Ouachita Mountains

Overview

The Ouachita Mountains are exposed in a belt from Little Rock, Arkansas to Atoka, Oklahoma. The length of the exposed structures in an east-west direction is approximately 200 miles (along latitude line 34° 30′). The Ouachitas are approximately 70 miles wide (north-south) along Scenic 7 (Fig. 35). These folded and faulted mountains are similar to the Appalachian Mountains, not only in geologic structure, but also in age. Both mountain ranges contain Paleozoic Era-aged rocks (250 to 540 million years ago) and are complexly folded and faulted.

The Ouachitas in Arkansas are buried on their eastern and southern borders by the sediments and rocks of the Mississippi River Alluvial Plain and the West Gulf Coastal Plain (Fig. 1). The folds of the Ouachita structures underlie these younger sedimentary materials and are not visible at the surface; however, they are encountered during drilling operations in the search for oil and gas. These subsurface structures are also revealed by gravity, magnetic, and seismic surveys. The northern boundary is formed by the Arkansas River Valley Province which is considered to be the structural transition zone between the Ouachita Mountains and the Boston Mountain Plateau of the Ozark Province.

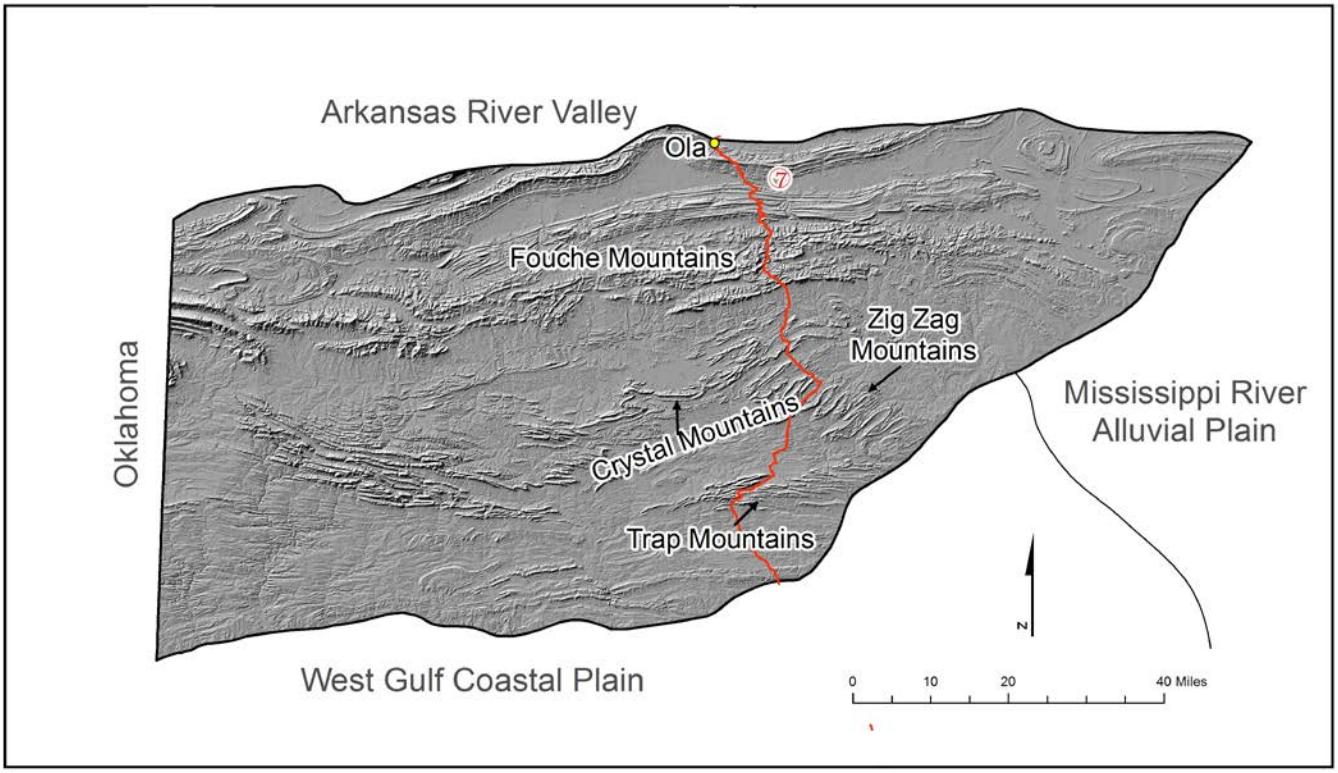

Figure 35. Shaded relief map of the Ouachita Mountains
(source, Arkansas Geological Survey)

Geologic History of the Ouachita Mountains

The Ouachita Mountains developed as a result of a 290 million-year-long plate tectonic process. This mountain-building event is known as the Ouachita Orogeny. It consisted of the following processes: continental splitting (rifting), ocean-basin widening and sinking, accumulation of sediments, and ultimately a collision. The collision was between ancestral North America including its southern, sediment-laden ocean basin, and a north-moving and rising southern highland (ancestral South America-Africa). The energy for such tectonic movements comes from the heat of the Earth's core and mantle. Mountain-building forces resulting in fracturing, faulting, and folding of the Earth's crust are caused by rising molten rock (magma) and sinking of colder masses of solid or semi-solid rock.

During this long history, subsidence of the crust occurred permitting the accumulation of sand, silt, and clay in a deep narrow trough along the continental margin. Farther offshore in the deep ocean basin, clay and silica-rich oozes were deposited, which after being compacted and recrystallized, became shale and chert (novaculite). This slow subsidence process lasted until the Late Devonian Period (359 million years ago).

During the Early Mississippian Period (beginning 359 million years ago) there was a dramatic increase in the rate of sedimentation due to erosion of rising highlands, and a dramatic deepening of the submarine trough. Very thick accumulations of sand, silt, and clay, known as flysch, developed along steep continental slopes where submarine sand and mud slides (turbidity-flow deposits) occurred.

As the mountain-building episode progressed, the sediment-laden trough advanced northward against the more stable mass of the Ozark Dome and its associated shallow-water continental shelf. This movement formed the overturned folds and thrust faults of the Ouachita Mountains that are exposed today between Ola and Caddo Valley. The physiographic subdivisions that display the different structural styles and rock types of the Ouachitas are shown on Figure 36. This process was completed by Late Pennsylvanian-Early Permian time (approximately 290 million years ago).

Rifting south of the Ouachitas began in the Triassic Period (251 to 199 million years ago) due to the buildup of tensional forces in the basement rocks. This structural unrest continued during the Jurassic and Cretaceous Periods (199 to 65 to million years ago) resulting in the formation of the ancestral Gulf of Mexico. Submergence of the southern continental margin allowed the sea to invade the region.

Igneous activity (volcanism and plutonism) flourished during the Cretaceous (145 to 65 million years ago) causing numerous dikes and small plutons (Little Rock, Benton, Magnet Cove, Potash Sulfur Springs) to form in the eastern part of the Ouachitas and parts of the Arkansas River Valley.

Continuing subsidence during the Tertiary Period (65 to 2.6 million years ago) and Quaternary Period (2.6 to present million years ago), allowed the deposition of additional West Gulf Coastal Plain and Mississippi River Alluvial Plain sediments, causing more covering of the Ouachita structures on their southern and southeastern borders.

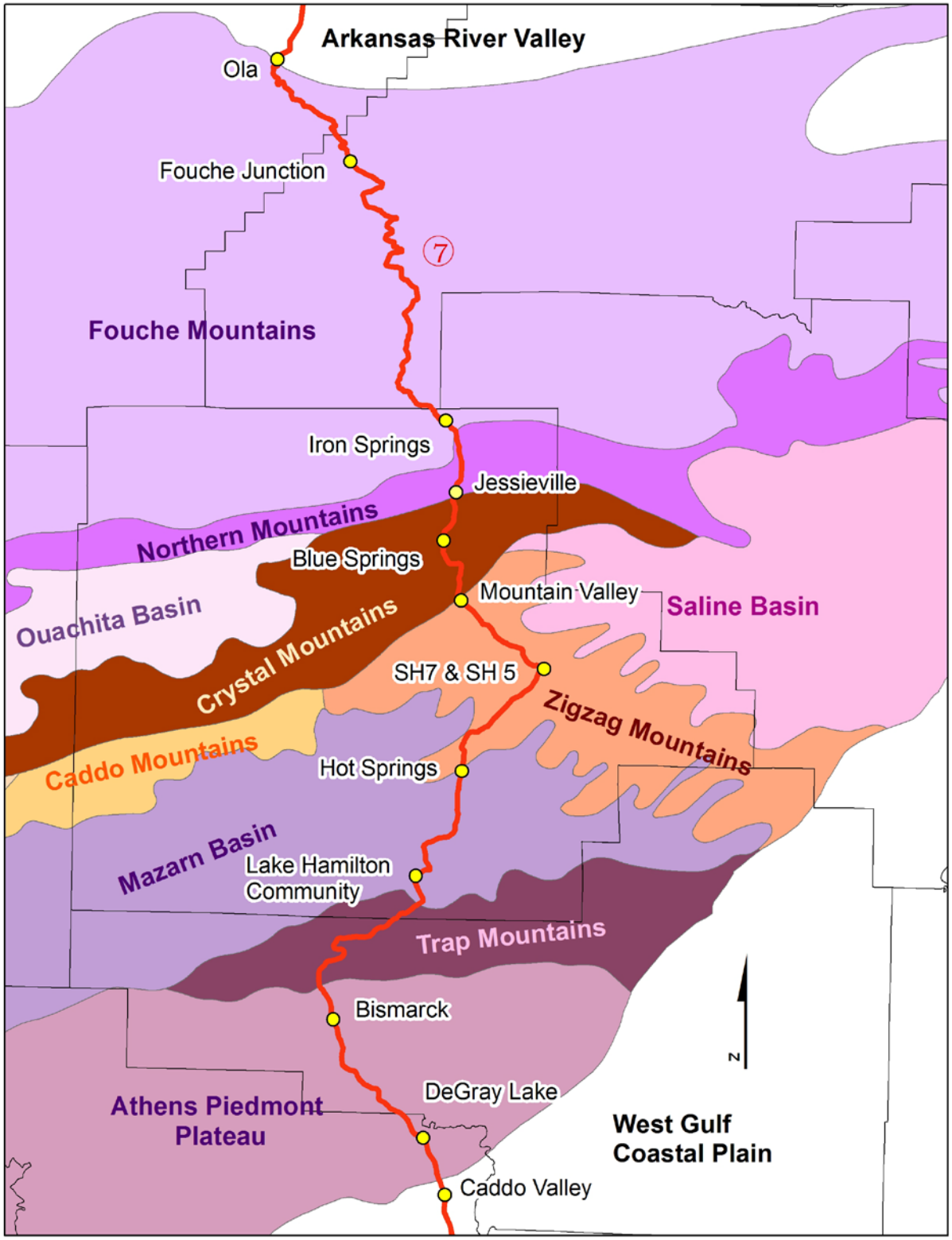

Figure. 36. Physiographic subdivisions of the Ouachita Mountains
(source, Arkansas Geological Survey)

Rock Types Exposed Along Scenic 7 in the Ouachita Mountains

(Based on McFarland, 2004; and Johnson and Hanson, 2011 for the Hot Springs area; rock types are listed from youngest to oldest, map symbols follow the formation name.)

Atoka Formation (ℙa)
Age: Pennsylvanian (299 to 318 million years ago)
Description: tan to gray, silt-containing sandstone, silty gray-black shale with fragmented plant fossils, and a few thin coal beds; divided into lower (ℙal), middle (ℙam), and upper (ℙau) subdivisions in some areas. The formation is the thickest (+ 20,000 feet) exposed in the Ouachitas; however, the complete formation is not exposed at a single locality.
Environment of deposition: shallow marine and deltas in the northern Arkansas Valley region, with submarine slump and slide (turbidity current) activity on the continental slope to deep water (abyssal) environment in the southern part of the Ouachita Mountains.

Johns Valley Shale (ℙjv)
Age: Pennsylvanian (299 to 318 million years ago)
Description: grayish-black shale containing several beds of brown-gray sandstone, some chert may be present. Exposures of the shale in the northern Ouachitas may contain various rock types (limestone, dolostone, chert) that are interpreted to have formed elsewhere, probably from a northern source, and were transported into accumulating sediments by submarine slumping. Thickness is not well measured due to folding and faulting but probably is more than 1,500 feet.
Environment of deposition: deep marine.

Jackfork Sandstone (ℙj)
Age: Pennsylvanian (299 to 318 million years ago)
Description: fine to coarse-grained, brown, tan, or blue-gray, quartz-cemented (durable) sandstone, with some silty sandstone, and gray-black shale. The Jackfork is from 3,500 to 6,000 feet thick.
Environment of deposition: poorly preserved plant fossils may indicate an alluvial or deltaic environment of deposition for some strata within the Jackfork. Northern exposures of shale may contain masses of sandstone with chaotic structure indicating submarine slumping on a continental slope. Considered to be deep marine in the Athens Plateau area.

Stanley Shale (Ms)
Age: Mississippian (318 to 359 million years ago)
Description: dark-gray shale with a thick sandstone member (Hot Springs sandstone is a prominent ridge-former in the Hot Springs area, Garland County); minor amounts of tuff (volcanic ash deposit), chert and conglomerate occur in some areas. Thickness is from 3,500 to 10,000 feet.
Environment of deposition: deep marine.

Arkansas Novaculite (MDa) (Fig. 37)
Age: Mississippian- Devonian (350-370 million years ago)
Description: Three subdivisions are known: Lower division is white, massive-bedded chert with minor gray shale near the base of the division; Middle Division is green to dark-gray-black shale with numerous thin beds of chert; Upper Division is white, thick-bedded chert that is usually calcite-bearing (calcareous).

Environment of deposition: deep marine.
The source of the silica (SiO_2) necessary to form massive beds of chert is uncertain. Potential sources include: marine micro-organisms, volcanic ash, or weathering of rocks, especially those composed of feldspars.

Figure 37. Arkansas Novaculite boulder
(Parking lot east of Park Avenue /Central Avenue intersection,
Hot Springs 34°31′11″N 93°03′19″W)

Missouri Mountain Shale (Sm)
Age: Late Silurian (416 to 430 to million years ago)
Description: gray, green, black, or red shale that alters to green, yellow, or red-brown color when weathered; may contain limited amounts of novaculite, sandstone, and conglomerate. Maximum thickness is approximately 300 feet.
Environment of deposition: marine.

Blaylock Sandstone (Sb)
Age: Middle-Early Silurian (430 to 444 million years ago)
Description: tan to gray sandstone, some siltstone and black shale interbeds, not present in the Zigzag Mountains, but is present in the Trap Mountains, south of Hot Springs, where it may be up to 1,200 feet thick.
Environment of deposition: marine.

Polk Creek Shale (Opc)
Age: Late Ordovician (444 to 458 million years ago)
Description: black shale with small amounts of black chert and gray quartzite. Shale is soft and light gray to white when weathered. Thickness ranges from 50-100 feet.
Environment of deposition: marine in oxygen-starved water.

Bigfork Chert (Obf)
Age: Upper Middle Ordovician (approximately 460 million years ago)
Description: thin-bedded, dark-gray chert with some interbedded black shale, siltstone, and limestone. Thickness ranges from 450 feet in the northern part of the core area of the Ouachitas to 750 feet in the southern Ouachitas.
Environment of deposition: marine.

Womble Shale (Ow)
Age: Middle Ordovician (approximately 470 million years ago)
Description: black shale containing thin layers of limestone, silty sandstone, and chert. Rock cleavage cutting across the bedding may show ribbon-like bands of color, thickness ranges from 500 to 1,200 feet.
Environment of deposition: marine.

Blakely Sandstone (Ob)
Age: Middle Ordovician (approximately 475 million years ago)
Description: black and green shale interbedded with gray sandstone and limestone. Shale comprises from 50 to 75 % of the formation, but the sandstone is prominent due to its resistance to weathering. Thickness ranges from a few feet to 700 feet.
Environment of deposition: marine.

Mazarn Shale (Om)
Age: Early Ordovician (approximately 480 million years ago)
Description: gray to black shale containing minor amounts of siltstone, sandstone, and chert. Rock cleavage surfaces across the bedding plane direction may show alternating color-bands (ribbon-like streaks). Fractures are commonly filled with milky-colored quartz, especially in fault zones. Thickness ranges from 1,000 to 2,500 feet.
Environment of deposition: marine.

Crystal Mountain Sandstone (Ocm)
Age: Early Ordovician (approximately 485 million years ago)
Description: thick-bedded gray sandstone. Locally includes gray shale, black chert, blue-gray limestone, and conglomeratic sandstone. Usually contains numerous quartz veins with cavities containing well-formed clusters of quartz crystals. Ranges from 50 to 800 feet in thickness.
Environment of deposition: marine.

Collier Shale (Oc)
Age: Late Cambrian-Early Ordovician (485-490 million years ago)
Description: black shale with a few thin beds of fractured chert and some thin beds of blue-gray limestone. Deformation structures (fracturing, faulting, and folding) are commonly present as are numerous quartz veins. The exposed part of the Collier is more than 1,000 feet thick; however, its base is not exposed. The Collier is the oldest formation exposed in the Ouachitas and in the state.
Environment of deposition: marine.

Rock and Mineral Resources of the Ouachita Mountains

Yell County

Over the years the following mineral and rock resources have been produced in the county: coal, natural gas, sandstone, and sand and gravel (Fig. 38). Most of the coal was produced in the northern portion of the county, and the relatively small amounts mined were used for local needs.

Natural gas wells located in the western part of the county produced nearly 18 million cubic feet of gas in 2007, which amounted to approximately 7 percent of gas produced in the state that year. There is significant interest in drilling additional wells in various gas-producing zones in the Atoka Formation.

The deepest oil/gas test well in Arkansas was drilled to a depth of 20,661 feet in the early 1990's near Danville. The well was positioned to probe the frontal fault zone of the Ouachita Mountains and the adjoining deep portion of the Arkansas River Valley Province. The drilling target was the Arbuckle Group, Cambrian/Ordovician-age, consisting of porous limestone and dolomite. The Arbuckle is a significant oil/gas producer in Oklahoma and Kansas. This deep test was a dry hole. However, it is assumed that significant geological and technical drilling information was acquired.

Perry County

The main mineral-rock resources in Perry County are sandstone, sand and gravel, and coal. Sandstone is an abundant resource which occurs in both thin-bedded and thick-bedded varieties. This locally abundant resource has been quarried for specific construction projects, such as building the Lake Nimrod Dam and bank stabilization along the Arkansas River.

Coal has been mined from the upper Atoka Formation in an area known as the Rose Creek Coal Basin located near Adona, approximately 20 miles east of Ola. It is estimated that approximately 1,000 tons of coal were mined prior to 1969 and reserves in this area are estimated to be a few thousand tons (Stroud, et al., 1969, pgs. 316-317).

Sand and gravel deposits are available throughout the county adjacent to the Arkansas River and its tributaries.

Garland County

Garland County is situated in the heart of the Ouachita Mountains and the variety of mineral and rock resources is greater here than in any other county traversed by Scenic 7. Historically, four of these resources have provided the majority of the income produced by mining. They are novaculite, quartz crystals, tripoli (fine-grained disintegrated chert), and vanadium ore. At least eight additional potential mineral resources have been identified (Stroud, et al., 1969, p. 232).

Novaculite, a form of massive-bedded chert, is quarried and manufactured into high-quality whetstones of various sizes and abrasiveness. The variation in grain size that determines abrasiveness is due to the amount of recrystallization of the chert. This results from low-grade metamorphism that occurred during the Ouachita orogeny. The most fine-grained stones are used to sharpen medical surgical instruments. You will find a number of different types of whetstones for sale in the Hot Springs area.

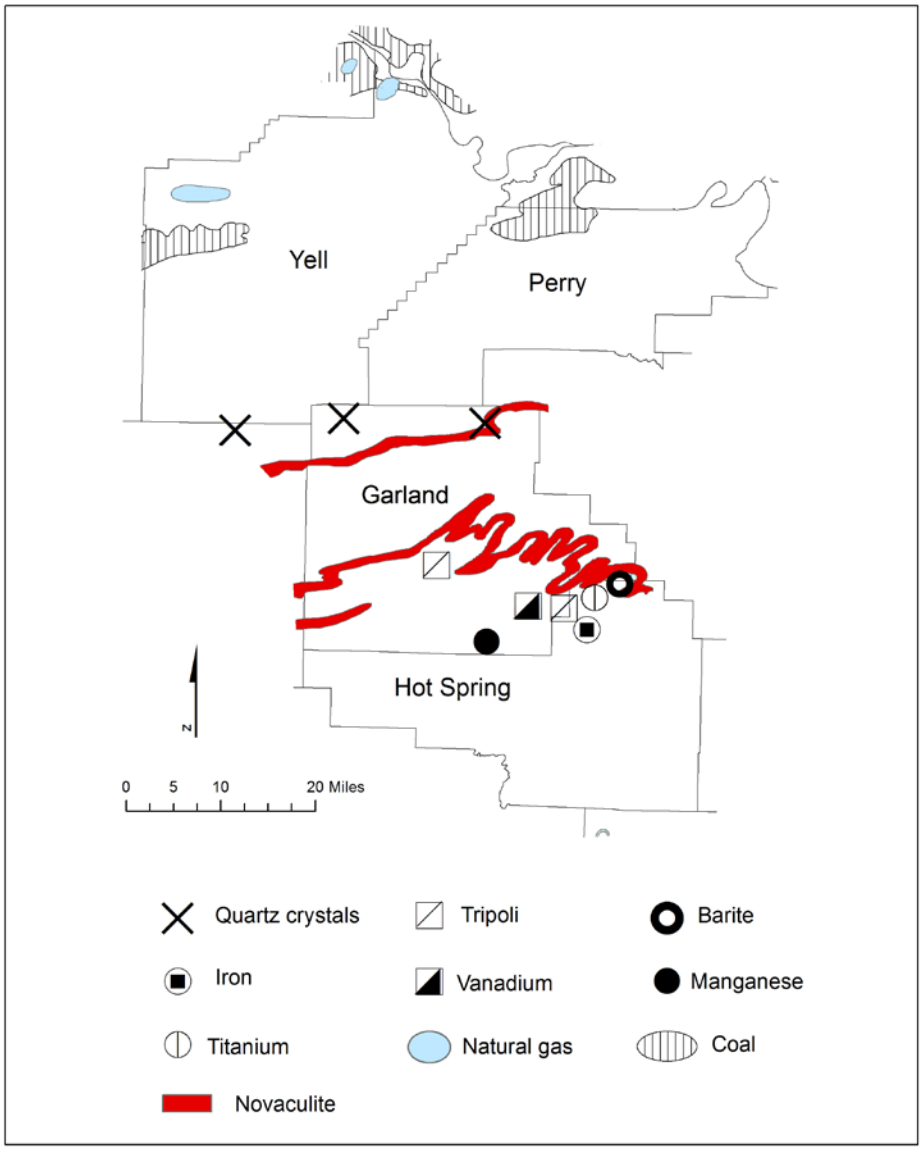

Figure 38. Location map of rock and mineral resources in Yell, Perry, Garland, and Hot Spring Counties
(from Arkansas Mineral Resources, page size map)

Quartz crystals are highly sought after by collectors, and "world-class" crystals and crystal clusters are mined in the region. During World War II, crystals were mined for the manufacture of frequency standards utilized in radio transmitters and receivers. Today, cultured (man-made) crystals have replaced natural crystals for this purpose, but the zeal of crystal collectors has only increased. There are numerous commercial crystal mines in the county, especially near Blue Springs, that are open to those who may wish to collect their own crystals.

Tripoli is mined for use as an additive in specialized industrial coatings. The raw tripoli is converted into a manufactured product known as "Novacite". This powdered material is known for its hardness and low oil absorption characteristics. It is especially utilized in chemical-resistant and marine-service coating products.

In the 1960's vanadium ores were discovered in eastern Garland County near the Wilson Springs community. Vanadium is used as an alloying ingredient in steel making. The development of several mines by Union Carbide Corporation began in 1967. Arkansas was "Number One" in the U.S. in vanadium production for six years from 1972 to 1978. The mining and ore refining operations continued, with some interruptions, until 1989 (Owens, 2010).

Hot Spring County

Scenic 7 enters Hot Spring County after leaving the city of Hot Springs. The county line is crossed approximately 3.2 miles south of Lake Hamilton. The county is rich in mineral resources; however, most are concentrated in the northeastern part surrounding the well-known Magnet Cove igneous intrusion. In 1969 a U.S. Bureau of Mines report identified the following minerals or rocks of value in the area: barite, clay, tripoli, slate, titanium and vanadium minerals, vermiculite (mica), molybdenite, columbium minerals, apatite, and pyrite (Stroud, etal., 1969, p. 246).

The Chamberlin Creek Barite Mine was opened in 1940 and between 1952 and 1966 the value of barite extracted was $44.7 million (Stroud, etal., p. 246). Barite is an unusually heavy mineral, being almost 60 percent heavier than the average non-metallic mineral. This unusual density makes it valuable. Water or oil-based fluids (muds) used in drilling oil/gas wells are made heavier through the addition of ground barite in order to manage the high pressures encountered as well bores enter oil/gas zones. Blowouts are very dangerous and costly, as we all learned from the British Petroleum (BP) "Deep Water Horizon" well blowout in the Gulf of Mexico in 2010. Mining of the deposit ended in 1977, as the operation of the underground mine workings and deep open pit became unprofitable.

The Magnet Cove igneous intrusion is well known to mineralogists and mineral collectors worldwide. The first mention of the unique minerals in this locality was made in 1806. Since that time numerous mineralogic and petrologic studies have been completed in the area. An informal review of these studies indicate that over 100 mineral species (types) have been identified in the rocks of the intrusion and veins (dikes) that surround Magnet Cove. Titanium-bearing minerals (rutile, brookite) occur in the rocks and rutile was mined during World War II between 1941 and 1944. The U.S. Bureau of Mines estimated that from 450,000 to 500,000 tons of ore were extracted from open pit mines during that period. Combined reserves are estimated to be in excess of 8 million tons of ore containing 4 to 8 percent titanium oxide (Stroud, etal., 1969, p. 250).

Currently, Martin-Marietta Materials Company is quarrying rock from the southeastern margin of the intrusion where the igneous rock (nepheline syenite, approximately 100 million years old) is in contact with the Stanley Shale (Mississippian age, 318 to 359 million years old). The heat of the intrusion caused the shale to recrystallize into a durable contact metamorphic rock known as hornfels. This rock, which is crushed to various sizes, is excellent road-building aggregate. The quarry also produces crushed stone from the igneous rock (nepheline syenite).

Fourche Mountains Overview

The Fourche Mountains (Rover Structural Belt), the northernmost part of the Ouachitas, begin just south of Ola and extend to approximately 2.5 miles north of Jessieville, a distance of approximately 32 miles along Scenic 7 (26 straight-line miles) (Fig. 39). The ridges of the Fourche Mountains are often quite long extending in an east-west direction many tens of miles. For example, the Ola Mountain fold extends approximately 80 miles to the east from Plainview in Yell County into Faulkner County, northeast of Conway.

The rock types exposed in the region are sandstones and shales of the Atoka Formation of Lower to Middle Pennsylvanian age. These elongated ridges are structurally complex. The anticlinal-synclinal folds are broken by large east-west trending, south-dipping thrust faults. Parts of the Atoka are displaced as much as 15,000 feet to the north by the faults. The number of mappable faults along Scenic 7 averages about 1.4 faults per mile. Generally, the faults are stacked, shingle-like, with the upper fault plate displaying a northerly displacement.

As we travel from north to south, the structural style changes dramatically. In the north there are long anticlinal/synclinal ridges (e.g. Ola Mountain, Fourche Mountain) with closely-spaced groupings of four to six thrust faults in the Atoka Formation. Approximately 1.1 miles north of the S.H. 314 junction near Hollis, the structural style changes to more evenly-spaced thrust faults (one or two per mile) in the Johns Valley Formation. The brittle sandstones of the Johns Valley are also thoroughly fractured (jointed) due to the intense mountain-building pressure exerted from the south.

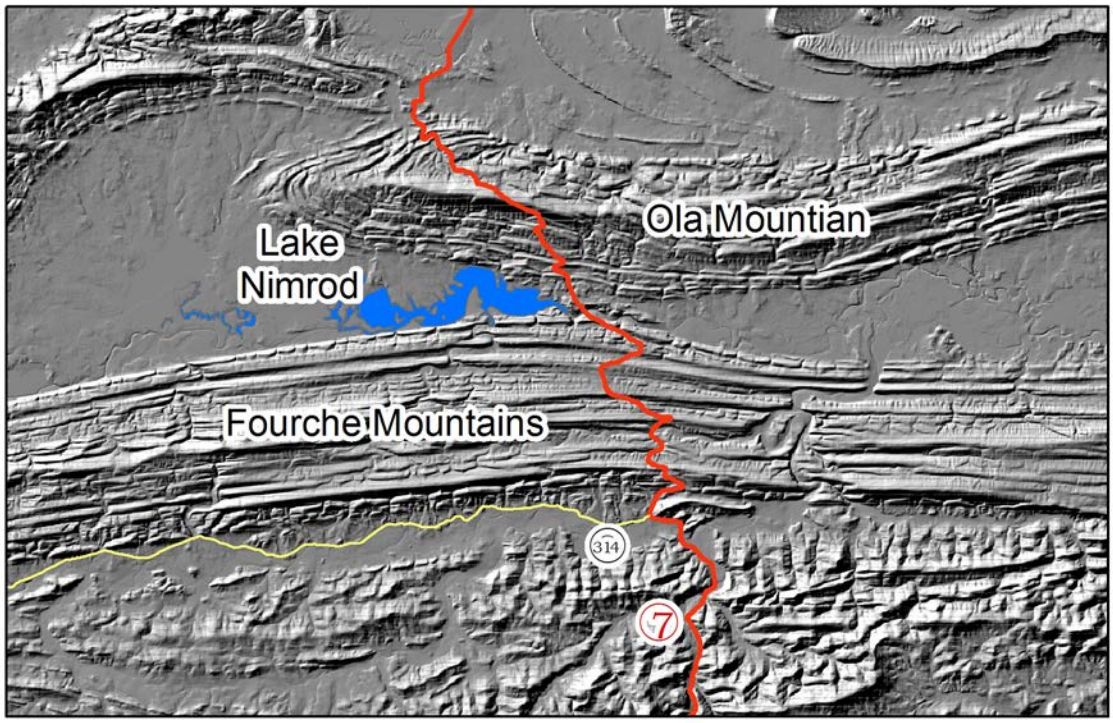

Figure 39. Fourche Mountains, Shaded Relief Map of Arkansas
(Source, Arkansas Geological Survey)

Road Log – Ola to Fourche Junction

On the southern edge of Ola, Scenic 7 turns west at the junction with SH 10 and SH 28. After a short distance (0.2 miles), Scenic 7 turns south toward Hot Springs. As you begin the uphill drive to the summit of Ola Mountain, it is obvious that you have entered the Ouachita Mountains. After crossing a thrust fault near the junction of Scenic 7 and SH 28, the lower Atoka Formation is exposed in several shallow road cuts before reaching the summit. A total of three east-west trending thrust faults are traversed before reaching the summit. Also, before reaching the summit, there is an excellent view of the Arkansas River Valley to the north (left side of the road). Unfortunately, there is not a place to pull-off the road to take advantage of the view, but there is a gap in the trees lining the road where you can get a quick look at the Arkansas River Valley.

At the summit of Ola Mountain (elevation 1,206 feet) there is a roadside park with picnic tables on both sides of the road. Several interesting things may be seen here. First, note the excellent view of the Ouachitas (Fourche Mountains subdivision) to the southeast (Fig. 40). This is best seen by looking along the highway as it trends downhill. Several distant peaks are visible. A short walk (a few hundred feet) along an informal path toward the south from the picnic area, on the west side of the road, will bring you to a spectacular view of Fourche Mountain and Cove Mountain to the south. You will also see Lake Nimrod (Fig. 41) in the valley of the Fourche LaFave River. Seven major thrust faults are present between the overlook and Fourche Mountain (Fig. 42). The strata of the lower and middle Atoka Formation exposed in this area have dips ranging from 45 to 70 degrees to the south due to thrust faulting.

Figure 40. Fourche Mountains
(Southeast from Ola Mountain, 34°00′00″N 3°12′00″W)

Figure 41. Fourche Mountains and Lake Nimrod
(South from Ola Mountain, 34°59′52″N 93°12′04″W)

On your walk back to the picnic area take a close look at the sandstone. Several of the boulders display color banded zones and contain a weathering feature known as boxwork (Fig. 43). These patterns developed because the sandstone, when several thousand feet below the surface, was fractured during the folding and faulting of the Ouachitas. The fractures (joints) and bedding planes in the sandstone were avenues along which iron-rich fluids migrated. Later because of erosion the rock entered the weathering zone, closer to the surface, where the iron-rich fluids were oxidized and precipitated as hematite and limonite (iron oxides). This resulted in the development of red, brown, or yellow-orange zones, which are called Liesegang bands. The bands where the cements are more concentrated are more resistant to weathering and the bands of lesser concentration tend to weather away faster resulting in the boxwork patterns. Such features, locally known as "carpet rocks", are especially common in the Hartshorne Sandstone in Petit Jean State Park, 15 miles east of Centerville on SH 154. For more geologic information about the Park, see the Arkansas Geological Survey's website at www.geology.ar.gov/catalog/state_park_series/sps02.htm for "The Geologic Story of Petit Jean State Park".

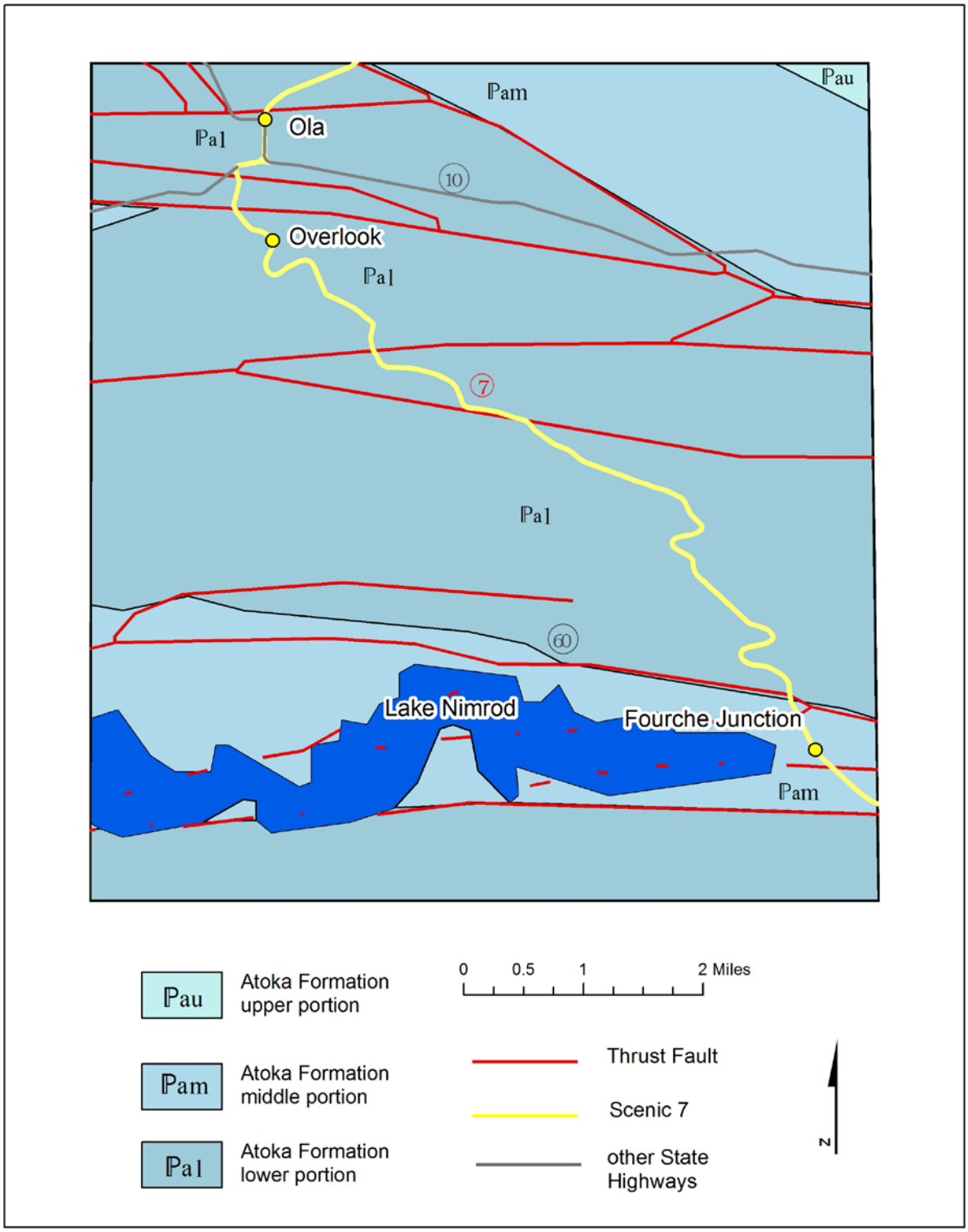

Figure 42. Geologic map from Ola to Fourche Junction
(from Geologic map of Arkansas, 1:500,000 scale)

Figure 43. Boxwork Pattern and Liesegang Banding in Atoka Formation
(Ola Mountain)

As you leave the picnic area and descend to Fourche Junction, a distance of 3.8 miles, a drop in elevation of approximately 800 feet occurs. Two thrust faults are crossed during the descent and a cluster of six thrusts occur in the Fourche Junction area. The rock units bounded by the faults consist of lower and middle Atoka sandstones and shales (Fig. 44). As one can imagine, field mapping in this densely forested area is difficult. A thorough knowledge of the characteristics of the rock strata (stratigraphy) and aerial photography is required to develop a geologic interpretation of this complex region.

Figure 44. Steeply-dipping Atoka Formation
(Fourche Mountains, 35°50′33″N 93°06′28″W)

A short but interesting side trip to Nimrod Dam can be made just south of Fourche Junction, just follow the signs. Nimrod Dam, completed in 1942, was primarily built for flood control. The 1,012 foot-long dam controls the flow of water through the 680 square miles of the Fourche River drainage basin. The thrust faulted middle and lower Atoka can be examined north of the road between the Dam and Project Point Recreation Area. Also, the Lake provides excellent recreational possibilities. A hiking opportunity is provided by Long Hollow Trail that begins on Scenic 7, 2.2 miles south of the Nimrod Dam road.

Road Log - Fourche Junction to Iron Springs

On the road again, you begin to note a challenging feature of Scenic 7 - there are a lot of curves, hills, and valleys, so please do not distract the driver. From Fourche Junction to Hollis (junction with SH 314) you will cross six thrust faults, five of which are in the lower Atoka Formation. The dip of the strata in this region is generally 60 to 80 degrees to the north.

Approximately 1 mile north of the SH 314 junction with Scenic 7, the Johns Valley Shale is crossed in the proximity of a thrust fault (Fig. 45). Magie Creek and the South Fourche LaFave River flow around an isolated inlier (older rock surrounded by younger rock). This stratigraphic anomaly was caused by erosion of a thrust fault that shoved the older Jackfork Sandstone over the younger Johns Valley Shale. This unusual relationship is graphic evidence of the extreme tectonic forces that caused the folding and faulting of the Ouachitas. The Johns Valley Shale may be examined in a road cut on the west side of Scenic 7 at the junction with SH 314. Thin sandstones, iron-rich concretions, and evidence of small faults have been reported at this location. Faults may be recognized by the presence of scratches and grooves, known as slickensides, on rock surfaces and a thin coating of a white clay mineral known as dickite (Stone, Haley, and Viele, 1973, p. 24).

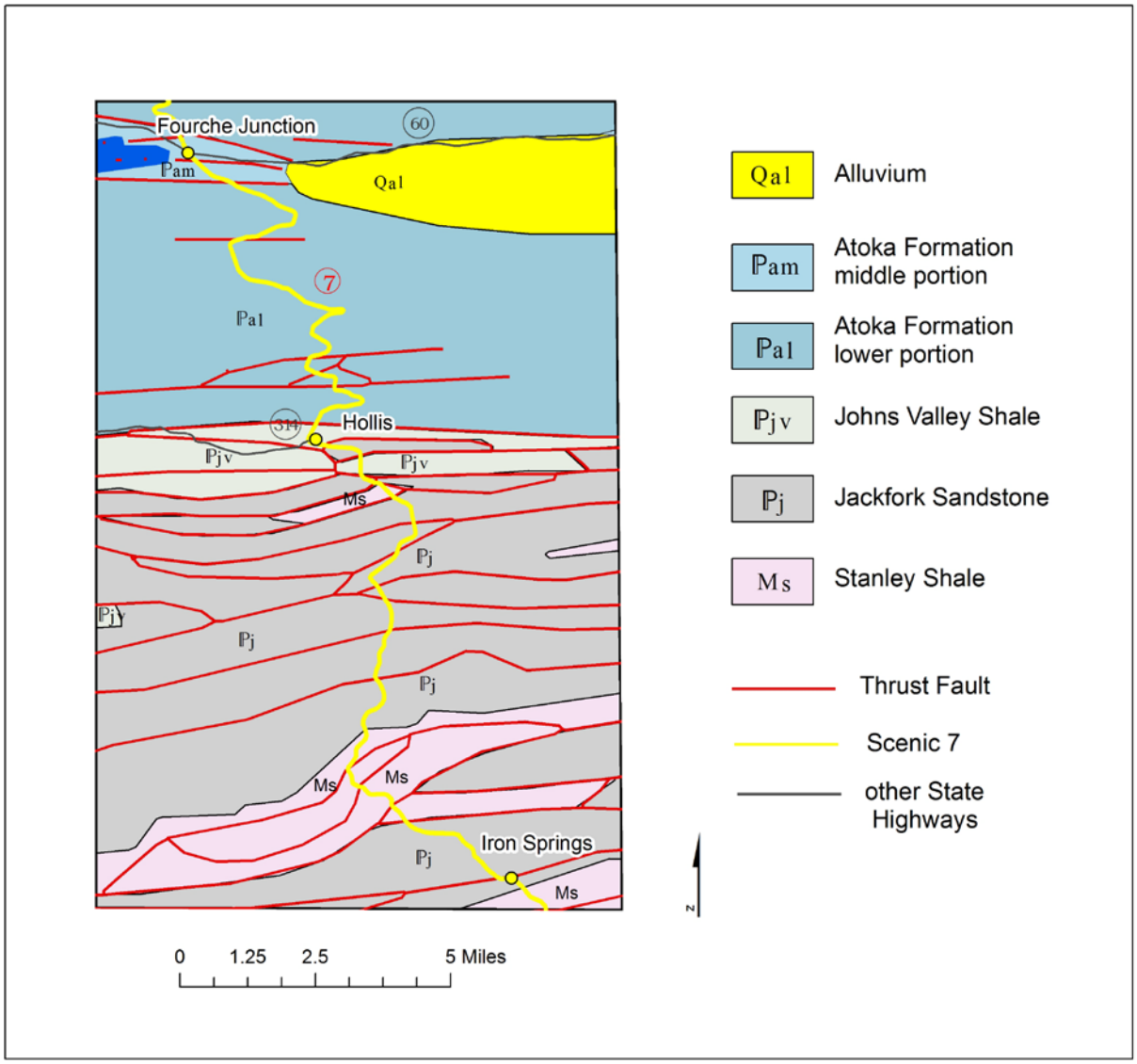

Figure 45. Geologic map from Fourche Junction to Iron Springs
(from Geologic map of Arkansas, 1:500,000 scale)

Between the South Fourche River bridge and Bear Creek (distance 1.9 miles) the road crosses four thrust faults in the Jackfork Sandstone. The dips of the strata are generally at high angles and are oriented both north and south, a condition that is typical in a terrain disrupted by faulting.

Proceeding south from Bear Creek bridge to the Iron Springs Recreation Area, 14 thrust faults are crossed. Jackfork Sandstone outcrops are more commonly exposed; however, the Stanley Shale is exposed on the southern limb of a faulted syncline near Dry Run Creek (4.3 miles south of Bear Creek bridge). From Dry Run Creek to Iron Springs an additional six thrusts

are crossed in both the Jackfork and Stanley Formations. Also, one end of the 223 mile long Ouachita Backpacking Trail is passed approximately a mile before reaching Iron Springs.

A stop at Iron Springs Recreation Area is a must. It is a pleasant picnic area on the Middle Fork of the Saline River. Here you will see the lower Jackfork Formation, which at this locality consists of massive to thin-bedded sandstone and shale containing numerous quartz veins and a hydrothermal clay mineral known as rectorite (Stone, Haley, and Viele, 1973, p. 29). The presence of numerous fractures, springs, quartz veins, and rectorite is a strong indication that a fault passes through the area and it is so mapped by Stone and others (1973) (Fig. 46). The contact with the Stanley Formation can be found approximately 0.3 mile downstream from Iron Springs.

The Stanley Shale has well-defined bedding and is somewhat slate-like due to low grade metamorphic recrystallization of its grains caused by increased heat and pressure during the formation of the Ouachitas. The Stanley is also thoroughly fractured (jointed), as is to be expected in a fault zone. Often during field mapping in the Ouachitas, fault zones are also recognized by the presence of abundant milky-colored quartz veins.

Figure 46. Faulted Jackfork Formation
(Iron Springs Recreation Area, 34°44′45″N 93°04′15″W)

Crystal Mountains Overview

The Crystal Mountains are considered to be the "Core Area" of the Ouachitas since the oldest rock (Collier Shale, Late Cambrian-Early Ordovician) is exposed. The area contains numerous overturned anticlinal and synclinal folds, high-angle reverse faults, and low-angle thrust faults. This area is bounded on the north by the Fourche Mountains and on the south by the Zigzag Mountains (Fig. 36). The rocks of the region include sandstone, shale, and chert, ranging in age from the Mississippian-Devonian to Late Cambrian Periods (360 - 490 million years ago)

a 130 million year record of sedimentation. The folding trend is more northeast-southwest than the east-west trend displayed in the Fourche Mountains. This condition is interpreted to have been caused by a late phase of folding, known as the Benton Uplift, being superimposed over the original fold trend. Field evidence indicates that the upper thrust plates were moved in a northerly direction, being stacked shingle-like by the uplift, while folds were backfolded and overturned toward the south (Stone, et al., 1994, pg. 5).

Road Log – Iron Springs Recreation Area to Blue Springs

Returning to Scenic 7 and continuing south toward Jessieville the road crosses the Stanley Formation for approximately 1.75 miles, where dips are still northerly at angles from approximately 45 to 75 degrees. Five major thrust faults are crossed in this distance. Also, another inlier (older strata on top of younger strata) formed by thrust faults is present. The inlier consists of an eroded anticline/syncline complex approximately 0.7 mile wide of the Bigfork Formation (Ordovician Period) at its core, surrounded by the Missouri Mountain, Blaylock, and Polk Creek Formations (Silurian and Ordovician Periods) and the Arkansas Novaculite Formation (Mississippian-Devonian Periods). Near the thrust fault on the south edge of the inlier, strata dip in a northwest direction at an angle of 30 degrees. After crossing the fault at the bridge of the Middle Fork of the Saline River, another narrow anticline composed of the same age strata is exposed between thrust faults only 0.5 mile apart

The Core Area is entered approximately 2 miles south of Iron Springs Recreation Area at a thrust fault that brings the Arkansas Novaculite into contact with the Stanley Shale (Fig. 47). Two more thrust faults are crossed between the contact and Jessieville. Also, tight northeast-trending folds composed of Arkansas Novaculite, Missouri Mountain Shale – Polk Creek Shale, and Bigfork Chert are crossed. Dips of the strata, generally to the northwest, range from 25 to 75 degrees. One and one-half miles north of Jessieville, the Mazarn Shale (Early Ordovician Period) is exposed after crossing a thrust fault.

Just north of the Jessieville School, another major thrust fault is present bringing the Collier Shale into contact with the Mazarn Shale. The Collier, the oldest rock formation exposed in the Ouachitas, is present along Coleman Creek and for approximately 1.75 miles south of Jessieville along Scenic 7. Less than 0.1 mile south of SH 298 junction the Collier comes into fault contact with the Crystal Mountain Sandstone (Early Ordovician Period). The Crystal Mountain is present in an overturned tightly-folded anticline that is broken by a thrust fault at Blue Springs.

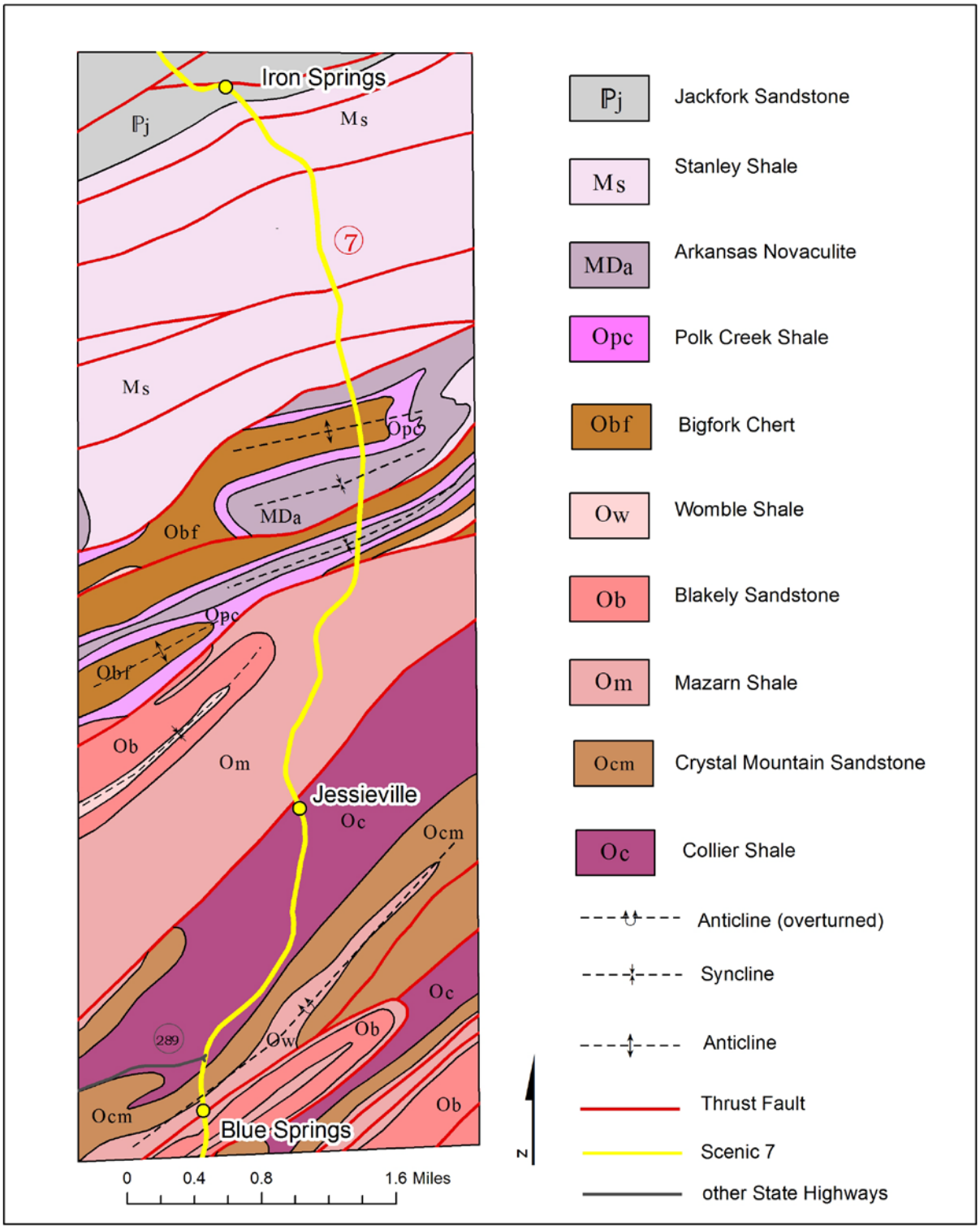

Figure 47. Geologic map from Iron Springs to Blue Springs
(from Geologic map of the Ouachita Mountain and a portion of the Arkansas River Valley regions, 1:100,000 scale)

Road Log - Blue Springs to Mountain Valley

The geologic structure between Blue Springs and Mountain Valley is very complex. The structural style of tightly-folded overturned anticlinal and synclinal folds has been obscured by numerous thrust faults. The Blakely Sandstone and Womble Shale are exposed because of repetition of the strata as a result of crossing eight thrust faults over a distance of 3.7 miles (Fig. 48). The strata generally dip north-northwest at angles from 30 to 60 degrees. The steeper dips are generally present near thrust faults. The ridge (Cedar Mountain), upon which the entry to Hot Springs Village is located, is composed of the Blakely Sandstone. As Scenic 7 descends from Cedar Mountain, three thrust faults, exposing the Womble Shale (Fig. 49), are crossed.

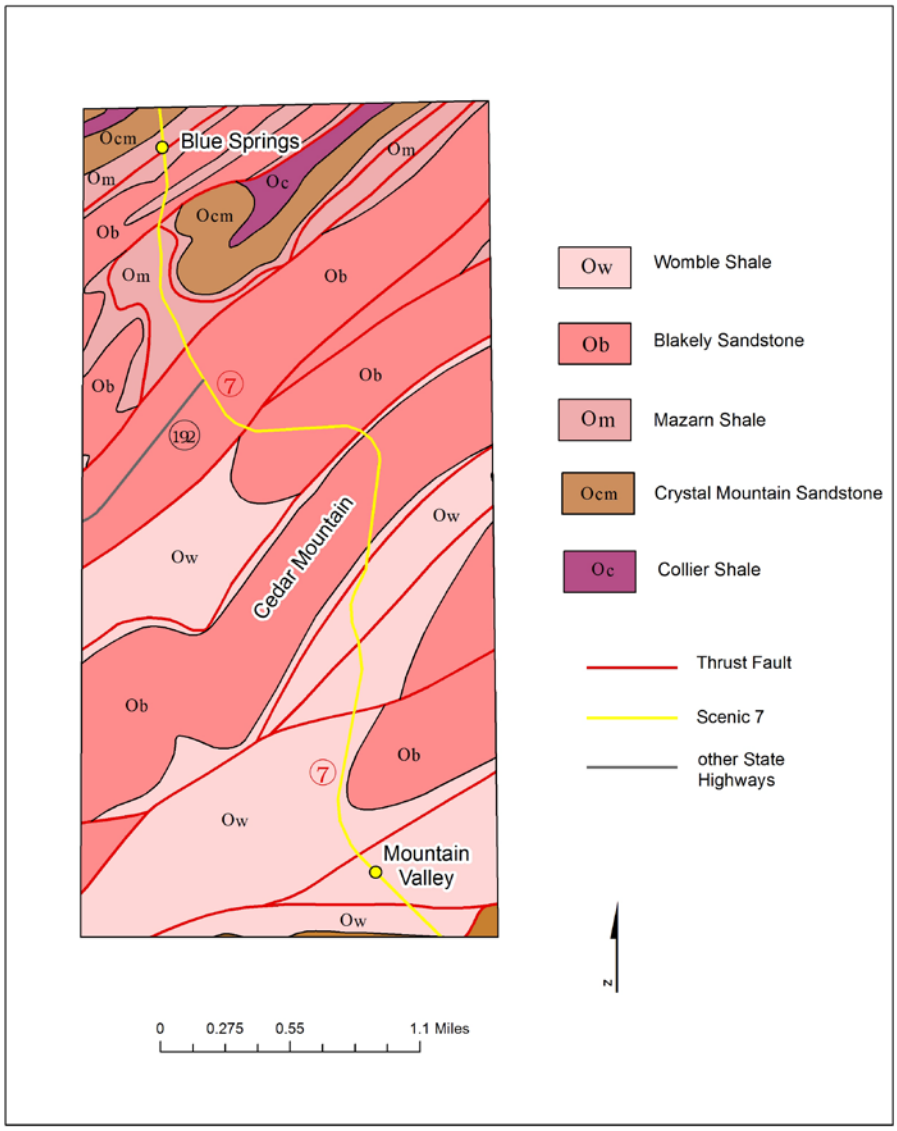

Figure 48. Geologic map from Blue Springs to Mountain Valley
(from Geologic map of the Ouachita Mountain and a portion of the Arkansas River Valley regions, 1:100,000 scale)

Figure 49. Womble Shale
(South of Hot Springs Village, 34°38′03″N 93°03′30″W)

Zigzag Mountains Overview

These prominent ridges and valleys trend northeast-southwest, and when viewed from above, the zigzag pattern is very obvious (Fig. 50). Their sharp topographic relief is due to the presence of erosion-resistant strata (Bigfork Chert, Arkansas Novaculite, and Hot Springs Sandstone Member of the Stanley Formation). The change in direction of the ridge lines from east-west, as present in the Fourche Mountains, to northeast-southwest in the Zigzags, is interpreted to have been caused by a late-phase folding stress during the Ouachita Orogeny that affected the entire Benton Uplift (Crystal Mountains and Zigzag Mountains). One interpretation suggests that the younger more rigid strata resisted additional northerly movement, while the older more deeply buried, and more ductile (plastic) strata allowed additional deformation. The result was that the younger folded and faulted strata were overturned and thrust toward the south (Fig. 52), while fold axes and thrust fault orientation were rotated toward the northeast-southwest. Geophysical (seismological and gravitational) studies suggest that the late-phase stresses could have been caused by uplift of the igneous basement rock (Benton Uplift) caused by sinking (subduction) of the continental margin.

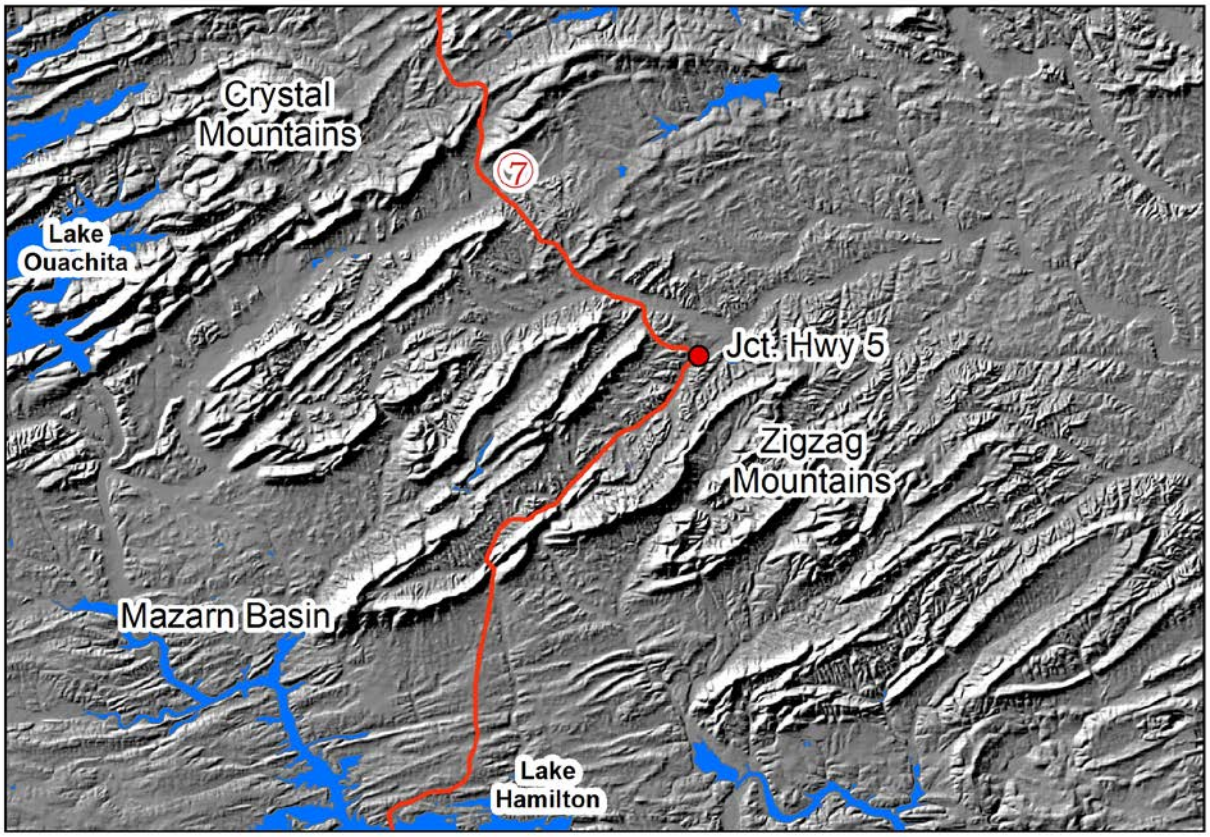

Figure 50. Zigzag Mountains, Shaded Relief Map of Arkansas
(Source, Arkansas Geological Survey)

Road Log – Mountain Valley to Junction of SH7 and SH 5

The Bigfork Chert (Middle and Late Ordovician) is exposed for approximately 1.5 miles south of Mountain Valley, in a characteristic pattern for the Zigzag Mountains (Fig. 51). The pattern consists of asymmetrical anticlines and synclines that are overturned toward the south and have their axes oriented in a northeast-southwest direction (see Glazypeau Mountain in Fig. 52).

A basal thrust fault (lowest thrust, in a series of shingle-like thrusts) block is crossed for the next 1.6 miles. This fault places a folded mass (nappe) of Blakely Sandstone and Mazarn Shale over Womble Shale, resulting in a reversal of normal stratigraphic order.

At the Ozark Lithia community another thrust fault brings the Bigfork Chert into contact with the Womble Shale. This folded (plunging to the southwest synclinal-anticlinal) complex of Bigfork Chert comes into normal stratigraphic contact with the Womble Shale 0.3 mile northwest of the Junction of Scenic 7 with SH 5 (Fig. 53).

WOW, what a complex structural mess! It is a graphic record of the gigantic compressive forces that were operating during the Ouachita Orogeny.

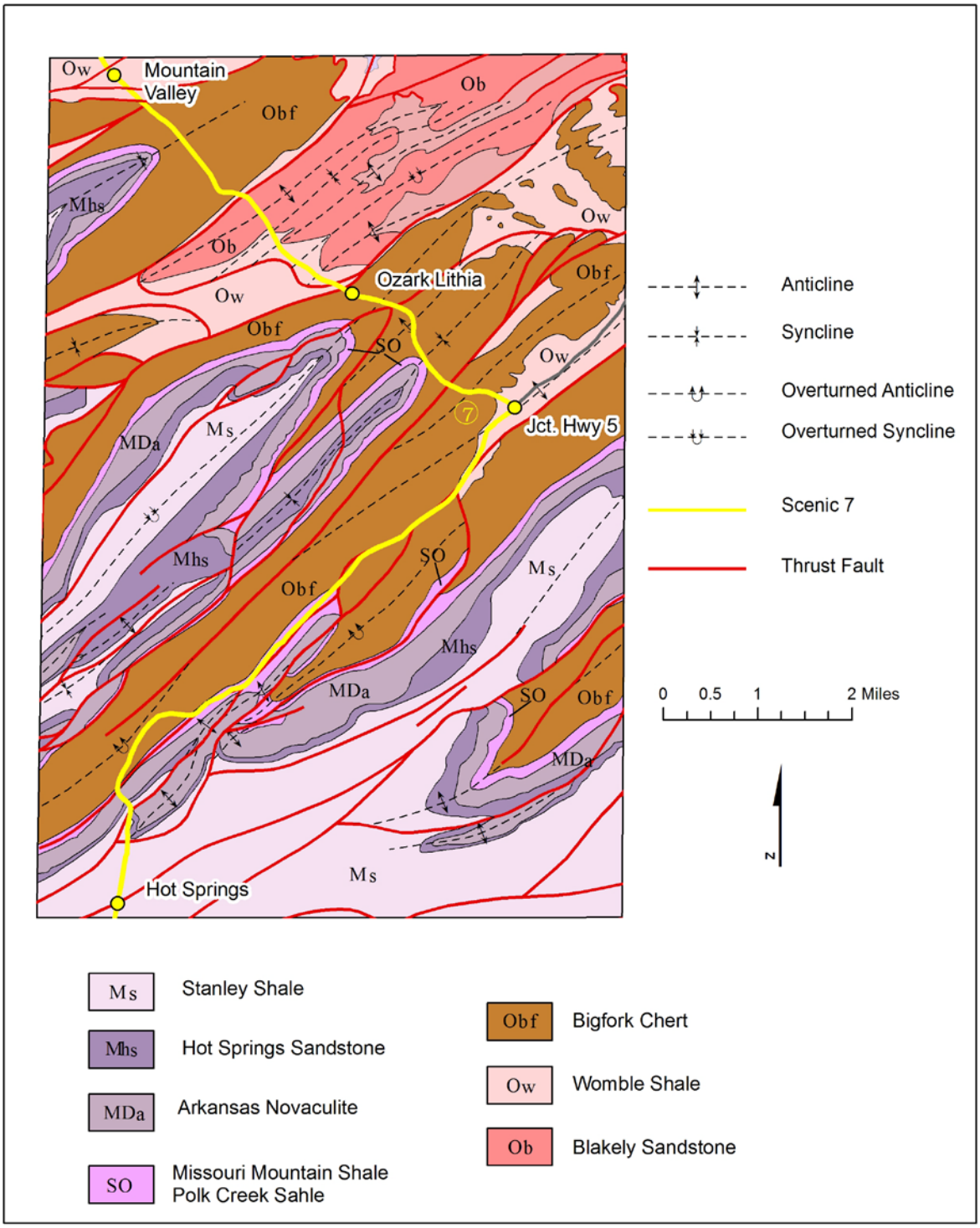

Figure 51. Geologic map from Mountain Valley to Hot Springs
(from Geologic map of Hot Springs North, Hot Springs South, Fountain Lake, and Lake Catherine, 1:24,000)

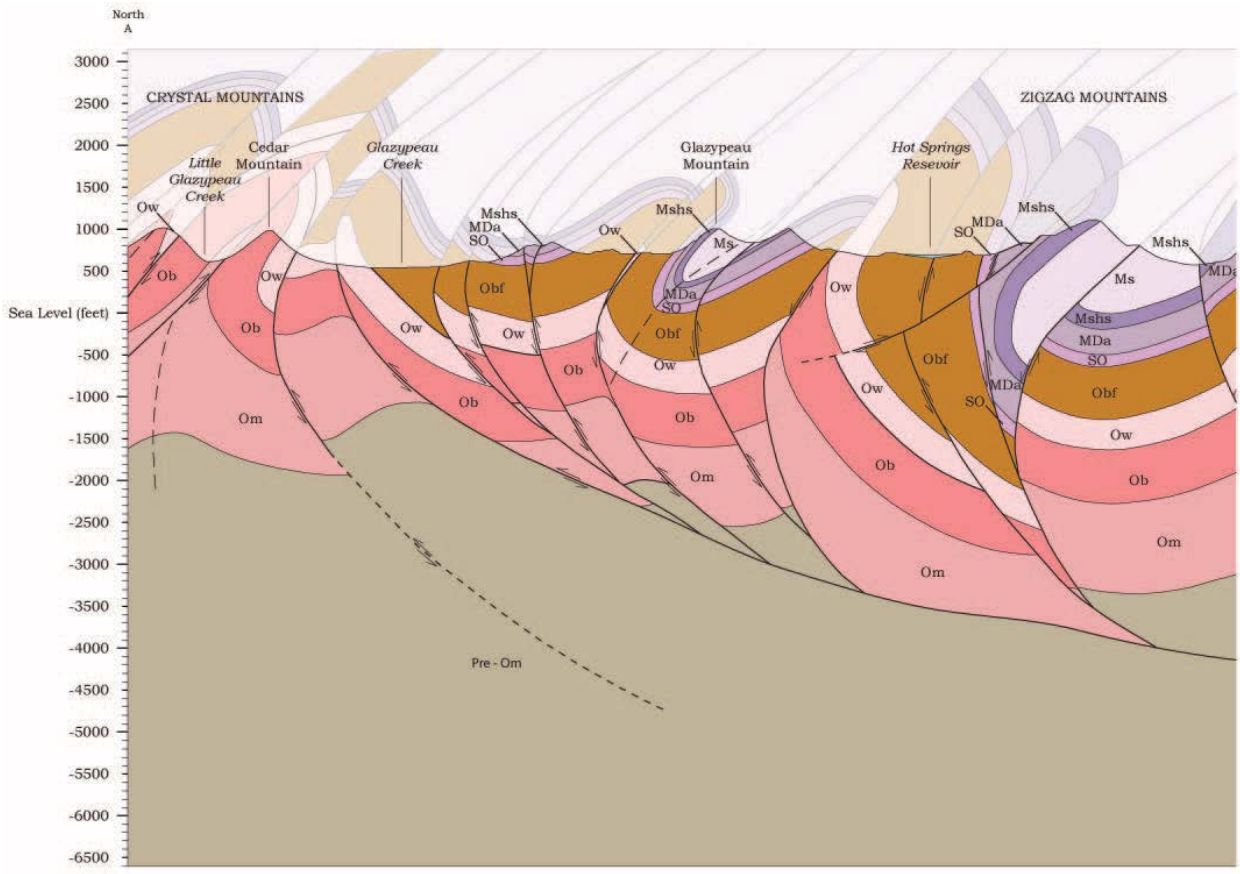

Figure 52. Zigzag Mountains Cross Section
(from Geologic map of Hot Springs North, Hot Springs South, Fountain Lake, and Lake Catherine, 1:24,000)

Road Log SH 7 – SH 5 Junction to Hot Springs

Scenic 7 turns toward the southwest at the junction and, more or less, parallels the folding trend (Fig. 51). At the junction, and for approximately 1.1 miles, the road is on the Womble Shale exposed along an anticlinal axis. The road then intersects a thrust fault in the Bigfork Chert. The highway follows the fault trace for another 1.6 miles before crossing an outcrop of the Missouri Mountain-Polk Creek Shale. Gulpha Creek flows parallel to the road and the fault for about 0.7 mile before turning southeast into Gulpha Gorge in Hot Springs National Park. The direction of overturning in the Zigzag Mountains is to the south while the high-angle overturned reverse faults are interpreted as propagating upward from a detachment (sole) fault estimated to be 4,000 feet below sea level (Fig. 52).

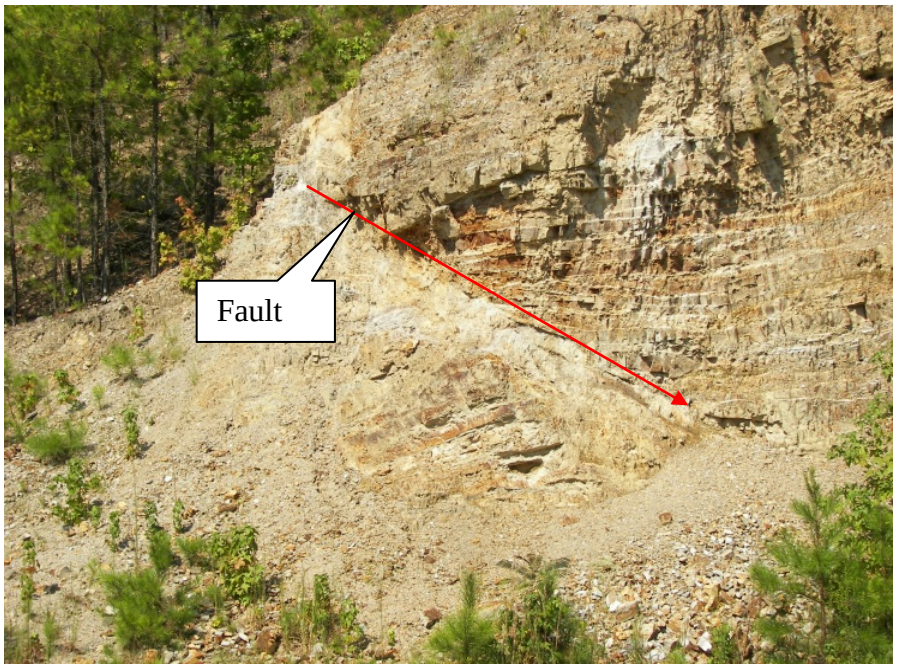

Figure 53. Womble Shale
(Fountain Lake Community, 34°33′48″N 92°59′43″W)

Approximately 0.7 mile past the Gulpha Gorge road, Scenic 7 (Park Avenue) turns west and crosses a normal stratagraphic contact between the Missouri Mountain-Polk Creek Shale and the Bigfork Chert. Park Avenue approaches the axis of an overturned anticline in the Bigfork Chert. The direction of overturning is to the south. The Bigfork forms the core of the plunging anticline, the south flank of which is known as West Mountain, while the northwest limb is known as Sugarloaf Mountain. After 1.2 miles the road crosses another narrow exposure of Missouri Mountain-Polk Creek Shale and encounters the Arkansas Novaculite. At this point Scenic 7 becomes Central Avenue (city of Hot Springs) that turns southeast and cuts across the overturned south limb of the anticline (West Mountain). The Arkansas Novaculite is well exposed at the back of the large parking lot to the east of the intersection of Park Avenue and Central Avenue (Fig. 37).

An excellent exposure of the overturned, northwest-dipping Stanley Formation (shale and sandstone) is located at the back of a parking lot on the west side of Central Avenue before reaching the "art deco" Medical Arts skyscraper across the street from the Arlington Hotel. A portion of the rock surface was covered with gunite (a type of construction cement) several years ago to prevent rock falls. Well, as you can see, it wasn't altogether successful since much of the covering has sloughed-off exposing the sandstone-shale sequence (Fig. 54). Both professional and amateur geologists especially appreciate the work of gravity, in this case.

Figure 54. Overturned Stanley Formation
(Central Avenue, Hot Springs, 34°31′02″N 93°03′16″W)

Hot Springs National Park

Hot Springs National Park was designated a "Reservation" by the U. S. Congress in 1832 to protect the thermal waters, which were recognized as a "unique natural resource worthy of preservation." Therefore, it is the oldest area in the United States National Park System, since it was established 40 years before the establishment of Yellowstone National Park.

The healthful benefits of the hot spring water were known for hundreds, perhaps thousands, of years before 1832. Native Americans used the springs and legend has it that the Spanish Conquistador Hernando DeSoto and his men enjoyed the rejuvenating effect of the hot waters while exploring Arkansas in 1541. Today, the combined 47 springs on Hot Springs Mountain, east of Central Avenue, flow at an average daily rate of 850,000 gallons. The mineralized water temperature is 143° F. The sterile water contains several dissolved chemicals. The most abundant are the following: bicarbonate, silica, calcium, carbon dioxide, and sulfate. Also, there are lesser amounts of magnesium, chloride, sodium, potassium, and fluoride.

The spring water began its journey into this artesian system as rain or snow that fell on the mountains to the north and northeast of the Park. Rain and snow meltwater percolated slowly into the fractured novaculite, sandstone, and chert to depths estimated to be 4,500 to 7,000 feet These sedimentary rocks were folded, fractured, and faulted during the Ouachita Orogeny that occurred over a span of millions of years beginning approximately 300 million years ago.

The water we see at the surface today fell as rain or snow approximately 4,000 years ago, as measured by carbon-14 radiometric dating methods. However, its return trip to the surface probably takes much less time. The water is not believed to be heated by local igneous sources but by the natural geothermal gradient present throughout the Earth's crust. The average rate of temperature increase in non-volcanic areas of the continent is approximately 1.0° F per 70 feet of descent (Frideleifsson, et al., 2009). Such an increase, considering the average annual surface

temperature of 54° F, could result in the 143° F temperature of the water in the hot springs (Fig. 55). There are also several cold water springs with different chemical characteristics in the area.

Figure 55. Display Hot Spring
(Central Avenue, Hot Springs National Park, 34°30′59″N 93°31′11″W)

Mazarn Basin Overview

The Stanley Shale is exposed at the surface in the Mazarn Basin between the Zigzag Mountains on the north and the Trap Mountains on the south. The Basin, that is approximately 7 miles wide along Scenic 7, is classified as a synclinorium, meaning that it is a broad down-folded region consisting of numerous anticlinal and synclinal folds. The synclinal folds are estimated to depress the Stanley as much as 1,800 feet below the surface between Hot Springs Mountain on the north and Trap Mountain on the south. The fold axes are tilted toward the north, as a rule, and the reverse faults are generally on the north side of the axis of the folds (Fig. 56).

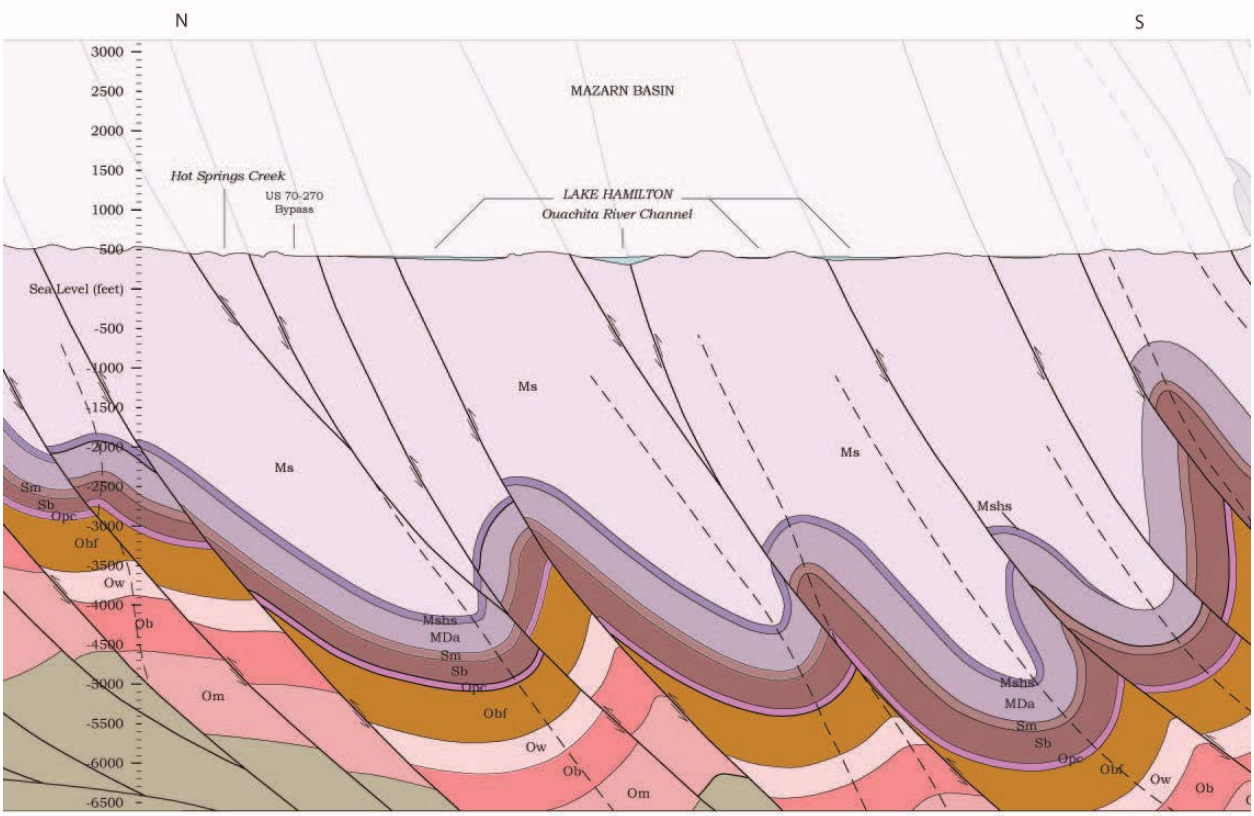

Figure 56. Mazarn Basin Cross Section
(from Geologic map of Hot Springs North, Hot Springs South, Fountain Lake, and Lake Catherine, 1:24,000)

Road Log – Hot Springs to Lake Hamilton Community

As we continue south on Central Avenue (Scenic 7) along Bath House Row, Hot Springs Mountain (Hot Springs Sandstone and Arkansas Novaculite) is visible to the east in the National Park. The 47 hot springs that provide the famous healing waters are located on the slopes of the mountain. Also, note the imposing building that originally was a National Veterans Hospital and is now the Arkansas State Rehabilitation Center. Past Bath House Row, Scenic 7 continues south crossing the Stanley Shale. Most of the Hot Springs urban area is situated on the Stanley, which is exposed because of numerous reverse faults and the broad down-warped structure (Fig. 56).

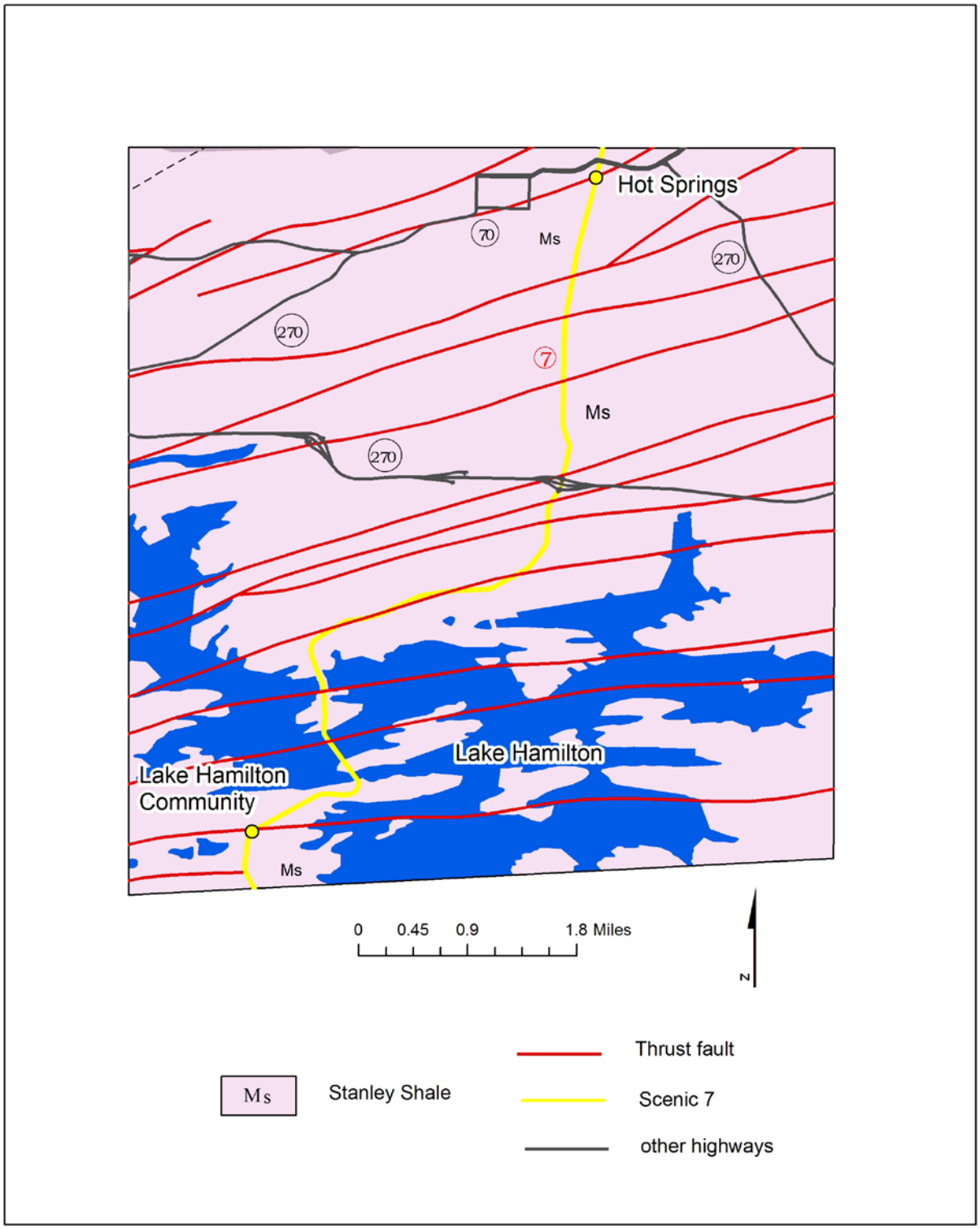

Figure 57. Geologic map from Hot Springs to Lake Hamilton Community
(from Geologic map of Arkansas, 1:500,000 scale)

Continuing south past the junction with U.S. 270/70, ten reverse faults are crossed by Scenic 7 before reaching the Lake Hamilton Community (Fig. 57). Two of the faults actually bound the island in Lake Hamilton which Scenic 7 crosses. The dips of the Stanley Shale in this area are both toward the north and south, with some strata being overturned because of the intense folding and faulting (Fig. 58).

Figure 58. Stanley Shale
(Lake Hamilton, 34°25′52″N 93°05′08″W)

Trap Mountains Overview

The Trap Mountains subdivision of the Ouachitas is located south of the Zigzag Mountains subdivision. West of the city of Malvern, the ridges and valleys have an almost perfect east-west orientation (Fig. 59). Structurally, they are overturned anticlines and synclines that have been shattered by high-angle reverse faults which are the surface expression of lower-angle thrust faults several thousand feet below the surface. The ridges are composed of the Arkansas Novaculite and the Blaylock Sandstone, while the valleys are floored by the Stanley Shale. The strata have high dip angles to the north and south with quite a few that indicate overturning. Some folds plunge east (Trap Mountain and Shinn Mountain) while others plunge west. In the Mount Carmel Creek area an anticlinal fold axial plane is overturned toward the south. All of this structural complexity is strong testimony to several stages of northward directed compressional forces being applied during the Ouachita Orogeny.

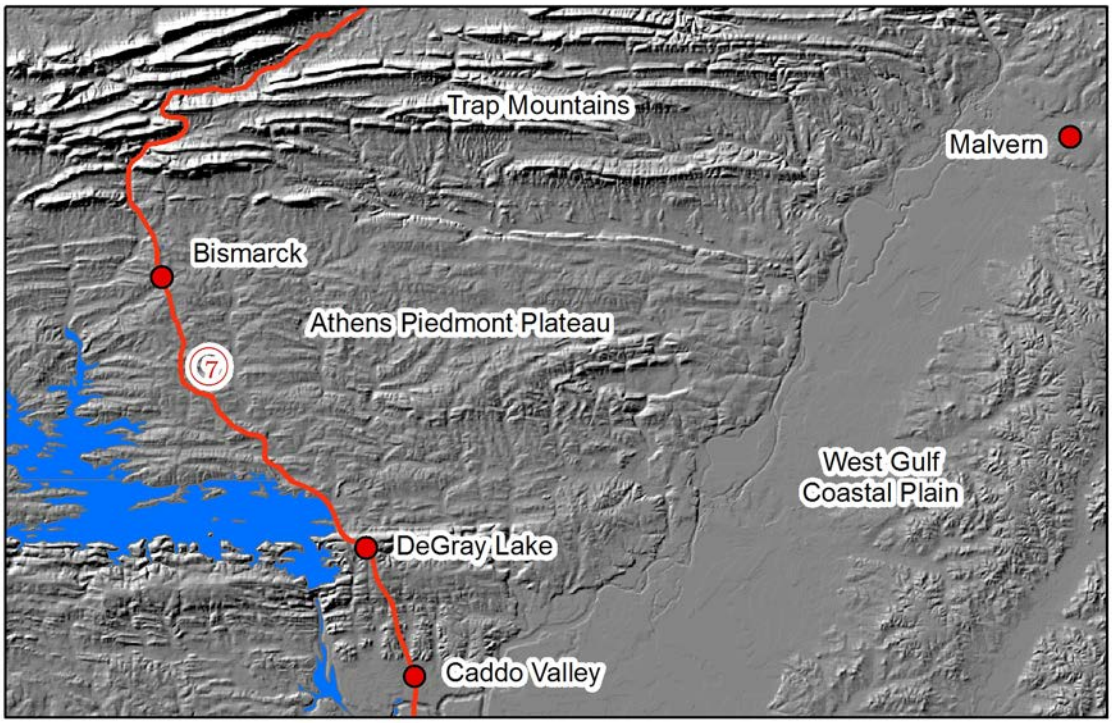

Figure 59. Shaded Relief Map of Arkansas
(Source, Arkansas Geologic Survey)

Road Log – Lake Hamilton Community to Bismarck

Approximately 1.5 miles south of the Lake Hamilton Community, Scenic 7 veers toward the southwest to avoid crossing an Arkansas Novaculite ridge (Fig. 60). The highway runs parallel to Fourche a' Loupe Creek that flows northeast into Lake Hamilton. The creek and highway are both situated on the Stanley Shale for a distance of approximately 5.6 miles before the road and creek turn sharply toward the south and pass through a water gap in a complexly faulted Arkansas Novaculite ridge. The road crosses three thrust faults in approximately 0.6 mile prior to turning sharply toward the east and crossing a narrow outcrop of Missouri Mountain Shale and a broader exposure of Blaylock Sandstone (Fig. 61).

Once again, Scenic 7 turns and "snakes" around a novaculite ridge taking advantage of the less rugged terrain of the Blaylock Sandstone. The road continues to avoid as many ridges as possible, simply because it is less costly to build on relatively flat ground. However, it isn't possible to avoid all of the ridges, so the road turns sharply to the south, as another novaculite ridge, bounded on the north and south by thrust faults, is encountered. Continuing on, Scenic 7 takes advantage of the Big Hill Creek water gap, and the novaculite ridges of the Trap Mountains are finally seen in the rearview mirror. However, the Ouachitas aren't through yet.

There are five mappable thrust faults in the Stanley before reaching the community of Bismarck (Fig. 61). Most of the bedding in the Stanley dips south at angles from 20 to 70 degrees; however, erratic dip patterns (overturning and reversals to the north) are present near most of the fault traces.

Figure 60. Trap Mountains
(South of Lake Hamilton, 34°24′17″N 93°02′26″W)

Athens Piedmont Plateau Overview

The Athens Plateau is the southernmost division of the Ouachita Mountains. Along Scenic 7, the Plateau is bounded on the north by the Trap Mountains and on the south by the West Gulf Coastal Plain (Fig. 59). The Plateau ranges from a north-south width of approximately 8 miles, near the Ouachita River, to nearly 18 miles near the Oklahoma border. Some references refer to the area as the Athens Piedmont Plateau. The term piedmont, literally means "at the foot of the mountains." The elevations in the area range from approximately 1,100 feet above sea level, near the Trap Mountains, to about 400 feet above sea level near the southeastern contact with the West Gulf Coastal Plain.

The sandstones and shales of the Athens Plateau are the Mississippian-aged Stanley Shale (318 to 359 million years ago) and the Pennsylvanian-aged Jackfork Sandstone and Atoka Formation (299 to 318 million years ago). These rocks have a typical Ouachita Mountains structural style. The rocks are folded and faulted, much as the same stratigraphic units are farther north. However, their topographic expression is greatly subdued. The ridge-forming sandstones do not stand in high relief as they do in the Zigzag Mountains or Fourche Mountains. A plausible explanation for this anomaly is that the area was eroded nearly to sea level and then slowly uplifted as a unit after the Ouachita orogeny but before Cretaceous time (145 million years ago). In technical terms this is known as peneplanation. During this process, drainage patterns established prior to uplift were not significantly altered by the presence of resistant rock

formations. As a result, river systems such as the Cossatot, Saline, Little Missouri, and Caddo eroded the softer shales and formed rapids, waterfalls, and water gaps across the sandstones.

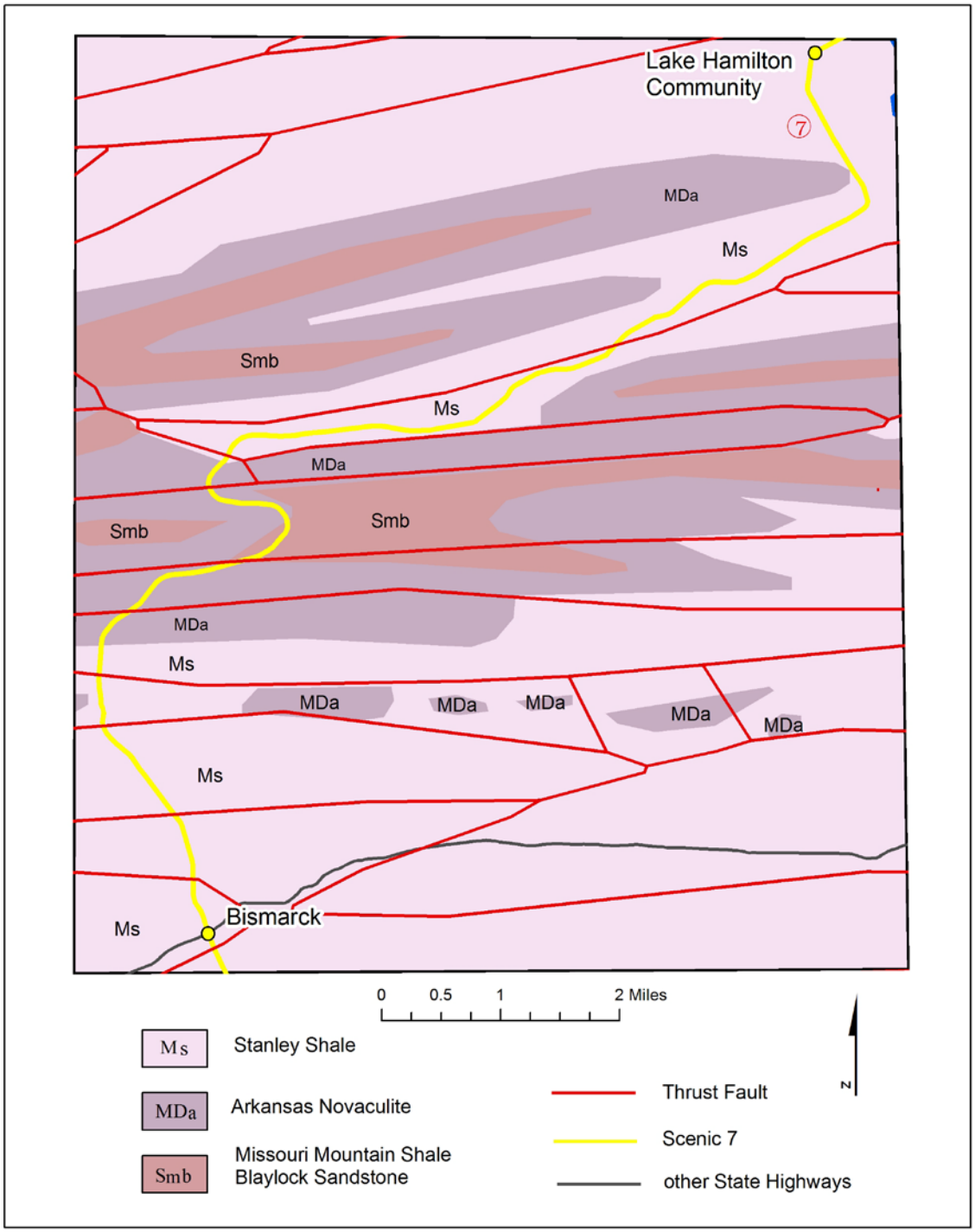

Figure 61. Geologic map from Lake Hamilton Community to Bismarck
(from Geologic map of Arkansas, 1:500,000 scale)

Road Log – Bismarck to DeGray Lake

Scenic 7 enters the Athens Plateau after passing the southernmost Arkansas Novaculite ridge approximately 2 miles north of the Bismarck community. The thrust faulted Stanley Shale is present and the topography takes on a more open and subdued aspect. The last Arkansas Novaculite ridge has an elevation of 880 feet above sea level while Bismarck's elevation is 560 feet above sea level.

Between Bismarck and DeGray Lake Spillway Dam entrance road, you will cross eight mappable thrust faults in the Stanley Shale (Fig. 62). The fault planes are tilted toward the north and the dip of the shale is generally toward the south at angles from 20 to 80 degrees. Also, a significant number of north-dipping strata, especially near the faults, are present. Just north of the Lakeview Recreation Area road, Scenic 7 crosses a thrust fault contact between the Stanley Shale and the Jackfork Sandstone.

Between the Lakeview and Spillway Dam turnoff roads, Scenic 7 crosses the Cretaceous-aged Brownstown Marl (Late Cretaceous Period, approximately 85 million years ago) for approximately 1 mile. This is the first rock type exposure of the West Gulf Coastal Plain to be crossed by Scenic 7 (see p. 85 for a complete description). This dark-gray-colored marl is a calcareous (calcite-bearing), clay-rich, sometimes sandy, soft rock. The marl was deposited in a shallow-water marine environment as indicated, not only by the type of sediment, but also by the presence of fossil oyster shells (*Exogyra ponderosa*). Several sand and gravel mining operations have been operated in the Brownstown Marl outcrop area over the years.

DeGray Lake Spillway

Every year many professional geologists and students of geology visit the Jackfork Formation exposed in the DeGray Lake Spillway excavation. The rocks exposed in this 1,000-foot long cut provide an excellent cross section view of an ancient process of sedimentation. The sandstone, siltstone, and shale of the Jackfork exposed in the spillway and the Scenic 7 road cut were deposited approximately 320 million years ago in a long-gone deep ocean trough. These rocks are of particular interest to oil and gas exploration geologists because sedimentary rocks of these types contain oil and gas in localities all over the world. An understanding of these unusual sedimentary structures and stratigraphic sequences, so well displayed here, are helpful in locating and producing more oil and gas.

These sedimentary rocks are interpreted to have formed on the continental slope by a process known as turbidity flow. The slope upon which the sediments were deposited was steep enough to allow water-saturated sand, silt, and mud (clay) to flow rapidly down slope like a thick soup. Once the flatter part of the ocean bottom was reached the flow stopped and sediments came to rest in a "graded sequence". That is, heavy large-grained material (gravel and sand) dropped out of suspension first, followed by ever-finer grains until only mud (clay) was deposited. This resulted in what is known as a "fining-upward sequence". The three-dimensional shape of such a deposit is fan-like, therefore, they are called submarine fans.

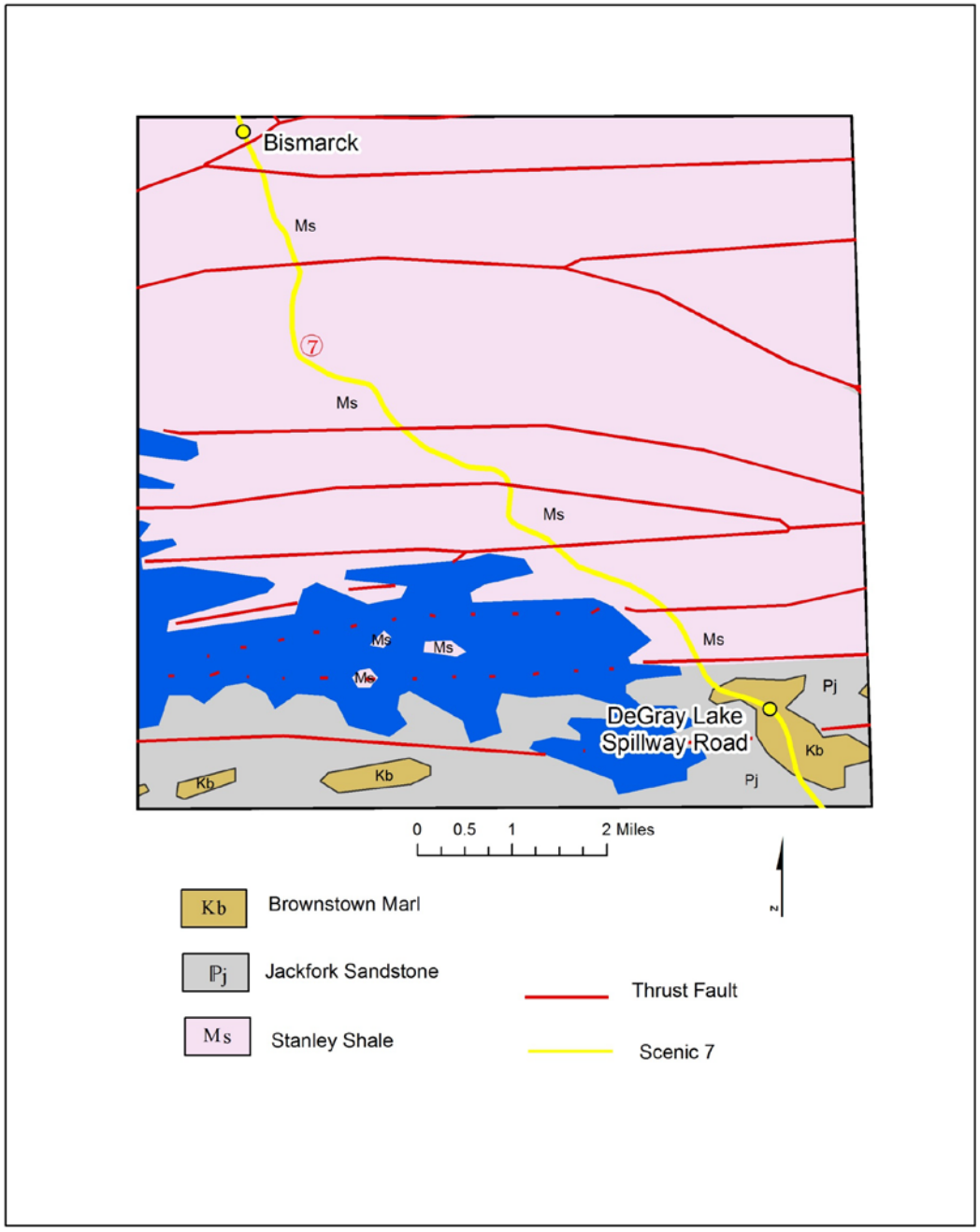

Figure 62. Geologic map from Bismarck to DeGray Lake
(from Geologic map of Arkansas, 1:500,000 scale)

Figure 63. Jackfork Formation Turbidite Sequence
(Scenic 7 near DeGray Lake, 34°13′53″N 93°05′55″W)

The alternation of thick shales and turbidite sequences was controlled by changes in sea level. Lower sea level or elevation of the land mass allowed more land-derived sediment (sand and silt) to be deposited. Higher sea level produced deep water over the same area leading to the deposition of clay (much finer grained than silt and sand), which after a process known as lithification (compaction, loss of water, and possibly cementation) became shale. The fluctuation of sea levels occurred many times during the mountain-building period of several million years, so alternating turbidite sequences and thick shale deposits, as seen in this area, were the result (Fig. 63).

Road Log – DeGray Lake Spillway Road to Arkadelphia

Continuing south on Scenic 7 from the DeGray Lake Spillway road toward Arkadelphia, we will cross the last four mappable Ouachita thrust faults visible in this area. The dips of the Jackfork Sandstone remain essentially toward the south at angles from 30 to 60 degrees. These are the last Ouachita rocks exposed at the surface before entering the Gulf Coastal Plain Province.

Approximately 1.8 miles south of the Spillway Road, Scenic 7 crosses Quarternary-aged terrace and alluvial sediments (gravel, sand, silt, and clay). Farther along, about 2.5 miles south of Caddo Valley and the junction with I-30, Scenic 7 crosses approximately 0.8 mile of Upper Cretaceous-aged (65-70 million years old) Nacatoch Sand Formation (Fig. 65). This mostly loose, fine quartz sand, sandy limestone, and clay-rich sand contains many fossil types characteristic of a shallow marine environment (see p. 85 for a complete description). For example there are corals, echinoderms, bryozoa, annelids, clams, brachiopods, gastropods,

cephalopods, crab parts, and shark teeth (McFarland, 1998). The City of Arkadelphia is situated on the Nacatoch.

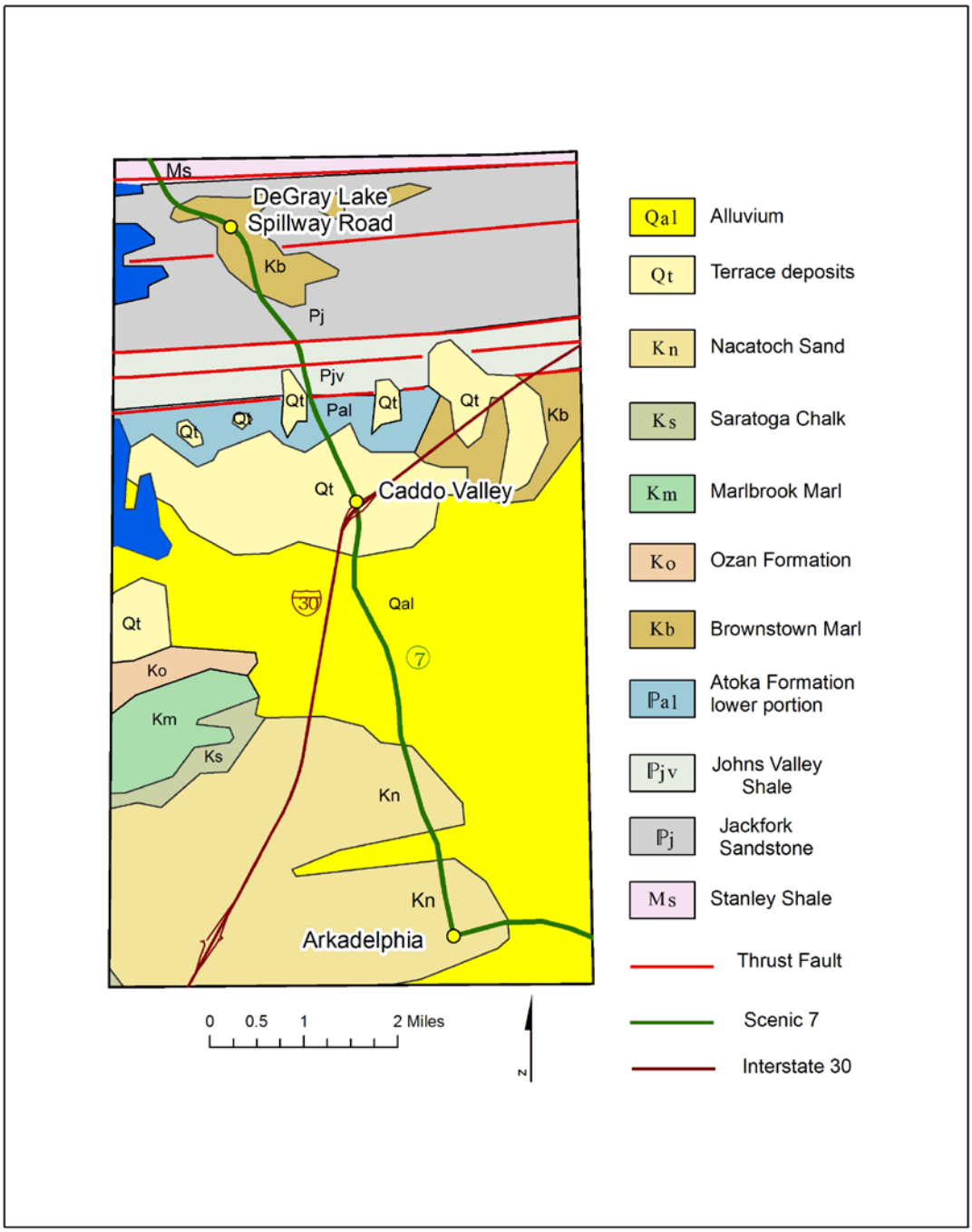

Figure 64. Geologic map from DeGray Lake to Arkadelphia
(from Geologic map of Arkansas, 1:500,000 scale)

Figure 65. Cretaceous Nacatoch Sand near Arkadelphia.
(courtesy of Doug Hanson, AGS)