocks nearer than the peridotite areas at Murfreesboro. A dike of ouachitite, as stated on page 100, was found recently by Mitchell a few miles east of Gillham. If the origin of the veins is related to the intrusive rocks, then, as stated by Hess, "their age would be but little less than that of the intrusions"—early Upper Cretaceous. Hess says:

> With such a deep-seated origin it is probable that the lenses of ore will alternately make and pinch out to a considerable depth, and in times of high prices for ore * * * some of the mines might be worked at a profit. It can not be stated, however, what the vertical extent of any ore shoot may be, and below the ground-water level varying amounts of impurities consisting of zinc blende, chalcopyrite, and iron pyrite are to be expected.

SLATE [94]

GENERAL FEATURES

In 1902 the Southwestern Slate & Manufacturing Co. was organized to operate in Polk and Montgomery Counties, Ark. Title was acquired to large tracts of land, and much money was invested in preparations for conducting an extensive slate business when shipping facilities, which were expected soon, could be had. Failure to obtain transportation caused the reorganization of the company and the change of its name to the Southwestern Slate Co., in 1903. The operating plant, which is at Slatington, in the Caddo Gap quadrangle, contains one saw, one planer, and one rubbing board. So far as known only milling slate has been produced, a considerable amount of this having been put on the market, principally for electrical equipment.

The work of these two companies gave an impetus to prospecting for slate, and various persons and companies acquired title to slate lands in the northeast corner of the De Queen quadrangle and the northern part of the Caddo Gap quadrangle. A small production of roofing slate has been reported from time to time.

Five formations of the quadrangles contain slate. These are the Mazarn, Womble, Polk Creek, and Stanley shales and the Missouri Mountain slate. Only the last two of these have been prospected

[94] Full descriptions of these deposits may be found in the following reports:

Dale, T. N., and others, Slate Deposits and Slate Industry of the United States: U. S. Geol. Survey Bull. 275, 1906; Slate in the United States: U. S. Geol. Survey Bull. 586, 1914.

Purdue, A. H., The Slates of Arkansas, Arkansas Geol. Survey, 1909; The Slates of Arkansas: U. S. Geol. Survey Bull. 430, pp. 317–334, 1910.

much, and most of the prospecting and developing has been done in the Missouri Mountain slate.

MAZARN AND WOMBLE SHALES

As their names imply, the Mazarn and Womble shales are composed mainly of shale. They generally show no indication of slaty cleavage, but parts of the Mazarn shale and the base of the Womble shale show well-developed slaty cleavage, which is conspicuous in the stream beds, by the roadside, and in other places where the shale is exposed. The cleavage usually is at a high angle to the bedding, and as it appears to be developed best in those parts of the formation where the layers are of different colors, "ribbons" are very common on the cleavage surfaces. (See pl. 6, *A*.) These ribbons consist of alternating green and blue bands from one-fourth of an inch to 2 inches thick and are due to original differences in the color of the shale from which the slate was formed. In places the slate is sufficiently indurated for temporary roofing, but generally it is too soft to withstand the weathering agencies long. It is also, in all places where observed, so closely jointed as to prevent the quarrying of blocks of commercial size, and its banded or "ribbon" structure would render it undesirable for commercial slate, even though it possessed all the other requisite qualities.

POLK CREEK SHALE

The Polk Creek shale in most places is only about 100 feet thick, and owing to this fact and to the folding in the rocks of the region it crops out as narrow belts, most of which run along the bases of the mountains. This formation, like the Mazarn and Womble shales, is commonly a shale, but locally slaty cleavage is well developed in it. In places this slate is banded, but elsewhere it is of a uniform black color, is hard, has a metallic ring, and contains large numbers of graptolite fossils. Jointing is very common in both the shale and the slate. On account of the comparatively small part of this formation in which slaty cleavage is well developed and the abundance of the joints it does not give much promise as a producer of commercial slate; there may, however, be places from which such slate could be obtained.

MISSOURI MOUNTAIN SLATE

The Missouri Mountain slate is widespread over the quadrangles and crops out in many places near the bases of the mountains, though it is found also high on some of the slopes, or even in notches on the crests of the ridges. Though it does not enter into the minute folding of the region, like the Polk Creek shale, it partakes of the principal folding.

This slate has been rather extensively prospected all the way from Board Camp Creek, in the De Queen quadrangle, eastward across the Caddo Gap quadrangle and to Ouachita River beyond. It has been most extensively worked at Slatington, in the Caddo Gap quadrangle, but there are other prospects of considerable magnitude. It has been so widely prospected not only on account of its promising character as a source of commercial slate but also because of the favorable location and nature of its outcrops, most of which are in bluffs or well up on the mountain slopes. As the slate is exposed in the face of the bluffs, no labor or expense for removing surface material is imposed upon the prospector; and the height of the outcrop on the slope permits all waste material to be dumped easily. It ranges in thickness from about 300 feet to 50 feet or less, the thickest portion running along the northern edge of the quadrangles. In some of the closely compressed anticlines it is folded over upon itself, and its thickness appears to be double the real thickness. There is such a fold in the part of Caddo Mountain that is south of Wagner Creek, in sec. 15, T. 4 S., R. 26 W., where the slate is exposed for 600 feet and lies between heavy walls of the Arkansas novaculite.

The formation produces buff, red, and green slate. Though all these colors may and commonly do occur in the same quarry, the red is predominant. It is a clay slate of remarkable homogeneity, sandy or other impure layers being absent. In shade it ranges from scarlet to dark red, but that of any particular quarry is likely to be uniform. On exposed surfaces it presents a rich, pleasing appearance. On account of its homogeneous nature no traces of the original bedding are to be seen. This fact, together with its great thickness, make it impracticable in most places to determine the direction of the cleavage with reference to the bedding planes. In some places where it is near the overlying Arkansas novaculite the cleavage is plainly parallel with the bedding, but it is probable that the cleavage is usually oblique to the bedding.

In most parts of the formation this slate is intersected by joints that run in all directions, but in favorable places these are not so numerous as to prevent the quarrying of large blocks. The slate cleaves with fairly even surfaces and can readily be split into sheets a quarter of an inch thick and less. Some parts have a semimetallic ring, but most of it produces a dull sound when struck. In many places the intense folding of the region has produced short, wave-like wrinkles in the slate, which quarrymen call "curl" and which are avoided in prospecting. Any quarry that shows a considerable amount of "curl" may as well be abandoned. In other parts two sets of cleavage planes are locally developed. These may be detected by the splitting up of the exposed surfaces into small prisms shaped like shoe pegs. Such exposures as this should be avoided by the prospector.

Sheets of a considerable size are seldom found on the slopes, and hence it appears that this slate weathers readily. If this inference is correct, the slate could not be used for roofing. It is hoped, however, that this statement will not prevent anyone from experimenting with it by putting it into actual use for roofing, as this alone can determine its fitness for this purpose. In the only instance that has come to the writer's attention in which shingles of this slate were used for roofing, they went to pieces after a few years' service. But the result of this one trial should not be taken as final, for slate from another quarry might last many years. The best way to test it is for the people of the slate area to use it on small and temporary buildings. Such a test should be made of the slate of every quarry that will produce shingles, for if any of this slate should be discovered with lasting qualities its beautiful color would at once put it in great demand, especially for buildings with gray walls or trimmings.

At present slate is in demand for inside fittings, such as laundry tubs, wainscoting, lavatories, switchboards, and floor tile. This slate is too soft for flooring but is well adapted for all the other purposes, especially for switchboards, for which practically all the product of the quarries at Slatington has been used. Several samples of this slate have been tested for conductivity. The results of the tests are given in United States Geological Survey Bulletin 430, pages 329–330, 1910, and "The slates of Arkansas" (Arkansas Geological Survey), pages 59–62, 1909.

Because of its softness and homogeneity, this is in all ways a desirable slate to work. It splits, saws, and planes easily and soon takes a polish on the rubbing bed, but in drying after it has been polished, it is liable to check, and the number of pieces thus lost greatly reduces the profit of working it. The checking is sometimes at right angles to the cleavage and sometimes parallel with it—that is to say, the worked pieces may either crack perpendicularly to their faces or they may split apart. If some method of working can be devised that will avoid this checking, the slate industry of Arkansas will become important and profitable.

Red and green varieties of this slate have been quarried half a mile south of the village of Caddo Gap, and have been ground for use in the manufacture of asphalt roofing.

STANLEY SHALE

Shale at the base of the Stanley has been altered to slate in some parts of the closely folded synclines in the mountainous districts in the northeast corner of the De Queen quadrangle and the northwest corner of the Caddo Gap quadrangle. To much of this slaty phase of the Stanley, particularly the basal 150 feet or less, the name "Fork Mountain slate" has been applied in the above-mentioned reports. This slate lies normally above the Arkansas novaculite, but in many places, owing to overturning, it lies beneath that formation on the mountain slopes. If on one side of a valley or a ridge it lies above the novaculite, on the opposite side it is most likely to lie below the novaculite. Where the slate dips into the mountain it can easily be detected, for in these places it forms bluffs; but where it dips with the mountain slope it may be overlooked.

This is a hard slate, usually gray, but portions are black, and on weathered surfaces it is green or chocolate-colored. Thin sandy or quartzitic layers are numerous. The cleavage usually is well developed and occurs at all angles to the bedding planes. "Ribbons" not uncommonly occur in the gray portion. Some of the slate has great strength and toughness and is highly sonorous, but much of it is so soft that it does not give much promise of producing commercial slate. In most places jointing is so common as to render the slate worthless, but it must not yet be concluded that exploiting will find all of it so. Prospectors should not neglect this slate. Though it certainly never would do for milling, if found sufficiently free from joints and sandy seams it would make shingles of exceptional quality.

ASPHALT DEPOSITS

GENERAL FEATURES

The asphalt impregnates nearly horizontal beds of loose sand in the basal part of the Dierks limestone lentil or still lower in the Trinity formation. The deposits thus consist of asphaltic sand except at one place where the asphalt impregnates the Pike gravel member at the base of the formation. The layers containing the asphalt range from an inch to 12 feet in thickness.

LOCAL DETAILS

PIKE

A deposit of asphaltic sand occurs on the west side of the Pike-Delight highway, about 2½ miles south-southeast of Pike, in the Caddo Gap quadrangle. It was worked from 1903 to 1906, inclusive, by the Arkansas Asphalt Co., and yielded 4,815 tons of asphaltic sand, valued at $22,368. A tram road about half a mile long conveyed the sand to the St. Louis, Iron Mountain & Southern Railway (now the Missouri Pacific Railroad), whence it was shipped to Little Rock for use in paving streets. The old open cut out of which the sand was mined is 100 feet wide, 200 feet long, and 15 feet deep, and is in a depression which is drained eastward into Wolf Creek. The hills to the west and south show exposures of the Dierks limestone, but the beds in the cut consist chiefly of coarse sand, in some places rather calcareous, with beds of clay in the bottom of the cut. The sand is much cross-bedded and is incoherent except where charged with asphalt. The most productive part seems to have been at the north end, where some 4 feet of the base is asphaltic. The asphalt is not confined to any definite layer, the upper limit of it being very irregular. The only asphalt exposed in the south half of the cut in 1908 was 8 to 12 inches thick, but beneath it was clay with thin streaks of more or less asphaltic material.

Hayes,[95] who last visited the deposit in November, 1902, when the opening was new and not caved and not partly filled with water as at present described the deposit as follows:

> The deposit is in the form of a sand stratum, which varies in thickness from 6 to 12 feet, more or less thoroughly saturated with asphaltum. The deposit was discovered by the escape of small quantities of asphaltum to the surface in a spring, and this led to prospecting for its source. A pit was dug about 12 feet in depth, passing through the bed, and the thick, viscous asphalt has slowly oozed out into this pit for the last 30 years.
>
> The asphaltic rocks show considerable variation in character and in the amount of asphaltum which they contain. * * *
>
> By means of test borings the asphaltum bed has been proved to extend over a number of acres, under a cover sufficiently thin to permit profitable mining by stripping. * * *
>
> The utilization of this deposit is a technical matter which can not be entered upon here. Its chief value will doubtless be as a paving material. As stated above, some portions of the bed form a natural paving mixture, which hardens on exposure to the sun and, so far as could be judged, would be fully as durable as the ordinary artificial mixtures made from Trinidad asphalt. Other portions are too rich to be used in a natural state. Tests of these portions in the preparation of a paving mixture have been made by the St. Louis Testing & Sampling Works, with excellent results. * * *
>
> No experiments have yet been made in refining the asphaltic sand for the preparation of pure asphaltum, and this may be found to be more profitable than shipping the crude product.

DELIGHT

An asphalt deposit that was prospected in 1914 by the Grayson-McLeod Lumber Co. lies in the head of a hollow about 4 miles north-

[95] Hayes, C. W., Asphalt Deposits of Pike County, Ark.: U. S. Geol. Survey Bull. 213, pp. 253–254, 1903.

northwest of Delight, just east of the highway, in the Caddo Gap quadrangle. A number of pits and cuts have been made, but at the time of visit (June 29, 1916) they had caved somewhat and were partly filled with water so that the asphalt bed could not be seen. Asphalt was found on the dumps of several openings for a distance of 175 feet down the hollow and was presumably thrown out of them. The other openings from which no asphalt was taken appear not to have extended deep enough to reach the asphaltic bed, which occupies a nearly horizontal position. About 10 feet of coarse quartz sand is exposed above the water in the openings. Above this there is 20 to 25 feet of loose gravel extending to the crest of the ridge. Several feet of the gravel may have slipped down the slope and thereby concealed beds of sand higher than the sand exposed in the openings. The gravel is the basal bed of the Tokio formation, whose higher beds are exposed farther south near Delight but have here been removed through erosion. The sand belongs to the part of the Trinity formation that is above the Pike gravel member and below the Dierks limestone lentil. This limestone is exposed on Little Wolf Creek 2 miles farther south but is absent at the asphalt locality, as it is overlapped northward by the Tokio formation, at whose base there is, as previously stated, an unconformity.

The asphalt bed is said to range in thickness from 3 to 5 feet. Clay below the asphalt is said to contain seams of oil.

The asphalt on the dumps softens and flows in the sunshine, becomes plastic under the stroke of a hammer, is pliable in the hands, and adheres to the fingers. It contains quartz sand and a few nodules of iron pyrites. An analysis supplied by the Grayson-McLeod Lumber Co. shows the asphaltic sand to contain 17.21 per cent of the asphaltum and 82.80 per cent of white sand. Only sample lots have been shipped.

MURFREESBORO

A viscous asphalt impregnating a few inches or more of the Pike gravel member of the Trinity formation is exposed at the water's edge on the east side of Prairie Creek about 1 mile northeast of Murfreesboro in the Caddo Gap quadrangle. The thickness and extent of the deposit are not known.

Asphalt several feet thick is said to have been found in digging a well on the Irving farm, in sec. 1, T. 8 S., R. 25 W., 5 miles east of Murfreesboro. It affected the water to such an extent that the well has since been converted into a cistern.

LEBANON

Asphaltic sand is exposed by the roadside on a low hill adjoining the Saline River bottom half a mile southeast of Lebanon, in the

De Queen quadrangle. It occurs in lenticular layers, the thickest of which is only a foot thick. It is much weathered in the exposures, being dark brown and falling to a powder when struck with a hammer, but it becomes viscous when heated with a match. The asphalt impregnates sand which is below the Dierks limestone exposed to the southwest south of Woolsey School and which, as shown in the following section at this locality, overlies the Pike gravel:

Partial section of Trinity formation half a mile southeast of Lebanon

	Feet
Yellow sand partly concealed by surficial gravel extends to the top of the hill. A 2 or 3-inch layer of asphaltic sand is 3 or 4 feet above the base of this bed of sand	12–25
Yellow sand, lenticular layers of which are impregnated with asphalt. The thickest layer is 12 inches thick	2–3
Gray and yellow sand, some of which is indurated	5
Gravel with pebbly sand in its upper part. The exposure extends down to the edge of the second bottom of Saline River (Pike gravel)	16

Asphaltic sand is exposed in a gully by the roadside at the foot of a hill about 2½ miles west-southwest of Lebanon, apparently in the southeast corner of sec. 1, T. 8 S., R. 30 W. This sand is much weathered, being brown and friable, and is in two layers each 1 inch thick, which are separated by a few inches of sand and are overlain and underlain by sand. The sand containing the asphalt appears to be between the Pike gravel and the Dierks limestone.

Sand impregnated with asphalt is exposed on the south side of the road half a mile east of Sardis School and 4 miles west-southwest of Lebanon. The asphalt here also is much weathered and is brown and friable. The following section was measured up the hill southwest of the deposit:

Section 4 miles west-southwest of Lebanon

	Feet
Terrace deposits: Gravel and cobbles occupying crest of hill. The thickness of the gravel bed is less than 35 feet, for the gravel has probably slipped down the slope, thus concealing beds of the Trinity formation	35
Trinity formation:	
Dierks limestone lentil—	
Red and yellow clay containing some pieces of limestone	12
Platy limestone containing fossil oyster shells	4–5
Gray compact sand	6
Sand impregnated with asphalt, a few inches.	
Gray compact sand	1½

Asphaltic sand is revealed in a shallow pit by a road leading up the hill just northwest of Moody Shoal Ford, on Cossatot River 6½ miles west-southwest of Lebanon. The following section was measured here:

Section west of Moody Shoal Ford, 6½ miles southwest of Lebanon

	Feet
Terrace deposits: Gravel and cobbles. The thickness is probably less than 55 feet, as some of the gravel and cobbles have doubtless slipped down the slope and thus conceal beds of the Trinity formation	55
Trinity formation:	
Dierks limestone lentil—	
Red clay	2
Limestone containing fossil oyster shells	1
Clay	5
Asphaltic sand. A limestone layer 1½ inches thick was found in the base	2½
Red clay	10

VALUE OF DEPOSITS

The asphalt deposit near Pike is the only one from which asphalt has been shipped in commercial quantity. The asphaltic sand mined at that locality from 1903 to 1906 by the Arkansas Asphalt Co. is said to have amounted to 4,815 tons, valued at $22,368. It was used in Little Rock in paving West Markham Street from Main to Cross Street, a distance of 12 blocks, and in paving part of Center Street. A 2-inch surface of the asphalt was laid upon a 5-inch concrete base, which rested upon clay. Owing to improper preparation of the asphalt the paving was not entirely satisfactory.

The asphalt deposit near Delight is thin, the reported thickness being 3 to 6 feet. If the deposit is later proved to maintain that thickness under a considerable area, it might be profitably worked, but the overburden is so thick, 30 to 35 feet or more, that underground mining would probably be necessary. The asphalt exposed at the other localities is not thick enough to be mined and probably is no thicker away from the outcrops.

ORIGIN OF THE ASPHALT AND POSSIBILITY OF OIL AND GAS IN THE QUADRANGLES

The Trinity formation contains petroleum and asphalt at many places in northern Texas and southeastern Oklahoma. The asphalt in these two States and in Arkansas, as in other regions, is doubtless a residue of crude petroleum, whose lighter and more volatile parts have escaped by evaporation. The petroleum yielding the asphalt in Arkansas may have originated in the basal part of the Trinity formation, which contains some fossiliferous limestone.

On the assumption that the petroleum yielding the asphalt herein described originated in the Trinity the petroleum has probably migrated northward. The Cretaceous rocks in southwestern Arkansas have a southward dip of about 100 feet to the mile and, although they have been slightly warped, no pronounced anticlines or synclines occur in these rocks in the quadrangles under discussion. Thus, if petroleum occurs in the region south of the asphalt deposits, its accumulation into quantities of possible commercial importance would probably be controlled by terrace structure, lenticular character of sands, or irregularities in the Cretaceous floor.

The peridotite masses near Murfreesboro may have lifted the Trinity so as to produce structure favorable for the accumulation of oil about them, just as volcanic necks or plugs have done in Mexico and probably in Texas, but such phenomena have not been observed around the peridotite masses.

There is no possibility that either oil in commercial quantities or gas in large pools will be found in the Ouachita Mountain region of west-central Arkansas or in most of this region in Oklahoma. The Carboniferous and older rocks have been so highly tilted and so much fractured and metamorphosed that if oil or gas were ever present in them the gas and much of the oil would have made their escape to the surface and the remainder of the oil would have been distilled to asphalt.

DRILLING FOR OIL

The presence of asphalt in the southern parts of these quadrangles has from time to time attracted the attention of those interested in oil development. Land has been leased at different times, and a few wells have been sunk with the hope of finding oil. Thus far oil has not been discovered in commercial quantity.

TRIPOLI

Tripoli deposits were examined at four localities during the field work for this report. The tripoli at two of the localities is a weathered phase of the upper division of the Arkansas novaculite, that at the third represents a similar phase of the lower division of the novaculite, and that at the fourth is in the Bigfork chert. The deposits have apparently been formed not merely through the removal by solution of the small quantity of calcium carbonate that was originally present in these rocks but through a recrystallization of the silica. Other occurrences of tripoli may be expected in the Arkansas novaculite, especially in its upper division, which is exposed in many narrow, nearly eastward-trending belts in the northern parts of the quadrangles.

Three of the deposits have been prospected, and two of them have furnished a small quantity of tripoli, which has been sold. The available quantity is great at some places, and the quality appears to be good. If there should be an increased demand for tripoli in the future some of the deposits may then be worked on an extensive scale.

One deposit is at the south base of the easternmost of the three mountains in this area called Fodderstack Mountain, 7 miles west of the village of Caddo Gap. It appears to be in and near the top of the lower division of the Arkansas novaculite, which at this locality is nearly horizontal and lies near the axis of a syncline. The deposit at the time of visit (1916) was exposed in two cuts. The longer one, 50 feet long, is on the north edge of the bed of a dry branch which flows east along the base of the mountain, and the cut extends into the mountain about 10 feet. The following section of the Arkansas novaculite was measured in it:

Section of rocks in cut at south base of Fodderstack Mountain

	Ft.	in.
Face of débris, above which the mountain slopes 30° toward the south	5	
Hard, white, much jointed novaculite	4	
Pure white tripoli; not iron stained except along a few of the joints	2	
White tripoli containing in places a large quantity of hard. white novaculite; the bed is much shattered and shows iron oxide along the joints and some disseminated through the tripoli. This bed may be freer of iron oxide farther back into the mountain	1	2
Plastic yellow clay		2½
Hard, white novaculite		3
Pure white tripoli	1	
Pure white tripoli containing hard pieces of novaculite		3
Concealed to bed of dry branch	2	

The other cut at the base of Fodderstack Mountain is 60 feet west of the cut above described and is on the north side of the dry branch. Here a thickness of 6 feet of shattered, altered novaculite is exposed. Although most of the novaculite is hard, it has softened to tripoli in several layers a few inches thick. The tripoli is yellow from iron oxide, but it may become whiter with depth from the surface.

To mine more than a very small quantity of tripoli at this locality would require underground mining, because of the nearly horizontal position of the tripoli beds and of the steepness of the mountain slope; but the thickness and extent of the deposit as shown in the cuts probably would not justify opening a mine. Further prospecting, however, may prove the presence of a deposit large enough to be worked at a profit. Much of the tripoli in the larger cut is firm and would require grinding to reduce it to a powder. Some of it might be suitable for filter stones, but it would probably yield only small filter stones, as it is much jointed. It is suitable for polishing powders. After it is ground it passes through a sieve of 150 meshes to the inch. It consists of sharp quartz grains from 0.01 to less than

0.001 millimeter in diameter; most of the grains are 0.005 millimeter or less. A few hundred pounds of this tripoli has been shipped for use as polishing powder.

A similar tripoli deposit, apparently near this locality, is described by Griswold,[96] who gives the following analysis of the tripoli described by him:

Analysis of tripoli from Fodderstack Mountain

[Material dried at 110°–115° C. Analysis by Arkansas Geol. Survey]

Silica (SiO_2)	97.32
Alumina (Al_2O_3)	1.61
Ferric oxide (Fe_2O_3)	.35
Lime (CaO)	Trace.
Magnesia (MgO)	Slight trace.
Potash (K_2O)	.13
Soda (Na_2O)	.12
Loss on ignition	.63
	100.16
Water at 110°–115°C	.029

A deposit of tripoli in the Bigfork chert is exposed in a small cut at the south base of a low hill half a mile southwest of the village of Caddo Gap. The Bigfork chert at this locality is closely crumpled and much shattered and in parts has altered to tripoli. Some tripoli is mixed with broken fragments of chert in most parts of the exposure. The largest mass of tripoli free of chert fragments is 5½ feet wide and several feet high, but the exposure is not sufficient to show the horizontal extent. Fully half of the tripoli is stained yellow with iron oxide; the rest is white. It is composed of angular quartz grains 0.05 to less than 0.001 millimeter in diameter, few exceeding 0.005 millimeter. As the tripoli readily slacks in water and is slightly plastic, it probably contains a small percentage of clay. After it is subjected to slight grinding practically all passes through a sieve with 100 meshes to the inch and a large portion passes through a sieve with 150 meshes to the inch.

A deposit of tripoli occurs one-fourth mile east of Blocker Creek, in sec. 1, T. 5 S., R. 27 W., 2½ miles north-northeast of Langley, in the Caddo Gap quadrangle. It was worked in 1914 and 1915 by the W. C. Ross Manufacturing Co., of Little Rock, which shipped two carloads of the tripoli and stored a large quantity of it in a shed to dry before shipping. The workings consist of an east-west cut, with a face of 15 or 16 feet and length of 70 feet, on the north side of a westward flowing wet-weather branch. The rocks exposed in the top part of the cut consist of a bed of pebbles and cobbles of novaculite

[96] Griswold, L. S., Whetstones and the Novaculities of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, pp. 384–388, 1892.

that underlie a stream flat, and below this bed is the upper division of the Arkansas novaculite, which dips 10 feet toward the west in the length of the cut. The novaculite at this locality lies in a syncline that plunges or deepens toward the west. The following section was measured in the cut:

Section in cut in tripoli 2½ miles north-northeast of Langley

	Feet
Pebbles and cobbles of novaculite underlying narrow stream flat	3-5
Arkansas novaculite:	
Hard jointed novaculite interbedded with a less quantity of yellow tripoli. This bed thins out in the east end of the cut	0-4
Tripoli bed described below	8½
Thin layers of hard yellow novaculite interbedded with an equal quantity of yellow tripoli in thin layers	12

The 8½-foot bed of tripoli included in the above section has yielded the two carloads of tripoli that have been shipped and the tripoli that has been stored. Except for two layers, each 6 to 8 inches thick, of hard novaculite near the middle of the bed, it consists of even-textured tripoli about half of which is snow-white and the other half light cream-colored. The bed is cut by joints, which are most abundant at the east end of the cut. The tripoli in the shed ranges from particles as fine as flour to boulders as much as 18 inches in their longest dimension. Although the tripoli is tough it is easily reduced to a fine powder, consisting of angular quartz grains from 0.01 to 0.001 millimeter in diameter; the average size is about 0.005 millimeter. After it is slightly ground it passes through a sieve with 100 meshes to the inch, and about half of it passes through a sieve with 150 meshes to the inch. It is suitable for polishing powder, but the rock may not be tough enough for the manufacture of filter stones. The tripoli apparently underlies at least 2 acres north and west of the cut, where the overburden is thin enough for open-cut mining.

A deposit of tripoli is exposed in and near the wagon road at the east base of a hill in the southwestern part of the village of Bog Springs, in the De Queen quadrangle. The exposure reveals 20 feet of tripoli in the upper division of the Arkansas novaculite, and it does not show either the base or top of the tripoli. The tripoli is in beds from a few inches to 18 inches thick and is cut by joints 3 to 20 inches apart. Only one or two layers of hard novaculite were observed. The rest of the tripoli, though soft, is tough enough to receive the impressions of a hammer without breaking. Much of it, even at the surface, is white after the iron-stained portions along the joints are removed, but some of it is cream-colored, and one layer a few inches thick contains stains of manganiferous iron oxide. It consists of angular quartz grains which range from 0.02 to 0.001 millimeter in diameter, but most of which are about 0.005 millimeter in diameter. It is sufficiently hard and tough for shaping into filter blocks, though it has not been tested, so far as known. Crushing and grinding would be required to reduce the tripoli to a powder fine enough to pass through a sieve of 100 meshes to the inch.

LEAD AND ZINC DEPOSITS

GENERAL FEATURES

Two mines, the Bellah and Davis, have been worked from time to time in the De Queen quadrangle and have produced small quantities of lead and zinc ores, and a few prospects in this quadrangle have been opened in search of these ores. The ore deposits occupy fissure veins associated with quartz in steeply dipping sandstone and shale of Carboniferous age, and there is evidence of faulting along some of the veins. The ore minerals are sphalerite and galena, and the associated minerals besides quartz are chalcopyrite, pyrite, siderite, calcite, azurite, and malachite, the last two occurring only near the surface. The occurrence of the ores in faulted fissure veins combined with their nearness to the antimony deposits near Gillham, which in origin are probably related to igneous rocks, suggests that the lead and zinc ores were also similarly related.

Some of the lead and zinc deposits in the De Queen quadrangle can probably be worked spasmodically in the future, just as they have been in the past, but the known deposits are comparatively small and hence are not capable of a large production of ores.

BELLAH MINE

The Bellah mine is in secs. 27 and 28, T. 7 S., R. 32 W., about 6 miles southwest of Gillham, in the northwest corner of Sevier County. It was idle and was filled with water at the time of the field examination by the authors, and the description of it given herewith is abstracted largely from the report by Bain,[97] who visited the mine many years ago, and from field notes by D. F. Hewett, who entered the mine in 1912.

The mine was worked during the Civil War by the Confederate government for lead, but since then it has been operated at times as a zinc mine. The slag and furnace remains indicate that work at that early date was carried on for some time. The owners of the mine in 1912 were Tyler & Hippach, and the lessees were Sober, Williford & Lynn, who reopened the mine and operated it for several months before the fall of 1912.

[97] Bain, H. F., Preliminary Report on the Lead and Zinc Deposits of the Ozark Region: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, p. 133, 1901.

The workings consist of a shaft 165 feet deep with drifts to the east at depths of 44, 115, and 165 feet; an air shaft 44 feet deep; and a third shaft 115 feet deep. When the mine is idle water stands at the 115-foot level. The shafts and a few pits have been made at places along the length of the ore body for a distance of about 1,000 feet.

The country rock is the Stanley shale, and the part of the formation occurring in the vicinity of the mine is a bluish-black clay shale. The ore body occurs in a zone with a maximum width of 8 feet, in which there are irregular fractures filled with quartz. The zone strikes N. 80° E. and is practically vertical at the surface, but at moderate depth it dips 60°–70° N. The hanging wall of the zone is well defined, as it is marked by a clay selvage. It has striations with a dip of 15° E., showing that there has been faulting with both a vertical and a horizontal component. White massive quartz, which constitutes much of the zone, carries abundant sharp-angled pieces of the country rock, but some of the quartz occurs in small crystals lining the vugs and druses in the vein and in streaks and bands running through the zone. It is arranged with the ore in ribbon structure, though there is no uniform sequence for the deposit as a whole. The metallic minerals that are associated with the quartz are sphalerite, galena, chalcopyrite, and pyrite. Galena was the most abundant ore above the 44-foot level, but at present at and below the 115-foot level sphalerite of a rosin-yellow color is the most abundant. With it are minor quantities of galena and chalcopyrite, and negligible quantities of pyrite. Some of the chalcopyrite has yielded a little azurite and malachite, especially near the surface. Associated with the quartz is a small quantity of siderite. The exact order of deposition of all the minerals is not known, but to judge from material on the dump the sphalerite, chalcopyrite, galena, and pyrite followed at least most of the quartz and siderite.

The ore-bearing zone has been partly stoped east of the 165-foot shaft above the 44-foot level. It has also been stoped for a distance of 60 to 80 feet from this shaft above the 115-foot level, though no connection has been made with the 44-foot level. The workings on the 115-foot level extend from this shaft a distance of 200 feet.

The ore that has been milled is said to have yielded 21 per cent of zinc sulphide, and the ore sold is said to have contained 60 per cent or more of metallic zinc.

DAVIS MINE

The Davis mine is in the NW. ¼ sec. 10, T. 7 S., R. 32 W., 4 miles west-southwest of Mineral, on the Kansas City Southern Railway, in the northwest corner of Sevier County. It is reported that Julius Folsom, a Choctaw chief, opened the mine in 1842, and that a zinc smelter was erected at the mine in 1875 or 1876. Sam Davis worked the mine in the eighties and sold it about 1900 to the Southern Zinc Copper Mining Co. This company, which operated the mine for six years ending in 1906, produced both lead and zinc ores, which were hauled to Mineral for shipment. During the period of greatest production the shipments averaged one carload of ore every week. In 1911 and 1912 the mine was worked by Karl Shuey, who shipped 15 or 16 carloads of ore, half of it sphalerite and the other half galena. The mine was next worked by A. V. Oliver, beginning in March, 1916, and then by the Boston & Arkansas Mining Co., of Okmulgee, Okla.

The workings at the time of visit (1916) consisted of four shafts from which several drifts had been run. The deepest shaft is said to have been 204 feet deep.

The rocks at this locality are black shale and hard gray sandstone, which are a part of the formation known as the Stanley shale. They dip 50° or more to the north, and they have been cut by two or more faults, as is indicated by the presence of smooth slickensided planes with steep dips. The fault farthest south dips about 60° N. and strikes N. 85° E. The shale and sandstone above this fault are much fractured and crumpled and contain quartz veins through a zone as much as 40 feet wide.

The quartz veins in this zone, especially those adjacent to the footwall, carry sphalerite, galena, chalcopyrite, and calcite, the most abundant named first. In addition there are small quantities of azurite and malachite near the surface, and small quantities of calamine were reported to be present at some places. The sphalerite, galena, and chalcopyrite are more or less intermixed; they occur as single crystals and aggregates of crystals disseminated through the quartz veins and as solid veins, some of which cut through quartzite without quartz. Assays of specimens of these minerals that have been made by the Arkansas Geological Survey showed the presence of a trace of gold and from 17.5 to 31 ounces of silver to the ton.[98]

The workings at the time of visit appeared to show that the deposit has a length of at least 300 feet, a width of as much as 30 to 40 feet, and a depth of 204 feet, which is said to be the depth of the deepest shaft.

PROSPECTS

The Copper King prospect is in the W. ½ sec. 8, T. 7 S., R. 32 W., 2 miles west of the Davis mine and 6½ miles west of Gillham. Work was done at this locality many years ago, and so far as the authors are aware no ore from the mine was ever sold.

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[98] Comstock, T. B., Report upon Preliminary Examination of the Geology of Western Central Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, pp. 233, 252, 1888.

The openings include an east-west cut on the right bank of Robinson Creek, having a length of 36 feet and a face of 12 to 15 feet, an inclined shaft 12 to 14 feet deep at the west end of the cut, two shallow pits east of the cut, and a short north-south cut and an incline which are 150 feet west of the east-west cut, on the hill slope 75 feet above the creek.

The rocks penetrated by the openings are a hard gray sandstone that has a dip of 45° or more toward the north and strikes N. 80° W. Some beds of the sandstone have been much fractured and contain many quartz veins, most of which are less than 1 inch wide, though a quartz vein 3 feet wide was seen at one place. Quartz is the only mineral that was seen in place, but a few small specimens of it containing calcite, chalcopyrite, azurite, and malachite were found on the dump.

The Buzbee prospect is near the center of sec. 13, T. 7 S., R. 29 W., about 2½ miles northwest of Dierks. Work has been carried on here from time to time, beginning in 1850, but no ore is known to have been sold. The country rock is the Jackfork sandstone, which dips 65° N. 20° W. The deepest of the three shafts is a little more than 80 feet deep and was driven down in a 5-foot bed of brecciated sandstone whose fragments are cemented together with quartz. A second shaft was sunk into a bed of shale 3½ feet thick. The third shaft was not visited by the authors. A small pile of rock lying near the first shaft and apparently taken from it shows a small quantity of sphalerite of a rosin-yellow color, with still smaller quantities of galena and chalcopyrite.

The New Discovery shaft is in the SE. ¼ sec. 6, T. 7 S., R. 30 W., about 5 miles east and a little north of Gillham, in the vicinity of the antimony mines. The shaft, which is said to be between 100 and 125 feet deep, was sunk in 1902. None of the geologists who have visited the region have entered this shaft, and the vein is not visible at the surface. To judge from a small amount of ore in the bin it is a brecciated sandstone which is cemented with small veins containing sphalerite, galena, quartz, and siderite. There are also small amounts of pyrites, which may be copper bearing. Only one piece showing stibnite was found, and that it came from this shaft is not certain. The ore bears little resemblance to that from the antimony-bearing veins, and the amount of quartz is very much less. It is said that no ore has been shipped from this property.

There is a lead-zinc prospect three-quarters of a mile northeast of Vandervoort, on the Kansas City Southern Railway, in the southern part of Polk County. A shaft was sunk here about 35 years ago, and another was sunk in 1916, 20 feet east of the old shaft. The old shaft had caved before the time of visit (July, 1916), and the new shaft was then filled with water. The rocks penetrated by the shafts are shale and sandstone, which are a part of the Stanley shale. The fragments of these rocks on the dumps contain veins of quartz and calcite as much as several inches wide. A small quantity of galena and sphalerite was found associated with these vein minerals.

MANGANESE ORE

Only the general geologic and economic relations of the manganese deposits will be discussed here, for detailed descriptions of them have been given in another report by Mr. Miser.[99]

The manganese deposits occur in the mountainous parts of the quadrangles. They are found in the Arkansas novaculite and are mainly confined to two stratigraphic horizons, one in the upper division of the formation and the other near the top of the lower division. Some deposits, however, are found in other parts of the lower division. The Arkansas novaculite and other formations have been thrown into a series of folds whose trend is parallel with the ridges. This formation is very resistant; the upturned edges stand up as ridges on which rock ledges or their débris abound. The beds at the two ore horizons, which show ore at the surface in many places, may thus be followed for long distances along the slopes, and their outcrops, owing to the numerous folds, are repeated on the slopes or crests of the many parallel ridges, or even on a single ridge. The outcrops of these ore-bearing beds are sometimes called "lodes" or "leads."

The depth to which the ore extends is not known. An 8-foot vein of solid manganese ore is, however, reported to have been found in the lower tunnel at the North Mountain mine at a distance of about 615 feet from the portal. This tunnel is 250 feet above the road along the south base of North Mountain; it is 530 feet below the crest of the mountain and is 216 feet below the upper tunnel, which penetrates the exposed ore body near its main outcrops. At other places ore is found only in the present shallow workings. These workings and the outcrops of ore occur at all altitudes on the high ridges, from the level of the streams that cut through them up to their crests, which are even and probably represent a Cretaceous peneplain. The deposits that have been examined range from 900 to 1,800 feet above sea level, but the greatest difference in altitude in any single locality is about 800 feet. This range does not necessarily mean that a shaft sunk from the crest of a mountain would find ore at a depth of 800 feet or that a tunnel driven into the base of a mountain 800 feet below its crest would find ore, for the lower limit of the

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[99] Miser, H. D., Manganese Deposits of the Caddo Gap and De Queen Quadrangles, Arkansas: U. S. Geol. Survey Bull. 660, pp. 59–122, 1917.

ore, which may not extend much below water level, may be higher in the mountains than in the valleys, just as the water level is higher in the mountains than in the valleys.

The manganese ores occur as nodules, pockets, and short irregular veins from a fraction of an inch to 4 feet thick. Thicknesses of 4 feet, however, are rare, and those of 1 foot are not common. The ore bodies are scattered through the hard novaculite and can doubtless be found on every mountain where the Arkansas novaculite is exposed. The ores occupy bedding planes or joint cracks or form a cement in a novaculite breccia, in which the rock fragments range from a fraction of an inch to over a foot in diameter. Iron and manganese ores may be intimately mixed in the same pocket or vein, they may occur separately in different parts of the same vein, or they may occur in separate masses.

The manganese ores consist of oxides, four of which, psilomelane, pyrolusite, manganite, and wad, have been identified; if others are present, they probably occur in minute quantities. Although these minerals may be found separately, as a rule two or more are intimately mixed in the same deposit, and in some places they are associated with iron ores and manganiferous iron ores. Psilomelane, pyrolusite, and manganite form the larger part of the manganese ore in this region. A material consisting of rock fragments and clay cemented together by soft manganese oxide is present at a number of places; locally it is known as "bog ore." The iron ores comprise various hydrous sesquioxides, of which limonite is probably the most common. The most abundant material with which the iron and manganese ores are associated is clay, some of which has been brought in by ground water and some of which is residual and probably in place.

The mode of occurrence of the manganese ores in the Arkansas novaculite suggests that their origin and that of the novaculite are intimately associated. The novaculite is regarded by the writers and some others as having been deposited through chemical or organic processes, or both, and thus belonging to the class of cherts. The manganese was probably deposited as a manganese-bearing calcite at the two main ore horizons, but some of it was doubtless deposited as a carbonate in other parts of the novaculite and in the overlying and underlying shales.

The concentration of the ores has been effected by ground water, which has carried down their constituents from the vast mass of rock that has been eroded from the region. The local concentration of the ores into deposits large enough to be of value appears to have been dependent upon the amount of open space in the Arkansas novaculite, which is hard and compact and usually has no visible openings between the layers or along the joints. The places where fissures are largest and most numerous would be most favorable for the circulation of underground water and consequently for the deposition of the ore, little of which replaces the novaculite. The fissures were formed during the folding, faulting, and fracturing of the novaculite late in the Carboniferous period. The ores would be expected to occur in those places where the novaculite has undergone much fracturing and close folding, as on and near faults and at the noses or ends of plunging anticlines. A number of such places where deposits occur have been observed. It is noteworthy that many cold springs and even the hot springs at Hot Springs, Ark., issue on the noses of plunging anticlines, showing that such places are especially favorable for the circulation of ground water.

The following are analyses of manganese and manganiferous iron ores from these quadrangles:

Analyses of manganese and manganiferous iron ores from the Caddo Gap and De Queen quadrangles, Ark.

	1	2	3	4	5	6	7	8	9
Manganese (Mn)	60.28	58.36	55.80	51.54	48.65	48.34	40.51	27.68	26.20
Iron (Fe)	--------	--------	.50	--------	2.03	--------	25.53	35.39	16.83
Silica (SiO_2)	--------	9.02	3.72	--------	11.86	--------	.80	1.88	29.00
Phosphorus (P)	.413	--------	.038	.167	.308	.449	.767	.230	.343

	10	11	12	13	14	15	16	17
Manganese (Mn)	22.84	11.93	2.06	30.93	48.02	56.66	49.24	52.16
Iron (Fe)	--------	22.26	50.38	9.21	5.55	.18	2.04	4.00
Silica (SiO_2)	.42	44.40	--------	5.86	.52	.15	2.98	.24
Phosphorus (P)	.047	.576	1.450	.320	.310	Trace.	.380	.390
Manganese dioxide (MnO_2)	--------	--------	--------	42.09	71.73	82.10	71.41	77.60

	18	19	20	21	22	23	24	25
Manganese (Mn)	42.75	59.55	25.99	30.95	16.45	23.96	60.54	43.52
Iron (Fe)	2.72	.74	10.75	12.80	5.11	7.45	--------	6.72
Silica (SiO_2)	10.46	.52	5.21	6.20	17.16	25.00	8.30	[a] 5.17
Phosphorus (P)	.450	None.	.387	.461	.181	.264	.22	.35
Manganese dioxide (MnO_2)	62.75	90.52	--------	--------	--------	--------	--------	([b])
Alumina (Al_2O_3)	--------	--------	8.44	10.04	8.62	12.55	--------	4.80
Lime (CaO)	--------	--------	.04	.05	.04	.06	--------	1.42
Magnesia (MgO)	--------	--------	.04	.05	.04	.06	--------	Trace.
Sulphur (S)	--------	--------	.024	.029	.028	.041	--------	.02
Moisture	--------	--------	16.04	--------	31.35	--------	--------	--------

[a] Silica and insoluble in HCl. [b] Oxidizing power equal to 64.60 per cent MnO_2.

Analyses 1 to 12 from Age of Steel, vol. 62, p. 9, Sept. 3, 1887; 13 to 19 from Penrose, R. A. F., jr., Manganese—Its Uses, Ores, and Deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, p. 319, 1891; 20 to 23 furnished by Mississippi Valley Iron Co.; 24 furnished by Dierks Lumber & Coal Co. Analysts: 1, 4, 6, 12, Regis Chauvenet & Bro.; 2, 3, 5, 7–11, St. Louis Sampling & Testing Works; 13–19, R. N. Brackett; 24, Kansas City Testing Laboratory; 25, George Steiger.

1–12. Polk County, locality unspecified.
13. Line Mountain, Pike County.
14. Fancy Hill Mountain [W. R. Porter prospect], Montgomery County.
15. North Mountain [mine], Montgomery County.
16. McKinley Mountain, Polk County.
17. Tall Peak Mountain, Polk County.
18. Manganese Mountain, Polk County.
19. Cossatot Mountain, Polk County.
20–23. Still mine, Pike County. 20, One car, natural; 21, same, dry; 22, another car, natural; 23, same, dry.
24. Dierks Lumber & Coal Co.'s prospect, Montgomery County.
25. Composite sample from 39 localities in Pike, Polk, and Montgomery Counties.

The possibilities of manganese mining in west-central Arkansas are ably discussed by Penrose,[1] from whom the following is quoted:

The aggregate amount of manganese in the region is undoubtedly large, but it is distributed over an extensive area, and in almost all places it is hopelessly scattered through the rock in small nests and seams. If these nests and seams were in sufficient quantities the rock might be crushed and the ore concentrated by washing, but the pockets containing them are too small to permit the expense of machinery. It is a popular idea that the ore will increase in quantity at a depth, but there is absolutely no reason to expect this, as such deposits are just as likely and sometimes even more likely to become poorer at a depth than they are to improve.

From the nature of the deposit it is to be expected that the ore at a depth is, at the very best, no more plentiful than in the surface outcrops of the so-called "lodes"—that is, that it exists as a series of pockets separated by greater or less distances of barren rock. With very few exceptions the pockets of ore seen on the surface can not be worked at a profit, and in the rare cases where a small profit might be made the amount would not be enough to pay for sinking through the barren rock that separates the pockets from each other. The intervening thickness of barren rock is much greater than the depth of any one pocket.

The quantity of manganese ore that can be mined at a profit from any one deposit is therefore small, which means that under normal conditions manganese mining will never become one of the chief industries in this region.

The manganese deposits have been worked only in a very small way and so far have yielded not more than a few hundred tons of ore that has been sold. Most of the work has been done during two periods of activity, one beginning about 1885 and ending in 1889, and the other beginning in 1915 and still in progress. The geologic map (pl. 3) shows the location of many of the prospects and mines.

IRON ORE

Iron oxides, of which the most common is probably limonite, are found in many parts of the quadrangles, but the deposits that are largest and that have at times attracted the attention of prospectors occur in the Arkansas novaculite in the mountainous areas. Most of the deposits are confined to the upper division of the formation and the upper part of the lower division. They occur as pockets, seams, or veins along the bedding and along joints, and in places they cement together fragments of brecciated novaculite. They have been concentrated by descending ground water, and their source is probably pyrite, which occurs as small crystals disseminated through the unweathered novaculite. In some places the iron ores are free of manganese, but in others there are all gradations from

[1] Penrose, R. A. F., jr., Manganese—Its Uses, Ores, and Deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, p. 306, 1891.

an iron ore with a little manganese to a manganese ore with a little iron.

The iron ores are usually too low in iron and too high in silica to be of commercial value, and where the quality is above the average the quantity of the ore is too small to permit profitable mining. Some of the ores contain too much phosphorus to command a high price. Moreover, the ores are associated with hard rocks, which stand vertical or almost vertical.

Further information on these deposits may be obtained by referring to Penrose's report,[2] from which much of the foregoing statement is abstracted.

QUARTZ CRYSTALS

Quartz crystals have been found at a number of places in the Crystal Mountains, in the Caddo Gap quadrangle. They occur in beautiful clusters that line the walls of pockets and cracks along the bedding and joint planes of the Crystal Mountain standstone. Some of the crystals are milky, owing to small air cavities, but many are perfectly clear. (See pl. 17, *B*.) They have been mined on a small scale from time to time on the head of Collier Creek and at other places. The mining has been done by means of pits and short irregular tunnels. After the crystals are mined they are freed from clay and are washed with oxalic acid to remove any coatings of iron and manganese oxides that may be present. They are sold as specimens for private and public mineral collections, but some are cut and sold for jewelry, and some are used in optical instruments. Supplies of crystals are kept for sale at Hot Springs and Womble.

GYPSUM

The gypsum deposits of these quadrangles are found in the De Queen limestone member of the Trinity formation. The thickest exposure is in Plaster Bluff, 3 miles south-southwest of Murfreesboro, where the gypsum is confined to a single bed 55 feet above Little Missouri River and about as far below the top of the bluff. This bed is 10 to 14 feet thick and consists of pure saccharoidal gypsum, though there are some thin seams of satin spar and as much as 3 feet of interbedded clay in its lower part. The thickest layer of gypsum is at the top and is 4 feet thick. The deposit at this locality has been worked on a small scale, especially by the National Gypsum Co. in 1922 and 1923. The gypsum sold by this company was used in the manufacture of cement.

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[2] Penrose, R. A. F., jr., The Iron Deposits of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 1, 1892.

Toward the west as far as Messer Creek, on the west side of the Caddo Gap quadrangle, there are a few outcrops and reported occurrences of gypsum, but it is not everywhere pure, and at no place does its reported or observed thickness exceed 3 feet.

CELESTITE

Celestite in a single layer or in lenses only a few inches thick is found here and there in the De Queen limestone member of the Trinity formation, but it is of no commercial importance. The largest outcrops are at a locality 1 mile northwest of Martha post office and at another locality a quarter of a mile north of Martha, in the De Queen quadrangle.

PHOSPHATE

Widely separated layers, lenses, and nodules of black phospate rock, which reach in places a thickness of 1½ inches, are found in shale in the basal part of the Stanley shale, both above and below the Hatton tuff lentil, in the vicinity of the Cross Mountains west of Wickes and Grannis. A few small phosphatic nodules were seen near Gillham, but these are probably near the middle of the Stanley. This rock is black, has a rather high specific gravity, and a fracture that varies from platy and uneven to conchoidal, and weathers to a white or yellow color on exposed surfaces. Chemical analyses of two samples show that they contain 6.08 and 10.56 per cent of phosphorus pentoxide, equivalent to 13.28 and 23.07 per cent of tricalcium phosphate, respectively. It is at once obvious that this rock does not contain a high enough percentage of phosphate and does not occur in sufficient quantity to be of commercial importance.

PYRITE AND MARCASITE

On the left bank of Caddo River at the west edge of the village of Caddo Gap is a prospect revealing a deposit of pyrite and marcasite. The first work at this locality, it is reported, was done about 1830, and the next in 1915 and 1916. The openings consist of a shallow pit and three shafts, of which the deepest is 40 feet deep. A drift was run 30 feet to the west from the bottom of the 40-foot shaft, and another drift 12 feet long was made in this shaft at a depth of 23 feet. In addition three drill holes have been sunk; one of these is 75 feet deep, another 78 feet, and the third 100 feet. At the time of the visit (1916) the pit and shafts were filled with water, which was standing at the same level as the water in the river. The rocks penetrated by the openings are very pervious, and water from the river seeped through them so rapidly that the prospectors at times could not keep it out of the openings with a 4-inch pump.

The openings penetrated black shale and black earth in the upper part of the Womble shale. The minerals on the dump, which amounted to 1 or 2 tons at the time of the visit, consisted mostly of marcasite but partly of pyrite. The character of the minerals thus observed indicates that they occur as irregular masses or veins with rounded and stalactitic forms in the shale, free from quartz or other gangue minerals, though the sulphides at places inclose fragments of shale which they have cemented together. One mass of ore that was found in the drift is said to have weighed a ton. The masses of ore and partings between them are said to dip 82° N., and nearly all the masses are said to have been found within a zone having this dip that is 6 feet wide and strikes N. 65° E. Analyses are said to show that the sulphides contain 51.54 per cent of sulphur, 0.004 per cent of arsenic, and 0.03 per cent of zinc.

The deposit of pyrite and marcasite at this locality has not been proved to be of minable size. Furthermore, if mining or additional prospecting is done, the pumping of the water that would seep from the river into the workings would be very expensive.

COPPER, GOLD, AND SILVER

Copper minerals are associated with the lead and zinc ores above described. These minerals, including chalcopyrite and native copper, have been prospected for very extensively in the mountains in the northern parts of the De Queen and Caddo Gap quadrangles, but they have not been found in commercial quantity at any place.

Gold and silver have also been prospected for at many places in the mountainous parts of the quadrangles, but no deposits of value have been found. Small deposits of silver-bearing galena have been prospected from time to time near Silver City, a few miles north of the northeast corner of the Caddo Gap quadrangle, but very little or no lead or silver has been sold from them.

CLAY

The largest clay deposits are the thick beds of variegated clay of the Trinity formation in the southern parts of the quadrangles, but yellow and red surface clays are found at many places in other parts. All these clays, if properly worked, are suitable for the manufacture of common building bricks and drain tile. Common building bricks have been made at Murfreesboro, Nathan, and De Queen. In the districts where building stone is not plentiful a small quantity of leached clay from "crawfish" lands is mixed with straw and used to construct chimneys whose framework consists of short timbers laid one upon another or nailed to upright pieces at the corners.

Beds of light-colored clay occur at many places in the Tokio formation from the vicinity of Tokio eastward beyond the east line of the Caddo Gap quadrangle. These clays include plastic ball clay and nonplastic kaolin, some of which is practically free from sand and from iron stains. The thickest beds are 6 feet thick. A 5-foot bed of nonplastic light-colored kaolin possessing the properties of fuller's earth occurs in the N. ½ SE. ¼ sec. 24, T. 8 S., R. 25 W. This kaolin, as well as others, is apparently altered volcanic ash and would be suitable for the manufacture of pottery and probably for enameled fire bricks and chinaware. The kaolin at this locality is present in large quantity in two hills, in one of which the overburden of sand and gravel is 15 feet thick at the crest of the hill and in the other the overburden, of the same character, is 24 feet thick at the crest. Many of the clay deposits in this part of the Caddo Gap quadrangle have been prospected by means of pits, but thus far no mining has been done. Some of the deposits have been described by J. C. Branner in Bulletin 351 of the United States Geological Survey, and they have all been described by C. S. Ross, H. D. Miser, and L. W. Stephenson in Professional Paper 154.

Beds of coal-black soft earth, which is known locally as graphite and "mineral black," occur near the top of the Womble shale in the Caddo Gap quadrangle. This material has probably been derived by weathering from beds of black sandy shale. A bed of such earth, 32 feet or more thick, has been prospected by means of a tunnel and an open cut 2 miles above the mouth of Gap Branch, near Caddo Gap. An analysis is said to show that it contains 10 per cent of carbon. Similar earth from other localities in western Arkansas has been tested to determine the presence of graphite. The carbon which gives the earth its black color was found not to be in the form of graphite.

SHALE

The Mazarn, Womble, and Stanley shales afford an inexhaustible quantity of shale suitable for the manufacture of red building bricks. In order to give these shales the proper plasticity for this use it might be necessary to mix with them some of the surface clay. Thus far none of the shale deposits have been developed.

LIME

The only limestones that crop out in these quadrangles are those of the Collier, Mazarn, Womble, and Trinity formations. Those in the Womble and Trinity have been quarried in a small way at several places for making lime. They have no value except for local use.

BUILDING STONE

Sandstone suitable for rough masonry occurs in large quantities in the Crystal Mountain, Blakely, Blaylock, Stanley, Jackfork, and Atoka formations, but thus far no quarries have been opened. The massiveness of most of this sandstone is its principal drawback for most purposes. The many joints would facilitate quarrying. Limestone in the Trinity and Womble formations, gravel conglomerate in the Trinity and Woodbine formations, peridotite near the mouth of Prairie Creek, and red slate from the Missouri Mountain slate have been used in small quantities for rough masonry. They are nowhere suitable for superstructural work. Boulders from the mountain slopes and cobbles from the terrace and alluvial deposits and the base of the Pike gravel are suitable for rubble work. Some of these stones have been so used at Murfreesboro. Variegated novaculite in such masonry presents a pleasing appearance. Some of it was used in the construction of parts of the Missouri Pacific Railroad station at Hot Springs, Ark., which was destroyed by fire several years ago. The results of physical tests made by the Bureau of Standards on a sample of dense chalcedonic novaculite from Caddo Gap were as follows:

Compression tests, specimens dry, average of three tests, 44,137 pounds to the square inch. Absorption tests, percentage of absorption by weight, average of three tests, 0.129. Apparent specific gravity, average of three tests, 2.614. Weight of dry stone, 163.4 pounds to the cubic foot.

SAND

Sand suitable for plaster and cement is abundant in the Trinity and Tokio formations in the southern parts of the quadrangles; in other parts it may be obtained along the streams where it has collected during high stages of the water.

NOVACULITE FOR POTTERY AND GLASS

The basal part of the Arkansas novaculite is composed almost wholly of silica, and it is sufficiently white and free from impurities to be quarried and pulverized for use in making pottery. The hardness of the novaculite precludes its use for the manufacture of plate or ordinary glass, because the work of crushing it would be very expensive. On the other hand, the purest grades might be suitable for optical glass.

OILSTONES

At Hot Springs, Ark., about 25 miles east of the Caddo Gap quadrangle, the Arkansas novaculite yields two varieties of oilstones—the "Ouachita" (sometimes spelled Washita), which is a rather porous stone of fine quality for sharpening carpenters' tools, and the "Arkansas," which is a dense stone suitable for sharpening the smallest pointed tools or giving a very fine edge to surgical instruments. Rock of these two varieties probably occurs in commercial quantities in the Caddo Gap and De Queen quadrangles, but no quarries have been opened. For further information on this subject the reader is referred to the Hot Springs folio (No. 215) of the Geologic Atlas of the United States, and to volume 3 of the Annual Report of the Arkansas Geological Survey for 1890.

PEBBLES FOR TUBE MILLS

The novaculite pebbles in the Trinity, Tokio, and Woodbine formations and in the terrace and alluvial deposits in these quadrangles have never been used in tube mills. They are, however, of such a character that the authors believe well-selected pebbles may be suitable for this purpose. The only way to determine their adaptability to this use is by actually using some of them in tube mills. If the pebbles are found to be suitable, the farmers living in the region could be employed at idle times to collect, grade, and size them. The industry would thus not require the investment of a great amount of capital.

The pebbles range from a small fraction of an inch to 10 inches in diameter, but the smallest ones predominate. The tube-mill pebbles in greatest demand are from 2 to 4 inches in diameter, though some as small as 1 inch and some as large as 7 inches are used. The 2 to 4 inch pebbles are most abundant in the basal part of the Pike gravel from Ultima Thule eastward, in the gravels of the Woodbine and Tokio formations, and in the terrace deposits and gravel bars along Muddy Fork, Little Missouri River, and other streams farther east. The gravel bars are largest along the two streams just named, some of them occupying several acres, and the gravel in them is in places roughly assorted according to size.

Most of the novaculite pebbles are of dense gritty fine-grained homogeneous novaculite that is translucent on thin edges. They break very much like flint or chert, with an uneven to conchoidal fracture, and usually have a waxy luster like chalcedony. Most of the pebbles are white with a bluish tint, but many of them show different shades of red, gray, green, yellow, and brown, and some are black. In some parts of the area all the pebbles are bleached white, but upon being fractured they show their original color.

In shape the pebbles vary from slightly rounded to well rounded. None of them are spherical, and very few are nearly so. Although the slightly rounded pebbles predominate, their edges are well rounded. Part of the rounding took place in the streams that carried the pebbles from the Ouachita Mountains, but most of it probably took place on the beaches of the Cretaceous sea. A few pebbles have smooth faces that are parts of joint planes of the beds from which they came. Most pebbles have such planes and other cracks within them, but many are free of these flaws. The pebbles, as a rule, have smooth surfaces; but some have pits, owing to the presence of cavities in the parent rock, and some have rough surfaces from impact with one another. A few are highly polished. A small proportion of the pebbles consist of porous novaculite that would wear down faster than the denser rock. Some of the pebbles have parallel laminae, and such pebbles usually have planes of weakness. The novaculite pebbles are almost pure silica, as is shown by the accompanying average of several analyses of the Arkansas novaculite,[3] and they are so resistant to weathering that they are usually as fresh as the unweathered novaculite found along its outcrops in the Ouachita Mountains.

Average analysis of Arkansas novaculite

Silica (SiO_2)	99.50
Alumina (Al_2O_3)	.20
Ferric oxide (Fe_2O_3)	.10
Magnesia (MgO)	.05
Lime (CaO)	.10
Soda (Na_2O)	.15
Potash (K_2O)	.10
Loss on ignition (water)	.10
	100.30

The specific gravity of dense chalcedonic novaculite from Caddo Gap has been determined by the Bureau of Standards to be 2.614. A determination, by C. E. Wait, of the specific gravity of what is called in the trade the "Arkansas stone," a variety of novaculite used for abrasives, gave 2.649.[4] A determination of the specific gravity of the same kind of stone at the standard temperature, made by the Arkansas Geological Survey, gave 2.648.[4] The specific gravity is less than that of quartz in crystals, which varies from 2.653 to 2.660, but it falls within the limits for pure cryptocrystalline forms such as flint or chert, which may have a specific gravity as low as 2.60.

The percentage of absorption by weight of the dense novaculite from Caddo Gap was determined by the Bureau of Standards to be 0.127. Similar tests of the "Arkansas stone" from two quarries near Hot Springs were made by the Arkansas Geological Survey; the percentages of absorption found were 0.06 and 0.07.[5]

[3] Griswold, L. S., Whetstones and the Novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, p. 90, 1892.

[4] Idem, p. 93.

[5] Idem, pp. 93–94.

The hardness of the novaculite is the same as that of quartz, but as shown by the slight protrusion of quartz veins, due to differential abrasion, on surfaces of many of the pebbles containing such veins the novaculite is somewhat less resistant to abrasion than vein quartz. Novaculite is comparatively brittle, being easily broken by a hammer. Its brittleness may, in fact, bar its economic use in tube mills.

The crushing strength, as determined by taking the average of three compression tests made by the Bureau of Standards on novaculite from Caddo Gap, is 44,137 pounds to the square inch.

The gravel in the Tokio formation is usually mixed with less red clay than those in the Trinity and Woodbine formations. The stream gravel is also in most places free of clay.

ROAD MATERIAL

The Caddo Gap and De Queen quadrangles are abundantly supplied with road material. The Bigfork chert, Arkansas novaculite, Trinity formation, Woodbine formation, Tokio formation, and terrace and alluvial gravels afford very large supplies for laying both foundations and surfaces.

A characteristic of the Bigfork chert which especially facilitates its use on roads is its minutely shattered or fractured condition. It is easily accessible and can be loosened at its outcrops in the sides of the hills by blasting and then dug out with picks and put on the road with little or no preparation. It also occurs in large quantities as finely broken talus at the bases of the hills. The comparative brittleness of this chert allows it to pulverize and become firmly compacted into a smooth, firm mass, though not hardened, for no calcareous material is mixed with it to act as a bond. Nevertheless, owing to the presence of more or less clayey material, it makes a firm, smooth road surface. It forms a natural macadam on many of the roads within its area of outcrop and is used to some extent in the construction of public roads.

The Arkansas novaculite is not so much fractured as the Bigfork chert, and the blasting of the massive beds in which it occurs and the crushing of the rock would be more expensive than the preparation of the Bigfork. On a few talus slopes large and small stones of novaculite have collected in considerable quantities.

The many beds and lenses of gravel, especially the basal ones, in the Tokio, Woodbine, and Trinity formations are widely distributed in the southern parts of the quadrangles. In fact they and their residual materials form the predominating surficial deposits found in those parts of the quadrangles that are underlain by Cretaceous sediments. They consist of novaculite and other hard pebbles intermixed or interbedded with clay and sand, and although the beds range in thickness from a few inches to 100 feet some of them maintain a thickness of between 25 and 50 feet over considerable areas. Enough sand and clay is usually mixed with the pebbles to make a firm, compact road. The gravel thus constitutes an accessible and enormous supply of good road material. Like the Bigfork chert it forms a natural macadam in those areas where it occurs on the surface.

Gravel of much the same character as that just mentioned constitutes a large proportion of the deposits along the large and small streams of the quadrangles. The larger areas of stream deposits are represented on Plate 3 and are there designated "alluvium" and "terrace deposits." Most of these areas are covered with a deposit of sand and loam a few feet thick. Where the gravel is thus covered the best places for obtaining road material are along slopes where the gravel crops out and from the gravel bars usually found along the streams. These bars are largest along Muddy Fork and Little Missouri and Caddo Rivers.

At the village of Cove, in the De Queen quadrangle, a large quantity of hard dark-bluish sandstone in the Stanley shale has been quarried and crushed for ballasting the Kansas City Southern Railway.

The cobbles and large pebbles commonly found more abundantly at the base of the Pike gravel than elsewhere are suitable for riprap and curbing. Great quantities of them occur in places along the streams.

WATER RESOURCES

The areas herein described are well watered, the mean annual precipitation being 53.27 inches at Center Point, in the Caddo Gap quadrangle; 54.21 inches at Amity, which is 2 miles east of the quadrangle; and 50.6 inches at Mena, which is 5 miles north of the De Queen quadrangle. A considerable portion of the water immediately flows off the surface into the streams, which are described in the section entitled "Drainage," and another portion sinks into the ground and into open spaces in the rocks, and after a longer or shorter period of time and by a more or less circuitous route much of it reaches the surface again as springs.

All the rock formations, including even the shales, contain water, which issues as springs or which may be reached by means of wells. The formations which contain the least water are the Missouri Mountain slate, the Polk Creek shale, and the Brownstown marl, and those which contain the largest quantities are the Crystal Mountain sandstone, the Bigfork chert, the Arkansas novaculite, the Trinity formation, and the Woodbine formation. Of these the Bigfork chert contains the most water because of its uniformly shattered condition, its considerable thickness, and its comparatively large area of outcrop. Many springs flow from it or find outlet to the surface through other formations. In fact, most of the fine springs in the Ouachita Mountains between Hot Springs and the western border of the State and some in Oklahoma come from this chert.

Wells.—Wherever spring water is not available, shallow wells that will yield a supply of water sufficient for at least household purposes, if not for stock, can be dug or drilled at most places, even on the uplands. Such a supply can usually be procured without exceeding 40 feet in depth. According to local conditions, water may be obtained at greater depths in some places in the Athens Plateau and farther north, but flowing wells there can not be expected because of the close folding and high inclination of the rocks.

A number of artesian wells, some of which are flowing wells, have been drilled in the Coastal Plain in the southern parts of the quadrangles. The water from all the wells except one at Delight is obtained from the Pike gravel member of the Trinity formation and from beds of sand that appear to be a short distance above this gravel. The well at Delight, which is a flowing well 112 feet deep, receives its water from a bed of sand near the base of the Tokio formation. Figures 8 and 9, maps of the southern parts of the De Queen and Caddo Gap quadrangles, show by contours the maximum depth to which wells should be drilled for artesian water in the Trinity, Tokio, and Woodbine formations and the areas within which flowing wells may be expected. Broken contours are based on incomplete data. The boundaries of the areas within which flowing wells may be expected are approximate, for they are based on incomplete data.

The contours in Figures 8 and 9 show the position of the base of the Trinity referred to sea level. Artesian water at most places occurs near the base of the Trinity, but water for a flowing well at Delight comes from the Tokio formation. No water should be expected in Paleozoic rocks underlying the Trinity.

Several wells ranging in depth from 80 to 258 feet have been drilled at and near Murfreesboro. Some of them are flowing wells, and in others water rises within a few feet of the surface. A number that formerly flowed ceased to flow when new wells were put down near by.

Two wells about 170 feet deep were drilled at the east end of the village of Kimberley by the Kimberlite Diamond Mining & Washing Co. They passed through 18 feet of gravel (Quaternary), then 60 feet of clay and thin sandstone (Trinity), then 85 to 90 feet of variegated clay (Trinity), and next 4 to 5 feet of pebbly sand (Trinity) containing some pyrite and some black sand (magnetite). Some water was found just above the variegated clay, and a large quantity was

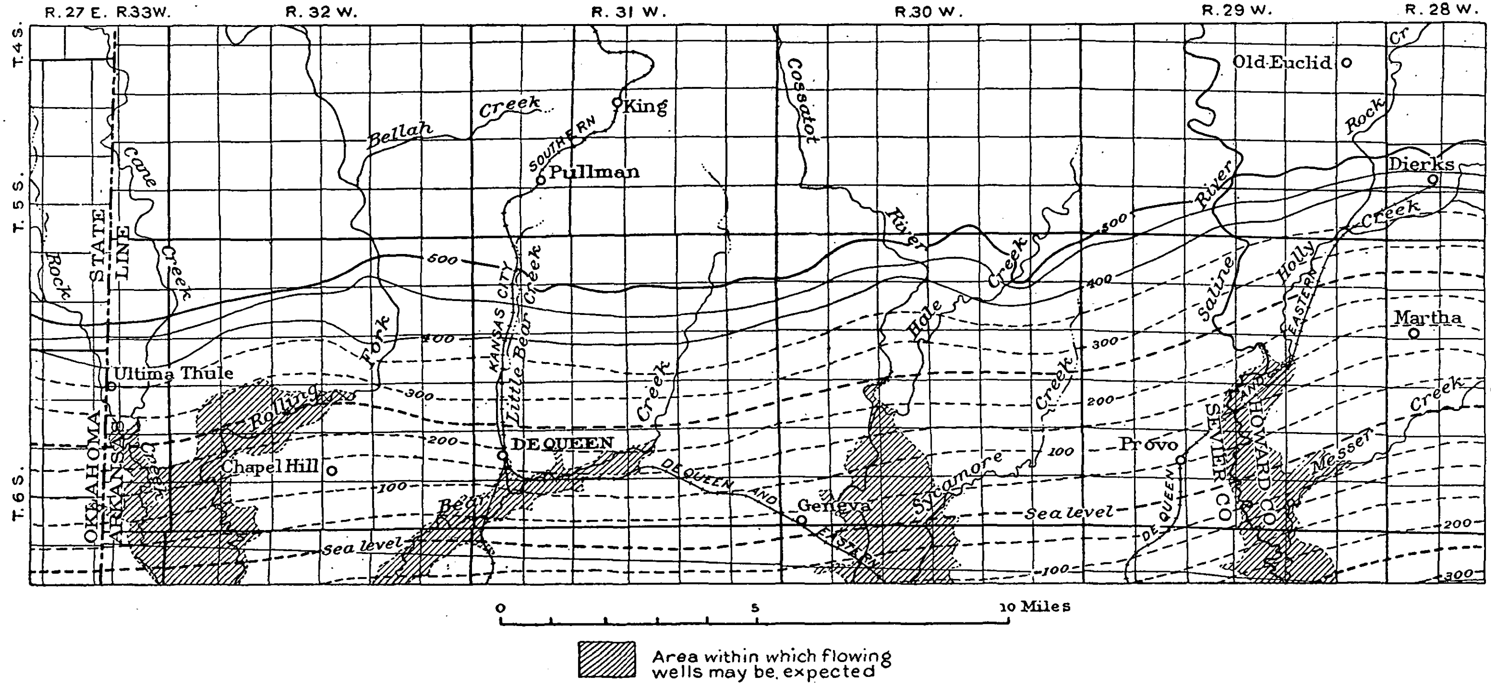

FIGURE 8.—Map of the southern part of the De Queen quadrangle, showing by contours the maximum depth to which wells should be drilled for artesian water in the Trinity formation and also the areas within which flowing wells may be expected. The contours show the base of the Trinity formation, referred to sea level. Broken contours are based on incomplete data

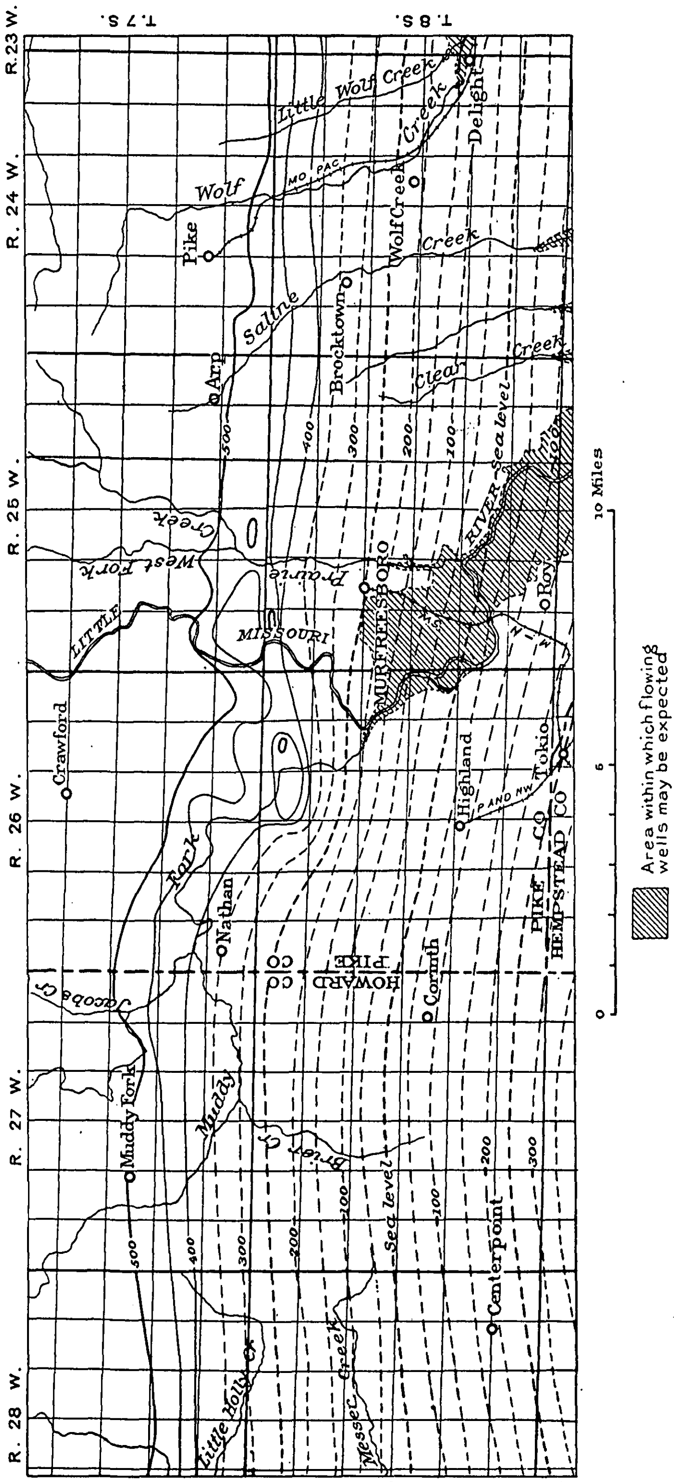

FIGURE 9.—Map of the southern part of the Caddo Gap quadrangle, showing by contours the maximum depth to which wells should be drilled for artesian water in the Trinity, Woodbine, and Tokio formations and also the areas within which flowing wells may be expected. The contours show the base of the Trinity formation referred to sea level. Broken contours are based on incomplete data

found in the bed of pebbly sand at the bottom of the wells. The wells flowed when they were completed, but they ceased to flow after Walter Mauney drilled a well a short distance to the north. The Mauney well was drilled at a lower altitude than the other two and to about the same depth. It penetrated the same water-bearing bed as the other two wells and reduced the pressure of water in that bed. At the time of examination (1916) the Mauney well did not flow except by means of a siphon whose lower end was near Prairie Creek. Water from the two wells of the Kimberlite Diamond Mining & Washing Co. was used in the diamond-washing plant of the company, which was operated from 1913 to 1919.

Three artesian wells have been drilled in the northern part of the city of De Queen to supply water for the roundhouse of the Kansas City Southern Railway Co. No. 1 well, 289 feet deep, is 50 feet north of the office at the roundhouse; No. 2, 253 feet deep, is 200 feet north of No. 1; and No. 3, 200 feet deep, is 200 feet north of No. 2. The water from all three wells is said to come from a very fine white sand. The wells do not flow, but the water rises to a point near the surface.

Three other artesian wells in De Queen supply water for the city and for the ice plant. Two of the wells are a short distance east of the railroad station and the other is at the ice plant farther south. The wells have an average depth of about 250 feet, and two of them originally flowed. The quantity of water that they are capable of producing is said to be about 2,000,000 gallons a month.

Two flowing wells, each 275 feet deep, are 1 mile south of De Queen, near the pumping station of the Prairie Pipe Line Co., which drilled the wells to obtain water for the pumping station.

A flowing well, 350 to 360 feet deep, is said to have been drilled in the valley of Rolling Fork in the W. ½ sec. 21, T. 8 S., R. 32 W., 4 miles west-northwest of De Queen.

Cold springs.—Cold springs are numerous in all parts of the quadrangles, but are most numerous and largest in the mountainous districts. Many of the springs yield water of great purity, but the water of others contains large quantities of mineral salts. On account of this great difference in the character of their waters and on account of the very large number of springs it is not advisable to enumerate and describe the springs without a special study, which has not been made. A few of the springs are shown on Plate 3.

Hot springs.—Hot or warm springs are known at four localities in the Caddo Gap quadrangle. One of these is in the gap through Caddo Mountain known as Caddo Gap; another is reported to be 2 miles southwest of the gap; the third is at the east end of Redland

Mountain, 11 miles west of Greenwood; and the fourth is on Little Missouri River, 6½ miles southeast of Big Fork post office.

The hot springs at Caddo Gap were discovered in February, 1908, by J. M. Davis, of that place. The hot water has its outlet in the bed of Caddo River, in the gap where this stream cuts through Caddo Mountain, and this peculiar location prevented the springs from being discovered earlier. The water rises between the vertical beds of the uppermost division of the Arkansas novaculite. Cement inclosures have been constructed around two points of issue, 22 feet apart, on the west side of the river, and the springs issuing through these inclosures are here called North Spring and South Spring. Much hot water still issues from the bed of the river. The surface of the North Spring stands about 15 inches and that of the South Spring about 10 inches above the river at average stage.

The temperatures of the springs were determined on July 2, 1910, by Mr. Purdue, who found the North Spring to have a temperature of 95° F. and the South Spring 96.5° F. Mr. Miser determined the temperatures at 6 p. m. May 8, 1916, at the places where the hot waters enter the concrete basins, and found them to be 94° F. for the North Spring and 96.8° F. for the South Spring. The flow of each spring was calculated from a rough determination to be 5 gallons a minute. A few bubbles of gas, which may be carbon dioxide, rise to the surface of the water. Analyses of the waters are shown below.

Analyses of water from hot springs at Caddo Gap, in parts per million

[Computed from analyses by W. M. Bruce]

	South Spring	North Spring
Silica (SiO_2)	15.600	18.700
Ferric oxide and alumina ($Fe_2O_3+Al_2O_3$)	7.000	7.200
Calcium (Ca)	38.876	41.680
Magnesium (Mg)	2.166	4.235
Sodium (Na)	7.526	3.349
Potassium (K)	.000	.000
Carbonic acid radicle (CO_3)	68.265	67.085
Sulphuric acid radicle (SO_4)	1.419	2.313
Chlorine (Cl)	4.848	7.138
	145.700	151.700
Carbon dioxide (free CO_2)	20.000	16.000

A hot spring is reported by Mr. W. B. Barton as occurring near the quarter corner on the line between secs. 23 and 26, T. 4 S., R 25 W., 2 miles southwest of the hot springs at Caddo Gap. The analysis given below has been furnished by Mr. Barton, who says that the sample of hot water contained some cold surface water that was entering the spring.

Analysis of water from hot spring 2 miles southwest of Caddo Gap, in parts per million

[W. F. Manglesdorf, analyst]

Silicia (SiO_2)	15.4
Iron (Fe)	1.2
Aluminum (Al)	.7
Calcium (Ca)	39.8
Magnesium (Mg)	2.3
Potassium (K)	1.3
Lithium (Li)	.6
Sodium (Na)	9.1
Carbonic acid radicle (CO_3)	69.0
Sulphuric acid radicle (SO_4)	8.3
Chlorine (Cl)	8.0
	155.7

A warm spring whose temperature was determined by Mr. Miser on August 7, 1916, to be 77° F., is on the east end of Redland Mountain and about 100 feet above Self Creek. The water issues from a crevice between two massive, steeply dipping layers of novaculite in the uppermost division of the Arkansas novaculite. The flow is sufficient to fill a 1-inch pipe leading from the spring. The water contains in solution much iron, which is deposited as a brown coating in the wooden troughs carrying the water down the mountain side and on the rocks over which the water flows.

A warm spring whose temperature was determined by Mr. Miser on August 1, 1916, to be 74° F. is on the left bank of Little Missouri River in the northern part of sec. 17, T. 4 S., R. 27 W. The water issues at a number of places within an area several feet across about 15 feet from the river bank. The aggregate flow would be sufficient to fill a 3 or 4 inch pipe leading from the spring.

The source of the hot waters of the above-described springs is not known. They may be meteoric waters that have been heated in some way deep below the surface, or they may be hot waters that are given off by cooling igneous rocks far below the surface. If the waters are meteoric the source of their heat may be due to chemical reactions within the rocks through which the water flows, accumulated heat from friction, the presence of hot igneous rocks beneath the surface, or the breaking down or other action of radium along the underground course of the water. This question, which has been raised also concerning the hot springs at Hot Springs, Ark., east of the areas under discussion, can not be definitely answered with the information that is now available, but the writers believe that the waters are meteoric.

Water power.—All the streams of the quadrangles are small, the largest ones being merely creeks which are easily forded at low stage. At a number of places water power has been utilized to run small grist and lumber mills and cotton gins, but this use has been largely replaced by steam and gasoline engines. Many places in the quadrangles, especially the water gaps where short rapids or low falls exist, afford favorable sites for small power plants. Among the most promising sites are Caddo Gap, through which Caddo River flows, the falls of Cossatot River in sec. 17, T. 5 S., R. 30 W., and the falls of the Little Missouri just north of the Montgomery-Pike County line.

SOILS

Except the wide belts of alluvium and patches of terrace deposits along the streams in the Coastal Plain and the small tracts of alluvium in the Ouachita region, the soils of the Caddo Gap and De Queen quadrangles are residual, having been derived from the disintegration of the different rock formations represented in the areas. The soils thus differ in character from place to place.

The Collier shale, Crystal Mountain sandstone, Blakely sandstone, Bigfork chert, Polk Creek shale, Blaylock sandstone, Missouri Mountain slate, and Arkansas novaculite have a prevailingly rocky thin soil, derived from either their own outcrops or adjacent beds. The slopes and crests of the ridges where they form the surface rock are, as a rule, not fit for agriculture but are best adapted for the growth of timber, with which they are densely covered in most places. Although such areas are forested, they grow wild grasses well and are thus suitable for grazing.

The soil overlying the Mazarn and Womble shales is not everywhere of the same character. Along Caddo River and other streams it consists in great measure of transported materials which occupy narrow stream flats or the lower parts of slopes, and although it is more or less stony it is fertile, whereas in the higher parts most of the soil is shallow, clayey, stony, and poor. The better land is well suited for general farming, the poorer for grazing and fruit culture.

The soils of the Stanley shale are prevailingly sandy though somewhat clayey in the higher areas, but in the valleys they are less sandy and more clayey. They are porous, thin, and brown, yellow, and gray, and in some places they are underlain by soft, altered sandstone, in others by red clay. Much of the tillable soil is stony, containing pieces of quartz and sandstone, and in many places, especially adjacent to the larger streams, boulders and rock ledges abound, making such land practically worthless except for grazing and for timber. The largest tracts of tillable land stretch along the divides between the streams and include the fairly even upland country along the Kansas City Southern Railway and around Galena, Burg, Umpire, and Mineola, in the De Queen quadrangle, and around Athens, Henry, Newhope, Daisy, Kirby, and Glenwood, in the Caddo Gap quadrangle. The soils in these parts of the quadrangles are adapted to general farming and fruit culture. They show considerable fertility after the timber is cleared away, but unless they are properly tilled and fertilized this richness lasts but a few years.

The Jackfork sandstone produces a very poor sandy soil and there are few farms on it. Those parts that have been cleared have been generally abandoned. The land is best suited for grazing and for the growth of pine timber, which prevails in the belts where this sandstone is exposed.

The Atoka formation in the more level tracts found here and there yields a soil of fair fertility.

The gravel of the Trinity formation, the pebbles of which are embedded in clay and sand, produces a valuable soil for general farming and especially for the cultivation of fruit. Its distribution is discussed under the description of this formation. Most of the area where the Trinity crops out is occupied by a poor sandy yellow or gray soil, but some of the "black lands" formed by the Dierks limestone lentil and the De Queen limestone member are more fertile. All these soils under proper care and fertilization are suitable for general farming.

The soil of the Woodbine and Tokio formations is gravelly almost everywhere in the quadrangles herein described. The pebbles, like those in the Trinity formation, are mixed with clay and sand. This soil is thus similar to that of the basal gravel of the Trinity just described. It is especially adapted for fruit culture.

The Brownstown formation yields a fertile soil that is black and waxy where not mixed with surficial deposits, but the subsoil is yellow.

The alluvial soils are usually dark, sandy loam and afford the best farming lands in the quadrangles.

TIMBER

The virgin forest which once covered all parts of the quadrangles has been largely destroyed through the cutting of the commercial timber. Most of the cut-over tracts have not been put under cultivation but have been permitted to reforest themselves, the result being that the greater part of the quadrangles is still timbered. Lumbering has thus been and is still an important industry and owing to the roughness of much of the country will remain so, although it is being rapidly succeeded by agriculture in those parts where the land is tillable. A considerable portion of the wooded areas in the northeast corner of the De Queen quadrangle and in the northern part of the Caddo Gap quadrangle is comprised in the Ouachita National Forest.

A short-leaved variety of yellow pine is probably the most common species, being found in all parts of the quadrangles. Magnificent forests, containing little else than this pine, are found in the belts where the Jackfork sandstone is the surface rock, in much of the area occupied by the Stanley shale, and in some of the gravel-covered areas of the Trinity and Tokio formations. Oaks, including white oak, red oak, post oak, and other varieties, are common, and the white oak is the most abundant of these. Other kinds of trees that grow to a large size are ash, wild cherry, walnut, hickory, sycamore, elm, cypress, holly, sweet gum, black gum, beech, red cedar, and maple. The cypress and holly trees are most numerous in the southern parts of the quadrangles, and red cedars are most plentiful along Cossatot River and Rolling Fork.

The timber on the higher ridges of the mountainous districts has a peculiar distribution; pines grow with the hardwoods on the south slopes nearly to the crests, and scrub oaks and small hickories occupy the crests, whereas on the north slopes the hardwoods grow larger than on the south slopes and few pines are seen.

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