DESCRIPTION OF THE HOT SPRINGS DISTRICT.

By A. H. Purdue and H. D. Miser.

INTRODUCTION.

LOCATION AND GENERAL RELATIONS OF THE DISTRICT.

The area shown on the maps in this folio, which includes Hot Springs and vicinity, in Arkansas, extends from latitude 34° 22′ 57″ to 34° 37′ 57″ N. and from longitude 92° 55′ 47″ to 93° 10′ 47″ W. and includes one-sixteenth of a "square degree" of the earth's surface, which in that latitude amounts to 245.83 square miles. It is a little southwest of the center of Arkansas, and most of it is in Garland County, but a narrow strip along its southern side is in Hot Spring County. (See fig. 1.) The city of Hot Springs is in the center of this area, which in this folio is called the Hot Springs district.

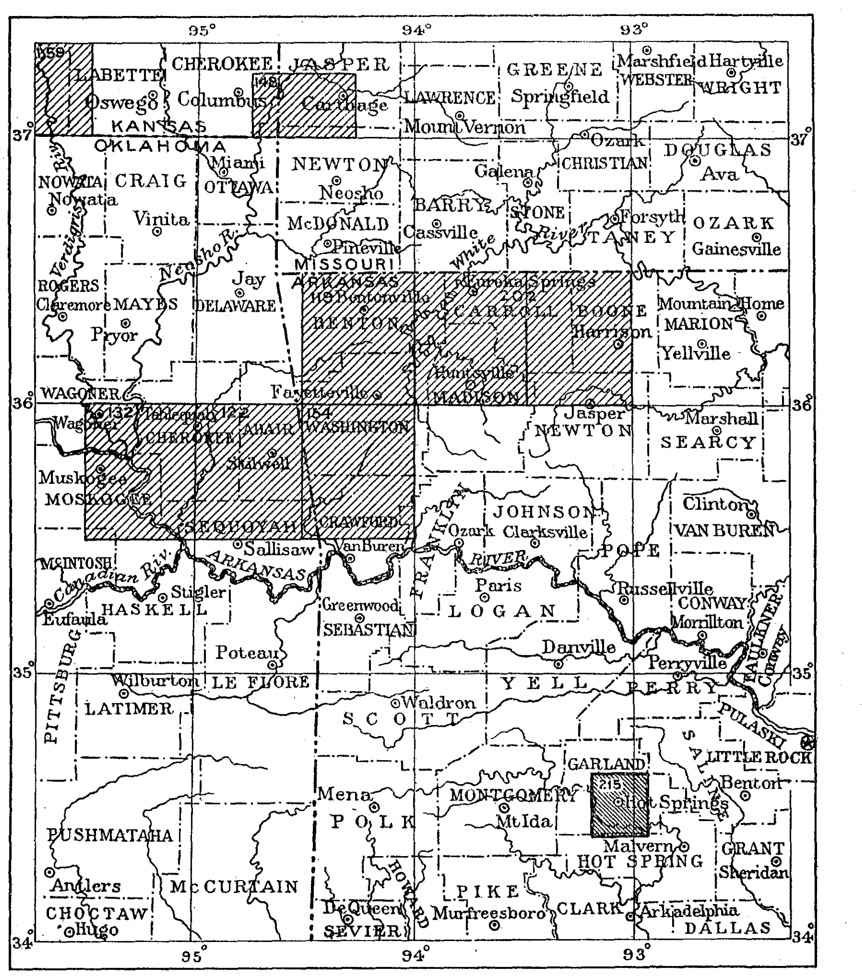


FIGURE 1.—Index map of northwestern Arkansas and portions of adjacent States.

The location of the area described in the Hot Springs folio (No. 215) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are the following: Nos. 119, Fayetteville; 122, Tahlequah; 132, Muscogee; 148, Joplin district; 154, Winslow; 159, Independence; 202, Eureka Springs-Harrison.

The Hot Springs district lies in the eastern part of the Ouachita (pronounced wash'i-taw) Mountain region, which extends from Little Rock, Ark., westward to Atoka, Okla., a distance of 200 miles, and which throughout the greater part of its extent is between 50 and 60 miles wide. The Ouachita Mountain region is adjoined on the north by a less mountainous region, most of it a wide, rather low valley which lies between the Boston Mountains of the Ozark Plateaus on the north and the Ouachita Mountains on the south. As a large part of this valley is drained by Arkansas River it is here called the Arkansas Valley. On the south and east the Ouachita Mountain region is adjoined by a comparatively low, gently rolling plain, which extends southward to the Gulf of Mexico and is called the West Gulf Coastal Plain. (See fig. 2.)

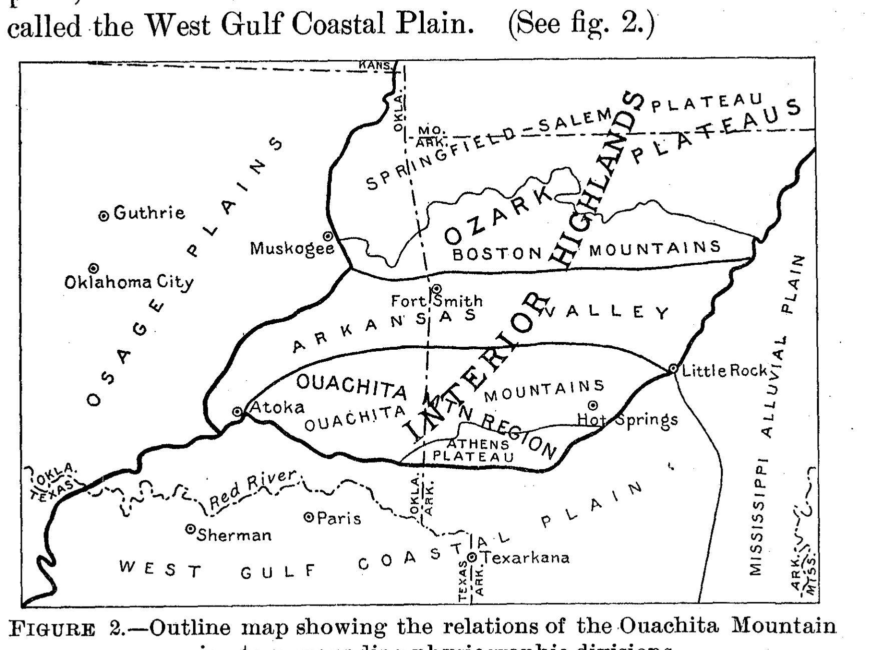


FIGURE 2.—Outline map showing the relations of the Ouachita Mountain region to surrounding physiographic divisions.

The geologic and physiographic history of the Ozark Plateaus and the West Gulf Coastal Plain differs markedly from that of the Ouachita Mountain region, but that of the Arkansas Valley is much the same as that of this region. The boundaries of these regions are shown in figure 2, and the age of the rocks that outcrop in them is shown in figure 3.

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 the Athens Plateau, which lies along the southern border of the mountains, most of it in Arkansas. A part of the east end of the Ouachita Mountains is embraced in the Hot Springs district.

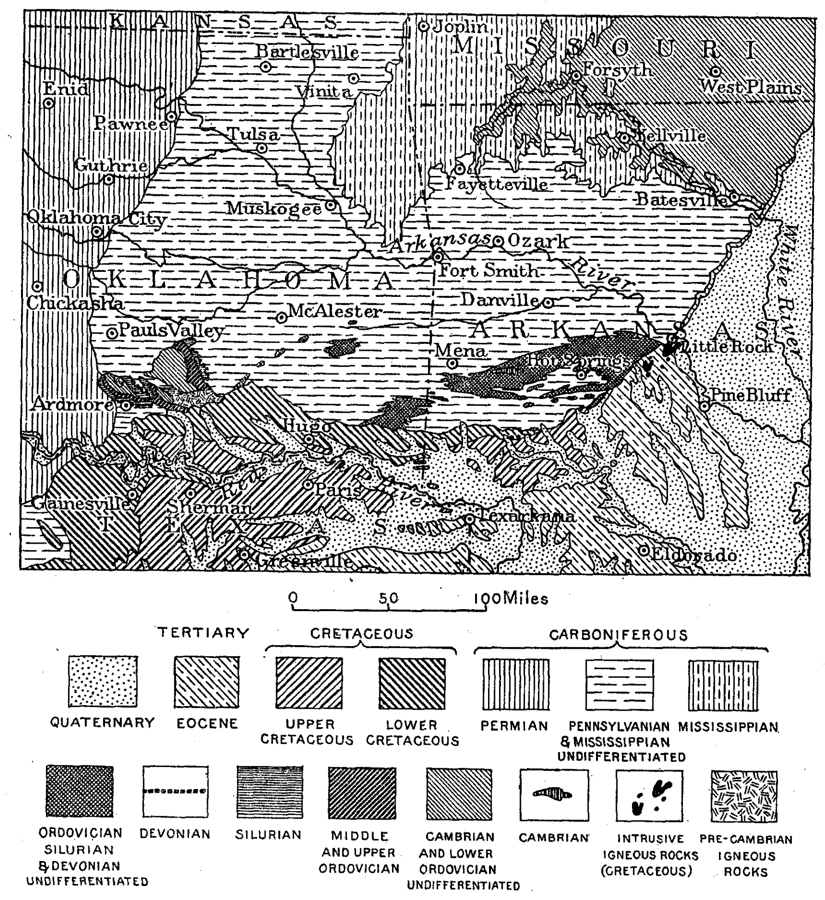


FIGURE 3.—Geologic map of parts of Arkansas, Oklahoma, and adjoining States.

The Ouachita Mountains are composed of many ridges, which trend in general nearly east, 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, at few points standing more than 750 feet above sea level or more than 250 feet above the valleys, but they gradually increase in height westward from Little Rock and eastward from Atoka to their culminating point at the west end of Rich Mountain in eastern Oklahoma, near the Arkansas-Oklahoma line, which is between 2,850 and 2,900 feet above sea level. The ridges in this part of Oklahoma and the adjoining part of Arkansas stand about 1,750 feet above the valleys. Many of the ridges are so grouped as to form small ranges, some of which stand in part within the Hot Springs district. (See fig. 4.)

Most of the intermontane basins are in Arkansas and in southern Oklahoma, near the eastern border of that State. They are wide areas, whose upland surfaces, which are lowest at the east end of the Ouachita region, range from about 500 to 1,200 feet above sea level, and they are channeled by many narrow valleys, most of which are less than 250 feet below the general level of the upland surface. The southern part of the city of Hot Springs is built in a basin that includes a large area in the south-central part of the Hot Springs district. Another basin is in part embraced in the northeast corner of the district. (See fig. 4.)

The Athens Plateau is a dissected piedmont plateau about 15 miles wide, which lies between the Ouachita Mountains on the north and the West Gulf Coastal Plain on the south. Most of it is in Arkansas, and its northern edge lies 2 or 3 miles south of the Hot Springs district. It is greatly dissected by the narrow, crooked valleys of southward-flowing trunk streams and by many valleys of small tributary streams, which flow at right angles to the trunk streams at levels 350 feet or less below the upland surface. The upland surface of this plateau, which is marked by the crests of low eastward-trending ridges, ranges in height from 400 to 1,100 feet above sea level. It is lowest at the east end and on the south side and highest on the north side, in Pike, Howard, and Polk counties, Ark.

Drainage.—The northern part of the Ouachita Mountains 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. Ouachita River, a tributary of Red River, runs southeastward across the Hot Springs district.

The position of many streams in the Ouachita Mountains is determined by the geologic structure. Most of the streams flow for considerable distances along the valleys between the ridges, but other streams in all parts of the province have cut their courses transverse to the ridges and thus run through narrow, picturesque water gaps.

Climate and vegetation.—The climate of the region on the whole is mild. The cold in winter is not extreme, but the heat in summer is at times intense. The rainfall, which is abundant, commonly reaches a maximum in the late spring and early summer and decreases to a minimum late in the summer and early in the fall, when in some years there are droughts. In spite of the rather poor soil the precipitation has produced a heavy forest cover over the entire region. The white oak and a yellow or short-leaf pine are the most abundant trees, and the pine predominates, especially on the southern slopes. Trees of these two kinds and of many others grow on the ridges as well as on the lower areas. Large areas of the forest are virgin, and extensive tracts are included in the Arkansas National Forest.

Only a small part of the region has been cleared and put under cultivation, and most of the remainder is unfit for agriculture. The cultivated land is on the upland, where the soil is usually poor, and along some of the main streams, where as a rule it is deep and good. Next to lumbering the chief industry of the region is agriculture, including general farming, stock raising, and fruit growing.

Stratigraphy.—The rocks of the Ouachita Mountains are nearly all of sedimentary origin, but igneous rocks occupy two small areas in their eastern part. One of these areas is at Potash Sulphur Springs, in the Hot Springs district, and the other is several miles farther east at Magnet Cove.

The sedimentary rocks consist of shale, sandstone, chert, novaculite, tuff, limestone, and conglomerate, named in order of decreasing abundance. Except for induration to hard rocks they have been only slightly affected by metamorphism, which, however, has changed some of the shale to slate and certain beds of sandstone to quartzite. The total thickness of the beds exposed in this province and in the adjoining Arkansas Valley, according to present knowledge of the area, amounts to a maximum of 37,000 feet or to a minimum of 23,000 feet. The beds range in age from Cambrian to Carboniferous. Their distribution is shown in a general way in figure 3.

The igneous rocks consist of intrusive masses of nephelite syenite and related types, which were injected upward into the sedimentary strata late in Lower Cretaceous time or early in Upper Cretaceous time.

Structure.—The sedimentary beds 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 beds, whose eroded edges now appear at the surface.

Among the many structural features in the region is a pronounced anticline whose axis extends west by south from a point a few miles southwest of Little Rock, Ark., to the vicinity of Glover, Okla. Its east and west ends are concealed by overlapping coastal-plain deposits, the east end by rocks of Tertiary and Quaternary age and the west end by rocks of Cretaceous and Quaternary age. The crest of this anticline is much lower near the Arkansas-Oklahoma line than it is either to the east or west, and it is in this way divided into two parts. Each of these parts is composed of numerous minor folds and is really an anticlinorium, and the major structural feature of the entire Ouachita region, in which they are included, is also a large but compound anticlinorium.

The smaller folds are only a few miles long and overlap one another lengthwise. Besides being closely compressed, they are in many places overturned, so that the beds on both sides of the structural axis dip in the same direction. Some folds are overturned toward the north; others are overturned toward the south. To the north, however, toward the Arkansas Valley, the folds become more open, overturning ceases, and the beds dip in both directions. At many places adjacent folds are nearly equal in height, and the same beds appear at the surface in each fold. In much of the Ouachita region most of the beds dip at angles of 40° or more.

Faults are common, though they are not so common as might be expected in beds that have been so closely compressed, because the great thicknesses of shale distributed throughout the folded beds permitted them to adjust themselves to the crustal shortening by shearing and crumpling instead of by great thrust faulting. Practically all the faults are parallel with the folds and are thrust faults. Most of them were produced by the breaking of the beds in closely compressed anticlines. The great Choctaw fault of southeastern Oklahoma, the largest in this region, is at least 120 miles long.

TOPOGRAPHY.

SURFACE FEATURES.

The surface of the Hot Springs district, which is in the east-central part of the Ouachita Mountains, is at most places rough. About half the area consists of mountains and the other half of intermontane basins. The mountains are groups of high, narrow ridges, which in any particular group are parallel or nearly so and which are separated by narrow valleys. At most places these valleys are parallel to the ridges, but at others they cut through them in gorges called water gaps. The ridges and most of the valleys, both large and small, are closely related to the structure and hardness of the rocks. The valleys that are parallel to the ridges were eroded in the softer rocks, and the hard rocks were left standing above the general level in the form of ridges or mountains.

The slopes of the ridges are steep and rugged and are scored by deep ravines, and the line of their crests, though it appears from a distance to be sharp and fairly even, is in reality broken in many places by saddles, low peaks, and the water gaps just mentioned. In the northwest half of the district the ridges range in general height from 1,100 to 1,300 feet above sea level, or from 500 to 700 feet above the basins, but in the southeast half they gradually become lower toward the southeast, until in the corner of the district they stand only about 700 feet above sea level, or from 200 to 300 feet above the general surface of the adjoining basins. Several low peaks on the crests of the ridges rise to elevations that range from 1,300 to 1,400 feet above sea level.

The intermontane basins lie mainly between 500 and 700 feet above sea level, and the narrow valleys that trench them reach depths of 200 to 250 feet.

Although the surface features of the district have certain general characteristics, some of which have just been noted, the district may be divided into five more or less distinct topographic divisions—three mountain groups and two basins, whose location is shown in figure 4. Of these the Zigzag Mountains and the Mazarn Basin comprise much the larger part of the district.

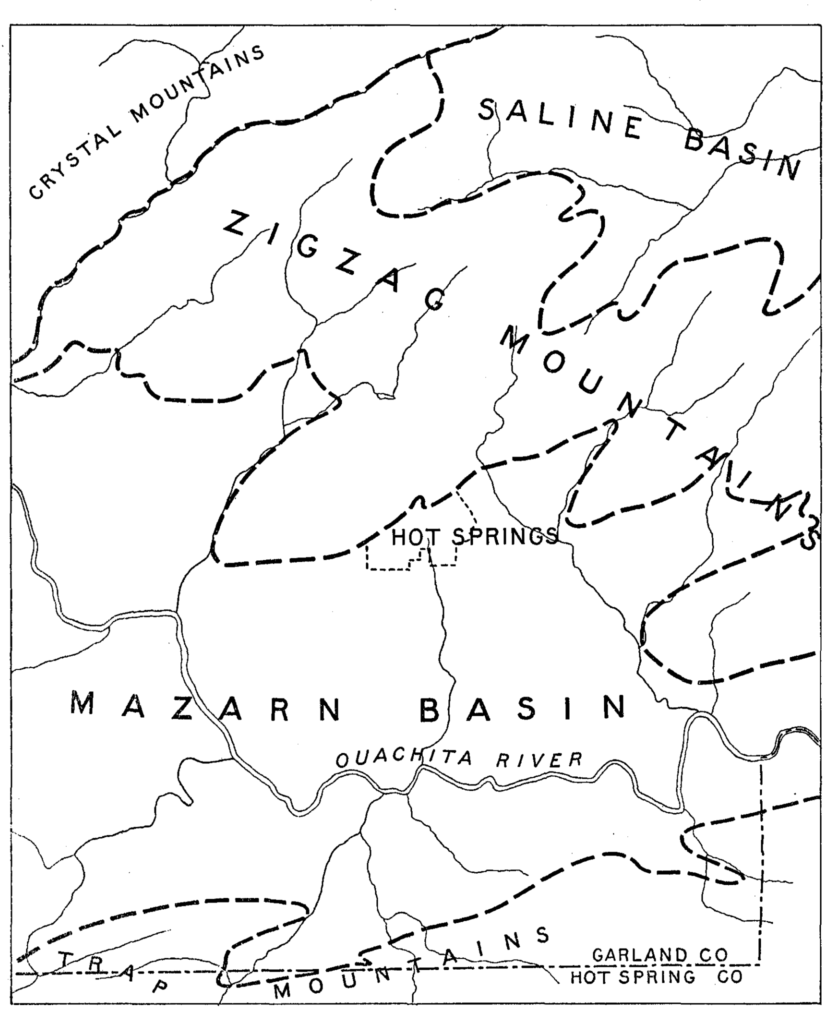


FIGURE 4.—Map showing the physiographic divisions of the Hot Springs district.

The Zigzag Mountains occupy a belt 6 to 8 miles wide, extending from the vicinity of Hawes post office, 6 miles northwest of Hot Springs, southeastward beyond the district to the western edge of the Gulf Coastal Plain, a distance of 25 miles. Their name, which was first applied to them by Branner, is clearly suggested by the peculiar zigzag course of the ridges, which have a northeastward trend, almost at right angles to that of the group. Mountains of this peculiar type have been formed by the truncation of parallel plunging anticlines and synclines. The intervening valleys, like the ridges, are narrow and rough and contain very little level land. The ridges, which are rather short, terminate abruptly to the southwest in the Mazarn Basin and to the northeast in the Saline Basin and have been cut at a number of places by streams. Noteworthy among the water gaps through which streams flow is the one between West and North mountains, which is traversed by Central Avenue, the principal thoroughfare of Hot Springs. The highest point on the ridges and also the highest point in the district is a peak near the west end of West Mountain, which stands a little more than 1,400 feet above sea level, or 900 feet above the level-crested hills in the Mazarn Basin. (See Pl. I.)

A small part of the east end of the Crystal Mountains, including Blakely, Cedar, and a few adjacent ridges, occupies the northwest corner of the district. The Crystal Mountains were so named from the abundance of quartz crystals in the hard sandstones that form their ridges. The ridges in this district are sharp, rugged, and narrow, trend northeastward, and have been cut through at several places by streams.

The Trap Mountains are represented in the Hot Springs district by a belt of high country, 2 to 3 miles wide, along its southern border, but most of the group of ridges to which this name is applied lies outside the district. The ridges have an eastward trend. They are separated by deep, narrow valleys, and have been cut through at many places by streams. Several of the ridges terminate with steep ends in the Mazarn Basin. A rather conspicuous feature of the group is the union here and there of two or more ridges, which produces zigzag ranges like those of the Zigzag Mountains but smaller. The most striking example of this type is Trap Mountain and its adjacent ridges, which unite within the quadrangle in the form of the letter M with its base to the west.

The Mazarn Basin, the east end of which is included in the Hot Springs district, is bounded on the north by the Zigzag Mountains, which project irregularly into it, and on the south by the more even edge of the Trap Mountains. It has been so greatly dissected by erosion that it contains little comparatively level upland. Its surface is undulating and consists of narrow parallel valleys and low ridges and hills that trend east by north. The ridges have been cut transversely by many small streams. The crests of the ridges and hills are fairly even, and most of them are between 500 and 600 feet above sea level. The highest are in the southwest corner of the district. The largest streams have cut their valleys 200 to 250 feet below this upland surface. The lowest point in this basin and in the district is at the place where Ouachita River leaves the district, where the surface stands a little less than 260 feet above sea level.

A small part of the Saline Basin, which extends eastward to the Gulf Coastal Plain, is included in the northeast corner of the district. This part of the Saline Basin is bounded on the south by the Zigzag Mountains, many ridges of which project into it. About the bases of these ridges, as well as farther to the northeast in the part of the basin that is included in the district, there are low, irregular foothills that rise 860 feet above sea level or 200 feet above the large streams, but a short ridge 3 miles southeast of Mountain Valley rises more than 1,080 feet above sea level. Away from these foothills the character of the surface of the Saline Basin differs greatly in different places. In the valley areas the surface is nearly everywhere gently rolling, though there are many steep hill slopes and a few low cliffs near the streams.

In the basin areas the few level tracts and the more gentle slopes are thinly mantled with stony residual soil or with wash from the higher ground. Rock ledges are common, especially 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 outcrops are numerous. There are, however, no large surfaces of bare rock except on the crests of some of the higher ridges and in the gaps, and there are few cliffs. Some of the slopes are bare ledges; others are covered with talus, which consists chiefly of boulders and small fragments of rock. Such material collects in large quantities at many places, especially near the heads of steep-sided ravines, where it forms barren talus slopes. A slope of this kind on Indian Mountain, east of Hot Springs, is known as Hell's Half Acre.

DRAINAGE.

The district is drained through two principal basins, which are separated by a crooked divide in the northeastern part of the Zigzag Mountains. These two basins coincide roughly with the Mazarn and Saline intermontane basins, just described. The principal stream of the Mazarn Basin is Ouachita River, which enters the district from the west and leaves it on the east. The Saline Basin is drained by South Fork of Saline River and other small streams which flow to the northeast and join Saline River after they leave the district.

Most of the streams are parallel with those of the near-by ridges, and the drainage basins that contain the larger streams coincide with the intermontane basins. Many of the streams, however, flow through the ridges, forming water gaps. In the Mazarn Basin Ouachita River and its larger tributaries have in many places cut their valleys transverse to the trend of the low ridges.

This arrangement of the streams, in which many are parallel with the ridges and many are transverse to them and which forms what is commonly known as the "trellis" system of drainage, is fairly well developed in parts of the Trap and Zigzag mountains and in the Mazarn Basin. (See fig. 5.) Drainage of this type is largely the result of the partial adjustment of an ancient system of drainage to the geologic structure, some of the streams having entrenched their courses across the strike of the beds of rock and many of them having cut their valleys wholly or partly in the more easily eroded strata. The cause of the development of this system of drainage is more fully stated under the heading "Geologic history" (p. 10).

Most of the streams are perennial and are supplied by clear water from numerous cold springs, nearly all of them in the mountains. Hot Springs Creek, however, is fed mainly by the waters from the famous hot springs at Hot Springs, whose daily flow aggregates a little more than 800,000 gallons. All

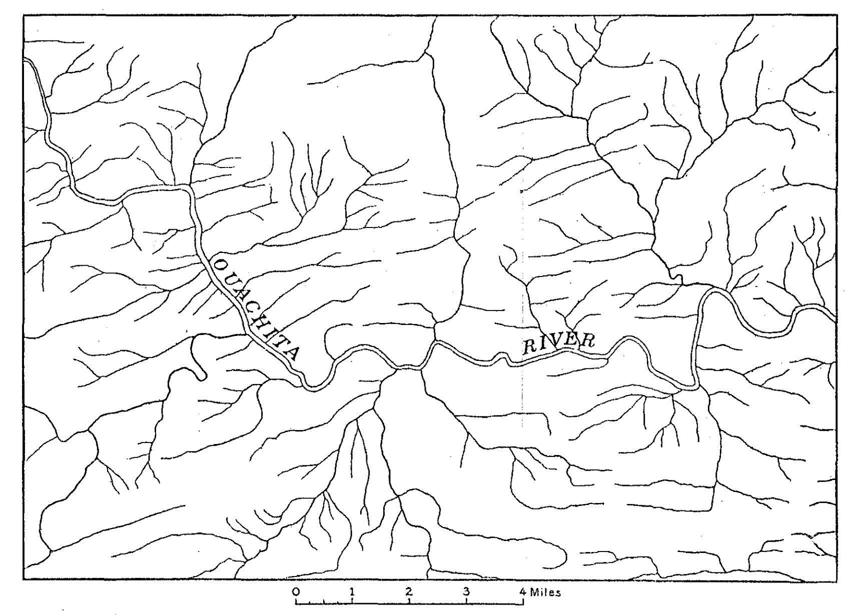


FIGURE 5.—Map showing the drainage of the south half of the Hot Springs district, which illustrates in places a trellis system.

the streams, including Ouachita River, can nearly always be easily forded, but after heavy rains they become dangerous muddy torrents, which subside within a few hours after the rain ceases. The streams form numerous riffles separated by quiet reaches, and they flow in deep, narrow valleys. The few flood plains are narrow and short.

CULTURE.

The district is not densely populated, though all parts of it except the mountainous areas are inhabited. The rural population, most of which is engaged in agriculture, is sparse, because much of the area is unfit for cultivation. Hot Springs, whose population in 1920 was 11,695, is the only city in the district. It has been built around the famous hot springs that issue from the southwest base of Hot Springs Mountain and has become a noted health and pleasure resort. In fact, the growth of the city has been due almost wholly to the utilization of the hot waters for bathing and for medicinal use. The thousands of visitors who annually patronize the springs find accommodation at numerous boarding houses and hotels, the largest of which have a capacity of a thousand guests. The mountains adjacent to the springs are permanently reserved as a national park, which, together with the springs, is under the control of the National Park Service.

Hot Springs is the terminus of three railroads — the Memphis, Dallas & Gulf Railroad, which enters the district from the west, a branch of the Missouri Pacific Railroad, and a branch of the Chicago, Rock Island & Pacific Railway, which enter it from the east. All parts of the district are reached by public roads, but as the soil is stony, the grades steep, and the rainfall heavy, nearly all the roads are poor. The travel is generally so light that little attention is paid to most of the roads, but a few of the main roads are maintained in good condition.

Most of the rural inhabitants are engaged in agriculture, but some of them are employed in lumbering. The operation of bathing establishments in Hot Springs and the sale of water from several cold springs in different parts of the area are important industries. The quarrying of novaculite for oilstones is the only mining done in the area, though some of the clays and shales have been mined from time to time for making brick and pottery, and a small amount of building stone is quarried here and there for local use.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

STRATIGRAPHY.

The rocks exposed in the Hot Springs district are all of sedimentary origin except those in two small areas composed of igneous rocks and numerous associated dikes and sills that were intruded into the sedimentary series late in Lower Cretaceous or early in Upper Cretaceous time. The sedimentary rocks consist of shale, slate, chert, limestone, sandstone, novaculite, and conglomerate and have an estimated maximum thickness of about 8,500 feet. They are grouped into ten formations composed of beds whose sequence, thickness, character, and diversity are shown in the columnar-section sheet. The fossils, lithologic character, and stratigraphic position of these formations show that they belong to the Ordovician, Silurian, Devonian, and Carboniferous systems. At a few places these older formations are overlain by beds of gravel of Tertiary or Quaternary age. The ages and names assigned to these formations from time to time as further knowledge of the Ouachita region has been gained are shown in the correlation table on page 12.

ORDOVICIAN SYSTEM.

LOWER ORDOVICIAN SERIES.

MAZARN SHALE.

Character and distribution.—The Mazarn shale is so named from Mazarn Creek, at the headwaters of which, in the northeast corner of the Caddo Gap quadrangle, it is conspicuously exposed.

In the Hot Springs district the Mazarn shale is exposed in narrow northeastward-trending rough valleys in the vicinity of Blakely and Cedar mountains. The formation consists predominantly of shale, although in places it includes some chert, limestone, and sandstone. Not all of it is exposed in the district, but about 1,000 feet of it is exposed in the valley north of Cedar Mountain, where the outcrop is widest, though the beds are so intricately folded that an accurate determination of the thickness is impossible. Much of the shale is black, clayey, and fissile, but some of it consists of green layers about an inch thick and alternating darker layers. Slaty cleavage at an angle to the bedding has been developed in the beds at many places, where the differently colored layers produce ribboned shale. (See Pl. IV.) Most beds of the shale weather to a red plastic clay, but some form a light-colored clay. Numerous thin veins of white quartz cut the shale in all directions, and in the more level areas where this formation is the surface rock much residual quartz derived from the veins is scattered over the surface.

The limestone, which appears to be near the middle of the Mazarn formation, is several feet thick, is hard, blue, fine grained, and thin bedded, and is also intersected by numerous veins of white quartz.

The sandstone of the formation, though small in amount, is found at many places. It is gray, laminated, fine grained, and quartzitic, and it occurs in layers that in some places reach a thickness of a foot or more. Flint in thin beds was observed near the top of the formation at a few places. It is dense, is gray to black, and breaks with a perfect conchoidal fracture.

Age and stratigraphic relations.—The Mazarn shale contains few fossils. Those that have been found in it and in younger Ordovician formations in this region consist chiefly of graptolites, which may generally be looked for only in black shale that splits into slabs that have smooth surfaces parallel to the bedding planes. On such surfaces the graptolites appear as white or black delicate pencil-like markings, which are usually toothed like a saw on one or both sides. No graptolites have been obtained from the Mazarn shale in the area here described, but two collections have been made from it near Womble, Montgomery County, and another at a locality 12 miles west of Little Rock. According to Ulrich the graptolites in these two collections indicate that the Mazarn shale is of the same age as the lower part of the Beekmantown (Lower Ordovician) limestone of the Appalachian region.

The base of the Mazarn shale is not exposed in the area here described, but it is exposed in the Caddo Gap quadrangle, where the Mazarn is underlain, conformably, it seems, by the Crystal Mountain sandstone, probably of Ordovician age.

An unconformity at the top of the Mazarn is suggested by the local occurrence of a conglomerate at the base of the overlying Blakely sandstone, but the unconformity is not established.

BLAKELY SANDSTONE.

Character and distribution.—The Blakely sandstone is so named from Blakely Mountain, in the northwest corner of the Hot Springs district, where it is typically developed.

The Blakely sandstone is exposed in the Hot Springs district in narrow northeastward-trending belts, which are all in the vicinity of Blakely and Cedar mountains, though there is a small exposure on a ridge about 3 miles southeast of Mountain Valley. The narrowness of these belts is due to the high inclination of the strata. The formation consists of about 500 feet of interbedded shale and sandstone, of which the shale forms probably 75 per cent. Though the shale thus preponderates, the sandstone is resistant enough to form sharp, rugged ridges that in places attain an elevation of 600 feet above the valleys and that form some of the roughest topography in the district. The shale is black and argillaceous and much of it is ribboned, and it is therefore not unlike the Mazarn and Womble shales. (See Pl. IV.) The sandstone occurs in beds that are at most places only a few feet thick but at others measure as much as 40 feet; and one bed on Little Glazypeau Creek is 80 feet thick. It is made up of medium-sized quartz grains firmly cemented together, in most beds by silica but in others by calcium carbonate. Thus there are two kinds of sandstone, one quartzitic and the other calcareous. The quartzitic sandstone is light gray to bluish gray, laminated, extremely hard, and much jointed, and it disintegrates slowly on weathering. As a result of its resistance to weathering the crests of the ridges are generally covered with large quantities of angular boulders, which are piled up in great heaps, suggesting numerous massive beds, though in fact most of the beds are thin and are separated by thick beds of shale. The calcareous sandstone is bluish black, and its limy material dissolves out on weathering, leaving a friable stone that ranges in color from gray to brown.

The sandstone is intersected by numerous veins of quartz, most of them less than half an inch thick, which are so abundant that they are found in most of the larger fragments. Magnificent quartz crystals, many of them clear and as much as 5 inches long, are found here and there in the thicker beds, where they form combs that line fissures along joints and bedding planes. Small quantities of these crystals are mined and are sold in Hot Springs as cabinet specimens or souvenirs. Most of the beautiful quartz crystals found in Arkansas, however, are obtained from the Crystal Mountain sandstone, which is exposed farther west in the State.

A conglomerate that is only a few inches thick and that consists of small rounded pebbles of black chert in a sandy matrix was observed at a few places at the base of the Blakely sandstone. Moreover, near the middle of the formation there is a conglomerate a few feet thick, which consists of small rounded pebbles of chert and limestone embedded in a sandy, calcareous bluish-black matrix. At one place near the top of the formation there is a conglomerate 18 inches thick, which consists of a black shale matrix with small pebbles of sandstone and numerous cavities that were once probably occupied by pebbles of limestone.

Layers of sandstone occur near the top of the shale that underlies the Blakely sandstone as well as near the base of the shale that overlies it, and the lower and upper contacts of the formation are therefore fixed arbitrarily except where they are marked by a characteristic bed, like the conglomerate at the base. This conglomerate suggests that the Blakely sandstone may be unconformable with the Mazarn shale below.

Age.—Graptolites have been obtained from shale near the middle of the formation in the deep ravine in the NE. ¼ sec. 29, T. 1 S., R. 20 W., which contains a northwestward-flowing intermittent stream. They indicate that the lower part, at least, 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.

Character and distribution.—The Womble shale is named from the town of Womble, part of which is built on the base of the formation. It is exposed over small areas in the Saline Basin, in the northeast corner of the Hot Springs district, and in the vicinity of Blakely and Cedar mountains, in the northwest corner. The exposures form narrow northeastward-trending belts, the largest of which is in the Saline Basin. These belts are valley areas containing low, irregular hills.

The formation is about 250 feet thick in the extreme northwest corner of the district, but farther south and east it is about 900 feet thick. It consists of shale and some thin beds of sandstone and limestone, and it closely resembles the Mazarn shale. The shale is black, rather hard, and argillaceous and splits into thin pieces when struck with a hammer, but on the whole it is somewhat darker than the Mazarn shale and its green layers are less numerous than those of the Mazarn. The occurrence of slaty cleavage at an angle to the bedding in the shale with the green layers produces ribboned surfaces. (See Pl. IV.) At the top of the formation there is some black chert in thin layers and black siliceous shale, both of which become gray on weathering. These beds greatly resemble the basal beds of the Bigfork chert, and the Womble shale therefore seems to grade lithologically into this chert. Most of the shale changes to light-colored plastic clay on weathering, but in many places the clays have been stained with iron oxide. White vein quartz is abundant in the formation, and the thin mantle of soil contains enough of it in places to make the surface white. The limestone occurs in lentils 20 feet or more in thickness and is confined almost entirely to the northwest corner of the district, where it is exposed at a few places. It is hard, blue, and compact, occurs in layers that range from half an inch to 12 inches in thickness, and is intersected by numerous quartz veins half an inch or less in width. The sandstone, which is a very subordinate constituent of the formation occurs as widely separated beds near its base and is exposed over considerable areas. It is hard, ranges in color from gray to blue, and its layers are commonly 6 inches or less in thickness, though some of them have a thickness of 3 feet.

Age.—Graptolites representing two faunas have been collected in the quadrangle. 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 by a single collection, obtained from a bed near the base of the Womble shale in the NW. ¼ sec. 29, T. 1 S., R. 20 W., and said by Ulrich to be a Mazarn shale fauna, but the field relations apparently indicate that the shale yielding the fauna overlies the Blakely sandstone.

MIDDLE ORDOVICIAN SERIES.

BIGFORK CHERT.

Character and distribution.—The Bigfork chert is named from Bigfork post office, Polk County, Ark., where it is typically developed over a rather large area.

It crops out in northeastward-trending belts in the Zigzag Mountains and the Saline Basin and in two small areas in the extreme northwest corner of the district and two narrow eastward-trending belts in the Trap Mountains in the southeast corner. These belts are characterized by shallow valleys and low, steep-sided rounded knobs. Owing to the intense crumpling of the beds its thickness can not be accurately measured, but it is estimated to be about 700 feet. (See Pl. II.)

The formation consists of chert interbedded with some shale and a little sandstone. It gradually passes into the overlying Polk Creek shale by a thickening of its shale beds at the top and a decrease in the number of its chert layers. The chert is commonly in even-bedded layers, but in places these layers become thinner or thicker abruptly. The thickness of the layers ranges from 1 to 18 inches and is commonly from 3 to 6 inches. Parts of it are finely and beautifully laminated. It is very brittle and under the blows of a hammer flies into small pieces that show an uneven or, less commonly, a conchoidal fracture. Where unweathered it is black and dense, but where weathered it varies from slate-colored to dark gray, chiefly the former, and some of it is rather porous. Parts of the formation contain small quantities of disseminated calcite and pyrite. Numerous joints, many of which are straight and have remarkably smooth glossy surfaces, form a network that cuts the layers in all directions. So numerous are these joints, along which the stone readily breaks, that it is rather difficult to obtain a hand specimen that shows fresh surfaces. Most of the joints are occupied by fine quartz veins, which contain a little calcite. The layers are generally very intricately folded, and the strain that accompanied this intricate folding probably produced the network of joints. (See Pl. II.) As a result of the minute jointing the formation breaks down rapidly on weathering, so that large quantities of finely broken material collect at the base of the knobs; but good exposures of rock are numerous along the steeper slopes and in the stream beds.

The shale, which is black and graphitic, occurs in layers that range from a fraction of an inch to several feet in thickness and is distributed in greater or less amounts through the formation. The thickest beds lie at the base, where much of the material is siliceous and on weathering changes to a light-gray rock that disintegrates into splintery fragments that have needle-like points.

The sandstone is exposed in places in the Zigzag Mountains. It is fine grained, gray, and thin bedded and is confined to the top of the formation. At one place on the northwest slope of Glazypeau Mountain it reaches a thickness of fully 50 feet.

Limestone was observed within a few feet of the top of the formation half a mile east of Bonanza Springs. It is dense, finely crystalline, and bluish black, occurs in layers that are 1 foot in maximum thickness, and is interbedded with chert and shale.

Age.—Fossils are rare in the Bigfork chert and consist chiefly of graptolites, though other invertebrate remains, which are indeterminable, have been found at a few places in the Ouachita Mountains. Sponge spicules occur in the chert in southeastern Oklahoma, but they have not been found in Arkansas. The only fossil collection from this formation in the Hot Springs district consists of poorly preserved graptolites from shale at the top of the formation half a mile east of Bonanza Springs. Ulrich states that these graptolites and also the graptolites from other parts of west-central Arkansas suggest species found in the lower Hartfell shale of Scotland rather than any found in standard American sections. 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 layer of chert and in associated limestone within 50 feet of the top of the formation on Blaylock Creek in the De Queen quadrangle. Concerning them Ulrich says that they represent possibly 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.

UPPER (?) ORDOVICIAN SERIES.

POLK CREEK SHALE.

Character and distribution.—The Polk Creek shale was named from Polk Creek, in the Caddo Gap quadrangle, along the headwaters of which it is typically exposed. In the Hot Springs district it is exposed on the slopes of the Zigzag Mountains or in valleys near their bases and is similarly exposed in two long, narrow areas in the Trap Mountains, in the southeast corner of the district. The outcrops form narrow belts whose slight width is due to the thinness and to the steep dips of the formation and whose trend is parallel with that of the higher ridges on or near which the exposures occur.

Most of the outcrops of this formation are found along ravines and stream beds; at other places it is covered by residual material either from the shale itself or from adjacent beds that crop out higher on the slopes. The shale is thickest near Hawes, at Hot Springs, at Potash Sulphur Springs, and in the Trap Mountains. At all of these places it reaches a thickness of 200 feet, but it becomes thinner northeastward, in the Zigzag Mountains, so that near the ends of the ridges, a few miles north and northeast of Hot Springs, its thickness at most places probably does not exceed 25 feet.

The Polk Creek shale is black, fissile, and graphitic. Some beds of it are clayey and are soft and graphitic enough to soil the fingers; others, especially in its lower part, have been changed to hard sonorous slate, which has a cleavage that is in places at an angle with the bedding and in others is parallel with it. On weathering it becomes a soft gray platy stone or changes to clay. Thin layers of dense black chert, like that of the Bigfork formation, and beds of hard quartzitic sandstone are common, but they constitute a very small part of the formation. The Polk Creek formation, like the formations below and above it, has been intensely crumpled and therefore contains many slickensides and joints. Thin veins of white quartz occur along the joints and bedding planes, and small crystals of disseminated pyrite can be found in nearly all fresh exposures.

Age and stratigraphic relations.—Fossils consisting almost entirely of graptolites are rather plentiful in the Polk Creek shale, especially in its basal part, and can be found in nearly all good exposures. According to Ulrich the graptolites are comparable with British species found in the Hartfell shale, chiefly in the upper Hartfell, which is at the top of the Ordovician.

In the Trap Mountains the Polk Creek shale is overlain by the Blaylock sandstone, of Silurian age, and in the Zigzag Mountains, where the Blaylock is absent, by the Missouri Mountain shale, also of Silurian age. That an unconformity exists between the Missouri Mountain and Polk Creek shales where the two are in contact is indicated by the presence and the character of a conglomerate between them. No physical evidence of an unconformity between the Polk Creek shale and the Blaylock sandstone has been observed in the Hot Springs district.

SILURIAN SYSTEM.

BLAYLOCK SANDSTONE.

Character and distribution.—The Blaylock sandstone is named from Blaylock Mountain, on Little Missouri River, in the southwest corner of Montgomery County, Ark., where it is well exposed at the east end of the mountain. The Talihina chert in southeastern Oklahoma, as defined by Taff, does not include the Blaylock sandstone, for the Blaylock is not found in Oklahoma except in McCurtain County, but the Talihina chert includes beds that are both older and younger than the Blaylock. (See correlation table on p. 12.)

The Blaylock sandstone is exposed only in the Trap Mountains, along the southern border of the Hot Springs district. Its outcrops, which are rough rocky strips that trend nearly east and west, lie in narrow valleys between high ridges. The estimated thickness of the sandstone on the head of Cooper Creek in the southeast corner of the district is 300 feet and that part exposed in the southwest corner is 550 feet. The formation thins out northward and is absent in the Zigzag Mountains, north of the Mazarn Basin.

The formation consists of sandstone and of varying though subordinate amounts of shale. At some places it is composed almost wholly of sandstone; at others of alternating beds of sandstone and shale. The sandstone occurs in remarkably even-bedded layers, most of them 1 to 6 inches thick, though at a few places they reach a thickness of 3 feet. Most of the sandstone is hard, dense, light gray to dark gray or green, homogeneous, and quartzitic, but some of it is soft, yellow, and laminated and splits into more or less parallel plates when struck with a hammer. It consists of fine grains of quartz and a little mica, with quartz as the cementing material. 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 loose angular fragments that lie scattered over the surface, and in places it has become brown, though in others it remains gray. The interbedded shale, which makes up a considerable part of the formation, is micaceous and dark and in many places black and fissile.

Age.—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 belonging to species that, according to Ulrich, are not comparable with any found in America but that have been found in the Birkhill shales of Scotland, which are considered the base of the Silurian system in Great Britain. Ulrich therefore regards the Blaylock as of early Silurian age.

Stratigraphic relations.—The Blaylock sandstone is conformable with the underlying Polk Creek shale so far as can be determined in the Hot Springs district, but a local conglomerate in the De Queen quadrangle suggests a stratigraphic break at this horizon. An unconformity at the base of the succeeding formation, the Missouri Mountain shale, also regarded as of Silurian age, is indicated by a conglomerate found at its base in the Zigzag Mountains, but the Blaylock sandstone, as already stated, is not found there. The sudden appearance of the Blaylock sandstone and its abrupt thickening from the north toward the south suggests an unconformity at its top, but the explanation here offered to account for this change in thickness is that it was laid down in a rapidly subsiding trough whose northern border extended east and west across the southern part of the Ouachita area.

MISSOURI MOUNTAIN SHALE.

Character and distribution.—The Missouri Mountain shale is named from the Missouri Mountains, in Polk and Montgomery counties, Ark., where it is well developed, but the term slate is applied to the formation in those areas because it has been so greatly changed by regional metamorphism that it can be split into thin, even sheets, which are in places suitable for commercial use.

The Missouri Mountain shale includes, in the area here described, from 50 to 150 feet of shale. The thinnest part is on the northeast ends of the ridges a few miles north and northeast of Hot Springs, and the thickest part is at their southwest ends. In the Trap Mountains it is generally about 100 feet thick, but in places it appears to be somewhat thicker.

The formation crops out in narrow belts in the Trap and Zigzag mountains. These belts are in some places on one side and in others on both sides of the ridges, their position depending on the structure, which may be either monoclinal or synclinal. The surface in these belts is in large part covered with residual material from the formation itself and with débris from other formations higher up on the ridges. Consequently exposures of the shale are not common except on the steeper slopes and in or near stream beds.

The formation consists of shale, a bed of conglomerate at the base, of at least local occurrence, and a few thin layers of sandstone and quartzite. The conglomerate as exposed on Glazypeau Creek, at the western edge of the district, is 4 feet thick and is composed of limestone pebbles and cobbles, the largest a foot in diameter, and of waterworn chert pebbles in a matrix of black sandy shale. A few other outcrops of the conglomerate were found at places in the Zigzag Mountains, but in these places the bed is thinner than it is on Glazypeau Creek and the pebbles are smaller.

The shale is soft and argillaceous, contains minute flakes of light-colored mica, and ranges in color from dark greenish drab to black, though in some exposures it is red and in others it is prevailingly black, as it is, for example, in the stream bed about half a mile southwest of Big Chalybeate Spring. The exposed parts are commonly buff, green, yellow, and reddish brown, and in many outcrops the black shale on weathering gradually changes through green to buff. In Polk and Montgomery counties, to the west, where the formation is thickest, the prevailing colors are red and green. In most if not all these places the green shale is less common. The shale is dissected by numerous joints, which run in all directions. Where it has been altered to slate it has well-developed cleavage, in some places parallel with the bedding and in others oblique to it, so that it can be split into thin pieces, which usually have even, glossy surfaces. Small crystals of iron pyrites are common in the shale.

The sandstone and quartzite are in layers 3 to 5 inches thick, near the base and the top of the formation. They are gray and hard and are composed of rounded translucent grains of quartz.

Age and stratigraphic relations.—In the Trap Mountains, along the southern border of the Hot Springs district, the Missouri Mountain shale overlies the Blaylock sandstone, of Silurian age, with apparent conformity. Farther north, in the central part of the district, it overlaps that sandstone and rests unconformably on the Polk Creek shale, of Ordovician age. The Missouri Mountain shale is apparently conformable with the overlying Arkansas novaculite, into which it seems to grade lithologically, as indicated by the presence of thin beds of shale, like the Missouri Mountain shale, in the lower part of the novaculite; but in the northern part of Hot Springs and on Indian Mountain the novaculite is separated from the Missouri Mountain shale by a 2-foot bed of conglomerate. This conglomerate, however, can not be considered basal. It may have been derived by surface wash from near-by land areas.

The position of the Missouri Mountain shale, which lies between the Blaylock sandstone, of early Silurian age, and the Arkansas novaculite, the lower part of which is probably of Oriskany (Lower Devonian) age, suggests that this shale also may belong to the Silurian system. This suggestion is supported by some indications of an unconformity at the top of the shale, but it is negatived by the fact that a conglomerate occurs, at least locally, at the base. The nearest exposures of Silurian rocks outside the Ouachita Mountains are in the southern Ozark region of northern Arkansas and northeastern Oklahoma, in the Arbuckle Mountains in southern Oklahoma, and on the southwest flank of the Nashville dome in Tennessee. The beds of this system are poorly represented in the Ozark region and the Arbuckle Mountains, and no part of them resembles the Missouri Mountain shale. They are, however, well developed on the southwest flank of the Nashville dome, where they are succeeded by strata of Helderberg, Oriskany, and later age. Their stratigraphic position with respect to the overlying rocks is thus essentially the same as that of the Missouri Mountain shale, except that rocks of Helderberg age are absent in the Ouachita Mountains or, if present, have not been recognized. Although these Silurian rocks of Tennessee consist mainly of pure limestone, they include considerable thicknesses of gray earthy and shaly limestone, which, in the basal part of the strata of Niagara age, becomes red as the Mississippi embayment is approached. It therefore seems reasonable to assume that the Missouri Mountain shale is equivalent to at least a part of the Silurian beds in Tennessee. The land area that supplied the red mud for these rocks probably lay to the south, in northern Louisiana and eastern Texas.

DEVONIAN SYSTEM.

ARKANSAS NOVACULITE.

Name.—The Arkansas novaculite consists predominantly of a rock to which the name novaculite was first applied by Schoolcraft in 1819. This name is now in general use. The authors of this folio regard the rock as a chert, though many different opinions concerning its origin have been expressed by other writers.

As compared with other sedimentary rocks, such as shale, sandstone, limestone, and ordinary chert, novaculite is uncommon; but in the Hot Springs district and in other parts of the Ouachita Mountains it is widely distributed, for its outcrops extend through much of their length, a distance of about 200 miles. It is thickest and best developed and has its largest areal extent in Arkansas, and the formation has therefore been appropriately called the Arkansas novaculite. In southeastern Oklahoma it constitutes the upper part of the Talihina chert.

Distribution and surface form.—The Arkansas novaculite is exposed at many places in the Trap and Zigzag mountains. In these places, as in others in the Ouachita area, the outcrops form narrow, more or less parallel belts, whose narrowness is due to the steep dips of the formation. The novaculite is very resistant to erosion and therefore forms high ridges, but in the Zigzag Mountains, where it is overlain by the Hot Springs sandstone, this sandstone forms many of the crests of the ridges. The crests produced by the Arkansas novaculite, though generally even, are in places interrupted by low peaks, such as the one at the west end of West Mountain and one at the east end of Trap Mountain.

The novaculite is brittle and much jointed, and it therefore breaks down into angular blocks of many sizes, which at many places on the ridges form a layer of surficial material. At other places, however, particularly along the crests of the ridges and in the water gaps, the edges of the beds themselves project through the surficial material and form rough, bare ledges.

Thickness.—The formation ranges in thickness from a maximum of 800 feet on Mount Carmel Creek, at the southern border of the district, to a minimum of 100 feet, near Hawes. Its thickness on Central Avenue, in Hot Springs, is about 510 feet. This thinning toward the north is partly due to an unconformity at the top of the formation and to one or more local unconformities within it.

Character.—In the Hot Springs district and in many other parts of the Ouachita Mountains the Arkansas novaculite consists of three lithologic divisions—a lower division, composed almost entirely of massive white novaculite; a middle division, composed mainly of thin layers of dense, dark novaculite interbedded with shale; and an upper division, composed of massive, highly calcareous novaculite.

The lower division reaches a maximum thickness of 425 feet on the south side of the district, but, like the whole of the formation, it abruptly becomes thinner to the north. It is only about 275 feet thick at Hot Springs and is absent at a few places near Hawes. This division is composed almost wholly of typical novaculite, whose color and massiveness make it the most conspicuous part of the formation. In fact, it is this division that occupies the crests of the high ridges produced by the formation. The beds are from 2 to 10 feet thick and are commonly of uniform thickness, though at some places they occur as thin lenses. Some of the exposed bedding planes show large uneven ripple marks. Thin layers of laminated gray sandstone, which is composed of rather well rounded quartz grains 0.25 millimeter or less in diameter, are interbedded with the novaculite at a few places in the lower part of the formation.

A 2-foot bed of conglomerate and a few thinner beds occur at the base of the formation on the northwest slope and near the southwest end of North Mountain in Hot Springs; they are separated from the heavy novaculite by 4 feet of red clay shale, like that of the Missouri Mountain shale. These conglomerates consist of partly rounded pebbles of sandstone and novaculite in a matrix of dense novaculite. In other parts of the district, as well as at other places in the Ouachita Mountains, a foot or more of such shale occurs near the base of the formation and is underlain by thin beds of novaculite.

The massive novaculite is commonly dense, gritty, fine grained, homogeneous, highly siliceous, translucent on thin edges, and white with a bluish tint or, where unweathered, bluish gray. Though the rock is mostly white, much of it shows various shades of red, gray, green, brown, yellow, and it is in many places black. These shades are produced by iron and manganese oxides and carbonaceous matter. It has an uneven to conchoidal fracture (see Pl. III) and a waxy luster like that of chalcedony. In places, especially near the base, it exhibits fine parallel laminae, and here and there it contains cavities that are oval in cross section and half an inch in their longest dimension, besides other cavities that are smaller or of irregular shape. The rock contains a little calcite, but exposures of the calcareous stone are not common and have been found only in stream beds. Much of the white novaculite, as pointed out by Owen, 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 noticeable are those that are normal to the bedding. (See Pl. VII.) Many of them are occupied by white quartz veins, most of which are so thin as to be inconspicuous. Slickensides along both joints and bedding planes are common.

The middle division of the formation ranges in thickness from 10 feet, on Hot Springs Mountain, to 345 feet, in the Trap Mountains. It consists of interbedded shale and novaculite. The novaculite is similar to that in the lower, massive division of the formation, except that it is dark gray to black and that the beds are much thinner, generally 1 to 6 inches thick. Some thin layers are argillaceous and possess a fairly good cleavage, resembling in these respects a highly siliceous shale. The shale is in beds that range in thickness from a few inches to as much as 100 feet. It is commonly black, fissile, and clayey, and much of it weathers buff or reddish brown, but near Hawes this division of the formation contains 100 feet of red slate. This red slate, which is fairly hard and has a good cleavage, has at a few places been prospected for use as building material. Although its color is the same as that of parts of the Missouri Mountain shale, it differs from that rock in having dull cleavage surfaces and in exhibiting faint elongated markings on surfaces that are parallel with the bedding.

At some localities in the Zigzag Mountains layers of conglomerate from 1 inch to 2 feet thick replace the layers of novaculite of this division. The matrix of this conglomerate is very compact novaculite, and the pebbles are small and well rounded to subangular. Most of them are novaculite, though some are sandstone or other hard material. (See Pl. V.) The fragments of this conglomerate form conspicuous débris, attracting attention because of the smooth, spotted joint surfaces, which are straight and even, irrespective of the hard pebbles. A similar though thicker conglomerate, which is of wide extent northwest of Hot Springs, rests at some places upon the massive novaculite and at others, where the heavy novaculite is absent, upon the Missouri Mountain shale.

The upper division of the formation is persistent in the Trap Mountains, where it generally ranges in thickness from 10 to 30 feet, but it occurs only here and there in the Zigzag Mountains. The maximum observed thickness, 179 feet, is at Hot Springs. This bed is so resistant that it produces many low ridges or knobs on the slopes of the high ridges of the Trap Mountains. It consists chiefly of massive, highly calcareous light-gray or bluish-gray to bluish-black novaculite, but it contains some thin layers of ordinary dense chalcedonic novaculite like that which is so characteristic of the middle and lower parts of the formation. Close lamination parallel with the bedding is common. On weathering the rock loses its calcium carbonate and becomes white or cream-colored, porous, and soft enough to receive impressions from the hammer without breaking. At Hot Springs and northwest of it, much of the rock weathers to a soft, porous fine-grained stone, which in some places consists of tripoli and in others resembles sandstone.

The study of thin sections of the novaculite shows that the calcite occurs as small rhombohedrons 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. Most of the rhombohedrons are 0.05 to 0.08 millimeter across and are bounded by straight walls of quartz, in which the granules are packed like courses of masonry, none of them being included in the calcite. Elsewhere the quartz granules have an irregular arrangement but fit closely together, without any pore space between them. They are angular and generally average less than 0.01 millimeter in diameter, 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 following analyses show the chemical composition of several varieties of novaculite from this formation:

Analyses of Arkansas novaculite.

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

[a] By difference. [b] Very slight.

1. "White novaculite," Hot Springs, Ark.
2. "Gray Arkansas stone," Rockport, 2 miles northwest of Malvern, Ark.
3. "Fine Ouachita," Sutton's quarry No. 6, on Indian Mountain.
4. "Ouachita," Barnes's big quarry, on Indian Mountain.
5. "White Ouachita stone," Ten Mile quarry, 8 to 10 miles east of Hot Springs.
6. "White novaculite," Hot Springs.

1–5. R. N. Brackett, analyst. Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, p. 161, 1892.

6. C. E. Wait, analyst. Am. Jour. Sci., 3d ser., vol. 7, p. 520, 1874.

The material used for the analyses was probably novaculite from which much if not all of the calcite had been leached out by weathering. The designations "Arkansas" and "Ouachita" refer to certain varieties of novaculite suitable for oilstones, which are described under the heading "Economic geology" (p. 10).

Within a belt from a quarter to three-eighths of a mile wide about the igneous intrusive mass at Potash Sulphur Springs the novaculite has been changed by contact metamorphism to a rather coarse grained rock resembling quartzite. The grains of this rock reach a diameter of 0.5 millimeter and gradually decrease in size away from the intrusive mass until the novaculite assumes its usual dense chalcedony-like appearance. Some beds on the southwest end of Hot Springs Mountain near the top of the formation have the appearance of weathered quartzite of extremely fine grain, and the unweathered beds there doubtless have the same texture. In this locality the difference from the usual type may be due to metamorphism by the waters of the hot springs.

The Indians used the novaculite extensively for their stone implements. Many tools made of this rock and the old workshops along the streams where they were fashioned are found in this region. Most of the material used was quarried from the massive novaculite at the base of the formation. Three excavations in this rock on Indian Mountain about a mile east of Hot Springs are said to have been formed in this way.

Stratigraphic relations and correlation.—The Arkansas novaculite conformably overlies the Missouri Mountain shale, but a conglomerate that is possibly of only local occurrence at the base of the Arkansas novaculite indicates a shore line in this region prior to or during the deposition of the lower part of the novaculite. The formation is unconformably overlain by rocks of Carboniferous age—in the Trap Mountains by the Stanley shale and in the Zigzag Mountains by the Hot Springs sandstone, a lenticular formation that underlies the Stanley and that thins out south of the Zigzag Mountains. This stratigraphic break is shown by the thinning out of the beds at the top of the novaculite toward the northwest and by a heavy conglomerate that is of wide though not general distribution at the base of the Carboniferous rocks.

The only fossils thus far found in the formation consist of a single collection of numerous conodonts in a minutely pebbled novaculite conglomerate and of conodonts, small linguloids, and sporangites in the associated shale. These fossils were obtained from the middle division of the formation at Caddo Gap, Montgomery County, Ark., and upon them Ulrich bases the opinion that the middle and perhaps also the upper division should be correlated with the Woodford chert, in the Arbuckle Mountains, and with the Chattanooga shale. As he assigns the Woodford and the Chattanooga to the Mississippian series, he accordingly assigns these two divisions of the Arkansas novaculite to the same series, but the United States Geological Survey classifies the Woodford chert as Upper Devonian and the Chattanooga shale as Devonian or Carboniferous, and as the whole of the Arkansas novaculite is still treated as a unit, of which the lower part is known to be Devonian, its upper divisions are also tentatively assigned to that age.

A study of fossils collected from novaculite beds near Tuskahoma, Okla., by Ulrich has convinced him that the lower division of the Arkansas novaculite is of Oriskany (Lower Devonian) age.

Schuchert in 1908 regarded the Camden chert as of Oriskany age, and the same opinion has been held by Ulrich, Pate, and Bassler; but Dunbar, who has recently studied the Devonian rocks and their faunas in western Tennessee, concludes that the typical Camden chert is of Onondaga and not of Oriskany age. Furthermore, Dunbar has identified and named certain formations that have been included by others in the lower part of the Camden chert. The oldest of those formations, which he calls the Decaturville chert, he regards as of Helderberg age; and both the next (his Quall limestone) and the youngest (his Harriman chert) as of Oriskany age. Of these formations the uppermost two (the Camden chert as restricted by Dunbar and the chert which he designates the Harriman chert) are described by him as really being novaculite, and it is these two formations that the authors have observed at different places in Tennessee and regarded as having much the same lithologic character as the Arkansas novaculite. If the lower part of the Arkansas novaculite is equivalent to the Camden chert, as restricted by Dunbar, it is, according to Dunbar, of Onondaga (Middle Devonian) age; if it is equivalent to the Harriman chert of Dunbar it is of Oriskany (Lower Devonian) age. The middle and upper parts of the formation, as already stated, have been tentatively assigned to the Upper Devonian series.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

HOT SPRINGS SANDSTONE.

Character and distribution.—The Hot Springs sandstone has been so named from the city of Hot Springs, in and near which it is exposed. In this city the formation is 137½ feet thick. Its thickness at some places diminishes to 86 feet, but at some other places it is perhaps more than 200 feet.

The sandstone is exposed along the mountain slopes or crests in the Zigzag Mountains, but it is not found in the Trap Mountains. The outcrops form narrow bands, whose narrowness is due to the thinness of the formation and to its steep dips. In places where the sandstone produces the crests it is no more resistant than elsewhere, but in those places the underlying Arkansas novaculite is generally relatively thin and contains considerable shale.

This formation consists of sandstone and some shale and conglomerate. The shale occurs near the top and the principal bed of conglomerate at the base. The sandstone, which is gray, hard, and quartzitic, is composed of grains of quartz sand that range in size from fine to medium. Its layers are from 3 to 8 inches thick, though here and there they reach a thickness of 6 feet. (See Pl. VIII.) At many places the sandstone shows close lamination parallel with the bedding. Freshly broken surfaces of the rock reveal many fine particles of white clayey material that may be a residue of grains of feldspar or some other mineral. Joints are numerous and extend in all directions, but they are generally normal to the bedding or form a high angle with it. Many are filled by veins of white quartz, the largest 6 inches thick. Some of the veins on weathering show fibrous or comb structure, due to the arrangement of the small crystals at right angles to the walls of the vein. The sandstone layers at the top are separated by thin beds of black shale, which increase in thickness upward in the section, so that the formation passes by gradual lithologic transition into the overlying Stanley shale. The sandstone on weathering breaks up into angular fragments, which lie scattered over the slopes and collect in large quantities as rough material at the heads of steep-sided ravines, such as the one at Hell's Half Acre, on Indian Mountain, east of Hot Springs.

The basal conglomerate appears to form a continuous bed, whose common thickness is 10 to 15 feet, though 2 miles southwest of Bonanza Springs the thickness is 30 feet and near the city water pumping station it is 25 feet. The pebbles are of all sizes up to a diameter of 6 inches, are round to subangular in shape, and consist of white to dark novaculite, principally the white, and a less amount of sandstone. The matrix is composed of sand and argillaceous material, which at a few places is so fine grained that it resembles novaculite. One bed of conglomerate and at many places two beds like that just described, though not so thick, occur higher in the sandstone.

Stratigraphic relations.—The formation overlies the Arkansas novaculite, and the two are unconformable, as is shown by the truncation of the beds of the novaculite and by the widely distributed basal conglomerate. The Stanley shale, which is of Carboniferous age, conformably overlies the Hot Springs sandstone, the two passing into each other by a gradual lithologic transition. These stratigraphic relations form the only evidence available to indicate the age of this sandstone, but they seem sufficient to show that it was the earliest Carboniferous deposit in this region.

STANLEY SHALE.

Character and distribution.—The Stanley shale is named from the village of Stanley, in the Kiamichi Valley, Okla., where it is extensively exposed. As the beds are plicately folded and as none of them possess distinguishable lithologic characteristics the exact thickness of the formation can not be determined, but the part of it that lies in the Hot Springs district is roughly estimated to attain a thickness of 3,500 feet. The thickness of the entire formation in the Caddo Gap quadrangle is 6,000 feet.

The Stanley shale is the surface rock over the whole of the Mazarn Basin and in many of the narrow valleys in the Zigzag and Trap mountains on either side of that basin, its area of outcrop comprising about half of the Hot Springs district and being much larger than that occupied by any other formation.

The formation consists of shale and large but subordinate amounts of sandstone. The shale is clayey and thinly fissile and is in most places bluish black but in others black. Parts of the base are sufficiently graphitic to blacken the fingers when fresh surfaces of it are rubbed. The dark colors prevail along most of the streams and in the deeper artificial exposures where the shale is not weathered; but where the rock is more or less altered by weathering, along the wagon roads and in the shallow exposures high above the streams, the colors are generally green, yellow, and brown. The shale breaks into thin, hard plates with smooth glossy surfaces, on which small flakes of mica are visible. It is so much crumpled in places that the bedding can not be distinguished except where the sandstone is exposed. The final product of weathering is red or yellow clay, in most places only a few inches thick, which covers the indurated rock.

The sandstone, which occurs throughout the formation, is in thick beds, but these are separated by thicker beds of shale. The sandstone beds weather so easily that they produce no prominent ridges. In fact the entire formation crops out only in valleys. Most of the layers of sandstone alternate with layers of shale and are only a few inches thick, but some of them reach a thickness of 2 or 3 feet. The fresh sandstone is hard, compact, quartzitic, rather fine grained, and greenish gray or bluish gray, but the weathered sandstone is soft, porous, and clayey and ranges in color from green to brown. Small flakes of mica are common. Joints in great numbers cut the sandstone and shale beds in all directions, and many of them are occupied by conspicuous veins of white quartz from half an inch to 6 inches thick. A few thin layers of conglomerate composed of small, rounded novaculite pebbles in a dense, fine-grained siliceous matrix that resembles novaculite are found near the base of the formation. Nodules of phosphate rock, which attain a thickness of 2 inches, occur in the shale at a few places. These nodules are black, have a rather high specific gravity and a fracture that ranges from platy and even to conchoidal, and weather white or yellow on exposed surfaces. Analyses of two similar nodules from the De Queen quadrangle show 13.28 and 23.07 per cent of tricalcium phosphate respectively.

Age and stratigraphic relations.—The Stanley, the younger formation of Carboniferous age in the Hot Springs district, conformably succeeds the Hot Springs sandstone but overlaps that formation toward the south, so that in the Trap Mountains, along the southern border of the district, it rests unconformably on the Arkansas novaculite. Though a stratigraphic break separates these Carboniferous rocks from the Arkansas novaculite, the erosion surface over which the Carboniferous sea transgressed was very even. Except the Tertiary and Quaternary gravels the Stanley is the youngest formation in the district, but in the parts of the Ouachita Mountain region to the north, south, and west of the district it is overlain by the Jackfork sandstone and other rocks, also of Carboniferous age.

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. The overlying Jackfork sandstone, which is of equal extent and thickness, has yielded only a few indeterminable invertebrate fossils, but the Caney shale, which rests upon the Jackfork in parts of Oklahoma, has furnished a rather large invertebrate fauna. These three formations, together with the Hot Springs sandstone at the base of the Stanley, are believed from lithologic and stratigraphic evidence to comprise essentially a single series of beds and are assigned by the United States Geological Survey to the Mississippian series. White reports that on the whole the plant material from the Stanley shale, which consists mainly of minute fragments, though it is in part closely related to species known from the Pottsville, appears to be more closely related to the floras of the Carboniferous limestone, probably of Chester age, of the Old World.

G. H. Girty has supplied the following statement regarding the age of the Caney shale:

> When the formation was first mapped and its fauna was first described the Caney shale was referred, as it is now, to the upper part of the Mississippian series, and since this conclusion was formed much evidence has accumulated that tends strongly to corroborate the opinion that it is of Mississippian age. The Caney fauna has conspicuously the facies of the Mississippian faunas of the adjacent areas in Oklahoma and Arkansas. Furthermore, the fauna of the Wapanucka limestone, which overlies the Caney shale, is closely allied to that of the Morrow, which overlies the Mississippian rocks in near-by areas, and without much doubt represents the same geologic period.

TERTIARY (?) AND QUATERNARY DEPOSITS.

Unconsolidated deposits of variable thickness, ranging from a thin mantle to a bed at least 30 feet thick, occupy a narrow, flat-bottomed valley near the southeast corner of the Hot Springs district and cap a few hills near Hawes and Lawrence and a hill southwest of May. These deposits consist mainly of pebbles of novaculite and sandstone, some of them several inches in diameter, which are here and there interbedded and intimately mixed with sand and clay. At some places the pebbles are well rounded; at others they are subangular. These deposits, which were once probably very extensive, were probably laid down in Tertiary time or later by Ouachita River and other streams when they ran at a higher level than at present. Most of the loose material of these deposits was removed while the streams were cutting their valleys into the underlying hard upturned rocks. The deposit of gravel in the valley near the southeast corner of the district may be an outlier of larger deposits of Tertiary gravel that occur about 2 miles farther southeast.

Alluvial deposits are rare along the bottoms of the valleys, but those that occur form small tracts of the best farming land in the district.

STRUCTURE.

GENERAL FEATURES.

The sedimentary rocks of the Hot Springs district were originally laid down on the bottom of the sea in nearly horizontal beds. At present, however, the beds are not generally horizontal but are inclined at many angles, so that their edges appear at the surface. When the formations are crossed north and south, they are seen to lie in a series of folds (anticlines and synclines), and at a few places the beds have been displaced by faulting. The beds in the district, as well as in other parts of the Ouachita Mountain region and in the Arkansas Valley, were compressed into folds near the middle of the Pennsylvanian epoch, although they were slightly warped much earlier.

in the valleys. Many adjacent folds are nearly of the same height, and the same beds reappear at their several crests. The dip of the beds in places changes in magnitude or in direction within a mile along the strike, and this change may cause a single fold to break up into two or a symmetrical fold to pass into a closely compressed one in which the beds are parallel. Two structure sections of the same mountain or valley only a mile apart may therefore be quite different. Most of the folds have been compressed until their sides are parallel, so that the rocks on one side have been bent through an angle of more than 90°. Folds whose sides are parallel and therefore dip in the same direction are known as overturned folds. They are numerous in the Trap Mountain and Crystal Mountain anticlinoria. The folds in the Crystal Mountain anticlinorium have been overturned from the northwest, toward the Mazarn synclinorium, whereas those in the Trap Mountain anticlinorium have been overturned from the south, toward the same synclinorium. (See fig. 6.) In most places the folds are smallest, most numerous, and most closely squeezed in the shales and thin-bedded sandstones and cherts. (See Pls. II, V, and VI.) Joints in several sets and slickensides are found in all the rocks but are most numerous in those just named. (See Pl. VII.)

Faults are common, though not so common as might be expected in beds that have been so closely compressed, because of the great predominance of thin-bedded strata over massive beds like the Arkansas novaculite. Thrust faults are the usual type, and most of them were produced by the breaking of the strata in closely compressed anticlines, so that they are generally parallel with the folds or nearly so, and the fault planes dip in the same direction as the broken overturned strata.

The beds have been changed from unconsolidated sediments to hard, compact rocks, such as sand to sandstone and clay to shale, but have otherwise been metamorphosed very little.

FOLDING.

Crystal Mountain anticlinorium.—The small part of the south side of the Crystal Mountain anticlinorium that is included in the Hot Springs district comprises the Zigzag Mountains and adjoining areas to the north. The greatest uplift of this part of the anticlinorium, as well as the greatest in the district, is near Blakely and Cedar mountains, where the Mazarn shale is exposed. From these mountains southeastward to Potash Sulphur Springs the individual anticlines that constitute this large structural feature are not quite so high, though, together with their intervening synclines, they trend northeastward, like those of the Blakely Mountain and Cedar Mountain area. The axes of the folds in this belt have been tilted at comparatively high angles to the southwest, thus exposing the oldest rocks to the northeast and the youngest to the southwest. The plunging anticlines and synclines alternately interlock in such a way that the truncated upturned edges of the beds zigzag across the country, the more resistant ones forming the high ridges and the less resistant ones the valleys. The larger anticlines in the Zigzag Mountains are all of about the same height, and the same formations thus appear and reappear in them. The dips generally exceed 45° and are almost uniformly to the northwest, except at the ends of the folds, where they are in two directions, forming there somewhat symmetrical folds; but even in some of these places the dips, though of different magnitude, are in the same direction.

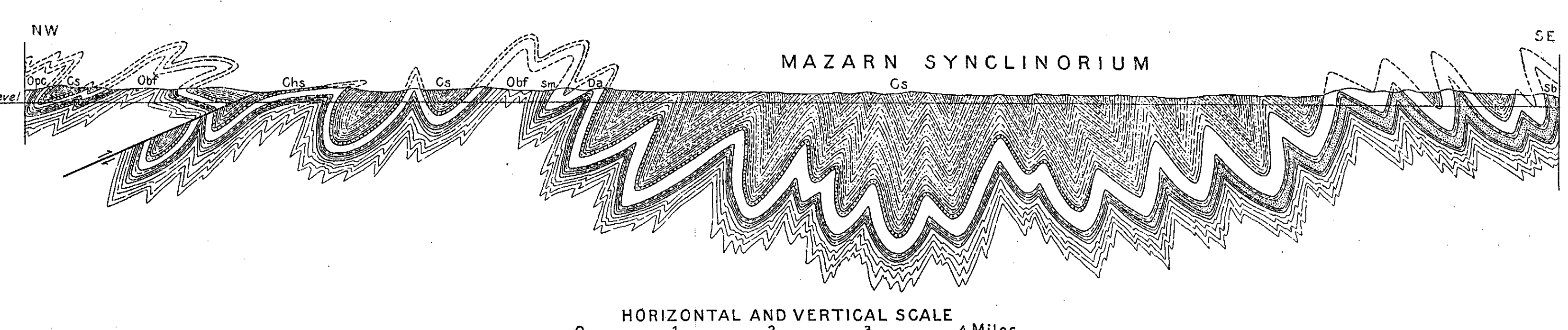


FIGURE 6.—Structure section across part of the Hot Springs district, showing the overturning of the folds of the Crystal Mountain and Trap Mountain anticlinoria toward the Mazarn synclinorium. Cs, Stanley shale; Chs, Hot Springs sandstone; Da, Arkansas novaculite; Sm, Missouri Mountain shale; Sb, Blaylock sandstone; Opc, Polk Creek shale; Obf, Bigfork chert.

The structure of the district is shown on the structure section sheet by six cross sections, which represent the strata as they would appear in the sides of a deep trench cut across the country. These sections represent the structure as it is inferred from the position of the layers observed at the surface, and as the vertical and horizontal scales are the same the sections show in miniature the actual form and slope of the land and the actual dips of the beds. Sections drawn on the scale of the map, however, can not represent the smaller features of the structure; they are somewhat generalized from the dips observed in belts a few miles wide along the lines of the sections. Faults are represented on the map by a heavy solid or broken line and in the section by a line whose inclination shows the probable dip of the fault plane, the arrows indicating the direction in which the strata have been moved on opposite sides of the fault plane.

The Hot Springs district, which is in the eastern part of the Ouachita anticline, the largest fold in the Ouachita area in Arkansas, contains three rather broad structural divisions—the Mazarn syncline, which comprises the Mazarn Basin; the Trap Mountain anticline, a part of which occupies a strip along the southern border; and the Crystal Mountain anticline, a part of whose southern slope comprises the Zigzag Mountains and the country north of them. These folds are much complicated by numerous small folds, in consequence of which the Mazarn syncline is really a synclinorium and the above-mentioned anticlines are anticlinoria.

These large, composite folds can be followed for considerable distances, but the single folds overlap lengthwise, are narrow, and can be traced only a few miles along their axes. They all have the same direction as that of the ridges that compose any particular mountain group—northeast and southwest in the Zigzag Mountains and nearly east and west in the Trap Mountains. In general they thus bear a close relation to the topography, for the outcropping edges of the hard, upturned beds have formed the ridges and the softer intervening beds lie

The Bigfork chert and the Mazarn and Womble shales are so intensely crumpled that the details of their structure can not be determined. The sections on the structure-section sheet are therefore somewhat generalized; they do not show the crumpling in these beds nor, in fact, any of the crumpling in the overlying rocks.

Trap Mountain anticlinorium.—The Trap Mountain anticlinorium, a composite structural feature expressed by the conspicuous ridges along the southern border of the district, consists of about twelve anticlines and their complementary synclines. The anticlines are all less than a mile wide, generally overlap lengthwise, and are only a few miles long. They are parallel, and some of them plunge to the east and some to the west, and all are of about the same height, so that the same formations are exposed in most of them. Most of the beds are inclined 45° or more from the horizontal, some of them reaching an angle of 90°, and all commonly dip to the south, except near the ends of some of the folds, where some dips are to the north. The conspicuous zigzag topography formed by Trap Mountain and its adjacent ridges has been produced by the truncation of interlocking anticlines and synclines whose axes pitch steeply in a direction east by north.

Mazarn synclinorium.—The east end of the Mazarn synclinorium, which occupies most of the southern part of the district, is triangular, being 9 miles wide at its west border and narrower to the east. Around its margin there are narrow synclines, which extend into the anticlinal areas on either side and interlock with the numerous anticlines that plunge beneath the basin. In other places, however, the detailed structure is not known and would be extremely difficult to work out, even if the work was at all possible, because there are no distinctive beds in the Stanley shale, which is the rock formation over most of the basin, and because this formation, which has relatively low rigidity, has been thrown into small, closely compressed folds or wrinkles instead of large ones like those found in the Arkansas novaculite. The structure of the synclinorium, as it is shown in figure 6 and in the sections on the structure-section sheet, is therefore largely diagrammatic. The beds in general strike about N. 60° E. and, owing to the small folds or wrinkles, present a confusion of northward and southward dips, most of which are 45° or more.

FAULTING.

It is inconceivable that rocks could have sustained the enormous pressure that caused the intense folding seen in the Ouachita Mountain region without slipping or snapping here and there, and numberless slips are indicated by slickensides, and many faults show conspicuous displacement of greater magnitude. Sixteen faults, some of which are shown in the structure sections, have been mapped in the Hot Springs district. All of them are thrust faults except a single small normal fault about $1\frac{1}{2}$ miles northwest of Lawrence, and the amount of their thrust ranges from a few feet to many hundred feet. The longest one, which is about 7 miles long and has a displacement of many hundred feet, passes near Bonanza Springs. A short one that has a small displacement occurs at the city water pumping station a mile north of Hot Springs. Others, whose greatest displacement is at least 500 feet and whose greatest known length slightly exceeds 2 miles, occur in the Trap Mountains, mainly in the vicinity of Cooper Creek. Several short faults of greater or less displacement occur near Potash Sulphur Springs, and they probably formed a channel for the intrusion of the igneous rocks found at that place. The plane of a small thrust fault at the east end of Trap Mountain is occupied by an igneous dike (No. 130). The small normal fault about $1\frac{1}{2}$ miles northwest of Lawrence dips to the northeast, and its plane is occupied by a dike (No. 30).

METAMORPHISM.

Mechanical and chemical processes that accompanied the folding of the rocks of this region have produced changes in many of them. Alteration by these two agencies has perhaps been most effective in the shales, changing some of them to slate. Those that have been most affected are the Mazarn, Womble, Polk Creek, and Missouri Mountain shales and the shaly part of the Arkansas novaculite, although at most places these have been but slightly altered. The change of the shale to slate has involved 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 in the same direction, thereby producing slaty cleavage, which is usually at an angle to the bedding. (See Pl. IV.)

The sandstones that are not calcareous have all become more or less quartzitic. Examples of such alteration occur in the Hot Springs sandstone, which is distinctly quartzitic, and in certain beds of the Blakely sandstone. The sandstone beds of the Stanley shale are less so.

Contact metamorphism of the sedimentary rocks about the igneous mass at Potash Sulphur Springs is described below.

IGNEOUS ROCKS.

By E. Russell Lloyd.

GENERAL FEATURES.

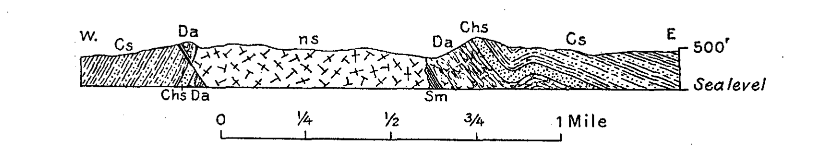
The Hot Springs district contains two small areas of igneous rock, one at Potash Sulphur Springs and the other at the mouth of Gulpha Creek, and many dikes and sills, most of which are in the southeastern part of the district.

The igneous rocks of Arkansas, including those at Potash Sulphur Springs and the associated dikes and sills, were described in detail by Williams and Kemp in 1891. Williams sums up their general relations substantially as follows:

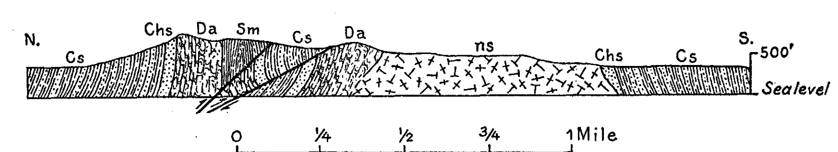
> The larger masses of igneous rocks occur on the southeastern side of the much disturbed and folded area known as the Ouachita uplift. The smaller dikes of intrusive rock are scattered here and there through the eastern half of the uplift and appear to be independent of the folds and ridges which were formed long before the intrusion of the igneous masses.
>
> The larger masses of igneous rock are in or near the main anticlinal axis of the uplift and occur in four well-defined areas—(1) the Fourche Mountain or Pulaski County region, (2) the Saline County region, (3) the Magnet Cove region, and (4) the Potash Sulphur Springs region.
>
> Outside of these four typical regions there are many dikes of igneous rock, which, so far as their petrographic characteristics are concerned, might be associated as well with one group as with another and which are probably directly connected with none of them, although formed from the same magma from which they all derived their material.

POTASH SULPHUR SPRINGS AREA.

General relations.—The igneous mass at Potash Sulphur Springs is irregular in outline and outcrops over less than a third of a square mile. It has been intruded into steeply dipping and faulted sedimentary rocks in a way which indicates that it is a stock. (See fig. 7.) On its north and southwest sides there are arms or apophyses of igneous rock, which extend into the sedimentary rocks. The exposed sedimentary strata in contact with the igneous rocks are the Arkansas novaculite, the Hot Springs sandstone, and the Polk Creek, Missouri Mountain, and Stanley shales. Of these the Arkansas novaculite, which occupies most of its periphery, borders it on the west, north, and east sides, and the Hot Springs sandstone forms a part of its southern boundary. These two formations, as a result of their resistance to weathering, which is greater than that possessed by the other rocks in this vicinity, form an almost complete circle of hills around the igneous area. Within the igneous mass itself, however, there have been included two small masses of novaculite, which are exposed near its northern border, and three of the Hot Springs sandstone and two of shale, near the southern border.



Section along line G–G′ on map.



Section along line H–H′ on map.

Figure 7.—Sections across the Potash Sulphur Springs igneous area, showing the relations of the nephelite syenite to the sedimentary rocks. ns, intrusive nephelite syenite; Cs, Stanley shale; Chs, Hot Springs sandstone; Da, Arkansas novaculite; Sm, Missouri Mountain shale.

A characteristic change in the kind of trees is noted in passing from the sedimentary to the igneous rocks, and in most places the kind of trees seen is a sure guide to the underlying formations. Thus, where there are only hardwood trees and no pines, the underlying rock is syenite. A few pines scattered among the hardwood trees indicate that igneous dikes cut the sedimentary rocks or that masses of sedimentary rocks are included in the igneous rocks.

The igneous rocks of the Potash Sulphur Springs area are of several types, ranging through a nearly continuous gradation from a very light-colored nephelite-feldspar rock to a dark-colored jacupirangite. This gradation would probably be shown still more completely if the rocks were better exposed. Over a great deal of the area only fragments on the surface give evidence of the kind of underlying rock.

The types of rocks represented include nephelite syenite, ijolite (?), jacupirangite (?), theralite, tinguaite, pegmatitic dikes, fourchite, and wollastonite rock.

Distribution.—Most of the exposures of the igneous rocks lie near the border of the Potash Sulphur Springs area, on the outer slopes of the hills and in the streams. The rocks in and near the stream at Potash Sulphur Springs consist of light-colored nephelite syenite and a dark rock, composed chiefly of biotite. This dark rock becomes more and more abundant to the east, toward the border of the nephelite syenite, and within a few feet eastward it forms the bulk of the rock, but the syenite penetrates it in the form of short dikes or intrusive veins. Many of these syenite dikes are pegmatitic in the center, and in some places they contain large crystals of biotite. The same complex body of rocks is shown in the stream above the spring as far as a small dam, where the pegmatitic facies of the dikes reaches its maximum development. In a few places these pegmatites are composed almost entirely of large crystals of biotite, which are very short and extremely irregular in width. Veins of calcite are abundant in the rocks at this place and run in all directions. They consist principally of coarsely crystalline calcite and a small amount of pyrite and pyrrhotite. Along the stream bed and in road cuts below the spring the rocks that are exposed are more or less weathered.

In a secondary road on the northwest side of this area nephelite syenite lies in contact with a well-developed wollastonite schist. The field relations of these rocks are somewhat obscure, on account of the covering of surface material. At least two types of syenitic rock are represented here; one is a typical light-colored syenite, and the other, which seems to be developed at the contact with the wollastonite rock, is a very dark jacupirangite, composed almost entirely of aegirite-augite and melanite.

Nephelite syenite was found at several places about the border of the mass, and, with the exception of the very narrow band of dark rock noted above, it represents the border type of the rock mass.

In the central part of the area there are almost no exposures of rock in place, and the character of the underlying material must be inferred from the fragmental material on the surface. The darkest rock was found in places along the secondary road that runs northward through the center of the area, where considerable amounts of magnetite and protovermiculite are scattered on the surface and embedded in a yellow clay. From the great amount of these two minerals, as well as the large size of residual fragments of the protovermiculite, some of them nearly a foot across, it is evident that they are not the products of the weathering of any of the rocks now exposed in the area. As the surface is covered with a thick mantle of residual soil, coarse-grained dark rocks probably exist in at least a small part of the area. A few small fragments composed almost entirely of melanite have been found, and fragments of a syenite very rich in aegirite-augite and melanite are abundantly scattered over a considerable part of the center of the area. Some of these fragments approach very nearly to the "ridge type" of syenite (ijolite) at Magnet Cove. Other weathered fragments seem to have been composed entirely of melanite and nephelite and still others of aegirite and nephelite. From this residual material it is inferred that both ijolite and jacupirangite are present but are weathered so deeply that they are nowhere exposed.

Theralite is exposed in a small stream near the western edge of the area and along the secondary road in its north-central part. A few dikes of tinguaite and fourchite occur as intrusions in and around the border of the igneous mass.

Metamorphism.—The sedimentary rocks that surround the igneous mass and that are included in it have been altered by contact metamorphism. Of these rocks the Arkansas novaculite has been most affected. Where it lies next to the intrusion it has been changed to a coarse-grained rock resembling quartzite, which is generally gray or white but in some places is black. It is made up of close-fitting translucent quartz grains, the largest 0.5 millimeter in diameter, and it weathers to a friable saccharoidal sandstone. Its quartz grains decrease gradually in size away from the igneous mass until at a distance of one-fourth to three-eighths of a mile the rock has been changed to a typical chalcedony-like novaculite, which consists of microscopic grains. The Hot Springs sandstone has also been changed to a coarse-grained quartzite. There are no outcrops of the Polk Creek and Missouri Mountain shales near the igneous mass, so the extent of their metamorphism is not known. At points a quarter of a mile north of the border of the intrusion the Stanley shale has been somewhat altered, but in other directions it has not been affected to so great a distance. The metamorphosed shale is black and hard and weathers to a light-colored porous rock, whereas the unmetamorphosed shale, which is also black, weathers to a green or buff shale before changing to clay.

AREA AT THE MOUTH OF GULPHA CREEK.

West of the mouth of Gulpha Creek stands a small wooded hill, which is composed largely of nephelite syenite and related igneous rocks. The outcrop of the igneous rocks forms a V-shaped area with its apex toward the south. The principal rock is a very dark gray fine-grained nephelite syenite, which contains numerous light-colored contemporaneous dikes or veins. These dikes or veins, which range from a few inches to several feet in thickness, consist almost entirely of orthoclase and nephelite and have a coarse texture. The rocks about the border are generally porphyritic in texture and contain augite, brown biotite, and in many places feldspar in a dark groundmass. In several places fragments of augitic rock are scattered on the surface. The relations of the different igneous rocks have not been worked out in detail, nor is their relation to the sedimentary rocks known, because of the small number of exposures. Associated with the igneous rocks are barite, pyrite, chalcedonic quartz, and green, purple, and colorless fluorite.

DIKES AND SILLS.

There are 132 dikes and sills shown on the areal-geology map, but these probably represent only a small fraction of the total number, the others being concealed by surface clay and rock débris. They occur mainly in the southern and southeastern parts of the district and are most numerous toward the southeast. Outside of the district, in the area to the east, they are still more numerous and suggest an association with the mass at Magnet Cove rather than with the smaller mass at Potash Sulphur Springs. They range from very dark fourchites and ouachitites through nephelite syenite to light-colored tinguaites. Practically all of them occur in the Stanley shale. They run in all directions, but predominately eastward, in general accord with the strike of the sedimentary rocks.

The rocks of the dikes and sills occur in various stages of decomposition, and many of them appear only as bands of reddish clay exposed in road cuts and show the spheroidal weathering characteristic of lamprophyric rocks. Others show rounded, very tough residual boulders, embedded in loose clay. The rocks composed largely of ferromagnesian minerals, such as pyroxene, amphibole, mica, garnet, and olivine, alter more rapidly than the rocks composed largely of feldspars and feldspathoids. A large number of the most completely altered dikes and sills show by their residual products that they were originally ouachitites or fourchites. Many of them are shown only by belts of boulders on the surface. The least-altered rocks occur along Ouachita River and a few of the larger creeks. The best exposures are in some of the larger railway cuts, but at most of these places the rocks are so much decomposed that they can not be studied under a microscope. The exposures can generally be followed for only short distances, most of them for only a few feet. Exceptions, however, are found in dikes that have left rows of boulders on the surface, for where these rows lie in forested areas they can be followed for long distances. Several dikes also have been traced by isolated exposures which are approximately in a line, have the same strike, and contain rocks of the same composition.

The width of the dikes and sills ranges from a few inches to as much as 45 feet. Fully 75 per cent of them are 5 feet or less wide, and only a few reach a width of 10 feet or more. The ouachitite, fourchite, and nephelite syenite dikes are the narrowest and the tinguaite dikes the widest.

The ouachitites and fourchites are richest in ferromagnesian minerals. They are olivine-free monchiquites that contain from 50 to 80 per cent of augite, the ouachitites with and the fourchites without large phenocrysts of biotite. The light-colored minerals form a matrix that fills the interspaces between dark minerals and are generally replaced by calcite and zeolites. The proportion of matrix to automorphic minerals varies within wide limits. There is a complete gradation from rocks in which the phenocrysts comprise 70 to 80 per cent of the material to the nonporphyritic fourchites, in which the texture is about the same as in the groundmass of the porphyritic rocks.

Where the light-colored material is more abundant its crystals are larger, and instead of filling the interspaces between the dark materials it incloses them and the texture is poikilitic hypautomorphic granular. These dikes, which are intermediate in character between the ouachitites and fourchites on the one hand and the tinguaites on the other, are called nephelite syenite dike rocks.

Where the amount of light-colored minerals in the rocks is still greater than it is in the nephelite syenite dikes, the feldspar or the nephelite is automorphic and the rock a tinguaite. Of these there are several types, in which the texture of the groundmass varies considerably in the different dikes.

RELATIONS OF THE IGNEOUS ROCKS.

The dark biotitic rock, jacupirangite, at Potash Sulphur Springs is apparently a segregation from the syenitic magma, and its occurrence along the border of the syenite mass at this place suggests a separation on crystallization. It seems reasonable to suppose that the earliest minerals to crystallize were segregated at the cooler surface and that the rock thus formed was intruded and broken up during the later stages of consolidation, which are represented by the nephelite syenite. Nephelite syenite, however, is the principal rock on the border of the rock mass, and near the center of the area it approaches the "ridge type" (ijolite) of Magnet Cove. Its relations to the theralite, near the center of the area, and to the ijolite and jacupirangite, which are also probably present near its center, are not known, on account of the covering of clay and other surface material.

The origin of the wollastonite in the wollastonite rock described above is not known, as no limestone has been found in the vicinity.

The rocks of the smaller intrusions are differentiation products from a nephelite syenite magma. There is apparently an almost continuous gradation from the mafic ouachitites and fourchites to the felsic tinguaites. There certainly is such a gradation in the amount of light-colored minerals in the groundmass, for this differs in almost all proportions from rock to rock.

At Potash Sulphur Springs tinguaite dikes (Nos. 36, 50, 54, and possibly 49 and 51) cut the nephelite syenite, and a fourchite dike (No. 35) cuts across the jacupirangite breccia and its nephelite syenite veins.

TIME OF INTRUSION.

By H. D. Miser.

The nephelite syenites and their associated types within the Hot Springs district penetrate sedimentary strata that range in age from Ordovician to Mississippian and also cut across the folds in the strata and occupy fault planes. The folding and faulting in this area, as previously stated, took place near the middle of the Pennsylvanian epoch, and therefore the intrusion of the igneous rocks was later than that epoch. Besides this there is no evidence in the district to fix exactly the time of the intrusion. In Saline and Pulaski counties, to the northeast, the eroded surfaces of the nephelite syenites and the associated types are overlain by Eocene sediments, which shows that their intrusion is pre-Tertiary. In the southern part of the Caddo Gap quadrangle waterworn pebbles and cobbles of tinguaite, fourchite, syenite, and peridotite occur in the Bingen formation, which there lies at the base of the Upper Cretaceous series. All these pebbles were probably derived from igneous masses in Arkansas, though some such masses are doubtless concealed by Upper Cretaceous or later sediments. The exposed igneous rocks in this State were all probably produced from one magma, and their intrusion thus took place about the same time. The peridotite exposed near Murfreesboro, Pike County, penetrates the Trinity formation of the Lower Cretaceous series. It therefore follows that the peridotite and the other igneous rocks in the State, including those in the Hot Springs district, were intruded late in the Lower Cretaceous epoch or early in the Upper Cretaceous.

GEOLOGIC HISTORY.

CHARACTER OF THE RECORD.

The geologic history of the Hot Springs district is recorded in its surface features and in the underlying rocks. The following account of the physiographic and geologic events is therefore a brief interpretation of the record embodied in the rocks and the surface features that have already been described. The history as thus interpreted is probably far from complete, because the record has been largely destroyed by erosion, yet many of the facts may be inferred from studies made in other parts of the Ouachita Mountain region and in adjoining provinces, for the same processes that affected this district affected similarly an extensive region around it.

The oldest formation exposed in the district is the Mazarn shale, of Lower Ordovician age. Still older beds, however—the Collier shale, of Cambrian age, and the Crystal Mountain sandstone, probably of Ordovician age—are exposed in the region to the west, between Black Springs and Mount Ida, Montgomery County, Ark., from which, therefore, the earliest geologic record for this region must be obtained.

PALEOZOIC ERA.

CAMBRIAN PERIOD.

The Collier shale is of unknown thickness, for its base is nowhere exposed, but at least a few hundred feet of the shale and limestone beds comprising it is visible south of Mount Ida. Collier deposition was brought to a close by an emergence of the land in at least the present Crystal Mountain area, where a period of erosion was begun.

ORDOVICIAN PERIOD.

After the period of erosion just mentioned the area was again covered by the sea, and the material that forms the Crystal Mountain sandstone, 850 feet thick, was spread over it.

Throughout most of Mazarn, Blakely, and Womble time mud was deposited in the sea in the Ouachita Mountain region, both in Oklahoma and in Arkansas. At the end of the Mazarn time 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, but sand and mud were afterward laid down in alternating layers. During Womble time mud and a very little sand accumulated, practically without interruption by the deposition of other kinds of sediment. The sea was probably shallow during the deposition of the 2,400 feet of mud and sand that makes up these three formations, so that the sea bottom must have been subsiding more or less gradually while these sediments were accumulating. Although the sea received mud and some sand during Mazarn, Blakely, and Womble time, it occasionally became clear enough to permit the deposition of material that formed limestone. But during some if not much of the time when these formations were being deposited limestone was being formed to the north, in the Ozark region; to the west, in the Arbuckle Mountains of Oklahoma; and to the east, in the southern Appalachian region. This change in the character of the sediments in these directions and the limited distribution of the Blakely sandstone, which is exposed only in the southern part of the Ouachita Mountains, strongly indicate that the clastic material for these formations came from the south—from a land area that is believed to have existed in northern Louisiana and eastern Texas.

At the end of Womble deposition layers of silica and thin 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 this formation the name Bigfork chert has been applied. The rhythmical deposition of chert and shale in alternating layers during much of Bigfork time and that of the limestone and shale of the Hermitage formation of Tennessee suggest that the Bigfork and the Hermitage, both of which are partly or wholly of Trenton (Middle Ordovician) age, were formed contemporaneously.

Bigfork time was ended and Polk Creek time was begun by an increased muddiness of the sea. The black mud which later formed the Polk Creek shale was rather uniformly spread over much if not all of the Ouachita Mountain region.

SILURIAN PERIOD.

After Polk Creek time the land area that is believed to have existed south of the Hot Springs district was probably elevated sufficiently to invigorate the streams, which in addition to a good deal of mud now carried to the sea large quantities of sand. Later the sand and mud hardened into sandstone and shale, respectively, to which the name Blaylock sandstone is applied. The sediment deposited at this time appears to have been laid down in a rapidly subsiding trough, for within a few miles the formation thickens southward from a feather edge to at least 550 feet in the Hot Springs district and to a maximum of 1,500 feet within a like distance in the Caddo Gap quadrangle. This trough, though it occurs only on the south side of the Ouachita Mountain region, extends from the Tertiary overlap east of the Hot Springs district, in central Arkansas, westward to the Cretaceous overlap in McCurtain County, in southeastern Oklahoma. The deposition of the Blaylock sand was ended by an emergence of parts of the region, including at least a portion of the Hot Springs district, but this emergence was probably not general and probably did not last long, else there would be more than local evidences of a period of erosion.

After Blaylock time the sea transgressed northward over the land, and in places there was put down a layer of coarse conglomerate that constitutes the first deposit of the Missouri Mountain shale. Afterward fine red and in some places black clay was laid down throughout the Ouachita Mountain region. The clay that was laid down in the Ouachita area during this time apparently came from the land area to the south.

DEVONIAN PERIOD.

The epoch in which the Arkansas novaculite was laid down, which was one of sedimentation throughout the southern part of the Ouachita Mountain region, was characterized by the deposition, through action by organisms or chemical precipitation or through both processes, of silica and a little calcareous material. In a few places the oldest deposit of this epoch is a conglomerate that consists of rounded pebbles of quartz and novaculite embedded in a matrix of novaculite. This conglomerate suggests the emergence of the land and its erosion in some areas prior to or early in this epoch, but as the water deepened silica and very small amounts of other materials, which later formed the white massive novaculite, accumulated. While this vast amount of siliceous material was being deposited the land from which it was derived was low or possibly remote, as is indicated by the delivery to the sea of only a very little detrital material, which consisted wholly of rounded quartz grains and mica, and the sea was relatively shallow, as is indicated by the presence of ripple marks in the heavy-bedded novaculite.

This part of the novaculite is of Oriskany age and was laid down at the same time as the Camden chert in western Tennessee and the uppermost part of the "Hunton formation" in the Arbuckle Mountains in Oklahoma. Next mud, generally black, was laid down in thin layers intermittently with layers of siliceous material, but later the siliceous material, some calcium carbonate, and a very small quantity of mud were deposited. The middle and upper divisions of the Arkansas novaculite, which are of the same age as the Woodford chert, in the Arbuckle Mountains, and as the Chattanooga shale, were thus formed. Some of the mud laid down at this time was red and formed red shale.

Sedimentation was not continuous during the period when the Arkansas novaculite was laid down, but after Oriskany 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 district. The absence of this conglomerate in the Trap Mountains and the absence there of other physical features that indicate a stratigraphic break at this horizon suggest that the land area over which the lower part of the formation suffered erosion at this time did not extend into the southern part of the district. Other conglomerates found higher in the formation are also confined to the northern part of the district and indicate that there was a land area in or near this part of the district.

This epoch was closed by the emergence of the land from the sea over much of the Ouachita Mountain region. While this district was land much erosion took place in its northern part, where the novaculite was planed off. Many rounded pebbles of novaculite are found in the heavy conglomerate that lies above the novaculite at the base of the Carboniferous rocks. In the Trap Mountains, however, as in many other parts of the Ouachita area, the character of the beds at the top of the Arkansas novaculite is so uniform that the only evidence of an unconformity at this horizon is the presence there at some places of a thin layer of conglomerate.

CARBONIFEROUS PERIOD.

After the period of erosion at the end of the Arkansas novaculite epoch a heavy bed of pebbles of novaculite and sandstone, mixed with some sand, was deposited in the Hot Springs district. In the central and northern parts of the district the bed is practically continuous, but in the southern part it was put down as thin, locally distributed lenses. In the northern part of the district a bed of gray sand, which later formed the Hot Springs sandstone, accumulated upon this gravel, but it did not extend into the southern part of the district nor into the Caddo Gap, Mount Ida, De Queen, and Lukfata quadrangles and other areas to the west. The distribution, character, and stratigraphic relations of this sandstone and its basal conglomerate in the Hot Springs district suggest that the material came from a near-by northern source.

The deposition of the Hot Springs sandstone was followed by that of the Stanley shale, during a time when mud and sand were alternately laid down to a depth of 6,000 feet over most of the Ouachita Mountain region. The black color of the Stanley shale and the presence in it of numerous fragments of plants indicate the existence of plant life on the land. Marine fossils have not been found in the Stanley shale except at a few places in McCurtain County, Okla. The practical absence of marine fossils in the Stanley shale, as well as the distribution of the shale and the fact that it was laid down in shallow water, indicate that most of it is of fresh-water origin and that the sediment that formed it was deposited in a great continuous delta at the mouths of several rivers.

Paleozoic deposits later than the Stanley do not occur within the district, but great thicknesses of shales and sandstones of younger Carboniferous rocks are widely exposed elsewhere in the Ouachita area and the Arkansas Valley. The youngest of these deposits are of the same age as the Allegheny formation in the Appalachian region, which forms a part of the Pennsylvanian series.

vanian epoch. Most of it has remained a land area and has consequently undergone subaerial erosion ever since its emergence. The highest peaks in the Ouachita Mountains are more than 2,000 feet above sea level, but some of them 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 stand more than 20,000 feet above sea level. They probably never attained such an altitude, however, because erosion progressed with elevation, so that the rocks may have been worn down nearly as fast as the region was raised.

Erosion has not gone along at a uniform rate, for at times it reduced the region to a low-lying area of moderate relief—a peneplain—from which very little more material was eroded. The evidence available indicates that two peneplains were formed in the district—the Ouachita and the Hot Springs, of which the Hot Springs peneplain is the younger. The Hot Springs peneplain is described under the heading "Cenozoic era." (See fig. 8.)

The Ouachita peneplain was produced by erosion that lasted through the Permian epoch and the Triassic and Jurassic periods. Only a few low peaks and ridges, which were more resistant to erosion than the rest, stood above this plain as monadnocks. At the beginning of the Cretaceous period this peneplain and a large area to the south, including the old land mass in Louisiana and eastern Texas that supplied most of the vast amount of sediment that formed the Paleozoic rocks of the Arkansas Valley and the Ouachita region, were depressed and the Gulf waters extended at least as far north as the central parts of Clark, Pike, and Howard counties, Ark. How much farther the sea extended and whether it covered the Hot

According to evidence obtained in the Caddo Gap quadrangle their intrusion occurred late in the Lower Cretaceous or early in the Upper Cretaceous epoch. The rather general northeastward alinement of the principal igneous masses in Arkansas along or near the old Upper Cretaceous shore line and the Tertiary shore line, both of which practically coincide, suggests, as pointed out by Branner, that the position of this shore line has been caused by faulting or other weakness. In fact, the intrusion of the igneous masses may have accompanied the downwarping that produced the transgression of the Upper Cretaceous sea in the Mississippi embayment.

Whether any of the igneous rocks reached the surface at that time is not known, but the rocks now exposed, as shown by their character, must have solidified at depths of at least several hundred feet below the surface. This means that the overlying rocks have been subsequently removed by erosion. This also indicates that the land surface in the Hot Springs district and the rest of the Ouachita region during late Lower Cretaceous or early Upper Cretaceous time stood as high as the crests of the mountain ridges which are believed to mark the elevation of the Ouachita peneplain.

During Lower Cretaceous time, when the Ouachita region was presumably a low, southward-sloping peneplain, it must have been drained southward into the Lower Cretaceous sea. It had then probably been reduced so nearly to a plain that the courses of the streams were largely independent of the structure of the rocks. When the region was elevated at the end of Lower Cretaceous time the streams continued to flow southward from the old rocks, across the newly formed, unconsolidated sediments.

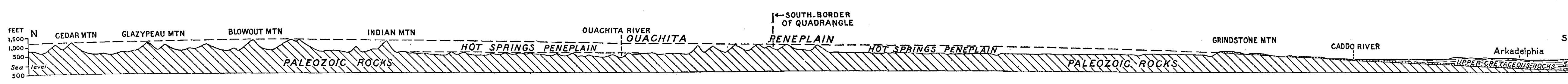


FIGURE 8.—Section showing the Ouachita and Hot Springs peneplains in the Hot Springs district and their relation to the Cretaceous floor at and near Arkadelphia, Ark.

The exposed Carboniferous rocks in the Arkansas Valley and the Ouachita area in Arkansas have a maximum thickness of 25,000 feet and a minimum of 21,000 feet. During the accumulation of this vast thickness of rocks the Ouachita area and the Arkansas Valley formed a subsiding synclinal trough. Its subsidence was more or less gradual, for practically all this enormous thickness of material consists of shales and sandstones that are obviously of shallow-water origin. The evidence at hand indicates that much if not most of the detrital material that formed these beds in the Ouachita Mountains and the adjoining Arkansas Valley came from the south, like that which formed most of the older beds that are exposed in these mountains. The clastic material that formed the Pennsylvanian rocks of north-central Texas, according to Drake, Plummer, and Moore, was derived largely from an extensive old land area to the east and southeast, which is now covered by later formations, and only a very small part from the older rocks to the south, at the center of the State. It therefore appears fairly certain that at least a part of the land area that supplied most of the material for the enormous thicknesses of Carboniferous rocks exposed in these provinces lay in Louisiana and eastern Texas. The location of this old land area may have roughly coincided with that of the Sabine uplift as described by Harris, Powers, and others.

FOLDING AND UPLIFT.

The subsiding synclinal trough of the Ouachita Mountain region and the Arkansas Valley was converted into dry land and its rocks were folded and faulted near the end of the Paleozoic era. In the Ouachita Mountain and Arkansas Valley regions the uplift, folding, and faulting were probably contemporaneous with extensive movements of a like nature in the Arbuckle Mountains, in southern Oklahoma, which took place, according to Moore, near the middle of the Pennsylvanian epoch.

The folding and faulting were produced by horizontal compression, and the movements over most of the region acted from the south or from the north, though in the Zigzag Mountains the movement was from the northwest or from the southeast. That the force causing the movements came from the south is suggested by the flattening of the folds northward from the axis of the Ouachita anticlinorium toward Arkansas River and by their final disappearance in the southern Ozark region. The strata in the Hot Springs district have been so much compressed that their present extent is only half to two-thirds of their original horizontal extent. The muds, sands, and other materials had become hardened, largely by their own weight probably, but the force that accompanied the folding further consolidated them into firm rocks, and the waters that permeated the rocks in places produced new minerals and cemented the particles firmly together. The shearing force and pressure further modified them by forming cleavage and joint planes.

MESOZOIC ERA.

The Hot Springs district, as well as the rest of the Ouachita Mountain region, so far as known, has been only partly submerged since its emergence near the middle of the Pennsyl-

Springs district are not known. During the northward advance of the Lower Cretaceous sea the peneplain was doubtless slightly lowered by wave erosion. The submerged part of the peneplain thus became the floor upon which the Cretaceous beds were deposited.

The Cretaceous floor is smooth, its plainlike surface being diversified only by minor irregularities and undulations. Its dip to the south, as indicated by wells that penetrate the Cretaceous deposits, is about 100 feet to the mile. The slope of the floor where the Cretaceous cover is partly removed in the Caddo Gap and De Queen quadrangles ranges from about 60 to 100 feet to the mile, but the usual dip is about 80 feet to the mile. If this plain were projected to the north with a slope of 80 feet to the mile it would coincide or nearly coincide with the summits of many of the high ridges on the southern border of the Ouachita Mountains in Arkansas but would rise above many of them. The imaginary plain passing through the higher summits farther north has a lower slope to the south than 80 feet to the mile. The higher ridges in the Hot Springs district northwest of Indian Mountain and in the southwest corner of the district approach a common level, which ranges in most places from 1,100 to 1,300 feet above sea level, but to the east and south, in the southeast corner of the district, they descend to an elevation of about 700 feet above sea level. These elevations mark approximately the level attained by the Ouachita peneplain, except that the peneplain may have stood a little above Blowout Mountain and other ridges farther north. (See Pl. I.)

At the end of the Lower Cretaceous epoch the Ouachita and adjoining regions were elevated, so that the waters of the Gulf retreated southward and erosion was accelerated. The amount of erosion during this time in the Ouachita Mountains is not known, but the Ouachita peneplain was probably not greatly reduced.

In Upper Cretaceous time the Ouachita and adjoining regions were again depressed. The depression was gradual and continued throughout much of the epoch. It was greatest in the present lower Mississippi Valley and permitted the sea to reach the southern end of Illinois. The shore line ran northeastward, probably not more than a few miles southeast of the Hot Springs district, and the waters may even have covered a part or all of the district itself. At any rate, the part of the Ouachita peneplain in Arkansas was apparently tilted to the east, toward the principal axis of depression. The high ridges attaining its level have an elevation of 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, between 1,100 and 1,300 feet above sea level at and near Hot Springs, and between 500 and 600 feet above sea level at and near Butterfield, in Hot Spring County. Not all the eastward tilting, however, took place during the Upper Cretaceous epoch, but much of it probably took place later, during the Tertiary period.

The igneous rocks of the quadrangle, as well as those in other parts of Arkansas, were all presumably produced from one magma and were probably intruded about the same time.

The downwarping of the Mississippi embayment during Upper Cretaceous time and later during Tertiary time was accompanied, as already explained, by an eastward tilting of much of the southward-sloping Ouachita region, so that the region then sloped to the southeast and much of the southward drainage was therefore diverted in that direction. 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 Branner believed that the Arkansas Valley was drained westward during Permian, Triassic, and Jurassic time. If so there has been a reversal of this drainage.

CENOZOIC ERA.

Erosion was accelerated by an uplift at the end of Upper Cretaceous time, and the surface was lowered more rapidly along the belts of soft rocks, so that the edges of the hard rocks stood up as ridges. In the larger belts of soft rocks a peneplain, known as the Hot Springs peneplain, was produced. The elevation of this peneplain is marked by much of the upland surface of the Athens Plateau south of the Ouachita Mountains and by the floors of the several intermontane basins in the mountains. The relations of this peneplain to the Tertiary deposits in Arkansas have not been fully worked out, but at the few places where the authors have studied the relations the plain appears to pass beneath the Eocene strata of the Coastal Plain, and the peneplain therefore appears to be of early Tertiary age.

During the formation of this peneplain the edges of the steeply dipping Arkansas novaculite and the Hot Springs sandstone resisted erosion and stood up as ridges, producing the Zigzag and other mountains while the Mazarn and Saline basins were being lowered. These ridges were cut through here and there by streams that produced water gaps. In the Hot Springs district this peneplain stood at the same elevation as the present dissected plateau surface of the Mazarn Basin, most of which lies between 500 and 600 feet above sea level. Ouachita River and its tributaries in the basin were graded, and they built up flood plains over which they meandered regardless of the structure of the hard sandstone of the Stanley shale that underlies the basin. Owing to the differences in the hardness of the rocks the part of the Saline Basin that is included in this district was apparently not reduced to a peneplain at this time, though much of it farther east was so reduced.

In the Eocene epoch of the Tertiary period the Mississippi embayment again subsided, and this subsidence resulted in the northward extension of the Gulf of Mexico. The sea reached a point within 2 miles of the southeast corner of the Hot Springs district, as shown by the presence there of marine deposits of Tertiary age. In fact, the waters of the Gulf may have extended into the narrow valleys of the Trap and Zigzag mountains and covered parts of the Athens Plateau and the Mazarn and Saline basins. Some of the thin deposits of sand and waterworn gravels found here and there on the plateau surface of the Mazarn Basin and similar deposits on the higher elevations at the east end of the Athens Plateau south of the Hot Springs district may be outliers of Tertiary deposits, but the character of the material indicates that at least most of it was deposited by streams.

Later a succession of uplifts during periods that were separated by periods of stability and depression elevated the region about 500 feet to its present altitude and forced the waters of the Gulf to the position they now occupy. By this elevation the streams were rejuvenated, and they soon carried away most of their former flood-plain deposits and dissected the Hot Springs peneplain so completely that little comparatively level upland is left on the present plateau surface. The larger streams, such as Ouachita River and its principal tributaries, have gradually incised their channels to a depth of 200 to 250 feet in the hard Paleozoic rocks. The crooked course of the Ouachita is probably inherited from a similar course on the Hot Springs peneplain. It bears no relation to the structure of the sandstones and shales in which the valley has been cut, but many of the smaller streams have partly or wholly eroded their valleys in the steeply dipping soft shales that occur between the ridges of hard sandstone. Many of the smaller streams are therefore straight, and some of them join the larger streams in such a way that their courses form right angles to the courses of the larger streams. A trellised arrangement of the streams has thus been produced in parts of the district.

Since the last uplift the streams have not had time to cut their channels down to base-level. In the larger part of their courses they flow in channels cut in hard rocks, which produce numerous rapids. Along Ouachita River, Saline River, and some of the creeks there are deposits of alluvium in a few stretches where the currents are comparatively slow and the valleys are somewhat widened.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

The most valuable mineral resources of the Hot Springs district are road material, oilstones, clays, and shales; others of less value are building stone, slate, and silica. Small quantities of iron and manganese oxides, iron pyrites, gold, and silver are also found in the district. Oil and gas have been unsuccessfully sought at several places.

OILSTONES.

Rock suitable for making oilstones or whetstones is obtained from the Arkansas novaculite at several quarries, most of which are on the ridges northeast of Hot Springs. In fact, the quarrying of oilstones in Arkansas, which has for many years led in the production of these abrasives in the United States, is confined to the vicinity of this city. The annual production has not exceeded a few hundred tons, but the annual value of the oilstones marketed has for some years exceeded $100,000. These stones are the only ones produced in the United States that are suitable for sharpening fine-pointed and fine-edged instruments and tools, and they are not only extensively used in the United States but are exported to other countries.

Novaculite suitable for two kinds of oilstones, the "Arkansas" and the "Ouachita," is obtained from the basal massive part of the formation. In commerce the term "Ouachita" is almost always spelled "Washita." Hard and soft stones of each kind, each adapted to sharpening particular tools, are marketed. The uppermost bed of the formation in the Trap Mountains and farther west generally yields only the "Ouachita stone."

"Arkansas stone."—The "Arkansas stone" is typical novaculite. It is a homogeneous, gritty stone, fine grained and siliceous. It is translucent on thin edges, has an uneven to conchoidal fracture, and a waxy luster like that of chalcedony. It is generally white with a bluish tint, but in places it is tinted red, gray, black, brown, and yellow, its color depending on the amount of iron and manganese oxides it contains and possibly in some places on its content of carbonaceous matter. It consists of microscopic grains of quartz in which are embedded a few comparatively large, rounded grains, and in places where the rock is not weathered it contains a small amount of calcite. The commercial stone, however, is obtained in parts of the formation from which the calcite has been leached. A study of thin sections of the rock shows that any calcite it contains occupies small rhombohedral and irregular cavities, many times larger than the small grains of quartz, and that the calcite has here and there been replaced by quartz. This secondary quartz and the larger grains of quartz contribute somewhat to the abrasive power of the stone, but the sharp edges of the cavities that are bounded by straight walls, in which the fine grains are packed like a course of masonry, contribute more. Experiments on the absorption of water by the "Arkansas stone" indicate that it is very dense, the actual pore space being about 0.17 per cent of the total bulk. Though this percentage is very small, it seems to give the stone considerable advantage as an oilstone over denser stones.

The strata from which the material for oilstones is quarried are inclined at high angles, and the quarries are therefore narrow, slanting open cuts, which conform in direction to the bedding. The pressure that tilted the strata has in many places crushed the novaculite into small fragments, and in others the cleavage or joint planes produce what the quarrymen call "splitting seams." Two or three sets of these planes may be found almost anywhere, and as many as six have been observed in a single quarry. Local hard or comparatively tough spots, cracks, small cavities known as "sand holes," and great numbers of fine quartz veins, some of them so thin that they can not be distinguished with the naked eye, are sources of trouble to the quarrymen. As the veins do not invariably appear at the surface they may not be found until the stone has been sawed and thus cause considerable loss, so that the manufacturers prefer medium-sized rather than large blocks. The hard "Arkansas stone" is shipped in blocks weighing more than 5 pounds, and the soft stone in blocks weighing more than 15 pounds. The blocks are trimmed at the quarries and sent to factories in different parts of the country, where they are sawed into the forms required and are then polished. The oilstones thus manufactured are used in many ways but are best adapted to finishing the sharpening of tools that have had a preliminary sharpening with a coarser abrasive.

"Ouachita (Washita) stone."—The "Ouachita stone" resembles the "Arkansas stone" in all its chemical and physical properties except that it is more porous. As a result of its porosity it has a subconchoidal fracture and the "dead" appearance of unglazed chinaware, not the waxy luster of typical novaculite. The many rhombohedral cavities in the dense groundmass give to the stone its remarkable abrasive properties, and these cavities, which constitute about 5 per cent of the total bulk in the densest "Ouachita" stones, are larger and much more numerous than those in the "Arkansas" stones. The silica around the cavities is more compact than that farther away from them, so that the sides of the cavities present fine cutting edges to tools.

This "Ouachita stone" resembles the "Arkansas stone" in its mode of occurrence. In fact, there is nothing in the structure of the two varieties to render impossible a gradation from the one into the other in the same bed, though such a transition is rarely observed. The "Ouachita stone" is liable to all the possible defects of the "Arkansas stone" and to others peculiar to itself. Though it is much freer from joints and quartz veins than the "Arkansas stone," it contains more and larger "sand holes." The hard spots in it do not have a flinty appearance, but some of them seem to be simply made up of dense material, and these parts of the stone are likely to become glazed by use. These spots may be places where a mineral cement binds the grains of silica together more firmly or they may be places where there are fewer cavities in the stone. This variety of stone is not injured by freezing, for it is sufficiently porous to permit some expansion, but it is injured by long drying, which causes the stone to lose its easy fracture and to become tougher and harder. A defect in the stone from some quarries is due to the uneven distribution of the rhombohedral cavities. This change occurs in the stratification planes and shows clearly that the amount of calcium carbonate deposited in the original rock differed at different times. The rock is therefore composed of bands of different densities, which may appear in the finished product as areas of unequal hardness.

The "Ouachita stone" has been found in much larger quantity than the "Arkansas stone," a fortunate circumstance, because the demand for the "Ouachita" is much greater than that for the "Arkansas." Blocks weighing 40 to 50 pounds are about as small as manufacturers care to buy, for small blocks produce more waste. From this minimum the blocks range in weight up to a maximum of 1,500 pounds or even more. The "Ouachita stone" is used chiefly for making whetstones for the larger or coarser tools.

OTHER MINERAL RESOURCES.

Road material.—The Hot Springs district is abundantly supplied with road material. The Bigfork chert and the Arkansas novaculite afford inexhaustible supplies for both foundation and surface stone. The Bigfork chert is specially adapted to use in making roads, for it is minutely shattered or fractured, is easily accessible, and can be loosened from the hillsides by blasting and then dug out with picks and put on roads with little or no crushing. It occurs also in large quantities as finely broken talus at the bases of the knobs. It is comparatively brittle, and it becomes pulverized and compacted into a smooth, firm but not hard road. Though it contains no calcareous material to bind it together, it includes more or less clayey material that serves as a fairly good bond. The chert forms a natural macadam along many of the roads within the area where it outcrops, and it is used to some extent on the streets in Hot Springs and on the roads that radiate from that city.

The novaculite is not so much fractured as the Bigfork chert and would therefore be more expensive to prepare, but on a few talus slopes considerable quantities of large and small sized material have collected.

Clay.—The clay in the Hot Springs district is of three types—recent stream deposits, clay residual from igneous rocks, and clay residual from Paleozoic shales.

The first type is represented by a few small beds of clay, which in places has been used for making a poor grade of common red brick.

The second type is represented by deposits of reddish clay produced by the alteration of some of the numerous igneous dikes in the district. Many of the dikes that have been so altered consisted originally of fourchite and ouachitite. At Klondike, Saline County, Ark., these two types of rock have been decomposed to clay to a depth of 200 feet below the surface. This clay is being mined for fuller's earth at that place, but such beds of clay probably do not extend to a sufficient depth in the Hot Springs district to be mined for this purpose.

The third type is represented by beds of light-yellow or light-red clay, formed through the disintegration of Paleozoic shales. The black shales in the Blakely sandstone and the Womble and Mazarn shales have been altered to plastic light-colored clays, which are exposed in a few pits and cuts on Cedar Mountain. The largest cut on this mountain, known as the Worthington clay mine, shows in its face about 50 feet of white clay, with which is interbedded some light-yellowish clays and a few layers of gray sand. The beds, as shown by their exposure in this mine, have been folded into a closely compressed syncline. The clay that was formerly mined at this locality was hauled in wagons to Hot Springs, where it was made into art pottery.

The Missouri Mountain shale on the south slope of Sugarloaf Mountain has disintegrated into a light-colored plastic clay, such as that which is exposed on the road leading from Hot Springs to the city water-pumping station.

The shale in the Arkansas novaculite has in places disintegrated to a plastic light-colored clay. An exposure on the southeast side of Hot Springs Mountain near the road that crosses its crest shows 6 to 10 feet of light-gray clay containing a few thin reddish bands. Across the divide between Hot Springs Mountain and North Mountain, near the northeast corner of the national park, a similar bed of clay, 8 feet thick, is exposed.

The Stanley shale at different places on the south slope of West Mountain and at the north base of Sugarloaf Mountain has weathered to a plastic gray clay.

The clay from the Worthington clay mine burns to a light buff or cream color and gives a dense body at a medium burning temperature. As already stated, it has been used at Hot Springs for the manufacture of art pottery. The other clays mentioned above would probably burn the same as this one, and all may be used for pressed brick, flooring tile, and second-grade fire brick or as a body for art pottery.

Shale.—Shale suitable for making brick is abundant in all parts of the Hot Springs district, but the only shale so utilized is that at Hot Springs. The slightly altered Stanley shale found south of the city is mixed with a small quantity of surface clay and made into common bricks by the stiff-mud process. The bricks are bright red and of excellent quality. With the proper machinery a face brick with a pleasing red color could be manufactured.

Building stone.—Stone for rough masonry occurs in large quantities in the quadrangle. The Hot Springs sandstone and the limestone in the Womble shale have been used to some extent for constructing retaining walls and foundations and for other purposes where rough stone is required. A gray stone that has been used for curbing, paving, and foundations has been obtained from an igneous dike (No. 10 on the map) about 2 miles east of Hot Springs. This rock is known to geologists as tinguaite.

Small quantities of rock from a few other dikes have been used for various purposes, notably a tough, dark rock known as ouachitite, which has been quarried near the east end of Trap Mountain from a dike (No. 131) 4 feet in width. This rock has been used in that vicinity for lining boiler furnaces, because it is so tough that it does not break when it is heated to the high temperature reached in such furnaces. Rock from the other ouachitite dikes in the district would also be refractory and could be used similarly. The Blaylock sandstone is suitable for use as building stone and occurs in beds of uniform thickness, but it is at present inaccessible for such use. Stone suitable for superstructural work has not been quarried in this district, but it could be obtained at some places in the igneous area at Potash Sulphur Springs and from some of the dikes in other parts of the district, though the rocks at such places are too deeply weathered at the surface to afford sound stone, and the expense of excavating down to more solid rock would be considerable.

Boulders from the streams and from the mountain slopes are used in rubblework. The sandstones, cherts, and variegated novaculite in such masonry present an attractive appearance when the boulders are artistically arranged. Crushed material from both the novaculite and the Bigfork chert could be used in pebble-dash work with pleasing results.

Slate.—A slate deposit has been prospected in the Polk Creek shale on the north slope of Glazypeau Mountain. As exposed in the quarries the slate is black, has a good ring, contains small crystals of iron pyrites, and splits into thin sheets that have smooth cleavage surfaces. Large blocks can be quarried, as the joints are few. Several thousand roofing slates have been made at one prospect near the center of the NE. ¼ NW. ¼ sec. 11, T. 2 S., R. 20 W., but none have been sold.

Several prospects have been opened in the red slate at the top of the Arkansas novaculite near Hawes. The joints are 4 inches to 6 feet apart, and blocks of large size can be taken out. This slate has a good ring, splits well, and can be sawed into thick blocks that may be suitable for milling stock. It can not be used for roofing slate, however, for it is not hard enough.

One small opening, near the center of sec. 11, T. 2 S., R. 20 W., exposes a gray slate near the base of the Stanley shale, which is here overturned to the south. This slate splits well and has a very good ring.

Silica.—The basal part of the Arkansas novaculite is composed almost wholly of silica, which is sufficiently white and free from impurities to be quarried and pulverized for use in the manufacture of pottery. Some of the waste novaculite at the oilstone factories has been pulverized for use as polishing powder. The novaculite is too hard to be used in making 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 making optical glass. On the east side of Central Avenue, in Hot Springs, a 50-foot bed of novaculite in the middle part of the formation has weathered to a soft, porous, fine-grained white to cream-colored tripoli. The material at the surface is soft enough to be crushed to a fine powder, but that a few feet from the surface may be much harder.

Quartz sand for structural use may be obtained in small quantities at places along the streams, where it has collected while the water was at high stages.

Iron and manganese.—Oxides of iron and manganese, either of one metal singly or of both metals intimately mixed, are found at a few places in the Arkansas novaculite as bunchy masses and as short veins from a fraction of an inch to a foot in width. The deposits occur in bedding planes or joints, as local segregations, or as cementing material in novaculite breccia. Nowhere in the area, however, have these oxides been found in sufficient quantity to be mined.

Pyrite.—Iron pyrites is distributed in fine grains through all the rocks in this region, but only at a place on the south slope of West Mountain, 2 miles west of Hot Springs, is it sufficiently abundant to be of possible use for the manufacture of sulphuric acid. The Hot Springs sandstone, which here dips 45° SW., is traversed by a zone, about 30 feet wide, of thickly set pyrite veins. These veins have a maximum width of 4 inches. Two prospecting shafts have been sunk here, and a good deal of drifting has been done.

Gold and silver.—Gold and silver in very small quantities are associated with the mass of nephelite syenite on the hill at the mouth of Gulpha Creek. A few shafts that have been sunk in this rock and in the associated much altered shales, have exposed a small quantity of vein minerals—chalcedony, a little purple fluorite, pyrite, and, exceptionally, barite. An assay of a specimen of vein material collected by Mr. Miser showed $2.10 in silver and 70 cents in gold to the ton. Rusty vein quartz assaying as much as $1.65 a ton in gold has been found at a few other places.

In none of these prospects has anything of economic importance been discovered, and although some gold ore may possibly be found in this region there is little chance that any deposits large enough to lead to extensive mining will be discovered.

Oil and gas.—Drilling for oil or gas in the Hot Springs district has been unsuccessfully carried on from time to time. There is no possibility that either will be found in commercial quantities in this district or in other parts of the Ouachita Mountain region in Arkansas, where the rocks have been so closely folded that they nearly everywhere stand at angles of 40° or more from the horizontal. The gas and much of the oil of these rocks, if any were ever present, would have escaped to the surface, and the remainder of the oil would have been distilled to asphalt or some other solid product of petroleum.

WATER RESOURCES.

GENERAL FEATURES.

The Hot Springs district is well watered, the average annual precipitation at Hot Springs being about 55 inches.

The Bigfork chert, the Arkansas novaculite, and the Hot Springs sandstone are the principal water-bearing formations in the area, although the other rocks, including even the shales, yield some water. The uniformly shattered condition of the Bigfork chert, its considerable thickness, and the comparatively large area of its outcrop render it the most valuable water-bearing formation. Numerous springs, for which this formation is the source, 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 come from the Bigfork chert. In the Trap Mountains many springs issue from the middle and upper parts of the Arkansas novaculite.

Wells that will furnish a supply of water sufficient for household use and generally also for stock may be obtained at almost any place in the Mazarn and Saline basins and in the narrow valleys between the higher mountain ridges by digging or drilling to depths not exceeding 50 feet.

COLD SPRINGS.

Cold springs, some of which yield waters of low mineral content, are common throughout the district but are largest and most numerous in the Trap and Zigzag mountains. About some of these springs resorts have been built for the use of their waters, and large quantities of water from some of them are marketed in Hot Springs and shipped to other cities.

The analyses of seven cold springs, which are described by Branner in his report on the mineral waters of Arkansas, are as follows:

Analyses of cold springs in the Hot Springs district, Ark.[a]

[Parts per million except as otherwise designated.]

	1	2	3	4	5	6	7
Silica (SiO_2)	3.8	14	6.5	15	16	32	28
Iron (Fe)	7.4	1.2	.17	6.3	.17	2.6	-------
Aluminum (Al)	--------	Trace.	.07	.51	1.2	Trace.	1.1
Calcium (Ca)	70	76	5.3	1.4	78	3.2	3.2
Magnesium (Mg)	4.1	2.9	.7	1.5	12	Trace.	.0
Sodium (Na)	1.4	2.0	1.5	2.4	6.5	294	222
Potassium (K)	3.1	.5	.3	.9	.5	6.8	23
Carbonate radicle (CO_3)	128	112	[b]9.1	4.4	[b]140	109	[c]146
Sulphate radicle (SO_4)	9.4	12	1.9	16	25	388	203
Chloride radicle (Cl)	2.0	6.2	2.7	4.4	4.4	52	40
Total solids	207	223	29	65	[d]284	888	660
Temperature, °F.	79	59	--------	65	---------	64	-------
Free carbonic acid (CO_2)	--------	[e]57	78	[e]110	---------	44	-------

[a] Arkansas Geol. Survey Ann. Rept. for 1891, vol. 1, 1892.

[b] Calculated.

[c] By difference.

[d] By summation.

[e] Including CO_2 in bicarbonates.

1. Big Chalybeate Spring. A. E. Menke, analyst.
2. Dripping Springs. Li and PO_4, 0.00. Sample collected Nov. 3, 1889. R. N. Brackett, analyst.
3. Happy Hollow Spring. PO_4 and Mn, traces; Li, Br, I, and Ti, 0.00. R. N. Brackett, analyst.
4. Happy Hollow Chalybeate Spring. Li, trace; Ti, Mn, Ba, Sr, Br, I, and PO_4, 0.00. R. N. Brackett, analyst.
5. Mountain Valley Spring. Ba, Sr, Br, I, Mn, Ti, Li, and PO_4, 0.00. R. N. Brackett, analyst.
6. Potash Sulphur Springs (West Spring). Mn and H_2S, traces. Sample collected October, 1887. C. B. Gannaway, analyst.
7. Potash Sulphur Springs (East Spring). H_2S, 0.00. F. W. Clarke, analyst.

HOT SPRINGS.

The hot springs in the district are at and near the southwest base of Hot Springs Mountain. The city of Hot Springs, which has been built about them, has become one of the prominent health and pleasure resorts of the United States.

Much of the following discussion relating to these springs has been taken from a report by Haywood and Weed.

The hot springs have been known since the lower Mississippi Valley was first settled. Although it is only a legend that they were visited by De Soto on his trip to the Mississippi, there is no doubt that they were used by the Indians before America was discovered, as abundant evidence was found in early days that they had quarried the novaculite near the hot springs for their arrowheads and other stone implements and had used the spring waters for bathing. William Dunbar and Dr. Hunter, of the Lewis and Clark exploring expedition, visited the place in 1804 and found that white visitors had already used the waters for bathing. The lands on which the springs issue were ceded in 1818 to the Government by the Quapaw Indians and afterward became a part of the Territory of Arkansas. The ground about the springs was located by several claimants before the organization of the Territory, but by Act of Congress the springs and the ground about them were reserved in 1832 for the United States Government, thus making the first national park reservation in the country. Owing to the claims made by different people to private ownership of the springs, they remained in the possession of these claimants until 1877, when the United States Supreme Court decided in favor of the Government. Under acts of Congress of March 3, 1877, June 16, 1880, and March 4, 1921, the mountains adjacent to the springs are permanently reserved for parks. These parks and the hot water, much of which is piped to the bathhouses, are under the control of the Superintendent of the Hot Springs National Park, appointed by the Secretary of the Interior.

Originally there were 71 of these springs, it is said, but on account of improvements, which necessitated the merging of two or more springs into one, and also on account of natural changes in the underground course of the water, this number has been reduced to 49. Of these 49 springs 44 are either in use or can be easily used by making some slight improvements. Five springs rise from the bed of Hot Springs Creek, which is now arched over and runs beneath the sidewalks and streets. The area in which they occur is a few hundred feet wide and a quarter of a mile long. At present all the springs are covered with masonry or concealed beneath turf and shrubbery. Some of the bathhouses are built directly over large springs. A deposit of gray calcareous tufa, in places 6 to 8 feet thick, has been formed by the hot springs over an area of 20 acres, though now it is largely covered by soil and vegetation.

The daily flow of the hot springs, according to Haywood, aggregates 826,000 gallons, and that of Big Iron Spring, which is the largest, is 201,600 gallons. Their temperature as determined by him ranges from 95.4° to 147° F. The hottest is Big Iron Spring. Almost half the water has a temperature of 140° or more, and less than 20 per cent is below 130°.

The following discussion of the source of the hot-spring waters and their heat is largely abstracted from an article by the senior author published in 1910.

As Weed has pointed out, "these waters rise through siliceous rock, and the fact that the hot waters contain so little mineral matter, particularly silica, is evidence of their meteoric origin and accords with the nature of the gases given off by the springs." The gases, as shown in the table of analyses, consist of carbon dioxide, oxygen, and nitrogen. The ratio of oxygen and nitrogen corresponds rather closely to that of atmospheric air, and, in view of the relative absorption of the two gases by water, Weed states that there can be no doubt that the oxygen and nitrogen given off by the water come from absorbed air.

The springs issue from the base of the Stanley shale and the top of the Hot Springs sandstone on the southwest end of the steeply pitching anticline that forms Hot Springs Mountain. The Bigfork chert is the underground reservoir for the hot waters, and their point of issue was determined by the altitude of the locality, by the southwestward pitch of the anticline in Hot Springs Mountain, and by the fracturing and possibly slight faulting in the process of folding. The collecting area must be near the springs, and a study of the topography, stratigraphy, and structure locates it with reasonably certainty in the anticlinal valley that extends northeastward between Sugarloaf and North mountains. The rocks that crop out in this valley are the Bigfork chert and the Polk Creek shale, but the Bigfork chert occupies most of the area.

The considerable thickness of the Bigfork chert, its much fractured condition, and the thin layers of which it is composed make it a water-bearing formation of great value to this region. At many places this formation outcrops in anticlinal valleys, where its beds are inclined at high angles which afford conditions favorable for the intake of water. A glance at the sections on the structure-section map will show that these conditions exist in the valley between North and Sugarloaf mountains. In addition to the favorable structure for the reception of water, the beds that overlie the formation—the Polk Creek and Missouri Mountain shales—enable it to retain the water which it receives. The water is thus collected in the basin between the ridges just mentioned and is conducted through the Bigfork chert beneath the syncline in North Mountain, from which it rises in the anticline in Hot Springs Mountain and emerges as hot springs at its southwest end. The level of the springs is lower than that of the general surface in the collecting area.

As Branner suggests, the heat of the hot springs waters is probably derived from masses of hot rocks, the cooled edges of which may or may not be exposed at the surface. The fact that with one exception these are the only hot springs in the Ouachita area, though scores of cold springs issue from the same formations and under practically the same geologic relations, gives this view great weight.

Kirk Bryan, who examined the hot springs in 1921, has discussed various theories of origin of the water. He has presented at length the hypothesis that the hot waters are given off by cooling hot rocks that are probably at a considerable depth below the surface. He has suggested that the hot waters rise along concealed fault fractures of probable Pleistocene age and on appoaching the surface follow the probable thrust fault whose location is shown on the areal-geology map.

The quantity of mineral matter is nearly the same in practically all the springs, ranging generally from 270 to 290 parts per million. Boltwood, who examined samples of water collected from 44 hot springs and 2 near-by cold springs, found that the waters from all of them are radioactive, but he does not give the names of the springs in his report.

Samples from nine of the springs examined had a radioactivity of 1 to 8.8 millimicrocuries per liter. (A millimicrocurie is the radioactivity produced by a millionth of a milligram of radium.) The radioactivity of water from 31 springs was from 0.1 to 1 millimicrocurie. In comparison with results obtained in tests of well and spring waters in many other places, the radioactivity of these waters is not remarkable.

The table of analyses on page 12 shows that the chief inorganic constituents of the hot waters are silica, calcium, and bicarbonate, with distinctly minimum amounts of magnesium, sodium, potassium, sulphate, and chloride and merely negligible amounts of other constituents. The waters may be classed as calcium carbonate waters of moderate mineral content. Moreover, except in the very notable features of heat and the amount of gases, these waters are similar to those of many ordinary cold springs in the Ouachita Mountains.

Average chemical composition of the inorganic material in solution in the waters of the Hot Springs of Arkansas, computed from analyses by J. K. Haywood.

[Average of 42 springs, except as noted. Besides the substances listed in the table traces of barium and strontium were determined in Big Iron Spring.]

Constituent.	Parts per million.	Per cent of total inorganic material in solution.
Silica (SiO_2)	47	16.7
Iron (Fe), Aluminum (Al)	.20	.1
Calcium (Ca)	46	16.3
Magnesium (Mg)	4.9	1.8
Manganese (Mn)	.1	.1
Sodium (Na)	4.8	1.7
Potassium (K)	1.7	.6
Lithium (Li)	Trace.	.0
Ammonium radicle (NH_4)	[a] .05	.0
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	164	58.7
Sulphate radicle (SO_4)	8.4	3.0
Chloride radicle (Cl)	2.6	.9
Nitrate radicle (NO_3)	[a] .4	.1
Nitrite radicle (NO_2)	[a] .001	.0
Phosphate radicle (PO_4)	Trace.	.0
Metaboric acid (BO_2)	Trace.	.0
Arsenic (As)	.0	.0
Bromine (Br)	Trace.	.0
Iodine (I)	Trace.	.0
	279	100.0

[a] Average of 41 springs.

Average quantity of gases in 43 springs of the Hot Springs district, Ark.

[Cubic centimeters per liter at 0° C. and 760 mm. pressure.]

Nitrogen	8.78
Oxygen	3.04
Carbon dioxide (free)	10.36
Carbon dioxide (set free from bicarbonates on evaporating to dryness)	29.66
Hydrogen sulphide	None.

STREAMS.

Ouachita River, though the largest stream in the district, may be easily forded at its low stage. A series of dams along it would collectively make available a large amount of water power. During long droughts this stream and its tributaries are entirely supplied by springs, but they are subject to sudden floods after heavy rains and then become torrents.

WATER SUPPLY FOR CITY OF HOT SPRINGS.

The public water supply for Hot Springs is obtained from a small stream a short distance north of the city. The water is pumped to a reservoir on the crest of the ridge that extends northeastward from Sugarloaf Mountain and flows from this reservoir by gravity to the city. A sufficient supply of satisfactory water is thus obtained, but water from wells and from the numerous hot and cold springs in and near the city is extensively used for drinking.

SOILS AND FORESTS.

Except for small deposits of alluvium along the streams the soil of the Hot Springs district is residual, having been derived from the rocks exposed in the district. The soil is commonly shallow, poor, and stony, except in the more level areas along the streams and in some of the level uplands, where it is rather fertile. The Blakely sandstone, the Polk Creek shale, the Blaylock sandstone, the Missouri Mountain shale, the Arkansas novaculite, and the Hot Springs sandstone are covered with a prevailingly rocky soil, which is derived either from their own hard outcrops or from adjacent beds. The crests of the ridges and the slopes where these formations make up the surface rock are in general suitable for little else then the dense forest growth with which they are ordinarily covered. Parts of the outcrops of the Stanley shale, the Bigfork chert, and the Mazarn and Womble shales are likewise very poor, but other parts are suitable for general farming. The igneous rocks at Potash Sulphur Springs on weathering yield a deep, rich, red clay soil that gives large crops and is well adapted to fruit culture. This soil, however, covers only a small part of the Hot Springs district. It is represented on the geologic map by the pattern that indicates the areas of nephelite syenite.

The district was formerly covered with a dense growth of timber consisting of oak and other hardwoods and yellow pine, but much of the commercial timber has been removed. The larger part of the district, however, is still covered with forest, though most of it consists of second growth and scrub timber. Lumbering has been and still is an important industry. A little of the timber is burnt into charcoal, which is hauled to Hot Springs to supply a demand for this fuel.

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		Carboniferous. Pennsylvanian. Atoka formation.	Carboniferous. Atoka formation.	Carboniferous. Atoka formation.	Carboniferous. Atoka formation.		
		[Not present.]	[Not present.]	[Not present.]	Caney shale.		
	Carboniferous. Jackfork sandstone.	Mississippian. Jackfork sandstone.	Jackfork sandstone.	Jackfork sandstone.	Jackfork sandstone.	Jackfork sandstone.	Lower Carboniferous. Sandstones and shales.
Carboniferous. Mississippian. Stanley shale.	Stanley shale.	Stanley shale.	Stanley shale.	Stanley shale.	Standley shale.	Standley shale.	
				Age unknown. Fork Mountain slate.			
Hot Springs sandstone.	[Not present.]	Hot Springs sandstone.	[Not present.]	[Not present.]	[Not present.]	[Not present.]	
Devonian? Upper (?) Devonian. Devonian. Lower (?) Devonian. Arkansas novaculite.	Devonian. Arkansas novaculite.	Devonian? Devonian. Arkansas novaculite.	Devonian? Devonian. Arkansas novaculite.	Arkansas novaculite.	Ordovician. Devonian and Silurian chert and black shale. Talihina chert.	Ordovician. Talihina chert.	Novaculites.
Silurian. Missouri Mountain shale.	Silurian. Missouri Mountain slate.	Silurian. Missouri Mountain slate.	Silurian. Missouri Mountain slate.	Missouri Mountain slate.			
Blaylock sandstone.	Blaylock sandstone.	Blaylock sandstone.	Blaylock sandstone.	Ordovician. Blaylock sandstone.			
Ordovician. Upper (?) Ordovician. Polk Creek shale.	Ordovician. Polk Creek shale.	Ordovician. Polk Creek shale.	Ordovician. Polk Creek shale.	Polk Creek shale.			Lower Silurian. "Shales, limestones, massive quartzose sandstones, cherty blue limestones, with gray, black, and yellow shales at the bottom."
Middle Ordovician. Bigfork chert.	Bigfork chert.	Bigfork chert.	Bigfork chert.	Bigfork chert.			
Lower Ordovician. Womble shale.	Womble shale.	Womble shale.	Womble shale.	Stringtown shale.	Stringtown shale. ?	Stringtown shale. ?	
Blakely sandstone.	Blakely sandstone.	Blakely sandstone.	Blakely sandstone.	Ouachita shale.			
Mazarn shale.	Mazarn shale.	Mazarn shale.	Mazarn shale.				
Not exposed.	Ordovician? Crystal Mountain sandstone.	Ordovician? Crystal Mountain sandstone.	Ordovician? Crystal Mountain sandstone.	Crystal Mountain sandstone.	[Not exposed in area of grahamite deposits.]	[Not exposed.]	
	Cambrian. Collier shale.	Cambrian. Collier shale.	Cambrian. Collier shale.	Age unknown. Collier shale.			