STATE OF ARKANSAS

Arkansas Geological Commission

Norman F. Williams, State Geologist

INFORMATION CIRCULAR 29

GENERAL GEOLOGY AND MINERAL RESOURCES OF THE CADDO RIVER WATERSHED

By

Charles G. Stone and William V. Bush

Little Rock, Arkansas
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ABSTRACT

The Caddo River watershed is located in a picturesque area typified by jagged peaks, hogbacks, and broad rather hummocky basins comprising approximately 480 square miles in west-central Arkansas. It is located primarily in the Ouachita Mountains with a small portion in the Gulf Coastal Plain.

The exposed sedimentary bedrock in the Ouachita Mountain portions of the area is shale, sandstone, chert, novaculite, limestone, conglomerate, and tuff. These rocks are considered to be of deep-water marine origin and exceed 30,000 feet in thickness. They are of Paleozoic age ranging from Early Ordovician (about 490 million years) to Middle Pennsylvanian (about 290 million years). The Ouachita Mountains were formed when these rocks were uplifted by northerly directed compressive forces during late Paleozoic time. This deformation caused extensive thrust faults and complex fold systems. Some rocks were subjected to very low-rank metamorphism and related hydrothermal events as evidenced by locally pervasive shear planes, recrystallization, and numerous milky quartz veins. Following the formation of the Ouachita Mountains there was a long period of erosion and minor arching with thousands of feet of rock being denuded from the area. In the southeast portions of the watershed the Paleozoic strata are overlain with a major unconformity by the slightly tilted mostly shallow-marine Late Cretaceous rocks. Covering the bedrock at places are unconsolidated, mostly flat-lying terrace, alluvial and colluvial deposits composed of clay, sand, gravel and cobbles of Quaternary age.

Mineral resources are quite varied in the watershed with barite, manganese, rock aggregate, slate and quartz crystals comprising most of the past production. Numerous additional mineral resources could have economic potential. Surface and groundwater are very important resources in the watershed.

INTRODUCTION

Location

The Caddo River watershed covers an area of approximately 480 square miles in west-central Arkansas which includes portions of Montgomery, Pike, Hot Spring, Clark and Garland Counties. It is located in the central and southern Ouachita Mountains with a small portion along the southeast boundary extending into the Gulf Coastal Plain.

Physiography

The Ouachita Mountains consist of several mountains and broad basins that extend from Little Rock, Arkansas westward to Atoka, Oklahoma. The mountains are long narrow ridges, many forming hogbacks, with steep slopes and sharp rather straight and even crests. The mostly mature trellis drainage patterns have primarily developed in the tilted alternating resistant and weak Paleozoic strata. The typically parallel subsequent streams (Caddo and tributaries) flow in fairly deep valleys separated by rather high topography, and exhibit some youthful transversing V-shaped water gaps. The Fall Line separates the older deformed strata of the Ouachita Mountains and the overlapping mostly shallow-marine Cretaceous deposits and other more recent poorly consolidated rocks of the Gulf Coastal Plain. Surfaces of planation are present inland from this ancient boundary indicating that the Ouachita Mountains have been deeply eroded since they were formed, but it is unlikely that they were ever completely covered by these seas. Low rolling hills with undulating narrow valleys typify the topography in the Gulf Coastal Plain. The gently southward dipping Cretaceous strata form a broad homoclinal feature with sluggish consequent trunk streams having a dendritic drainage pattern. Near the Ouachita River junction the Caddo is in an old age stream cycle with negligible downcutting and characterized by a low broad flood plain with meanders and oxbow lakes.

The principal physiographic subdivisions of the Ouachita Mountains in the Caddo River watershed are the Athens Plateau, Trap Mountains, Cossatot Mountains, Caddo Mountains, Crystal Mountains, Mazarn Basin and Caddo Basin (Fig. 1). The total relief is approximately 2000 feet ranging from 180 feet (above sea level) at the junction of the Caddo and Ouachita Rivers in Clark County to over 2200 feet in the Caddo Mountains.

Acknowledgments

We gratefully acknowledge the cooperation of Boyd R. Haley, U. S. Geological Survey; Drew F. Holbrook, consulting geologist; Gary Sick, U.S. Forest Service; Cynthia Shackelford, Arkansas Department of Pollution Control and Ecology; and John D. McFarland, III and George W. Colton, Arkansas Geological Commission, for their assistance in the preparation of this paper.

GENERAL GEOLOGY

All the rocks in the Caddo River watershed are of sedimentary origin with the exception of a small igneous dike. All formations in the Ouachita Mountains of Arkansas are present in the watershed and range from Early Ordovician to Middle Pennsylvanian age. They were originally deposited as nearly flat layers of mud, sand, gravel, marl, lime, volcanic ash and silica in the marine waters of an ancient deep basin that once occupied the region. With the load and weight of the overlying sediments they were subsequently converted to shale, sandstone, conglomerate, limestone, tuff, chert and novaculite. These rocks were then subjected to intense compressive forces in late Paleozoic time that transported them towards the north causing them to bend and fold and, in many places, to rupture and fault with ultimately the region being uplifted forming extensive mountain ranges. This deformation, called the Ouachita orogeny, caused intense pressures and elevated temperatures which slightly metamorphosed these rocks in places, changing some shale to slate and sandstone to quartzite. The Paleozoic rocks exceed 50,000 feet in thickness in the Ouachita Mountains, but only the lower 30,000 feet are exposed in the watershed. The oldest strata are exposed in the northern portions and the youngest in the southern portions of the watershed.

The uplift produced prominent east-west folds and large thrust faults in the strata. Almost without exception the present land forms are a reflection of the underlying bedrock. The softer less resistant shale, limestone and impure sandstone are more susceptible to erosion and form most of the basins, valley floors, and lower hills. The harder more resistant novaculite, chert, and relatively pure sandstone form the mountains, ridges and peaks.

Subsequent to the Ouachita orogeny the region has been eroded and dissected with minor arching and extensional faulting. Some sizable igneous intrusions, notably in early Late Cretaceous time, occur in adjoining areas at Magnet Cove and Murfreesboro. In Late Cretaceous and possibly early Tertiary time shallow warm seas lapped upon the southern portions of the area. The gently dipping clay, sand, gravel, marl and chalk of Late Cretaceous age represent the remnants of these deposits.

During Pleistocene and Recent times (Quaternary), the older rocks in the area were further eroded. Terrace, alluvial, and colluvial deposits represent some of the products of these climatically related cycles.

Formation Descriptions

Based on their lithologic character, stratigraphic position, and meager fossil content,

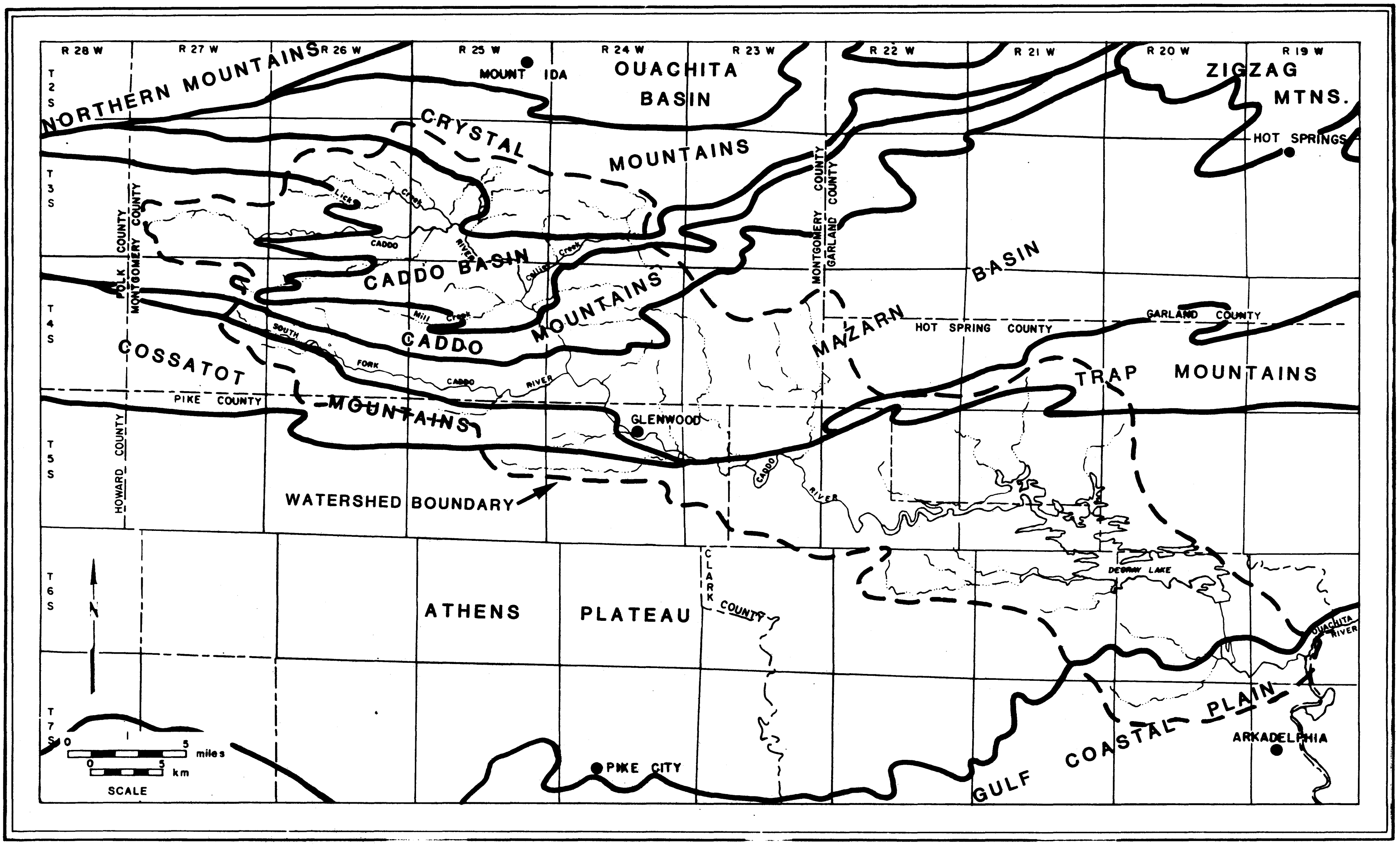

FIGURE 1 PHYSIOGRAPHIC SUBDIVISIONS OF PORTIONS OF THE SOUTHERN AND CENTRAL OUACHITA MOUNTAINS, ARKANSAS

19 formations of the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Cretaceous Systems (Fig. 2) are grouped into seven units on the generalized geologic map (Fig. 3). It was not feasible to show the Quaternary deposits on this map.

Collier Shale

The Collier Shale is the oldest formation exposed in the Ouachita Mountains of Arkansas. It was named by Purdue (1909) and further defined by Miser and Purdue (1929) for exposures along the headwaters of Collier Creek in the Crystal Mountains. The thickness of the Collier is thought to be over 1000 feet but the base is not exposed. It consists of graphitic to talcose shale with considerable amounts of interbedded, dense to very fine-grained, sandy, sometimes pellatoidal, or conglomeratic, bluish-gray limestone. There are minor quantities of bluish-black chert, gray calcareous siltstone, fine-grained quartzose sandstone, conglomerate and boulder-bearing breccia. Repetski and Ethington (1977) identified conodont microfossils from limestones in the formation and indicated they were of Early Ordovician age. Previously the Collier had been tentatively assigned to the older Cambrian Period.

Some road aggregates have been obtained from small pits in the Collier for local use. Limited reserves of limestone for agricultural purposes are also available.

Crystal Mountain Sandstone

The Crystal Mountain Sandstone overlies the Collier Shale and the name was proposed by Purdue (1909) for the massive sandstones containing clear quartz crystals that form the Crystal Mountains.

The Crystal Mountain Sandstone varies from approximately 550 to 850 feet in thickness. The formation is composed of very massive to thin-bedded quartzose, calcareous, light gray to brown, sometimes conglomeratic, medium-grained sandstones. Interbedded black, gray to buff shales are present and are more common in the upper part of the formation. Intervals of thin, dense, very fine-grained to sandy, bluish-gray limestone and calcareous gray conglomerate and boulder-bearing breccia occur in the lower portions of the formation. The massive sandstone interval is quite resistant and forms the tall ridges and peaks in the Crystal Mountains. Few fossils have been reported from rocks in the formation.

Large reserves of rock aggregate are potentially available from the massive sandstone intervals. Significant amounts of clear quartz crystal are mined from veins dissecting the formation at several sites in and adjacent to the watershed. Some small abandoned manganese mines and prospects are present in the Crystal Mountain Sandstone.

Mazarn Shale

The Mazarn Shale was named from Mazarn Creek northeast of Norman, Arkansas in the Crystal Mountains by Miser (1917) and later mapped by Miser and Purdue (1929). The Mazarn has a total thickness of about 2500 feet and consists mostly of black shale with some interbedded olive-green shale and silty shale, thinly laminated gray siltstone, brown quartzose sandstone, and dense blue-gray limestone. The alternating black and olive-green shale layers, often with cross-cutting cleavage, give it a banded appearance. Worm burrows and other trace fossils occur in the siltstones, and some conodonts and graptolites are found in the limestones and shales. The Mazarn typically forms fairly broad valleys with some noticeable low ridges. There have been minor quantities of commercial slate and also shale for rural road construction obtained from small pits and quarries in the Mazarn. Some of the limestone intervals could have potential for agricultural purposes.

Blakely Sandstone

The Blakely Sandstone was named from Blakely Mountain north of Hot Springs by Miser (1917) and later mapped by Purdue and Miser (1923). It ranges from 400 to 700 feet in thickness and consists of inter-

Figure 2. -- Stratigraphic section of rocks exposed in the Caddo River Watershed

Age	Formation	Maximum Thickness	Description
Quaternary	Alluvial Deposits	20′	clay, silt, sand, gravel, and cobbles
	Terrace Deposits	15′	sand, gravel, and some clay
Cretaceous	Nacatoch Sand	200′	sand and some clay and gravel
	Saratoga Chalk	60′	chalk and some marl
	Marlbrook Marl	80′	chalky marl and some sand
	Ozan Formation	125′	marl, sand, or sandy marl
	Brownstown Marl	175′	marl, clay, sand, and some gravel
	Igneous Intrusive		ultramafic dike
Pennsylvanian	Atoka Formation	7500′	shale, siltstone, and sandstone
	Johns Valley Shale	1500′	shale, sandstone, and some chert
	Jackfork Sandstone	6000′	sandstone, siltstone, and shale
Mississippian	Stanley Shale	11,000′	shale, siltstone, sandstone, and some chert and volcanic tuff
Devonian	Arkansas Novaculite	900′	novaculite, chert, shale, and some conglomerate
Silurian	Missouri Mtn. Shale	300′	shale with minor sandstone and conglomerate
	Blaylock Sandstone	1000′	sandstone, siltstone, and shale
Ordovician	Polk Creek Shale	175′	shale and some chert and limestone
	Bigfork Chert	750′	chert, limestone, and some shale and siltstone
	Womble Shale	1900′	shale, limestone, and some sandstone, chert and conglomerate
	Blakely Sandstone	700′	shale, sandstone, and some conglomerate and limestone
	Mazarn Shale	3000′	banded shale with some sandstone and limestone
	Crystal Mtn. Sandstone	850′	sandstone, shale, and some limestone and conglomerate
	Collier Shale	1000′	shale, limestone, and some chert and conglomerate

bedded thin to fairly massive, fine to medium-grained, sometimes silty or calcareous, quartzose brownish gray sandstones and black to green shales. A gray sandy limestone occurs in places in the upper part of the Blakely and a shale sequence ranging in thickness from 100 to 200 feet is near the middle. Graptolite impressions are present in some of the shales. The Blakely forms high ridges with small, narrow intervening valleys. Small amounts of quartz crystal have been mined at a few localities near Norman from veins dissecting the sandstone. The massive or thicker packets of sandstones are suitable for rock aggregate.

Womble Shale

The Womble Shale was named for outcrops near the town of Womble (now called Norman), Arkansas by Miser (1917). It likely ranges from about 1250 to 1900 feet in thickness and consists mostly of black shale with intervals of dense, bluish-gray limestone and calcareous siltstone. Minor amounts of gray chert, fine-grained quartzose sandstone and conglomerate are also present. Graptolite fossil impressions occur rather commonly in the shale. Repetski and Ethington (1977) describe conodonts in the limestones. Springs issue from joints in the limestone intervals at a number of places. The Womble characteristically forms low, fairly broad valleys with minor east-west trending, rather irregular hills. Recently several companies have tested rocks of the Womble and other formations for base metal deposits. The limestones have been prospected on a small scale for agricultural limestone and decorative black marble. Small amounts of road aggregate have been mined from the Womble.

Bigfork Chert

The Bigfork Chert was named for extensive exposures near Bigfork, Arkansas immediately west of the Caddo watershed by Purdue 1909). It ranges in thickness from about 550 feet in the north to 750 feet in the south. It is composed primarily of thin-bedded, highly fractured, gray chert, dense gray limestone, calcareous siltstone and some thin, interbedded black shale. Irregular-shaped "potato" hills are produced by the weathering of the Bigfork. Intense fracturing creates good aquifer conditions in the formation throughout most of the Ouachita Mountains. Some occurrences of the aluminum phosphate mineral wavellite (cats-eye) and variscite have been found in small veins. Because of its finely broken nature, the Bigfork Chert has considerable potential for local supplies of rock aggregate.

Polk Creek Shale

The Polk Creek Shale was named by Purdue (1909) for outcrops along Polk Creek in the Caddo Mountains. The Polk Creek ranges from 110 to 175 feet in thickness. It is a black sooty shale, with some very thin gray chert and a few thin blue-gray limestone intervals. Upper Ordovician graptolite fossils are very common in the formation. It is mostly exposed in narrow strips in valleys but occasionally outcrops on the mountain slopes. There are several old prospects in the sooty shales which likely were unsuccessful ventures for various precious elements.

Blaylock Sandstone

The Blaylock Sandstone was named from Blaylock Mountain on the Little Missouri River by Purdue (1909). It lies between the Missouri Mountain Shale and the Polk Creek Shale and is approximately 1000 feet thick in the Cossatot Mountains but it thins dramatically to the north where it is either absent or less than 20 feet thick. It consists of alternating thin brownish gray, very fine-grained, silty sandstone and gray shale layers. It typically forms narrow ridges or jagged strips on mountain slopes. A small quantity of sandstone has been used for local building stone. There are a few old misdirected prospects in the formation.

Missouri Mountain Shale

The Missouri Mountain Shale was named by Purdue (1909) for exposures in the Missouri

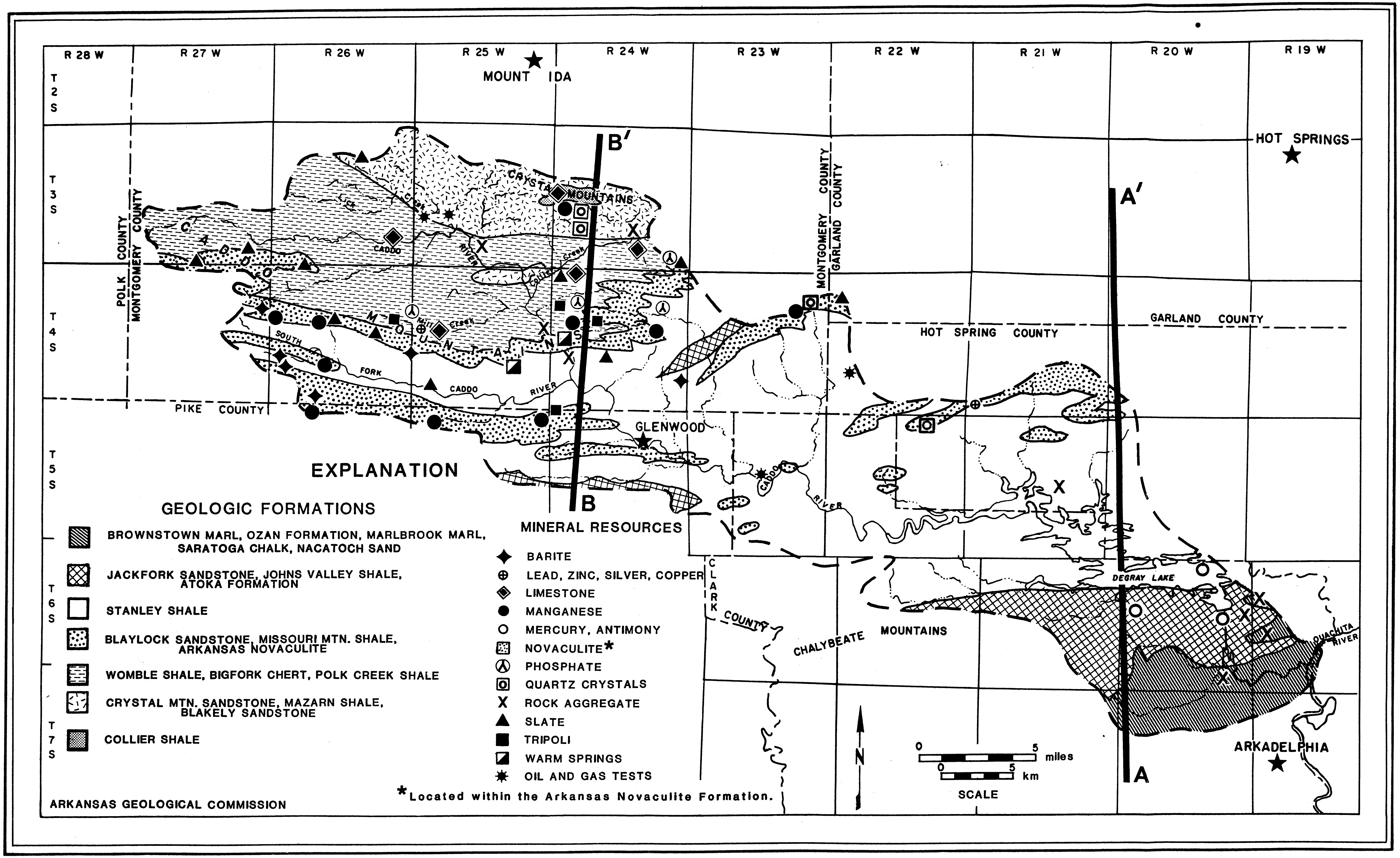

FIGURE 3. GENERALIZED GEOLOGIC AND MINERAL RESOURCES MAP OF THE CADDO RIVER WATERSHED

Mountains. The Missouri Mountain Shale lies between the Arkansas Novaculite and the Blaylock Sandstone or when the Blaylock is absent the Polk Creek Shale. It is typically a red, green or buff shale or slate with minor novaculite and conglomerate layers. It generally is poorly exposed and forms narrow valleys or slopes. The Missouri Mountain is about 50 feet thick in the south, reaches a maximum of 300 feet in the west-central part, and is between 175 and 200 feet along the east-central portions of the area. It has previously been quarried for ornamental red, green, olive and buff colored slates in the northwestern part of the area.

Arkansas Novaculite

A type locality has not been assigned for the highly distinctive Arkansas Novaculite. The exposures along the roadcut adjacent to the Caddo River at Caddo Gap have served as a classic example of the typical development of this formation (Fig. 4). The Arkansas Novaculite consists predominantly of white to light gray novaculite with lesser amounts of gray chert, olive-green to black shale, conglomerate and sandstone. It is about 850 to 900 feet thick in the south, about 650 to 800 feet thick in the central part, and 350 to 400 feet thick along the northeastern part of the watershed. Novaculite is a hard dense rock composed essentially of silica, usually white to light gray in color and resembling unglazed porcelain in general appearance and texture. The formation is divisible into three distinct Divisions throughout most of the area: a Lower Division of massive white novaculite, with minor shale and conglomerate; a Middle Division of dark chert and novaculite interbedded with olive green to black shale and some conglomerate; and an Upper Division of white, often tripolitic and calcareous, mostly thin-bedded novaculite. The Arkansas Novaculite is extremely resistant and forms high, sharp-crested ridges along east-west belts. Novaculite is probably best known as a raw material for making whetstones. There are no active whetstone operations in the area, but suitable materials are undoubtedly present. Tripoli prospects occur in the Upper Division at several localities and abandoned manganese mines and prospects are present in both the Lower and (less often) the Upper Divisions. Some quantities of copper, cobalt, nickel, and lithium are often associated with the manganese ore. In recent years the unusual iron phosphate minerals that occur mostly in association with the manganese occurrences have been prospected by mineral collectors. Rock aggregate is readily available from various portions of the formation.

Stanley Shale

The Stanley Shale was named by Taff (1902) for exposures near the town of Stanley (formerly called Standley) in Pushmataha County, Oklahoma. The Stanley Shale has been elevated to a Group in Oklahoma and in some areas in Arkansas, but mainly for the sake of simplicity, these subdivisions are not used in this report.

The Stanley Shale has a maximum thickness of about 11,000 feet and is composed mostly of black to brownish-green shale with lesser quantities of thin to massive, fine-grained, feldspathic gray to brown sandstone. Some thin black siliceous shales and cherts occur in parts of the Stanley and are useful in subdividing the formation. Minor conglomerate and quartzose sandstone (Hot Spring Sandstone Member) and tuff beds (mostly Hatton Tuff Member) are present in the lower part. Cone-in-cone and other mostly calcareous siltstone concretions typically occur throughout the formation. Some conodonts have been found in the shales and cherts and a prolific invertebrate fauna has been collected from erratic blocks at a few locations in the Stanley (mostly in the northern Ouachita Mountains). Plant fossils are present in some intervals and are useful for age determinations and correlations.

The sandstones decompose upon weathering and form rather low ridges. Thus the Stanley typically forms valleys with a series of low hills. It is the primary bedrock for the Mazarn Basin and much of the Athens

Plateau.

Significant barite has been produced from deposits in the lower Stanley in the area. Barite mining is expected to resume at a future date by the Milchem Company from their deposit at Fancy Hill. Slate used for roofing granules is currently mined by Bird and Son, Inc. from sheared shales in the Stanley near Caddo Gap and unlimited reserves are available. There are several small pits in the shales, siltstones and sandstones of the Stanley which are used mostly as local sources of rock aggregate. Significant mercury and antimony deposits occur in the Stanley Shale to the south and southwest of the watershed. There is one small antimony prospect known in the watershed on the east end of De Gray Lake.

Jackfork Sandstone

The Jackfork Sandstone was first used by Taff (1902) to designate a sandstone-shale sequence on Jackfork Mountain north of Daisy in Atoka County, Oklahoma. In the Ouachita Mountains of Oklahoma and in some areas in Arkansas, the Jackfork has been elevated to a Group and subdivided into a number of formations, but it will be retained as a formation in this report.

The Jackfork Sandstone of Early Pennsylvanian age has a total thickness of about 6000 feet along the southern part of the Athens Plateau. A classic section of the upper Jackfork Sandstone occurs at the Lake De Gray Spillway (Fig. 5). Approximately the lower 2500 feet of the Jackfork Sandstone is exposed in the Pigeon Roost Mountain area of the Mazarn Basin.

The Jackfork is composed of thin to massive, light-brown, fine-grained, quartzitic gray sandstone, blue-black to brown siltstone and interbedded gray-black shale. Some of the sandstones contain a few thin conglomeratic layers with pebbles that consist of rounded chert and metaquartzite. Many of the siltstones contain coalified plant fragments. A few intervebrate fossil fragments and molds occur in the sandstone and conglomerate beds. The massive sandstones are fairly resistant to weathering and typically form ridges with many rock exposures. Little mineralization has been noted in the Jackfork in this area. The possibility exists of discovering deposits such as mercury that occur in veins in the Stanley Shale and Jackfork Sandstone to the southwest near Lake Greeson. Small quantities of mercury have been noted near De Gray Lake. A massive sandstone interval in the upper Jackfork is worked sporadically for commercial aggregate east of De Gray Dam. Several units in the Jackfork have potential for commercial aggregate.

Johns Valley Shale

The Johns Valley Shale was named by Ulrich (1927) for exposures that Taff (1901) had identified as Caney Shale along Johns Valley in Pushmataha County, Oklahoma. The Johns Valley Shale has received much attention by geologists because of the enormous quantities and, in some cases, giant sizes of erratics derived from Arbuckle and Ozark foreland facies mostly in the frontal Ouachita Mountains of Oklahoma and portions of Arkansas. It is the general concensus of opinion that the erratics were derived by slumping from submarine scarps that flanked the north side of the unstable Ouachita trough.

Walthall (1967) first described the Johns Valley Shale in the southern Athens Plateau area of Arkansas. Stone, Haley and Viele (1973), Haley et al. (1976), Gordon and Stone (1977), and Stone, McFarland and Haley (1981) further defined and also expanded the upper boundary of the formation in this area.

The formation in the watershed is about 1500 feet thick and typically consists of gray-black clay shale and rather silty thin to massive brownish-gray sandstone. Some ironstone concretions are dispersed through the shales. Rather chaotic sandstone-shale intervals are present at places in the formation. A few

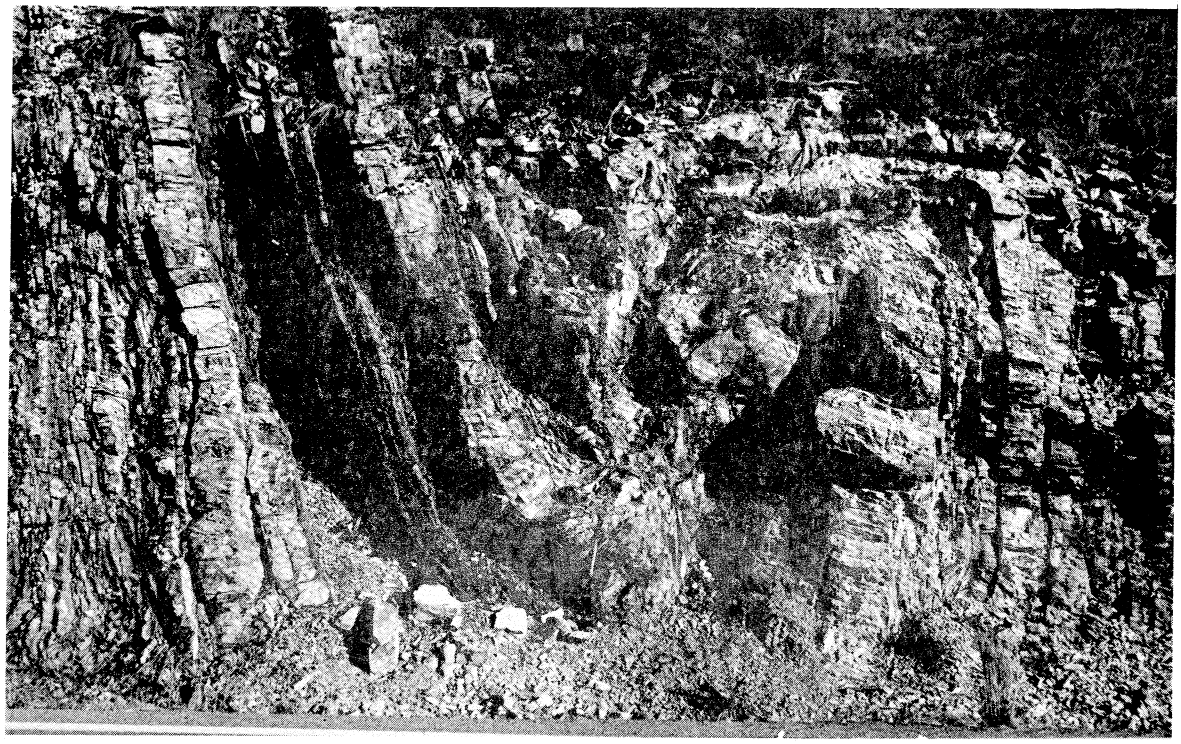

Figure 4. — Complexly folded intervals of dense novaculite and some thin shale in the Lower Division of the Arkansas Novaculite at the north end of the Caddo Gap section on Arkansas Highways 8 and 27.

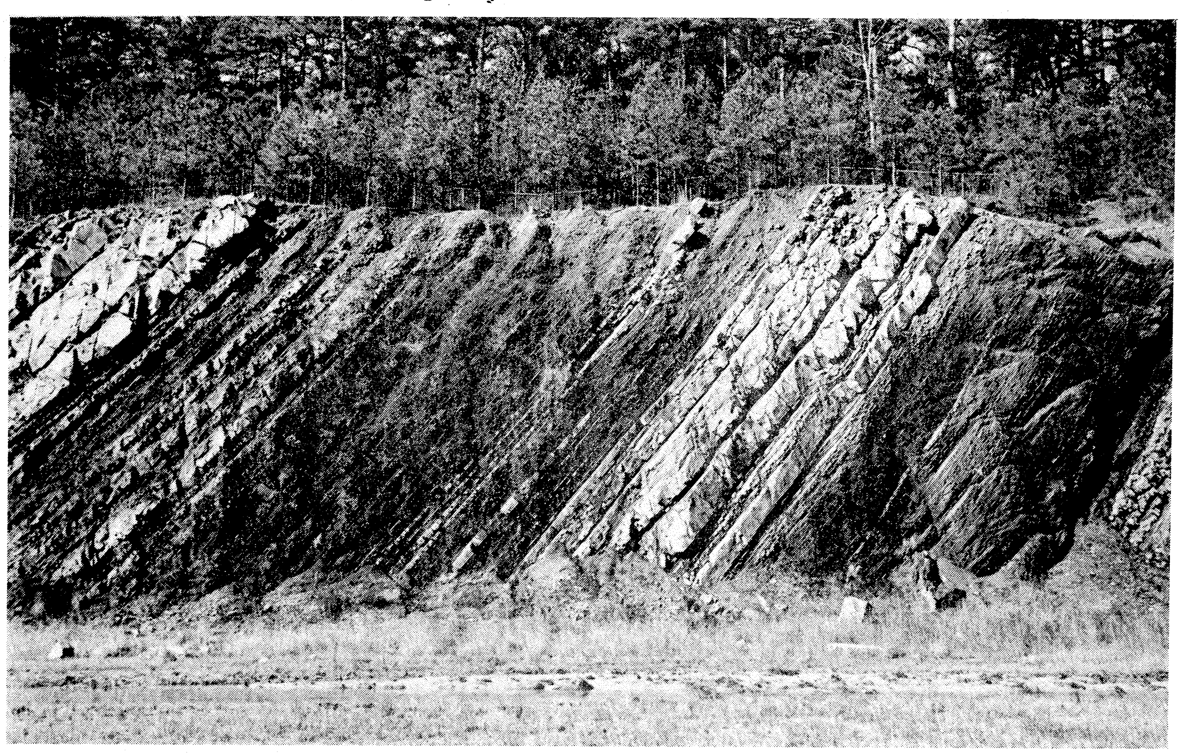

Figure 5. — Steeply dipping interbedded quartzose sandstones (light) and shales (dark) in the upper Jackfork Sandstone near the middle of the De Gray Lake spillway cut.

invertebrate fossils occur in a few lenticular siltstone masses that likely were deposited by submarine slumping from a southern source.

Atoka Formation

The Atoka Formation was described and mapped by Taff and Adams (1900) near Atoka, Oklahoma, but a type section was not designated. Reinemund and Danilchik (1957), Stone (1968), and Haley et al. (1976) further defined and established the Atoka Formation in the southern Arkoma Basin and Ouachita Mountains of Arkansas. The Atoka was first differentiated from the Jackfork in the Athens Plateau by Miser and Purdue (1929). Walthall divided the "Atoka Formation" in this area into the Johns Valley Shale and Atoka Formation. During the Arkansas state geologic map project (Haley et al., 1976), the Atoka-Johns Valley boundary was further adjusted.

The Atoka contains about 7500 feet of thin to rather massive, fine to medium-grained subgraywacke (silty) sandstones and interbedded gray-black shales. There are chaotic intervals containing masses of sandstone, siltstone, iron carbonate concretions and possibly some erratics that suggest extensive slurries and slumps derived from submarine scarps generally to the south. A few conglomerates and calcareous sandstones contain a transported invertebrate mold fauna. The top of the Atoka is not exposed in the area and it is believed that about 20,000 feet was removed by Early Cretaceous erosion. Small quantities of road aggregate have been mined from the Atoka.

Brownstown Marl

The name Brownstown Marl was first applied by Hill (1888) to strata of Late Cretaceous age outcropping in the vicinity of Brownstown, Sevier County, Arkansas. It was subsequently mapped and partially redefined by a number of investigators in southwest Arkansas.

In the eastern part of the Caddo River watershed, near De Gray Dam, the gently southward dipping Brownstown Marl caps hills underlain by the tilted Paleozoic rocks. The Brownstown was deposited in the Gulf Coastal Plain. The Fall Line between the older and younger rocks represents the break or a major unconformity with a long period of erosion along the eastern and southern Ouachita fold belt. The Brownstown has a thickness of about 175 feet and is composed of marl, clay, sand and gravel. These beds were deposited mostly in a shallow marine environment near an ancient shoreline. Some marine fossils, especially a microfauna, and a few lignitic logs have been noted in the formation. Sand and gravel from the Brownstown was used in construction at De Gray Lake.

Other Upper Cretaceous Formations

The Brownstown Marl is overlain by several rather thin, mostly marine and fossiliferous, younger Upper Cretaceous formations in a small area along the southeastern border of the watershed near Arkadelphia. The following brief description of these formations is mostly from Dane (1929). The Brownstown is overlain unconformably by about 125 feet of sandy marl of the Ozan Formation. The Marlbrook Marl unconformably overlies the Ozan and consists of about 80 feet of dark blue (fresh) to white (weathered) chalky marl. The Saratoga Chalk which rests unconformably on the Marlbrook contains about 60 feet of fairly hard, white chalk with some marl. The Nacatoch Sand unconformably overlies the Saratoga and consists of about 200 feet of cross-bedded, yellowish-gray, slightly glauconitic, unconsolidated quartz sand, with minor clay and gravel intervals. About three miles south of the area, the Arkadelphia Marl, which is the youngest Upper Cretaceous Formation in Arkansas, unconformably overlies the Nacatoch.

Terrace Deposits

Minor alluvial terrace deposits of Quaternary (Pleistocene) age occur along the Caddo River watershed. These deposits are thin, probably not exceeding 15 feet in thickness. They consist of sand, gravel and cobbles invertebrate fossils occur in a few lenticular siltstone masses that likely were deposited by submarine slumping from a southern source.

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In the eastern part of the Caddo River watershed, near De Gray Dam, the gently southward dipping Brownstown Marl caps hills underlain by the tilted Paleozoic rocks. The Brownstown was deposited in the Gulf Coastal Plain. The Fall Line between the older and younger rocks represents the break or a major unconformity with a long period of erosion along the eastern and southern Ouachita fold belt. The Brownstown has a thickness of about 175 feet and is composed of marl, clay, sand and gravel. These beds were deposited mostly in a shallow marine environment near an ancient shoreline. Some marine fossils, especially a microfauna, and a few lignitic logs have been noted in the formation. Sand and gravel from the Brownstown was used in construction at De Gray Lake.

Other Upper Cretaceous Formations

The Brownstown Marl is overlain by several rather thin, mostly marine and fossiliferous, younger Upper Cretaceous formations in a small area along the southeastern border of the watershed near Arkadelphia. The following brief description of these formations is mostly from Dane (1929). The Brownstown is overlain unconformably by about 125 feet of sandy marl of the Ozan Formation. The Marlbrook Marl unconformably overlies the Ozan and consists of about 80 feet of dark blue (fresh) to white (weathered) chalky marl. The Saratoga Chalk which rests unconformably on the Marlbrook contains about 60 feet of fairly hard, white chalk with some marl. The Nacatoch Sand unconformably overlies the Saratoga and consists of about 200 feet of cross-bedded, yellowish-gray, slightly glauconitic, unconsolidated quartz sand, with minor clay and gravel intervals. About three miles south of the area, the Arkadelphia Marl, which is the youngest Upper Cretaceous Formation in Arkansas, unconformably overlies the Nacatoch.

Terrace Deposits

Minor alluvial terrace deposits of Quaternary (Pleistocene) age occur along the Caddo River watershed. These deposits are thin, probably not exceeding 15 feet in thickness. They consist of sand, gravel and cobbles derived mostly from the more resistant Paleozoic rocks in the area. Near the confluence of the Caddo River with the Ouachita River, the terrace deposits reflect more of the source and transport of the Ouachita River system.

These several levels of terrace deposits were previously more extensive, but have been repeatedly altered by subsequent Pleistocene and Recent events that at times have caused intense erosion and deposition along the watershed.

Alluvium and Colluvium

Clay, silt, sand, gravel, cobbles and locally boulders derived from the resistant sedimentary rocks in the area compose the Recent alluvial deposits of the Caddo River and its tributaries. These deposits generally do not exceed 20 feet in thickness, except near the confluence of the Caddo River with the Ouachita River where they are somewhat thicker. The colluvial deposits are composed of clay, silt, sand, gravel, cobbles and locally boulders that were mostly derived by extensive slope wash from rocks on the surrounding hills and cover most of the valleys and slopes as a thin veneer. A few pimple mounds occur in the area of these deposits. Some of the silt may represent a windblown (loess) component.

Sedimentary History

The following summary on the sedimentological history of rocks in the Ouachita Mountains, Arkansas, with minor revisions, is from Stone and Haley (1982).

The Paleozoic sedimentary rocks of the Ouachita Mountains in Arkansas range in age from Early Ordovician to Middle Pennsylvanian and have an aggregate thickness in excess of 50,000 feet —— (about 30,000 feet crop out in the Caddo River watershed). The stratigraphic sequence including the Early Ordovician age Collier Shale through the Early Mississippian age Hot Springs Sandstone Member at the base of the Stanley Shale is from 7500 to over 12,000 feet thick. The shales, micritic-arenitic limestones, siltstones, sandstones, cherts, novaculites and conglomerates of the sequence are considered proto-Ouachita bathyal platform or trough deposits that represent: 1) indigenous pelagic or hemipelagic deposits; 2) turbidity or bottom current-submarine fan and related deposits combined with episodes of slump and slurry detachments producing the included erratics; and 3) minor Devonian and other intrusives(?). With the exception of Silurian age Blaylock Sandstone which has a probable southeastern source, these rocks were all derived from "northerly" flanking shelf, slope and submarine ridge sources.

Beginning with the Hatton tuff lentil in the lower Stanley Shale of early Chesterian time (Mississippian) and ending in the Middle Pennsylvanian upper portion of the Atoka Formation, over 40,000 feet of deep-water turbidites——sandstones and shales——and some cherts combined with submarine slope and platform erratics were deposited in the rapidly subsiding Ouachita trough. The Stanley Shale was derived from a volcanic island arc and other sources to the south and southeast with only a minor source of clay and olistoliths from the north. The Jackfork Sandstone, Johns Valley Shale and Atoka Formation represent coalescing submarine fan accumulations derived from major delta systems to the north, northeast, east, and southeast, and, in part, south with episodes of major slumping, particularly in Johns Valley time, from flanking platform deposits and slope facies to north and northwest. Preconsolidation sediment flow features demonstrate repeated cycles of "southward" slumping in rocks of all ages, except in the extreme southern part of the area, where the Johns Valley Shale and the lower part of the Atoka Formation have sedimentary structures indicative of northward slumping directions which suggests that they were deposited on the south side of the Ouachita trough as it was apparently being closed by converging structural plates.

Beginning with the uplift of the Ouachita Mountains in the late Paleozoic and continuing into Late Cretaceous times, the area, was, for the most part, extensively eroded. The minor deposits that were possibly formed during this long time span were mostly reworked by the partial inundations of the warm Late Cretaceous seas. Shallow marine and alluvial conditions probably prevailed in the area throughout most of early Tertiary time but were subsequently eroded from the immediate area. In the Quaternary (Pleistocene and Recent) there were periods of braided stream alluviation and extensive erosion. Remnants of the terrace deposits occur above the alluvium along the Caddo River watershed.

Quartz Veins

Quartz veins ranging in width from less than an inch to rarely many feet are locally numerous in the Paleozoic rocks. Large veins are especially common along the northern margins in the Crystal Mountains. Most of the veins consist of milky quartz with scattered inclusions of chlorite, adularia, platy calcite, and dickite. These veins contain crystals and clusters of clear to milky quartz that are renowned world-wide for their high qualities. The High Point deposit in section 19, T. 3 S., R. 24 W., in the Crystal Mountains is one of the larger occurrences that is sporadically mined for crystals. Numerous other sites occur in the adjoining sections. Locally in the central and southern parts of the area minor quartz veins contain very small complex crystals, some of which are "water-bubble" or "negative" types.

Sulfides are extremely rare in most quartz veins, but a few contain significant quantities of lead, zinc, copper, silver, antimony, mercury and other elements. At times considerable prospecting has been accomplished on these mineralized quartz veins in or adjacent to the area. These fracture-filling veins are considered to be of hydrothermal (epithermal) origin (Miser, 1943, 1959, and Engel, 1951). Bence (1964) indicated a maximum temperature of about 392°F (200°C) for quartz veins in the Crystal Mountains. Most of these quartz veins are considered of late Paleozoic age having formed during the closing stages of the Ouachita orogeny.

Igneous Rocks

Igneous rocks generally of early Late Cretaceous age occur as nepheline syenite plutons, volcanic and explosion breccia pipes, and numerous small lamprophyric dikes and sills to the east of the watershed at Magnet Cove, Bauxite and Little Rock. A diamond-bearing kimberlite pipe is present to the southwest near Murfreesboro. The only igneous rock known in the area is on the eastern end of Pigeon Roost Mountain in the SW¼ SE¼ section 11, T. 4 S., R. 23 W., where a carbonate-rich lamprophyric igneous breccia has intruded the Arkansas Novaculite and Stanley Shale. Other igneous rocks, especially small dikes and sills probably occur in the watershed, but they have not been noted due to the deep weathering, extensive soil cover and rather thick vegetation.

Some beds of volcanic tuff occur primarily in the lower Stanley Shale and were probably derived from volcanic sources to the south of the Ouachita trough. Volcanic and igneous detritus also occurs in some of the Upper Cretaceous rocks south of the area.

Minor igneous and epizonal metamorphic rock fragments, some as large as boulders, are incorporated in the rocks of the Collier, Crystal Mountain, Blakely and other formations within or adjacent to the area. These are considered to be derived by slumping from mostly Precambrian rock sources that occurred along submarine scarps that flanked the north side of the Ouachita trough.

General Structure

The Paleozoic rocks that crop out in the watershed were involved in the various tectonic stages leading to the development of the Ouachita Mountains, mostly in the late Paleozoic times. The intensity of structural deformation in the Paleozoic rocks increases from south to north across the area at the surface (Fig. 6). There are broad folds cut by

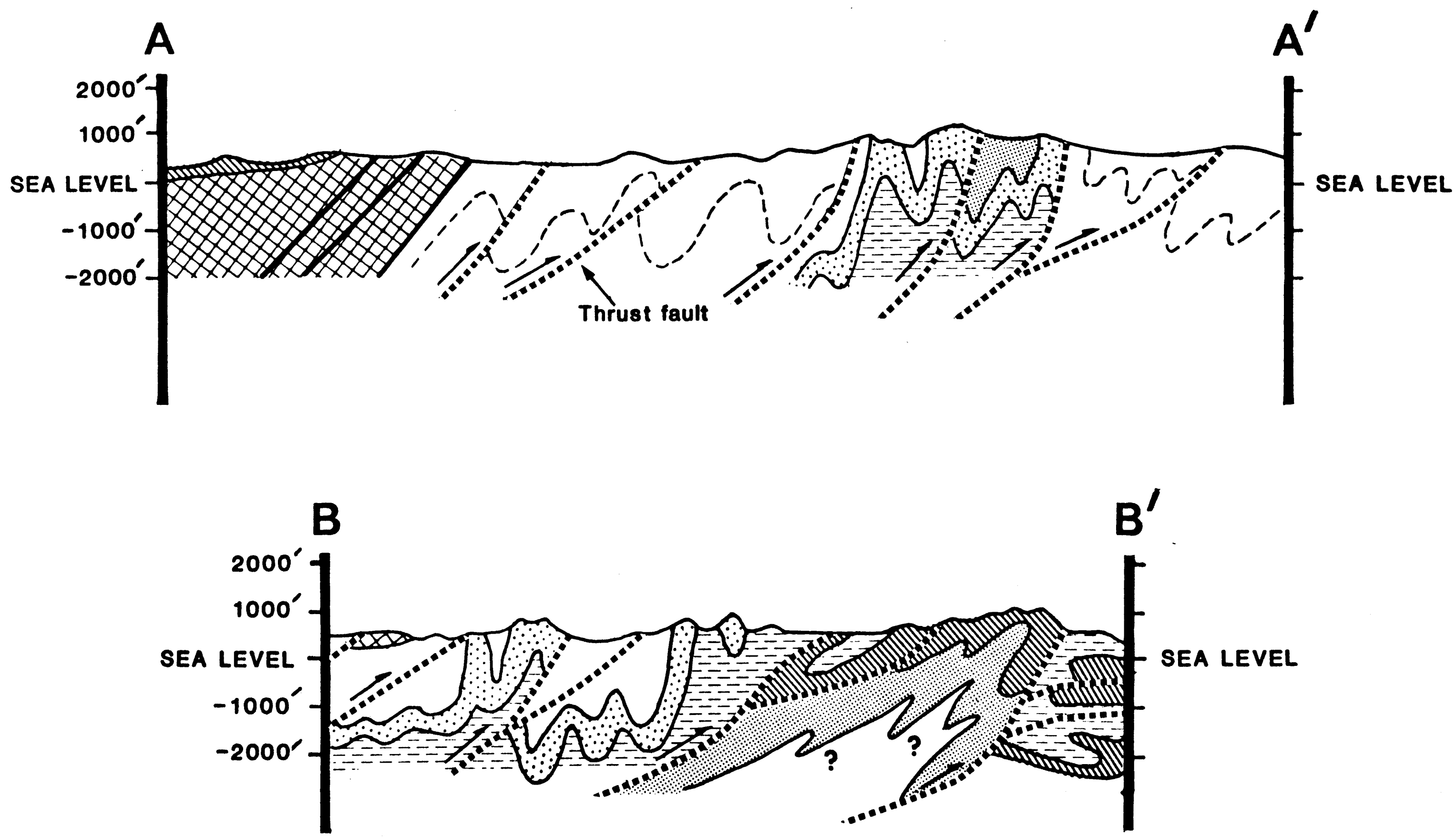

FIGURE 6. GENERALIZED STRUCTURAL CROSS-SECTIONS OF THE ROCKS IN THE CADDO RIVER WATERSHED.
(Lines of section and explanation are shown in Figure 3)

numerous southward dipping thrust faults in the Pennsylvanian rocks in the southern Athens Plateau. In the central and northern Athens Plateau within the Mississippian Stanley Shale there are tight folds broken by both high-angle and near bedding-plane thrust faults. Minor shearing occurs in some of the shales. The rocks in the Cossatot and Caddo Mountain ranges and the Mazarn Basin are very steep or even overturned, and locally exhibit some shearing. Thrust faults with displacements on individual plates varying from a few feet to many miles disrupt the strata. Small milky quartz veins fill fractures in some of the rocks. Strata in the Caddo Basin and the Crystal Mountains contain exceptionally complex folds (often recumbent) with several major low-angle decollements and many smaller thrust faults. These rocks are locally cut by sizeable quartz veins and a well-developed rock cleavage occurs in some shales.

Gently southward dipping Late Cretaceous strata cover deformed Paleozoic rocks along the southeastern boundary. These and all older rocks are subsequently overlain by nearly flat-lying terrace, alluvial or colluvial deposits of Quaternary age.

Structural History

The following summary on the structural history of the Ouachita Mountains, Arkansas, with some revisions, is from two abstracts by Haley and Stone (1981, 1982).

The rocks in the Ouachita Mountains may have attained their present structural setting through sequential periods of folding and faulting, with each period of deformation affecting the previous folds and faults to the extent that, in many of the areas, they were backfolded to the point of being overturned southward.

In most previous investigations the deformed Paleozoic rocks of the Ouachita Mountains of Arkansas have been divided into three poorly defined structural parts; the "core area", the "frontal zone" or "frontal belt" to the north, and the "southern Ouachitas" or "southern belt" to the south. Through recent studies of the surface geology the area has been divided into seven generally east-west trending structural belts. Each belt is a unit having similar structural features and is a northward moving imbricately faulted thrust plate with a major sole fault. From north to south these belts are named Rover, Aly, Nixon, Avilla, Mt. Ida, Hopper and Amity. The Mount Ida, Nixon and Avilla belts include most of the older Paleozoic rocks and are the most intensely deformed.

It is suggested that the simplified sequential phases in the structural development of the Ouachita Mountains are as follows: (A) extensional faults and minor igneous intrusions, (B) major uplift with folding and decollement of the more competent units; (C) thrust faulting; (D) folding with further decollement; (E) thrust faulting and related backfolding; (F) cross faulting and folding with arching; and (G) further arching. It is suggested that Step A took place during the early to middle Paleozoic, Steps B—D during Middle to Late Pennsylvanian, Steps E—F during Late Pennsylvanian through Permian and possibly Triassic, and Step G from Triassic to Recent.

We conclude that: (1) the Ouachita Mountains in Arkansas are allochthonous and formed by northward overriding imbricately faulted thrust plates with major sole faults; (2) some thrust plates possibly involved Precambrian rocks in the subsurface; (3) the structural deformation likely narrowed the initial width of the Ouachita depositional basin by as much as 250 miles, and (4) a northward(?) dipping fossil Benioff subduction system was present to the south of the Ouachita Mountain outcrop likely south of the Sabine Uplift in northern Louisiana.

ECONOMIC GEOLOGY

Mineral Resources

The principal mineral resources of the Caddo River watershed are barite, manganese, novaculite, quartz crystals, rock aggregate, slate and tripoli. Some of the other mineral occurrences include clay, copper, lead and zinc, limestone and chalk, mercury, phosphate, and iron ore. Significant development of the mineral resources started in the middle 1800's and has grown rather slowly. Through the years there have been many claims, prospects and related ventures for precious and base metals in the area, but they have met with little success. Currently slate is being produced for roofing granules; a barite mine and mill are slated for operation upon the resumption of higher rates and demands. Some quartz crystals are sporadically mined for mineral specimens and other uses and rock aggregates are mined throughout the area.

Potential for future growth is good, because of the demand for the various mineral commodities. The following is a brief discussion of the mineral resources of the watershed including their occurrence, history and potential.

Barite

Barite, a sulfate of barium, is a heavy nonmetallic mineral with a specific gravity of 4.5, usually gray in color, and granular to crystalline. The ore occurs in beds, nodules, or veins in the lower Stanley Shale and in the Middle Division of the Arkansas Novaculite.

Barite was first discovered in Arkansas in 1888 in Montgomery County and in 1900 in Hot Spring County just east of Magnet Cove. Production from the Magnet Cove area began in 1940 and from 1944 to 1966 yielded sufficient barite that Arkansas led the nation in its production. From 1944 to 1962 small scale mining in Montgomery County accounted for about 55,000 short tons of barite. From 1975 to 1981 significant barite was produced from three deposits in the watershed. Barite mining operations are expected to resume in the immediate future at the Fancy Hill deposit. The principal use of the Arkansas barite has been as a weighting agent for drilling muds in the oil industry.

Barite is found in the central part of the area extending west into the Cossatot-Little Missouri watersheds. In the Caddo watershed two general districts have been recognized and mined: the **Fancy Hill District** in T. 4 S., R.'s 25-27 W., and the **Pigeon Roost Mountain District** in T. 4 S., R.'s 23-24 W. The following description of the major mines and occurrences in the two districts is taken in part from Scull (1958).

The **Fancy Hill District** on the southwest border has six distinct deposits that have had extensive investigation with some mining in the past. The ore occurs in the Stanley Shale and the Middle Division of the Arkansas Novaculite. The Gap Mountain deposit is located in the SE¼ of section 19, T. 4 S., R. 25 W. and the NE¼ of section 23, T. 4 S., R. 26 W. The barite occurs in the Stanley Shale in four lenticular deposits. The barite beds are 3 to 30 feet thick and 300 to 1200 feet long. The percent of barite decreases to the west. The Fancy Hill deposit (Henderson) is located in the NE¼ section 29 and the SW¼ section 19, T. 4 S., R. 26 W., on the south flank of the Fancy Hill anticline and associated thrust faults. The barite occurs in the basal Stanley Shale in six lenticular deposits that range from 300 to 1800 feet in length with an ore-bearing zone ranging from less than 30 to about 80 feet in thickness. The barite beds dip very steeply to the south. A mill and some preliminary mining and processing were begun on this deposit by the Milchem Company in 1981-82, but the operation is temporarily closed awaiting an increase in the price and demand for barite. Sulphur Mountain deposit, also known as the McKnight deposit, is located in the northern portions of section 29 and the eastern portions of section 30, T. 4 S., R. 26 W. Mining operations by the Baroid Division of the National Lead Company began on this deposit in 1975 and concluded in 1981 when the cost of extracting and processing the ore exceeded its value. The barite occurs in the lower Stanley Shale. Several thrust faults disrupt the ore body. The strike of the rock is generally to the west-northwest. The Dempsey Cogburn deposit is located on the southeast side of Sulphur Mountain near the center of section 33 and the northern portions of section 32, T. 4 S., R. 26 W. The barite occurs in the lower Stanley Shale. A cross fault forms a boundary at the west end of the mineralized zone. Mining operations by the Baroid Division of the National Lead Company began in 1975 and continued into 1979 when it became impossible to mine the ore economically. The mineralized zone was about 50 feet thick and contained lenses of high grade ore that varied from 15 to 25 feet thick. Interestingly, a rather large orthoconic cephlapod replaced by barite was collected by Craig Brinkley near the top of the barite zone at the east end of the pit. It was identified as *Rayonnoceras vaughianum,* an early Chesterian (Mississippian) form, by MacKenzie Gordon, Jr., of the U. S. Geological Survey. The Boone Springs Creek deposit is located in the SE¼ of section 24, T. 4 S., R. 27 W. Barite occurs as a vein in beds of the Middle Division of the Arkansas Novaculite on the overturned south flank of the Fancy Hill anticline. The beds containing barite strike N. 45^{o} W. and dip 40^{o} NE. The vein material has a maximum thickness of one foot and a maximum length of 24 feet. The Polk Creek Mountain deposit is located in the SE¼ section 12, T. 4 S., R. 27 W. Occurrences of barite have been traced from the east portions of section 12 to the center of section 11, T. 4 S., R. 27 W. Barite occurs as nodules in beds of shale interbedded with novaculite in the Middle Division of the Arkansas Novaculite (Scull, 1958). Some vein material was located in prospect pits. There has been no recorded production from this locality. In the south-central part of the area in Pike County, an occurrence of barite has been located in the SE¼ NW¼ section 1, T. 5 S., R.25 W. A lens of quartz and barite one foot wide and 8 feet long occurs parallel to the bedding in the Stanley Shale near the contact of the Arkansas Novaculite.

The **Pigeon Roost Mountain District** is the easternmost occurrence of barite in the area. The barite occurs as three lenticular ore zones in the lower Stanley Shale in section 25, T. 4 S., R. 24 W. and section 30, T. 4 S., R. 23 W. The southwestern deposit is located in the S½ NE¼ SW¼ section 25, T. 4 S., R. 24 W. The Baroid Division of the National Lead Company began mining this deposit in 1975; and in 1978 when it became economically untenable to further mine the deposit, the operation shut down. The linear open-pit was then reclaimed. Barite occurs in shale and sandstone of the lower Stanley Shale which strikes N. 60^{o} E. and dips 50-66^{o} NW. Thrust faults cut the ore body and its exact stratigraphic placement is unknown. The central barite deposit is located in the SE¼ NE¼ section 25, T. 4 S., R. 24 W. Barite consists of two small lenses 100 feet in length in the Stanley Shale and appears to be at the nose of a small anticline. The rather shaly barite reaches a maximum thickness of 7 feet. The northeastern deposit is located in the W½ SW¼ NW¼ section 30, T. 4 S., R. 23 W. The barite occurrence here is similar to the southwestern deposit, but thinner. The mineralized zone occurs along the strike for approximately 500 feet with a maximum thickness of the ore zone of 16 feet and a total thickness of the ore beds of only 5 feet.

Clay

Clay deposits in weathered shale and slate occur in the watershed but they have not been utilized. There are no estimates on the reserves of clay or an evaluation of their ceramic properties. Some of the abundant shales should provide an adequate supply of quality material for use in making bricks. Clay has been produced in Garland County to the northeast of the area, and from near Mena in Polk County to the northwest of the watershed.

Copper

Traces of copper mineralization are

reported to be associated with many of the manganese occurrences in the Arkansas Novaculite. Immediately west of the area in the SE¼ NW¼ section 10, T. 4 S., R. 27 W., at the North Mountain mine significant copper mineralization is associated with the manganese ore. Some copper occurrences are also found in association with wavellite (aluminum phosphate) veins in the Bigfork Chert near the northwest portion of the area. These veins were tested for copper by the Copperlume Corporation in 1972, but commercial concentrations were not found. Some chalcopyrite (copper sulfide) occurs with the lead and zinc veins at the Housely (Point Cedar, Price-Williams) mine north of the community of Point Cedar in the NE¼ NW¼ section 31, T. 4 S., R. 21 W. The copper-bearing minerals found in fractured beds of Arkansas Novaculite are turquoise, malachite, azurite, chrysocolla, chalcopyrite and native copper. There is a slight possibility of copper deposits with economic potential being discovered during exploration in this and nearby portions of the Ouachita Mountains.

Gold

According to Comstock (1888) several prospects and claims were made in various rock formations and veins in or near the Caddo River watershed for gold and other valuable elements in the mid 1880's and earlier. While he indicates that some samples contained rather significant silver values, only a few contained traces of gold. From this period until 1980 there were but a few minor prospects for gold that were soon abandoned. In 1980 another flare of "fever" was revived in much of the area as a result of several newspaper articles. Then several companies, individuals and our organization initiated limited geochemical investigations of these rocks. While our data are very incomplete, we found no significant values of gold.

Iron Ore

Occurrences of limonite and goethite (iron oxides) and pyrite and marcasite (iron sulfides) have been reported in pockets, seams, and veins in the Arkansas Novaculite and occasionally in the Womble Shale, Bigfork Chert, Polk Creek Shale and Stanley Shale. The iron oxides are often associated with the manganese deposits in the novaculite, but they are usually too low in iron, too high in silica, or often too high in phosphorus to be of commercial value. In 1830, 1915 and 1916, a prospect was worked on masses or veins of pyrite and marcasite in the upper Womble Shale on the bank of the Caddo River on the west edge of the community of Caddo Gap. Water from the Caddo River seeped through the rocks filling the shafts and drill holes, thus ending the operation.

Lead, Zinc and Silver

Traces of lead, zinc, and silver are associated with quartz veins, in some Womble limestones and in a few manganese deposits. The most notable occurrence is at the Housely (Point Cedar, Price-Williams) mine located in the NE¼ NW¼ section 31, T. 4 S., R. 21 W., where galena, sphalerite, chalcopyrite, pyrite and other minerals occur in quartz veins mostly within a fault zone in the Arkansas Novaculite and lower Stanley Shale. The deposit was discovered in the 1890's and worked several years through shafts and two major levels, along a linear distance of about 210 feet. Formerly a mill was located at the site, but it burned in 1973. Significant quantities of silver in galena, sphalerite, and other minerals also have been reported near Silver, Arkansas, about four miles north of the area. A company has recently done some exploratory drilling on sites in upper Womble limestones a few miles west of Caddo Gap. The results of their testing are unknown at present. It is likely that these investigations pertained to zinc anomalies since portions of the Womble are reported to contain some quantities of this element.

At present no economic occurrences of lead, zinc, and silver are known but exploration will likely continue for these and associated elements if their economic value remains rather high.

Limestone

Thin to rather thick beds and intervals of limestone are found in most of the Ordovician rocks. Limestones are especially abundant in the Collier Shale, some portions of the Mazarn Shale and in the upper Womble Shale. Previously, there was sporadic production of limestone from the Collier north of the area. It was used locally for road material and agricultural purposes. There also has been some investigation of limestones near Black Springs and elsewhere for agricultural limestone, lime and as a black marble for use as a decorative building stone. Analysis indicates that the limestone contains 75 to 90 percent $CaCO_3$.

Descriptions of some of the many significant Womble limestone exposures in the area follow:

Location	Description
1. NW¼ SW¼ section 26, T. 3 S., R. 24 W.	dense bluish-gray limestone
2. SW¼ SE¼ section 6, T. 4 S., R. 24 W.	dense bluish-gray limestone, 50 feet thick, contains 86.2% $CaCO_3$.
3. NE¼ NE¼ section 35, T. 3 S., R. 26 W.	dark bluish-gray, hard limestone, 15 feet thick, exposed in creek
4. SE¼ SW¼ section 26, T. 3 S., R. 26 W.	dark bluish-gray, hard limestone, 1 to 8 inches thick in 10-foot thick zone on south bank of Caddo River.

Limestone is not presently being produced, but there is limited exploration of several deposits by a firm. Further exploration will be necessary to evaluate the apparently significant reserves.

Chalk occurs in the Saratoga Formation, but it is too thin in the watershed for economic uses.

Manganese

Manganese deposits in the watershed have been worked sporadically since 1859. Federal purchase supported the last activity in 1958-59 to the west and north of the area. Both the Upper and Lower Divisions of the Arkansas Novaculite contain manganese deposits which occur as nodules, pockets and short irregular veins varying from a fraction of an inch to rarely four feet in thickness in bedding planes, joint cracks, or as a cement between fragments of novaculite. The upturned folded novaculite is very resistant to erosion and forms ridges which extend for miles. Most of the ore can be found in highly fractured rock at or near the axes of folds and adjacent to faults. It is not known whether the manganese ore extends to a significant depth in the subsurface, but immediately west of the area on the North Mountain mine ore was reportedly found in the lower tunnel at 615 feet below the portal. Psilomelane, pyrolusite, and manganite make up the largest part of the ore, but there also are lithiophorite, wad and a few other minerals. The minerals may occur separately, but usually occur together in association with clay and iron oxides.

Table 1 gives the location and a brief description of many of the manganese mines and prospects in the area. Traces of psilomelane in novaculite were also reported at a number of other places including the W½ section 16, T. 3 S., R. 22 W. Some small manganese prospects occur in the northern portions of the watershed in the Crystal Mountain Sandstone at High Peak in the NW¼ NE¼ section 19, T. 3 S., R. 24 W.

Manganese reserves in the area cannot be accurately calculated with the limited amount of exploration that has been done. Improved milling techniques, such as blending of ores to provide a uniform feed, should lower costs and improve the value of the product. The quantity of manganese ore that occurs in any deposit is usually rather small, and would necessitate combined suppliers for milling operations. Higher prices

Table 1. — Manganese mines and prospects in the Caddo River Watershed

Name	Location	Description
Nelson Manganese Mine	SW¼ SW¼ sec. 13, T. 4 S., R. 24 W.	Psilomelane and a small amount of crystalline manganite are found in veins, pockets, and cavities in novaculite. In 1915, 58 tons were mined, which apparently depleted the deposit. A nearby claim was prospected in 1940.
Jones Valley Mine	NE¼ NE¼ sec. 18, T. 4 S., R. 24 W.	Thin veins of manganite and psilomelane occur in fractured novaculite. Two cuts were made but no production was recorded.
United Minerals Industries Mine	N½ sec's. 28, 29, T. 4 S., R. 26 W.	Manganese oxide cement in shattered novaculite and nodules of psilomelane occur in 2 to 8 foot wide clays. Select samples contained 27.04% manganese.
Plemmons-Woodall Mine	SW¼ SE¼ & NE¼ SW¼ sec. 11, T. 4 S., R. 23 W.	Concentrations of psilomelane, manganite and wad cementing terrace deposits are present. Gravels fill a valley adjacent to a ridge in which veins of psilomelane also fill fractures in weathered novaculite. Most of the gravel has been removed and the veins are insignificant. In 1937 two carloads were shipped and 20 tons were removed in 1940.
Willie Cogburn Claim	E½ sec. 18, T. 4 S., R. 26 W.	Fractures in novaculite contain manganese oxides. There are an estimated several hundred tons of manganese in the deposit.
Monroe-Knold	SE¼ sec. 14, T. 4 S., R. 26 W.	Manganese ore was produced before and during World War I.
Montgomery Manganese Corp.	E½ sec. 16, T. 4 S., R. 26 W.	Manganese ore was produced before and during World War I.
Polk Creek Mountain Prospect	Sec. 13, T. 4 S., R. 27 W. Sec. 18, T. 4 S., R. 26 W.	Manganese ore was produced before and during World War I.
Watkins White Prospect	S½ SE¼ sec. 1, T. 5 S., R. 24 W.	Seams and veins of wad and psilomelane occur with limonite.
Reynolds Mountain Prospect	SW¼ NW¼ sec. 6, T. 5 S., R. 24 W.	Veins of psilomelane, manganite, and brown iron oxide are present in the massive novaculite.

Table 1. — Manganese mines and prospects in the Caddo River Watershed, cont.

Featherstone Mine	SW¼ NW¼ sec. 6, T. 5 S., R. 24 W.	Psilomelane and limonite occur in fractures and nodular manganese in clay. The mine yielded 40 tons of ore in 1917.
Kettelberger Prospect (formerly Reynolds Mountain Prospect)	NE¼ SE¼, NE¼ SW¼, SW¼ NE¼, SE¼ NE¼ sec. 1, T. 5 S., R. 25 W.	Pyrolusite and manganite occur in fractured novaculite veins. One and one-half carloads of select ore was shipped. There are an estimated 400-500 tons raw ore and an additional 200-250 tons +40% manganese concentrates.
Fagan Mine	Center S½ N½ sec. 9, T. 5 S., R. 25 W.	There are thin veins of sparse manganite with iron oxides.
Bear Mountain Prospect	NE¼ NW¼ sec. 8, T. 5 S., R. 25 W.	Psilomelane and manganite lenses occur along bedding surfaces in the novaculite.
Brushy Mountain Mine	SW corner sec. 5, NW corner, sec. 8, T. 5 S., R. 25 W.	Stalactitic psilomelane and cement or vein occur in novaculite breccia. Four openings were made at the mine in 1916. Twelve percent manganese ore was concentrated to contain 40% manganese. One thousand tons of manganese concentrates were shipped in 1942.
R. M. Cogburn Prospect	NE¼ SW¼ NE¼ sec. 5, T. 5 S., R. 26 W.	Boulders of novaculite having small veins and pockets of psilomelane are present.
North American Manganese Co.	SW¼ SW¼ sec. 5, S½ SE¼ sec. 6 T. 5 S., R. 25 W.	Pockets of psilomelane with inclusions of pyrolusite occur in novaculite. Reserves are estimated at 18,000 tons of 10% manganese ore.

or government support are required for the commercial production of the manganese deposits in the watershed. In times of dire need the reserves could measurably augment the United States supply. Significant by-products, such as copper, might have economic value upon beneficiation of the manganese ore. In future years, these deposits may represent a valuable economic resource.

Mercury and Antimony

The Arkansas Mercury (cinnabar) district occurs along a 30 mile belt south-southwest of the watershed. It extends eastward from Howard County across Pike County and into Clark County. These deposits occur as epithermal veins in faulted and fractured intervals of the Stanley Shale and Jackfork Sandstone. Since their discovery in 1931 until 1946 about 11,400 flasks (76 pounds each) were extracted from the ores by retorts or furnaces. Minor mercury mineralization has been noted at two places in the southern part of the Caddo River watershed in faulted sequences of the Jackfork Sandstone.

The antimony district to the southwest of the area encompasses portions of Pike and Sevier Counties in southwestern Arkansas and McCurtain County in southeastern Oklahoma. The most significant mines are near Gillham in Sevier County. These epithermal deposits occur as stibnite and other minerals in quartz veins associated with fault zones in the Stanley Shale. Since their discovery in 1873 until 1947 approximately 5,390 tons have been produced.

Thin sparse veinlets of stibnite and pyrite are reported by Stroud et al. (1969) filling fractures and bedding planes in folded and faulted sandstones of the Stanley Shale in section 3, T. 6 S., R. 20 W., which is presently within the confines of De Gray Lake. It is reported that an adit exposed a silicified zone approximately 10 feet wide that contains metalliferous sulfides. This deposit apparently has little economic importance. Small quantities of antimony minerals also are found in several of the lead, zinc, copper and silver-bearing quartz veins in the area.

Novaculite (Whetstones)

The use of Arkansas Novaculite for whetstones dates back to the early 1800's. Even prior to this, Indians of the area diligently worked the novaculite for projectile points, scrapers and other purposes. Novaculite is a hard, very fine-grained variety of chert or flint rock that is often slightly recrystallized and composed mostly of silica. There are two commercial classes of abrasive grade novaculite: the hard, dense, rather translucent "Arkansas" stone and the more porous "Washita" stone. Most of the whetstone produced from the Arkansas Novaculite has been quarried in the Hot Springs area in Garland County. A small quarry operation (located in section 6, T. 5 S., R. 26 W.) west of the watershed has produced some Washita stone. Future whetstone prospecting and quarrying are anticipated in the novaculite of the area.

There is also some use and future potential for high quality novaculite in making several other products, including ferro-silicon which is used in the chemical industry, in fire bricks and interlayered sequences with plastics. Rock aggregate is produced from the novaculite at several sites in the surrounding region and it seems likely that quarries will eventually be situated at advantageous locations in the area.

Phosphate

Widely separated layers, lenses, and nodules of black phosphate-rich rock occur in the basal Stanley Shale. In some places they reach a thickness of 1½ inches. The Woodall prospect is located in the NW¼ SW¼ section 11, T. 4 S., R. 23 W. The rock contains from 2.20 to 3.12 percent P_2O_5 but the rock is not of commercial grade. Also some decomposed igneous rock that intrudes the Stanley Shale contains small percentages of P_2O_5.

Some rather unique phosphate minerals have been reported at the following localities:

Dufrenite (rare iron phosphate) — NW¼ SW¼ section 7, T. 4 S., R. 25 W.
Wavellite and variscite (aluminum phosphate) — SE¼ NE¼ section 35, T. 3 S., R. 24 W. and — NE¼ NW¼ section 8, T. 4 S., R. 24 W.

There are also numerous wavellite and variscite locations in adjoining sections near Bigfork, Arkansas. These minerals may contain some quantities of copper and vanadium. They have been prospected in places, for copper and also for mineral specimens.

Quartz Crystals

The Crystal Mountains comprise portions of one of the principal quartz-producing areas in the world. Clear to milky quartz crystals have been mined here for many years and they have mostly been utilized in the mineral and gem trade, although some quartz has also been acquired for fusing, lasca, oscillator quartz, and precast concrete aggregate purposes.

Veins in the Crystal Mountain Sandstone are the principal source of quartz crystals in the Caddo River watershed. Large quantities are also obtained from veins in the Blakely Sandstone, but mostly to the northeast in Garland County. Quartz occurs as veins filling joints and bedding planes in the sandstone and crystals occur as pockets or cavities lining or filling them.

For many years large quantities of small to medium size clear quartz crystals and clusters have been produced from the Fisher Mountain and other deposits located in the Crystal Mountain Sandstone along the southern border of sections 3 and 4 and the northern portions of sections 9 and 10, T. 3 S., R. 24 W., about one mile north of the watershed. There are several other adjoining mines that have also produced quartz crystals.

Some of the more significant quartz crystal localities in the area are:

1. The High Peak deposit in the NW¼ NE¼ section 19, T. 3 S., R. 24 W. High quality clear crystals have been produced at this deposit in recent years from veins in the Crystal Mountain Sandstone. Manganese occurs with the quartz and it also has been prospected.

2. Near the centerline of section 20, T. 3 S., R. 24 W., quartz crystals have been mined from the Crystal Mountain Sandstone.

3. Near the center of the west line of section 21, T. 3 S., R. 24 W., some quartz crystals are obtained from veins in the Crystal Mountain Sandstone.

4. In the NW¼ section 29, T. 3 S., R. 24 W., minor quantities of quartz crystals have been mined from veins in the Blakely Sandstone.

5. Rather unusual, very small, clear to smoky, complex crystal forms, some being "water bubble" or negative types occur in veins in Stanley sandstones at the Pigeon Roost deposit in section 11, T. 4 S., R. 22 W., and at other localities through the central portions of the watershed, including a prospect in the Arkansas Novaculite about 1½ miles northeast of the community of Point Cedar.

Large quantities of quartz crystals are likely present in the numerous quartz veins in the area. Many additional claims and prospects are expected as a result of the continued demand for clear quartz crystals.

Rock Aggregate

Vast tonnages of rock aggregate and road material are available from the sandstone, novaculite, chert, and sand and gravel deposits in the watershed. Massive sandstones meeting commercial quality specifications occur in the Crystal Mountain, Blakely and Jackfork Formations. Thick sequences of novaculite occur mostly in the Lower Division of the Arkansas Novaculite and intervals of thin chert occur in the Bigfork Chert. All of these rocks have been extensively mined for aggregate, but at present there are only a few commercial operations in the watershed. Shale is very abundant and is used locally for rock aggregate on rural roads and other purposes throughout most of the watershed.

The Murray quarry in the SE¼ section 13, T. 6 S., R. 20 W., about one mile east of De Gray Dam, has been active for a number of years. Several million tons of quartzose sandstone have been mined and processed from a 90 foot thick interval in the upper Jackfork Sandstone.

In 1963 gray sandstone from the Blakely Sandstone was quarried for building stone in the E½ SE¼ section 23, and the W½ SW¼ section 22, T. 3 S., R. 24 W. Hard sandstone beds 6 inches to 2 feet in thickness were quarried from a depth between 4 and 8 feet.

In recent years rather large quantities of rough field stone also have been obtained mostly from surficial deposits. Most of these are sandstones derived from the Crystal

Mountain, Blakely, Blaylock, Stanley and Jackfork Formations. There is no reliable estimate of the tonnages of field stone produced.

Sand and gravel deposits occur in the alluvium along the Caddo River and some of the larger streams. The following deposits have been worked along the Caddo River:

1. The E½ section 28, T. 3 S., R. 25 W., contains equal amounts of novaculite and sandstone gravel. Reserves above water level are estimated at 1,503,000 tons.

2. NE¼ NE¼ section 19, T. 4 S., R. 24 W., has mixed quantities of novaculite and sandstone, gravel and some large boulders. Reserves above water level are estimated at 235,000 tons.

3. The NE¼ NE¼ section 13, T. 4 S., R. 25 W., has equal proportions of novaculite and sandstone, gravel and a little shale. Reserves above water level are estimated at 2,916,000 tons.

4. The S½ of section 36, T. 6 S., R. 20 W., has mixed chert and sandstone gravel. There is no estimate of the reserves available.

Sand and gravel have also been obtained from deposits in the terraces along the Caddo River. Most of the larger pits are situated near the community of Caddo Valley and the material was used primarily in various projects in the construction of De Gray Lake and related facilities. Most of these deposits are included in the following locations:

1. S½ of section 19 and the N¼ of section 30, T. 6 S., R. 19 W., and the E¼ of sections 22 and 25, T. 6 S., R. 20 W.

2. The E½ of section 35 and the SW¼ of section 26, T. 6 S., R. 20 W.

Sand, gravel, and cobbles also have been mined from lenses in the Brownstown Marl in exposures near De Gray Lake where it has been used for aggregates related to the construction projects near De Gray Lake. Some of these stripping operations are as follows:

1. The S½ of section 12, the N½ of section 13, T. 6 S.., R. 20 W., and adjoining NW¼ of section 18, T. 6 S., R. 19 W.

2. The S½ of sections 16 and 17, T. 6 S., R. 20 W.

3. The SW¼ of section 22, T. 6 S., R. 21 W.

The Nacatoch Sand represents a potential source of high quality sand. It has been exploited on a limited scale in adjoining areas.

These abundant deposits of sandstone, novaculite, chert, sand and gravel, and shale can provide rock aggregate, road material, and building stone to meet local and many outside demands.

Slate

Slate for building purposes was first mined in T. 3 S., R. 27 W., in 1902. At present it is the foremost mineral product in the area and is being mined and crushed for roofing granules with the dust being used as a filler. Most of the slate mining has been in the Stanley and Missouri Mountain Formations but it also occurs in the Mazarn, Womble and Polk Creek Formations.

The Missouri Mountain slate is buff, red to green, usually soft but with some fairly hard and homogeneous layers. The slate interval varies from less than 50 feet to about 300 feet and may be duplicated by structure. The unit is widespread and has been extensively prospected.

The basal Stanley Shale has been changed to slate in the closely folded structures, particularly the synclines. The slate is hard, gray to black, and contains some thin sandstone layers. Horizons in the lowermost Stanley were previously known as Fork Mountain slate. The Polk Creek, Mazarn, and Womble Formations contain shale or slaty shale in most places and only portions of these units contain well-developed layers of slate.

Presently slate is being quarried from a large and rather deep pit in the Stanley Shale north of Glenwood in the SE¼ section 21, T. 4 S., R. 23 W., by Bird and Son, Inc. They previously quarried a similar deposit in the NE¼ NE¼ section 31, T. 4 S., R. 25 W., and upon abandonment of the site the dimensions were about 1300 feet in length, 200 feet in width, and some 150 feet in depth. Table 2 is a list of many of the abandoned slate quarries and prospects in the watershed.

Tripoli

Tripoli is normally considered a finely granular, porous, comparatively soft silica of a cryptocrystalline character. It is used principally for an abrasive, polishing agent, and as a filler or additive. The high silica tripoli occurs in the Upper Division of the Arkansas Novaculite, with smaller deposits in the Lower Division, and in the Bigfork Chert. Activity just west of the area took place sporadically from 1963 to 1972 when four mines produced 32,000 tons which were processed at Glenwood.

One of the larger known tripoli occurrences in the watershed is located in the SE corner of section 31, T. 4 S., R. 24 W., in the Upper Division of the Arkansas Novaculite. The tripoli at this deposit strikes nearly east-west and dips 18^{o} to the south and some 150 feet was penetrated by a drill hole. Indicated and inferred reserves amount to 75,000 tons.

Fodderstack Mountain prospect in the Upper Division of the Arkansas Novaculite is located in the NW¼ section 13, T. 4 S., R. 26 W., and it is 1000 feet in length, 28 feet in width, and at least 20 feet in depth.

Another occurrence is located in the SE¼ SW¼ section 12, T. 4 S., R. 26 W., and has a measurable ore of 20,000 tons and an indicated ore of 100,000 tons. A minor occurrence of tripoli is located in a small cut in the Bigfork Chert at the base of a small hill about one and a half miles southwest of Caddo Gap.

Other known deposits of tripoli are as follows:

1. NE¼	SW¼	section 10,	T. 3 S.,	R. 23 W.
2. NW¼	SE¼	section 12,	T. 3 S.,	R. 23 W.
3. SW¼	SW¼	section 7,	T. 4 S.,	R. 24 W.
4. SE¼	NE¼	section 17,	T. 4 S.,	R. 24 W.
5. SW¼	SW¼	section 13,	T. 4 S.,	R. 25 W.
6. S½	NE¼	section 33,	T. 4 S.,	R. 26 W.

Hauling distance to milling sites and lack of railroad facilities have probably hampered mining operations in the area. Future market price could alter this and an increase in activity is possible.

Uranium

Uranium prospecting has on occasion taken place in the watershed. Most of these investigations were concerned with the black carbonaceous shales of the Middle Division of the Arkansas Novaculite and the Polk Creek Shale. Some limited evaluations were made on anomalies in the Stanley Shale (mostly phosphates), in the igneous breccia at Pigeon Roost Mountain, and in other rock types. There are presently no reported economically important uranium deposits in the area, although several rock types contain radioactivity in excess of normal background.

Oil, Gas and Asphalt

Exploratory drilling in the rocks of the western Ouachita Mountains of Oklahoma and vicinity has resulted in the discovery of a few new oil and gas fields. These mostly occur in highly fractured reservoirs in cherts and novaculites of the Bigfork Chert and Arkansas Novaculite. This, combined with a few older oil fields producing from Mississippian and Pennsylvanian sandstones and some small to rather large asphaltite occurrences in the area, have kindled interests in the oil and gas potential elsewhere along the Ouachita fold belt.

Some of the surface rocks in the northern part of the Caddo River watershed are slightly metamorphosed, thus their thermal maturity

Table 2. — Abandoned slate quarries and prospects in the Caddo River Watershed

Location	Formation	Description
NW¼ SW¼ sec. 3, T. 5 S., R. 25 W.	Missouri Mountain Shale	Red slate, area was prospected but reserves were not evaluated.
E½ sec. 30, T. 3 S., R. 23 W.	Missouri Mountain Shale	A prospect at this location reveals a red slate, sonorous,with good cleavage.
NW corner sec. 36, T. 3 S., R. 24 W.	Missouri Mountain Shale	A prospect at this location reveals a dark red slate, semi-sonorous, splits easily and has a relatively rough surface; can be quarried in large blocks.
NE¼ SE¼ sec. 9 and NW¼ SW¼ sec. 10, T. 3 S., R. 26 W.	Mazarn Shale	A prospect uncovered a hard green slate, sonorous, which splits well and has widely spaced joints.
SW¼ SE¼ sec. 32, T. 3 S., R. 26 W.	Missouri Mountain Shale	The area was quarried from 1929-33 for flagstone. Slate is red and green and splits into thin pieces on weathering.
E½ SE¼ sec. 33, T. 3 S.., R. 27 W.	Missouri Mountain Shale	Red and green, soft, thin-splitting slate was found in four large openings.
SE¼ NE¼ sec. 18, T. 4 S., R. 26 W.	Missouri Mountain Shale	A red, green, and gray slate was quarried for roofing granules in 1909 and again in 1937.
N½ sec. 35, T. 3 S., R. 27 W.	Missouri Mountain Shale	Red slate was quarried in large blocks at two locations.
S½ NE¼ sec. 4, T. 4 S., R. 27 W.	Stanley Shale	A gray-blue micaceous slate which is sonorous, cleaves, has a rough surface and is weather resistant, was quarried in a pit 100 feet square and 50 feet deep. A blue-black slate was also quarried. It has a shiny cleavage surface and crumbles on weathering (neither micaceous nor sonorous).
Sec. 15, T. 4 S., R. 26 W.	Missouri Mountain Shale	A 600-foot exposure of red slate with tight folds and a good cleavage occurs on the south side of Wagner Creek.
SE¼ NW¼ sec. 6, T. 4 S., R. 24 W.	Womble Shale	Inactive quarry in black slate and was used as roofing granules.

is rather high. The intensity of deformation and recrystallization noticeably decreases in the rocks southward across the area and it is less likely that any generated hydrocarbons were degraded. This entire region is considered to contain allochthonous sequences of rock and the thermal histories are unknown beneath these postulated thrust faults (decollements). Many of the recent tectonic models for the Ouachita fold belt suggest that less deformed, and in some cases even foreland facies (shallow marine deposits), are at some depth beneath some of the surface rocks. A COCORP deep seismic reflection profile was recently run (Lillie et al. 1983) across the Ouachita Mountains of Arkansas to the west of the watershed and these data afford many insights into the origin of the structural complexities in the area.

In 1967 Max Ensinger drilled two oil and gas tests in Montgomery County. The No. 1 Van Steenwyk was drilled to an apparent total depth of 3627 feet in section 19, T. 3 S., R. 25 W., and the No. 1 Walter Gaston to a total depth of 472 feet in section 20, T. 3 S., R. 25 W. Both wells were spudded in the Mazarn Shale and they were abandoned as dry holes.

In the last few years three wells have been drilled for oil and gas in or near the watershed. The Sheraton Oil Corporation drilled two wildcat tests; one, the No. 1 Kyle in section 29, T. 4 S., R. 22 W. (Hot Spring County) was spudded in Stanley Shale and reached a total depth of 4545 feet; and another, the No. 1 Bean in section 15, T. 5 S., R. 23 W., (Clark County) was spudded in Stanley Shale and abandoned at 2902 feet. The Shell Oil Company drilled a well in the Trap Mountains within a few miles of the watershed in section 21, T. 4 S., R. 20 W., (Hot Spring County) that began in the Blaylock Sandstone and bottomed at a total depth of 7868 feet.

It is thought that these few wells have failed to evaluate the petroleum potential of the area. A deep test penetrating the various older formations is needed to assist in determining the thermal histories, porosities, permeabilities and other features of the rock at depth. Some asphalt occurrences are present in the Jackfork Sandstone and the Lower Cretaceous rocks to the southwest of the area near Murfreesboro and Dierks, but none have been reported in the watershed.

The Upper Cretaceous rocks that crop out in the area are thought to have been flushed by ground water, so it seems unlikely that they contain oil and gas.

Water Resources

The average rainfall for the watershed is about 50 inches per year. Ground water is often used for most domestic purposes. The area seems to have sufficient water supplies to meet current and most projected needs. It is suggested that extensive hydrologic studies be performed in an area prior to any major developments that would require large quantities of water. The following is a brief description of the water resources in the area.

Surface Water

The rather high quality and significant volume of water in the Caddo River, including its tributaries, and De Gray Lake is adequate and suitable for most projected needs.

Ground Water

Ground water occurs mostly in fractures, joints and separations along the bedding planes of the Paleozoic rocks. In these rocks the highly fractured Bigfork Chert is the best aquifer. The Crystal Mountain Sandstone, the Arkansas Novaculite, and limestone intervals in the Collier Shale, Mazarn Shale, and Womble Shale also may be good aquifers. Quantities usually sufficient for domestic purposes are found in most formations. Highly permeable zones occur in the sands and gravels of the Brownstown, Nacatoch, terrace and alluvial deposits and where suitable areas of recharge exist, afford good yields for local uses. Wells that yield 10 gallons of water per minute for a week of continuous pumping are considered high yield in most of the Ouachita Mountains. There are many small springs in the area which issue primarily from the Crystal Mountain Sandstone, Bigfork Chert, Arkansas Novaculite, and limestone intervals in the Collier Shale, Mazarn Shale and Womble Shale.

Ground water supplies are adequate in most areas for household use, but should generally not be considered for industrial developments or community water supplies. Ground water analyses by the U. S. Geological Survey indicate that it typically is of high quality.

Warm Springs

There are several warm springs in the central Ouachita Mountains of Arkansas. Two such springs are located in the watershed according to Miser and Purdue (1929). The warm springs at Caddo Gap in the Lower Division of the Arkansas Novaculite, flows directly into the Caddo River. Recorded temperatures in the early 1900's ranged from $94^{o} - 96.8^{o}$F. Another warm spring is located in the Arkansas Novaculite on the line between sections 23 and 26, T. 4 S., R. 25 W., about two miles southwest of Caddo Gap.

It is suggested that these warm waters represent ground water that has slowly percolated to a significant depth and has been heated by the geothermal gradient, then rapidly ascends to the surface through openings created by extensive fractures and/or fault zones. There is a likelihood that other small warm springs occur in the area. These warm springs afford little prospect as a geothermal resource.

SUMMARY

The information provided in this report has been generalized to give an overall view of the geology and mineral resources. The Caddo River watershed is located mostly in the central and southern Ouachita Mountain Province, but a small portion overlaps into the Gulf Coastal Plain. The rocks include numerous lithologic types; shale, sandstone, chert, novaculite, limestone, tuff, sand, gravel, marl and others. These rocks have been divided into 19 formations that range in age from Early Ordovician to the Recent alluvium and colluvium. The Ouachita Mountains were formed by intense late Paleozoic deformation which caused the uplift and northward transport of the basinal deposits through complex folding and thrusting. Erosion which started with uplift and continues to the present, has caused the removal of at least 30,000 vertical feet of sedimentary rock. The warm Cretaceous seas engulfed the southern and eastern portions of the area and deposited marl, chalk and sand that are very gently tilted. Also in Cretaceous times major igneous intrusions took place mostly in nearby areas. Throughout the Quaternary the region has undergone cycles of erosion and deposition related to the various climatic cycles.

Rocks of the watershed are presently the source of slate for roofing granules; sandstone, shale, chert, and other rock for road material; and quartz crystals. Soon there should be further production of barite for drilling mud. The area might have the potential for providing many other needed mineral resources. There is current interest in several other mineral resources. It is likely that the intensity in exploration and mining activity will further increase along with the projected demands.

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