RGS - 01

STATE OF ARKANSAS

ARKANSAS GEOLOGICAL SURVEY
BEKKI WHITE, DIRECTOR AND STATE GEOLOGIST

ROADSIDE GEOLOGY SERIES 01

Geologic Road Guide to

by
Richard R. Cohoon, Ed.D., P.G.
Distinguished Professor of Geology
Arkansas Tech University
Russellville, AR

Little Rock, Arkansas
2013

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Richard R. Cohoon

July 2, 2013

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All latitudes and longitudes are from Google Earth.

Introduction

This road guide was developed for those in the general public who are curious about our natural environment. Arkansas has a fascinating geologic history that spans approximately 500 million years. A road trip on Scenic 7 provides an opportunity to do what many have dreamed of for ages, that is, travel through time.

This narrative is somewhat technical, but a Glossary of Terms is provided at the end of the road guide and it is hoped that the road log descriptions will provide the reader with an overview of the rock types, structural framework, and geologic history of Arkansas. The road logs are written as if one were travelling from north to south; however, each physiographic province is treated as a unit and the entire trip does not have to be completed to learn about a particular area.

Arkansas is divided into five distinct physiographic regions and Scenic 7 crosses four of the regions in a north-south direction from Missouri to Louisiana over a distance of almost 300 miles. From north to south the regions are as follows: Ozark Plateaus, Arkansas River Valley, Ouachita Mountains, and West Gulf Coastal Plain. The fifth region, the Mississippi River Alluvial Plain, lies to the east of the others (Fig. 1).

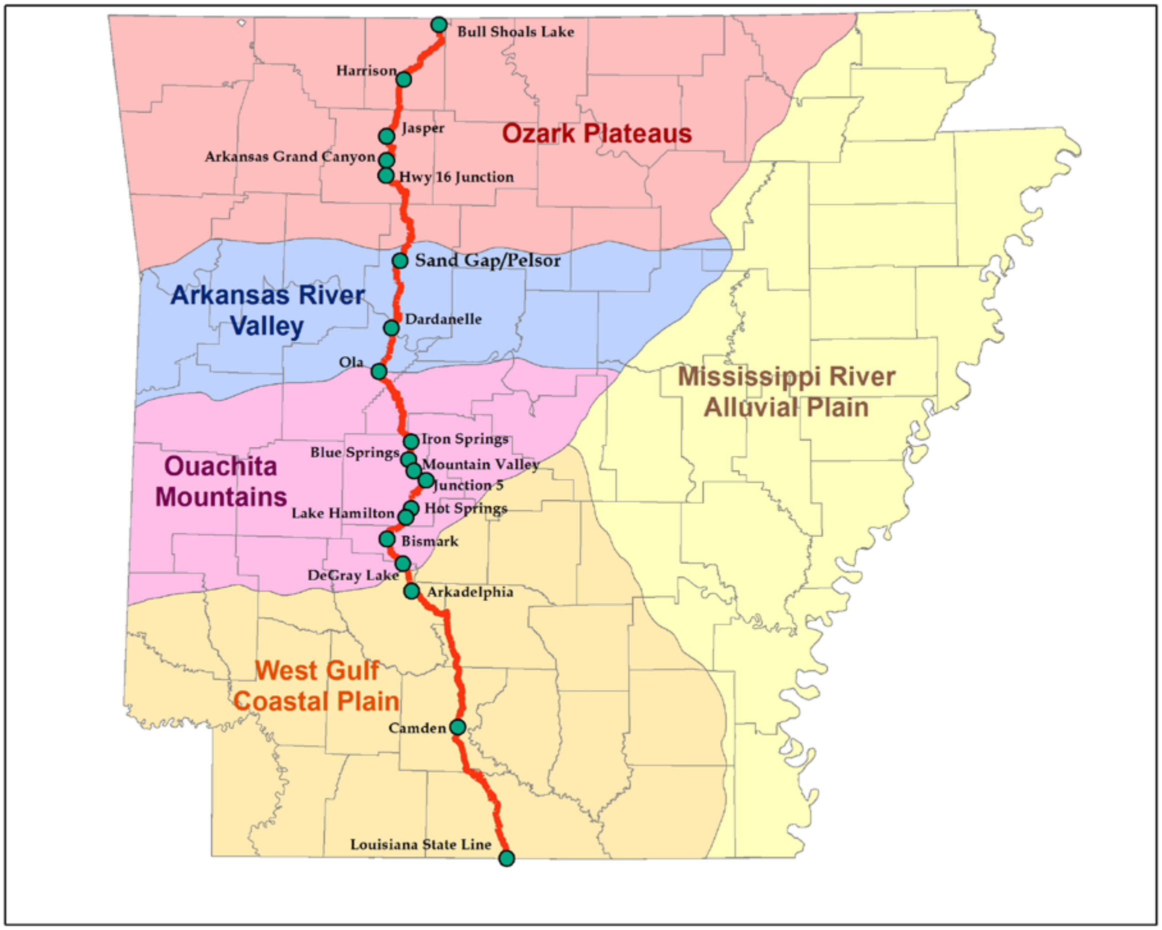


Figure 1. Scenic 7 route map across Arkansas' physiographic regions

Geologic Time

Geologists consider time much as astronomers think about space. "Deep time" (geologic time) is similar to "deep space". Both concepts, one dealing with enormous amounts of time and the other with vast distances, describe quantities that are difficult to comprehend.

Over many years simple observations and common sense led to the development of a relative geologic time scale that shows the order of deposition of sedimentary strata and the relative time of intrusion of igneous rocks. After 1900, it was discovered that decay rates of certain radioactive elements in rocks are measurable and constant. Thus, a natural clock mechanism is operating in some rocks of the Earth's crust and their absolute ages can be measured. Radiometric dating was used to corroborate and refine the relative time scale based on the order in which sedimentary rocks were deposited. The result of this combination of dating methods is known as the geologic time scale.

Geologic Time Scale

(Periods/subperiods in millions of years ago, epochs in years)
(Source, U. S. Geological Survey, GIP 141)

Periods	Eras	Years
	Cenozoic	
Quaternary		**present to 2.6**
Holocene Epoch		**present to 11,700 yr**
Pleistocene Epoch		**11,700 to 2,600,000 yr**
Tertiary		**2.6 to 65**
	Mesozoic	
Cretaceous		**65 to 145**
Jurassic		**145 to 199**
Triassic		**199 to 251**
	Paleozoic	
Permian		**251 to 299**
Carboniferous		**299 to 359**
Pennsylvanian		**299 to 318**
Mississippian		**318 to 359**
Devonian		**359 to 416**
Silurian		**416 to 443**
Ordovician		**443 to 488**
Cambrian		**488 to 542**
	Eon	
Precambrian		**542 to 4,600**

Geologic Maps

A geologic map depicts the ages of rocks and alluvial sediments exposed at the Earth's surface. Detailed geologic maps also include the position of the sedimentary strata. In many areas strata are in their original horizontal position, as they were deposited; however, some have been disturbed by tectonic forces causing the strata to become warped, folded, or broken by faulting. The Geologic Map of Arkansas (Fig. 2) displays broad patterns of sedimentary rock outcrops deposited during various geologic periods. The location of the larger igneous intrusions in the state are also shown.

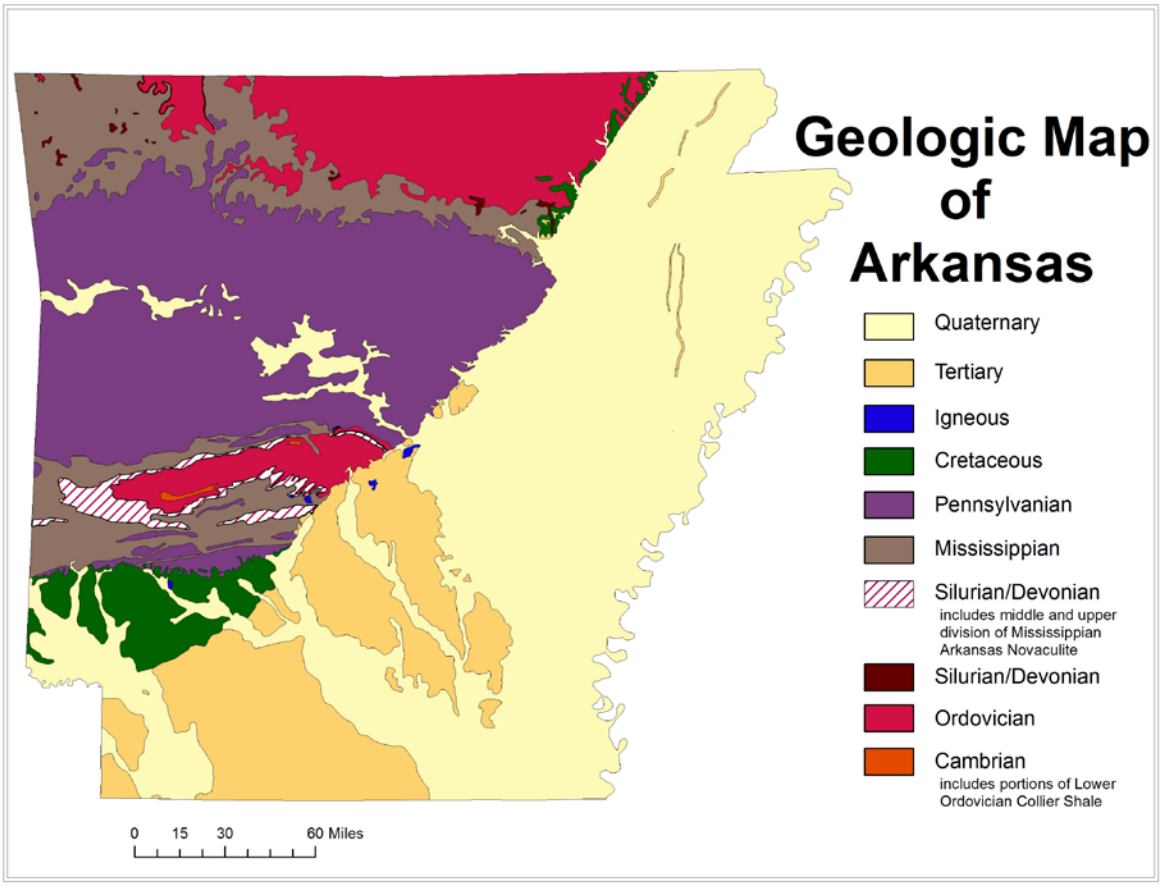


Figure 2. Geologic map of Arkansas
(Source, Arkansas Geological Survey)

Correlation Charts

Correlation charts are necessary in the study of geology because sedimentary rocks deposited in different areas during a geologic period will generally have different chemical and physical characteristics. The strata may be sandstone, shale, limestone, conglomerate, or some hybrid combination of sediments. This is because of differences in the source of sediments and a variation in the type of depositional environment. For example in the Ozark Plateaus the Boone

Formation was deposited during the Mississippian Period; however, during the same time period the Arkansas Novaculite (bedded chert) was deposited in the Ouachita Mountains. The depositional environment in the Ozarks was that of a shallow warm sea, while the Ouachita sediments forming at the same time had a different source and were deposited in a deep marine trough.

Rock units (formations) are often named for a geographic feature present in the area where the rock unit was first described. The formations are mapped across a region by reference to their fossil content and/or similar physical and chemical characteristics.

The correlation charts (Fig. 3) list the name and stratigraphic position (geologic age) of the geologic formations (sedimentary rock units) present in Arkansas. Also, detailed descriptions of the rock units encountered during the trip are included in the overview statement for each physiographic region.

Ozark Plateaus

Overview

The Ozark Plateaus cover an area of approximately 47,000 square miles in southern Missouri, northern Arkansas, eastern Oklahoma, and the extreme southeastern corner of Kansas (Fig. 4). These high plateaus (2,200 to 2,500 feet elevation), cut by deep valleys (500 to 1,500 feet deep), are underlain by a broad dome-like structure in the Earth’s crust. This feature, known as the Ozark Dome, formed about 1.5 billion years ago and is part of the early North American continent. Pre-Cambrian-aged (1,350 to 1,485 million years ago) granites and rhyolites form the igneous rock core of the dome. These rocks are exposed at the surface in the St. Francois Mountains in southeastern Missouri. Rocks of this age are not exposed at the surface in Arkansas, but are present below the sedimentary strata.

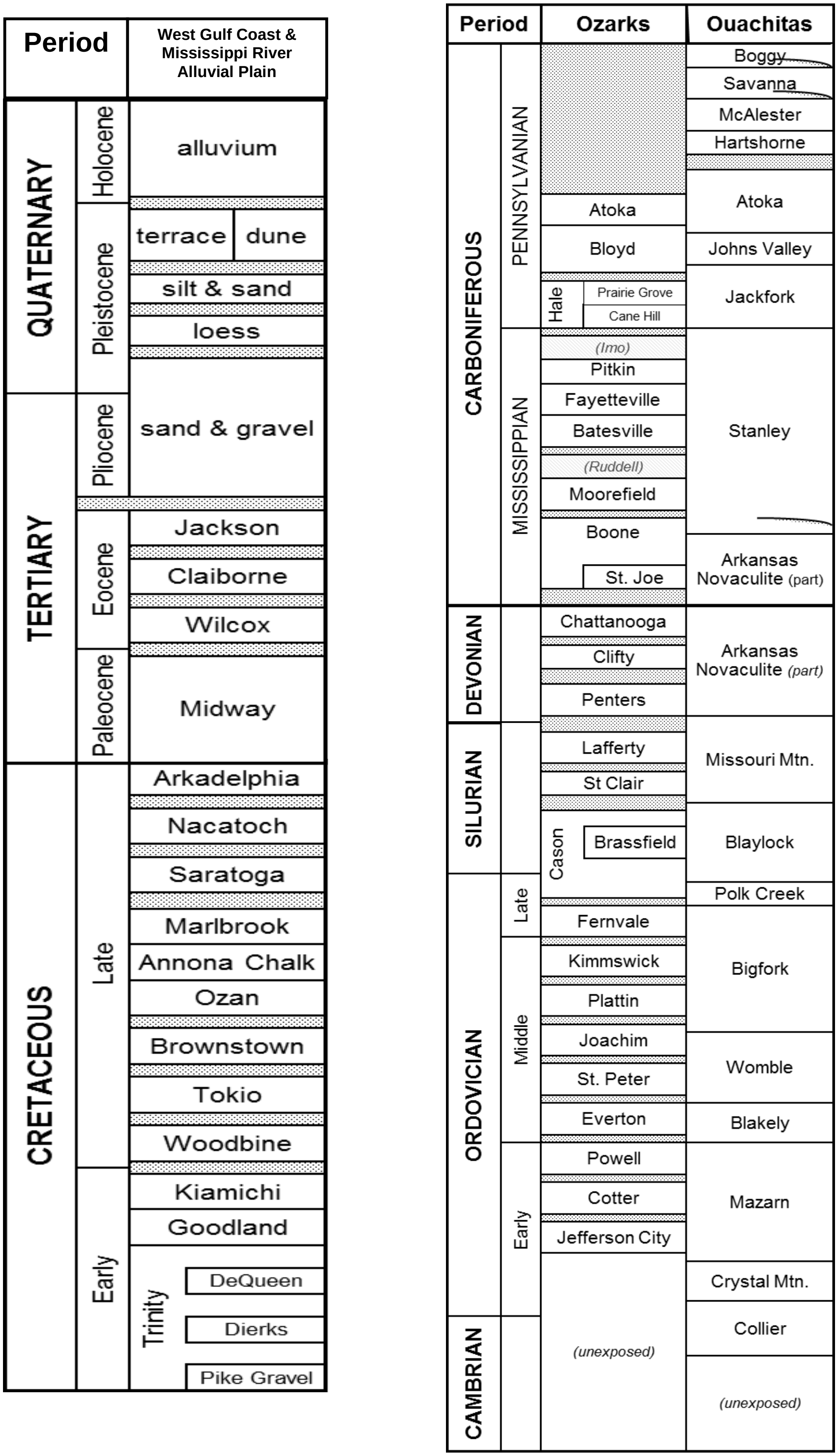


Figure 3. Correlation charts of Arkansas stratigraphic nomenclature
(McFarland, 2004)

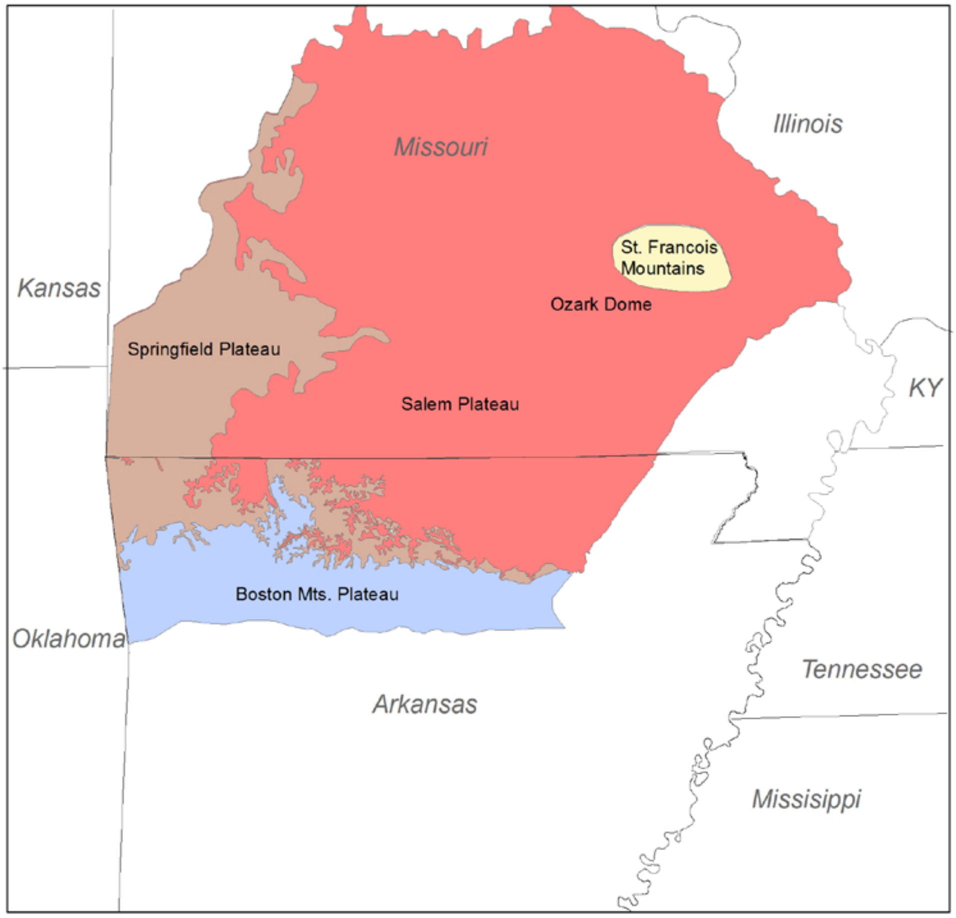


Figure 4. Location map for the Ozark Plateaus and Ozark Dome
(source, Arkansas Geological Survey)

Ozark Plateaus and Highlands

During most of the Paleozoic Era (251 to 542 million years ago), shallow seas deposited almost horizontal layers of sand, silt, clay, and calcareous mud across the southern and western flanks of the Ozark Dome. These sediments became rock after deep burial by a process known as lithification. This process involves compaction, loss of water, and crystallization of minerals resulting in cementation of granular sediment or the formation of crystalline sedimentary rocks.

The geologic rock record is not complete because there are many time gaps (unconformities) between sedimentary rock units. Periodic sea level changes interrupted the depositional process and exposed rocks to erosional processes over this nearly 290 million year span of time. Numerous types of marine fossils are present in these rocks, especially in the limestone that was deposited in warm, relatively shallow seas on the continental shelf. These fossils are often utilized as time markers for the various rock units.

The Ozarks are considered to be the most significant “Interior Highlands” between the Appalachian and Rocky Mountains. The region can be divided into the Salem Plateau, Springfield Plateau, and the Boston Mountains Plateau (Fig. 4). The rocks exposed in the Ozark Plateaus range in age from Early Ordovician (460 million years ago) to Middle Pennsylvanian (310 million years ago). The Salem Plateau consists of Ordovician-aged dolostone, sandstone, and limestone. The slightly higher Springfield Plateau is composed of Late Mississippian-aged (320 million years ago) limestone and chert. Arkansas’ highest part of the Ozarks is the Boston Mountains Plateau which is composed of shale, siltstone, and sandstone of Pennsylvanian-aged strata (299 to 318 million years ago).

The rate of sedimentation was relatively slow from Ordovician to Early Pennsylvanian time; however, the rate dramatically increased as highlands began to develop to the south due to the early stages of the Ouachita orogeny. It began in Mississippian (359 million years ago) and culminated in Late Pennsylvanian – Early Permian time (290 million years ago). The Orogeny was a result of the collision of ancestral South America-Africa with ancestral North America. This continent-changing event will be discussed later as we approach the Ouachita Mountains on our trip.

Structurally, the Ozark Plateaus are composed of nearly horizontal strata that are slightly folded (monoclines) in some areas and broken by normal (gravity) faults and numerous fractures (joints). The crustal blocks on the south side of most faults in the Ozarks moved down as a result of gravitational forces.

Rock Types Exposed Along Scenic 7 in the Ozark Plateaus

(Based on McFarland, 2004 and Braden and Smith, 2004)
(Rock types are listed from youngest to oldest and map symbols are included following 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. The Atoka has the largest area of surface exposure in the state. Thickness varies from a few tens of feet to over 300 feet in the Ozarks.
Environment of deposition: shallow marine and coastal swamp.

Bloyd Formation / Shale (ℙbh)
Age: Early Pennsylvanian (299 to 318 million years ago)
Description: various limestone, calcareous shale, siltstone, sandstone, and thin coal members. Thickness ranges from 175 to 200 feet.
Environment of deposition: shallow marine, coastal swamp and delta.

Hale Formation (ℙbh)
Age: Early Pennsylvanian (299 to 318 million years ago)
Description: Cane Hill Member – dark gray silty shale interbedded with siltstone and fine-grained sandstone. Prairie Grove Member – calcareous sandstone or sandy limestone with lenses of fossiliferous limestone. Thickness of the Hale is not well established due to the difficulty in

determining the position of the upper and lower boundaries; however, it is estimated to be from 200 to over 300 feet.
Environment of deposition: shallow marine.

Pitkin Formation (Mp)
Age: Late Mississippian (304-318 million years ago)
Description: fine to coarse-grained, fossil-bearing limestone with minor amounts of black shale, chert, and sandstone in some areas. A wide variety of marine invertebrate fossils may be present. Thickness ranges from 50 to 200 feet.
Environment of deposition: shallow marine

Fayetteville Shale (Mf)
Age: Late Mississippian (304-318 million years ago)
Description: black, fissile shale with minor amounts of gray, fine-grained limestone. Fossils preserved by the iron sulfide mineral pyrite (fool's gold) may be present. Thickness ranges from 10 to 400 feet.
Environment of deposition: marine in an oxygen-poor region due to limited current and wave action, such as in a coastal swamp or isolated basin.

Batesville Formation (Mbv)
Age: Late Mississippian (304-318 million years ago)
Description: fine to coarse-grained, light brown to brown sandstone with thin shales. Western outcrops may contain a fossiliferous limestone. Thickness ranges from very thin to over 200 feet.
Environment of deposition: shallow marine.

Boone Formation (Mb)
Age: Early and Middle Mississippian (318 to 344 million years ago)
Description: gray fossiliferous limestone with interbedded chert and irregular-shaped chert nodules. The Boone contains numerous crinoid fragments, as well as bryozoa, mollucks, corals, trilobites, shark's teeth, and conodonts. Thickness ranges from 300 to 400 feet. The limestone is the host-rock for karst topographic features such as sinkholes and caverns.
Environment of deposition: shallow marine.

St. Joe Member of the Boone Formation (Mbs)
Age: Early Mississippian (318 to 330 million years ago)
Description: fine-grained, crinoid-rich limestone that may be gray, red, pink, purple, brown, or amber in color. The St. Joe often forms bluffs in the landscape. Fossils that may be contained in the limestone include the following: crinoids, brachiopods, bryzoa, conodonts, blastoids, ostracods, and horn corals. Thickness ranges from a few inches to over 100 feet.
Environment of deposition: shallow marine.

Major Unconformity Early Mississippian to Middle Ordovician (time gap of 150 million years).

Everton Formation (Oe)

Age: Middle Ordovician (458 to 473 million years ago)

Description: a mixture of dolostone (rock dolomite), sandstone, and limestone. The limestone is light-gray to brownish gray, and may contain sand. The dolostone shows a range of shades of gray and also is sandy. Bedding may be thin to massive. Thickness varies from 300 to 650 feet.

Environment of deposition: shallow marine.

Powell Dolomite (Op)

Age: Early Ordovician (473 to 488 million years ago)

Description: Fine-grained, light gray to greenish gray dolostone containing thin beds of shale, sandstone, sandy dolostone, and minor amounts of chert. The thickness ranges from thin to over 200 feet.

Environment of deposition: shallow marine.

Jefferson City – Cotter Dolomite Formation (Ocjc)

Age: Early Ordovician (473 to 488 million years ago)

Description: Dolostones of this age have not been mapped separately in Arkansas, as they have in Missouri, due to the lower contact of the Jefferson City not being exposed in Arkansas. The Cotter is a fine-grained, white to tan or gray dolostone. It may be soft (cotton rock), or a massive-bedded gray dolostone that weathers to a rough surface. The Cotter may contain chert nodules. Fossils are rare in the Cotter.

Environment of deposition: shallow marine.

Karst Topography

Karst topography is a type of landscape in which sinkholes and caverns are well developed. The term was coined by European geologists after studying the Kras Plateau in Slovinia of south central Europe. The formation of karst landscape requires the presence of soluble bedrock, usually limestone or dolostone. In the Arkansas Ozarks, karst landscape features, consisting of sinkholes, caverns, springs, and blind (box canyon) valleys, are developed mostly in limestone, a rock composed of the mineral calcite (calcium carbonate). Other conditions that must be present during the development of karst features include the following: rock fractures and sedimentary bedding planes along which ground water can move, adequate rainfall to provide slightly acidic surface and ground water to dissolve the limestone, and the passage of much time.

The second stage of cavern development begins as deeply eroded stream valleys allow drainage of the caverns and air to enter the voids. During this stage, dripstones (speleothems) develop. The water dripping into the cavern is slightly acidified due to the presence of dissolved carbon dioxide derived from the interaction of water with the atmosphere and overlying soil. As it travels through the rock, the acidic water dissolves limestone and becomes supersaturated with calcium carbonate. Upon entering the air-filled cavern, some of the carbon dioxide evaporates resulting in the recrystallization of calcium carbonate (calcite) to form the speleothems.

A great variety of speleothems may form depending on the manner in which water enters the void (Fig. 5). Stalactites form attached to the cave's ceiling and stalagmites build upwards from the cavern floor. When these two forms join, columns result. Flowstones and rim stone basins may form on the cave floor, and ribbon stone forms along ceiling fractures. The variety of forms is almost endless contributing to the uniqueness of each cavern.

Figure 5. Speleothems
(Crystal Dome Cavern, northern Newton County, 36°07′10″N 93°07′37″W)

Arkansas' tour caves include the following: Blanchard Springs Cavern, Bull Shoals Caverns, Cosmic Caverns, Hurricane River Cave, Mystic Caverns and Crystal Dome, Onyx Cave, Old Spanish Treasure Cave, and War Eagle Cavern.

For more information on the caves of the Arkansas Ozarks check out the following website: www.Arkansas.com/places-to-go/caves-caverns/.

Rock and Mineral Resources

Boone County

The main rock and mineral resources in the county are limestone, dolostone, sandstone, sand, and gravel. However, over the years, more than 30 zinc and lead prospects or mines have been active (Fig. 6). It is estimated that approximately 9,800 tons of zinc ores and a small amount of lead ore were produced, mostly during World War I, from three districts located as follows: east of Harrison along Crooked Creek, west of Lead Hill, and surrounding the Zinc community (Stroud, et al., 1969, p. 193).

The Fayetteville Shale, which has received so much attention as a natural gas producer in Arkansas since 2004, is exposed on the slopes of the deeper valleys in the County; however, it is not considered a viable gas producer in this area because of its exposure at the surface. The center of the producing area lies about 70 miles southeast of Harrison where the Fayetteville is several thousand feet below the surface. The main counties where Fayetteville production has developed are Van Buren, Cleburne, Conway, Faulkner, and White.

Newton County

Limestone, dolostone, and sandstone are present in many localities in the county, so there are significant dimension stone and crushed stone resources available. Also, sand and gravel deposits are present along the Buffalo River and its tributaries.

Zinc and lead mineral deposits were mined in six districts in the northern half of the county located as follows: Ponca-Boxley, Little Buffalo River, Upper Cave Creek, Mount Hersey-Lower Cave Creek, Mill Creek, and Davis Creek-Hurricane Branch.

Veins of ore minerals are present in fractures associated with faults and joints in the Boone Formation, the Everton Formation, and the Batesville Sandstone (Stroud, et al., 1969, p. 307). Galena (lead sulfide), the chief ore of lead, was mined in the county as early as 1864. After 1900, especially during World War I, zinc ores became the chief mineral mined. Not much mining or prospecting occurred in the area after 1920. Total amounts of ore produced are approximately 1,700 tons of sphalerite (zinc sulfide), 7,000 tons of zinc carbonate and silicate minerals, and 2,800 tons of galena (Stroud, et al., 1969, p. 307).

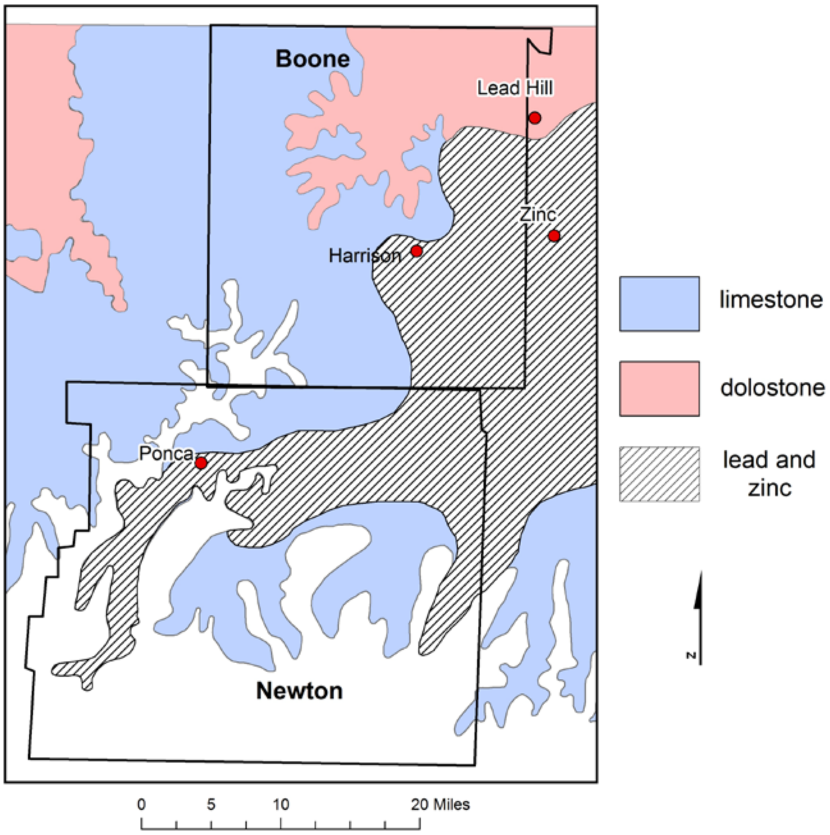


Figure 6. Rock and mineral resources of Boone and Newton County
(from Arkansas Mineral Resources, page size map)

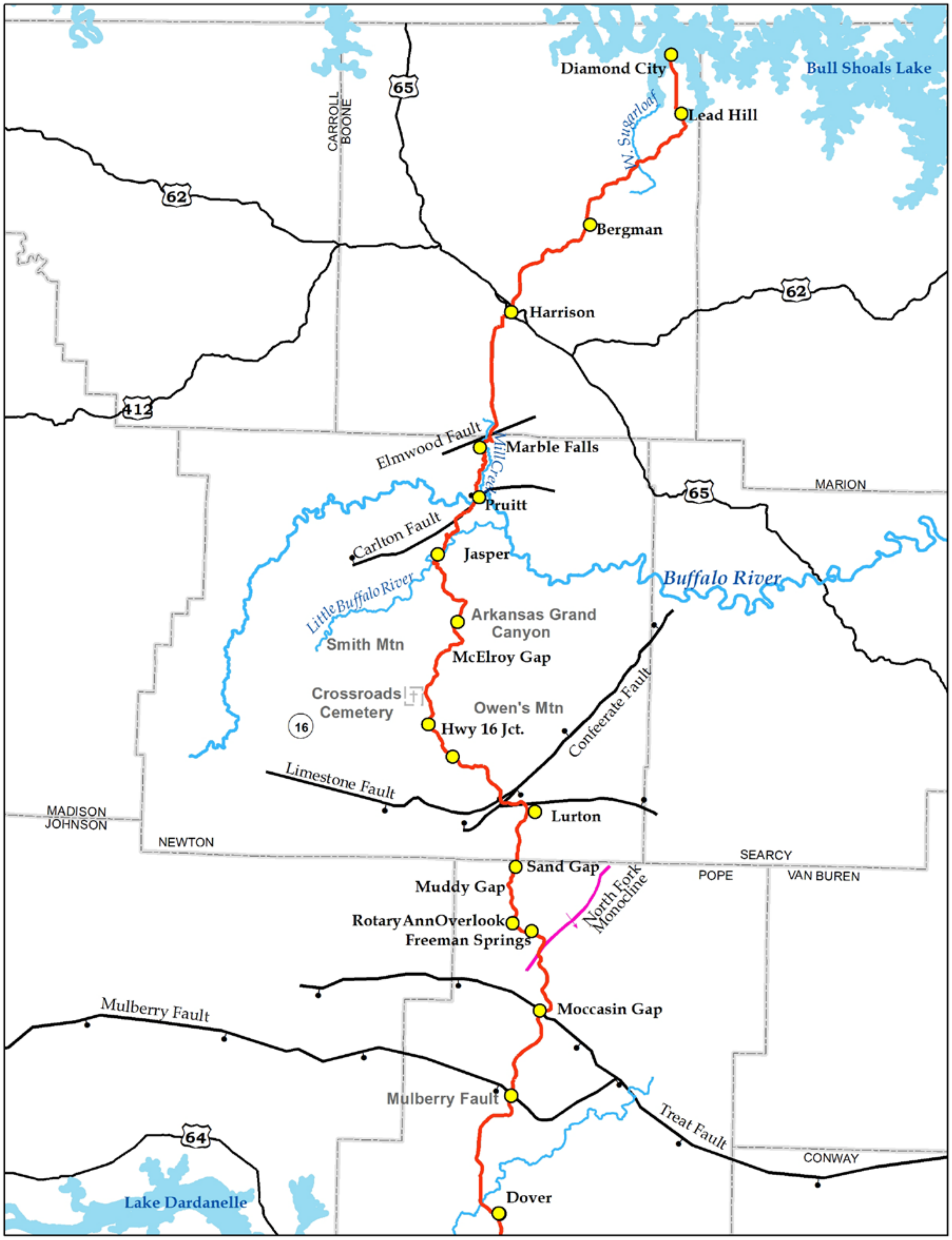


Figure 7. Scenic 7 route map from Bull Shoals Lake to Dover
(Major faults and monoclinal axes are shown, black dots are located on the downthrown side of the fault)

Road Log – Bull Shoals Lake to Harrison

Scenic 7 begins or ends, depending on your approach, in Boone County at Bull Shoals Lake on the border of Missouri and Arkansas (Fig.7). The northernmost community on the highway, Diamond City, is located on the Salem Plateau. The sedimentary rock formations exposed in this vicinity are the Jefferson City and Cotter Dolomite (Fig. 8). These two formations are mapped as a single unit in Arkansas. The Jefferson City Dolomite was originally defined at Jefferson City, Missouri, while the Cotter Dolomite was first described in the White River Valley near Cotter, Arkansas. Each formation is Early Ordovician Period (473 to 488 million years ago) in age. Both formations consist of white to tan or gray dolostone (calcium-magnesium carbonate) containing chert nodules that are irregularly-shaped masses of silicon dioxide. Fossils are rare; however, gastropods, cephalopods, and algae occur in the Cotter (McFarland, 2004).

From Diamond City to Lead Hill, Scenic 7 continues to cross the Jefferson City-Cotter Dolomite. Approximately 2.6 miles southwest of the South Lead Hill community, the road curves and passes between two hills that rise about 80 feet above the road. They are composed of the Powell Dolomite, the next younger rock unit that overlies the Jefferson City-Cotter Dolomite. The road continues across the Jefferson City-Cotter for approximately another 4.8 miles. After following a branch of West Sugar Loaf Creek in Cook Hollow, Scenic 7 leaves the Salem Plateau and enters the Springfield Plateau after crossing the Powell Dolomite for about 0.4 mile.

A major unconformity lies between the Powell Dolomite (Early Ordovician Period, 473 to 488 million years ago) and the Boone Formation (Early to Middle Mississippian Period, 318 to 338 million years ago) that forms the surface of the Springfield Plateau. The missing rock strata reflect a 150 million-year gap in the stratigraphic record! What happened? Where did the rocks go or did they ever exist?

These are the kinds of questions that geologists must deal with. We will never know the absolute truth about the missing rock record. However, we have reasonable explanations (hypotheses) to offer. Either the sediments were deposited in a shallow marine setting then eroded away after sea level dropped, or the continental shelf was uplifted above sea level, and possibly this portion of the continent remained above sea level and sediments were never deposited. We do know that there are sedimentary rocks of similar age preserved elsewhere in the Ozarks and in the Ouachita Mountains approximately 140 miles southwest of this area. However, the Ouachita rocks were deposited in a deep-water marine setting, not on a continental shelf. So, the margin of the continent during this time gap was somewhere between the Ozarks and the Ouachitas. Hopefully, a better understanding of this question will be developed as we follow Scenic 7 across the Arkansas River Valley and into the Ouachita Mountains.

From Bergman to Harrison, Scenic 7 crosses the mostly horizontally-bedded Boone Formation. The Boone consists of a fossil-rich gray limestone that often contains chert beds and nodules. The Boone is well known as a host rock of karst topographic features.

While not on Scenic 7, a drive of a few miles on U.S. 65 from Harrison toward the Missouri border is worthwhile. The large road cuts north of Harrison along U.S. 65 display the Boone Formation in a spectacular manner. You will see that the horizontally-bedded gray limestone is interbedded with numerous nearly white chert beds (Fig. 9).

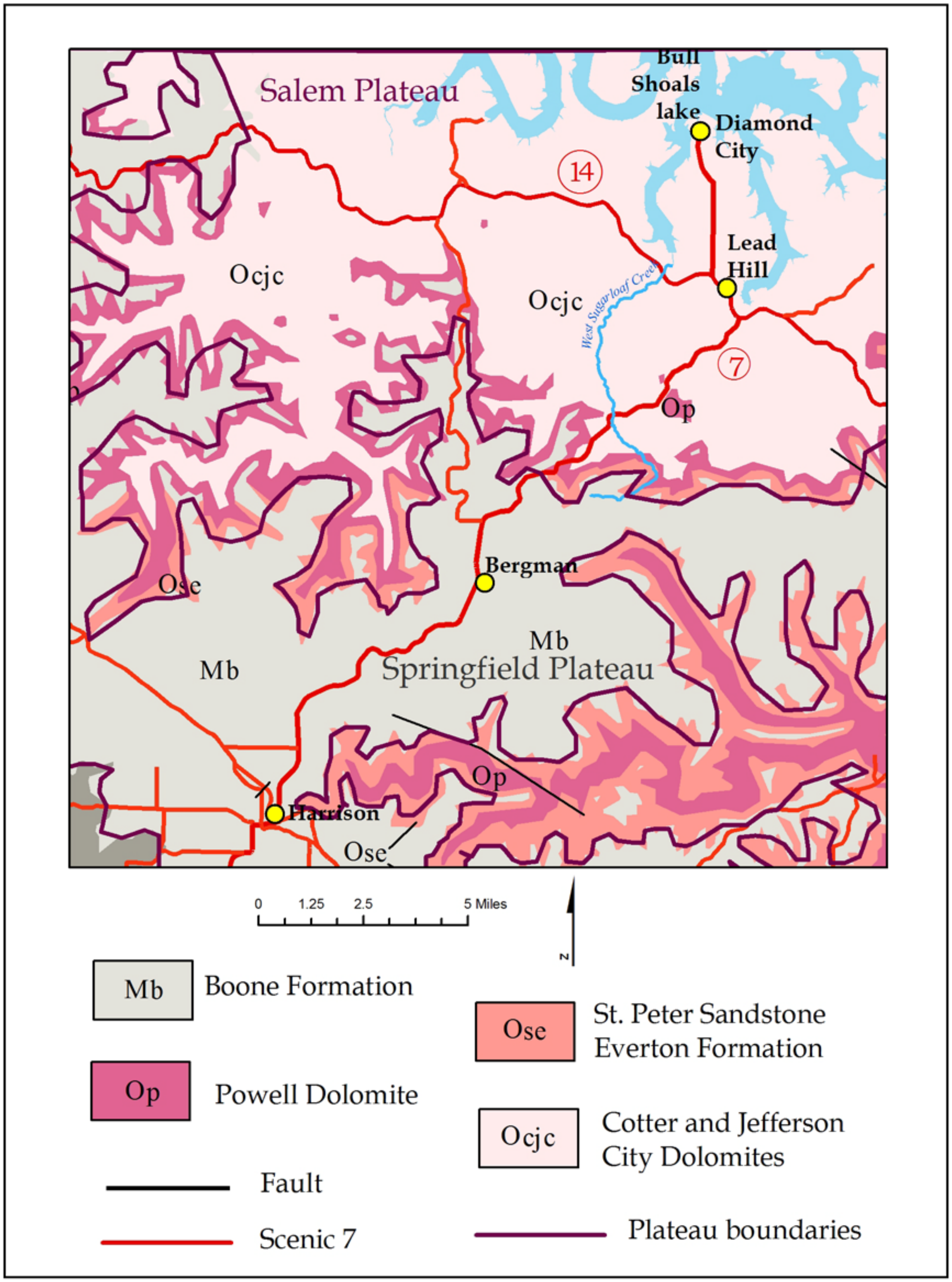


Figure 8. Geologic map from Bull Shoals (Diamond City) to Harrison
(from the Geologic Map of Arkansas, 1:500,000 scale)

Figure. 9. Boone Limestone with bedded chert
(North of Harrison on U.S. 65, 36°25′35″N 93°13′43″W)

The rolling, hilly surface of the Springfield Plateau is a few hundred feet higher in elevation than the Salem Plateau. The plateau surface reaches an elevation of 1,800 feet above sea level in several localities, but is dissected by deep ravines where stream systems have entrenched themselves. As, we return to Harrison, the hilly surface is well exposed (Fig. 10A).


(A) **(B)**

Figure 10. Springfield Plateau (A) north of Harrison (36°24′56″ N, 93°13′57″) **on U.S. 65 and (B) south of Harrison on Scenic 7** (36°09′20″ N, 93°07′18″ W)

Road Log – Harrison to Jasper

Heading south from Harrison, Scenic 7 continues to cross the Boone Formation and the broad rolling landscape typical of the Springfield Plateau (Fig. 10B). Approximately 8 miles south of Harrison, the road crosses the Elmwood Fault Zone (Fig. 11). The rocks of this region display mild structural deformation, as shown by the presence of broad domes, monoclines, and low displacement normal faults (Hudson, et al., 2001). These structures may represent gravitational settling in response to faults in the deeper igneous basement rocks.

The road roughly parallels the fault zone for approximately 0.6 mile before turning sharply to the southeast at Dogpatch (Marble Falls, Newton County), where it begins to follow the valley of Mill Creek for several miles. In this area, the St. Joe Limestone Member is exposed at the base of the Boone Formation.

Limestone from this area was quarried in 1836 for use in the Washington Monument. In 1954 the Newton County Historical Society erected a roadside marker at Marble Falls in commemoration of the donation. For more historical information please check out the following website: www.arkansasroadstories.com/washmon.

The St. Joe is exposed on the west side of Scenic 7 for approximately 1.7 miles before encountering the Everton Formation (Middle Ordovician Period, 458 to 473 million years ago). The Everton is an interbedded dolostone, sandstone, and limestone up to 230 feet thick where a complete section is present (Hudson, et al., 2001). Approximately 0.1 mile north of the Buffalo River, the road crosses the Carlton Fault Zone (Fig. 12) before splaying (dividing) into a graben structure that continues to the east. Scenic 7 crosses the Carlton fault again approximately 3.7 miles north of Jasper.

Massive sandstone of the Everton Formation is dramatically exposed in the bluff along the north bank of the Buffalo River near Pruitt (Fig. 13). A stop at the river access point and picnic area at the south end of the bridge is a must to just appreciate the beautiful scenery and marvel at the massiveness of the sandstone.

Leaving the picnic area, the road climbs from an elevation of 820 feet to about 1,400 feet above sea level over a distance of approximately 1.4 miles. In this distance, Scenic 7 crosses the Everton Formation and the St. Joe Limestone Member of the Boone Formation. For the next 0.5 mile the road runs parallel to the Carlton Fault Zone which brings the Everton into contact with the Boone, thus creating a 150 million year gap in the geologic record. As the road turns from southwesterly to a more southeasterly direction, the Everton and St. Joe Limestone are exposed again in the valley of a tributary of the Little Buffalo River.

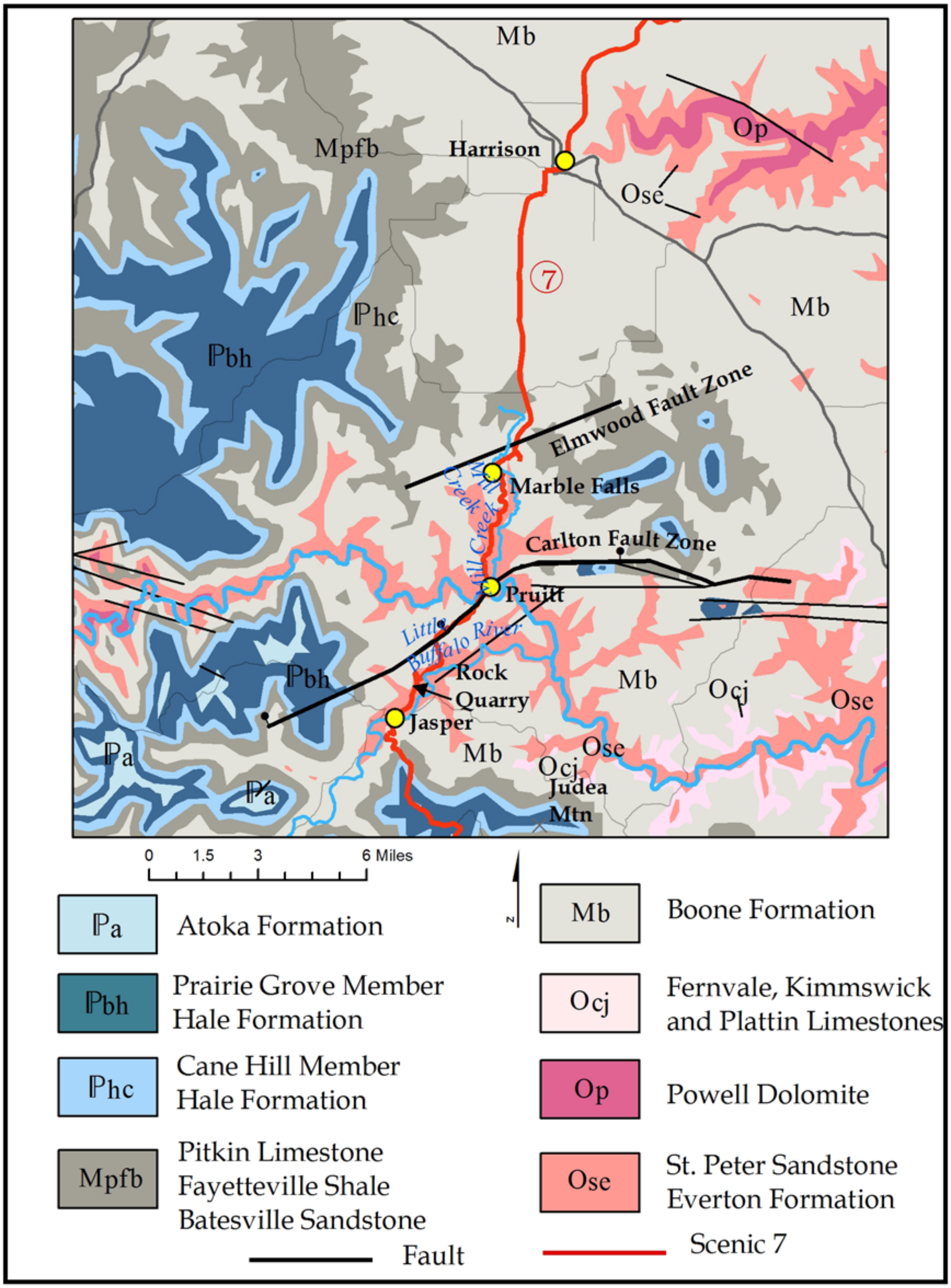


Figure 11. Geologic map from Harrison to Jasper
(from Geologic Map of Arkansas, 1:500,000 scale)

Figure 12. Carlton Fault Zone (3.7 miles north of Jasper, 36°02′42″N 93°09′31″W)

Figure 13. Everton Sandstone (Buffalo River near Pruitt, 36°03′41″N 93°08′20″W)

Figure 14. Little Buffalo River Landscape
(North of Jasper, 36°01′31″N 93°10′19″W)

Figure 15. Boone-St. Joe Limestone
(North of Jasper, 36°01′31″N 93°10′19″W)

Three miles south of Pruitt, Scenic 7 enters the valley of the Little Buffalo River (Fig. 14) and runs parallel to it on the Everton Formation and the St. Joe Limestone before reaching the Little Buffalo River Bridge. Approximately 3.7 miles south of Pruitt (1.6 miles north of Jasper), there is an abandoned rock quarry on the west side of the Scenic 7 roadway (Fig. 15). This is an easy pull-off area where you may collect limestone from the St. Joe and chert fragments from the Boone. There are many small fragments of white to gray chert and gray to red limestone containing numerous fossil crinoid column fragments. Other marine invertebrate fossils typical of the Boone may also be present.

After crossing the Little Buffalo River Bridge we arrive in downtown Jasper, the quaint county seat of Newton County. The town of Jasper is built on the Everton and Boone Formations

Road Log – Jasper to Arkansas Grand Canyon Overlook

As we leave Jasper on Scenic 7 there are excellent exposures of the Boone in roadcuts on the left (east) side of the road 1.9 miles from the Newton County Courthouse**.** The limestone contains numerous chert nodules, but not as much bedded chert as we saw north of Harrison. Heading south, the road begins a dramatic 3.6 mile climb from an elevation of 834 feet at Jasper to the summit of Judea Mountain, considered to be the beginning of the Boston Mountain Plateau, at 2,154 feet above sea level. During this drive, we will be travelling "upsection", as geologists say, that is, crossing all of the progressively younger sedimentary formations between the Everton and Bloyd, including a landslide deposit (Fig. 16).

The steep slopes of the Boston Mountains Plateau are especially prone to mass wasting (landsliding). Geologic maps of the region show numerous landslide deposit areas of Quaternary age (Recent to 2.6 million years ago). For example the "Geologic Map of the Parthenon Quadrangle, Newton County, Arkansas", the map that includes Judea Mountain, shows five landslide deposit areas. Such slope instability is especially likely during rainy periods in areas where shale underlies sandstone or limestone. The guilty parties triggering slope failure in this region are the Cane Hill Member (interbedded silty shale, siltstone, and thin sandstone) of the Hale Formation and the interbedded finely crystalline limestone and shale of the Fayetteville. Periodically, Scenic 7 and other roads in the Springfield and Boston Mountain Plateaus are affected by slope failure.

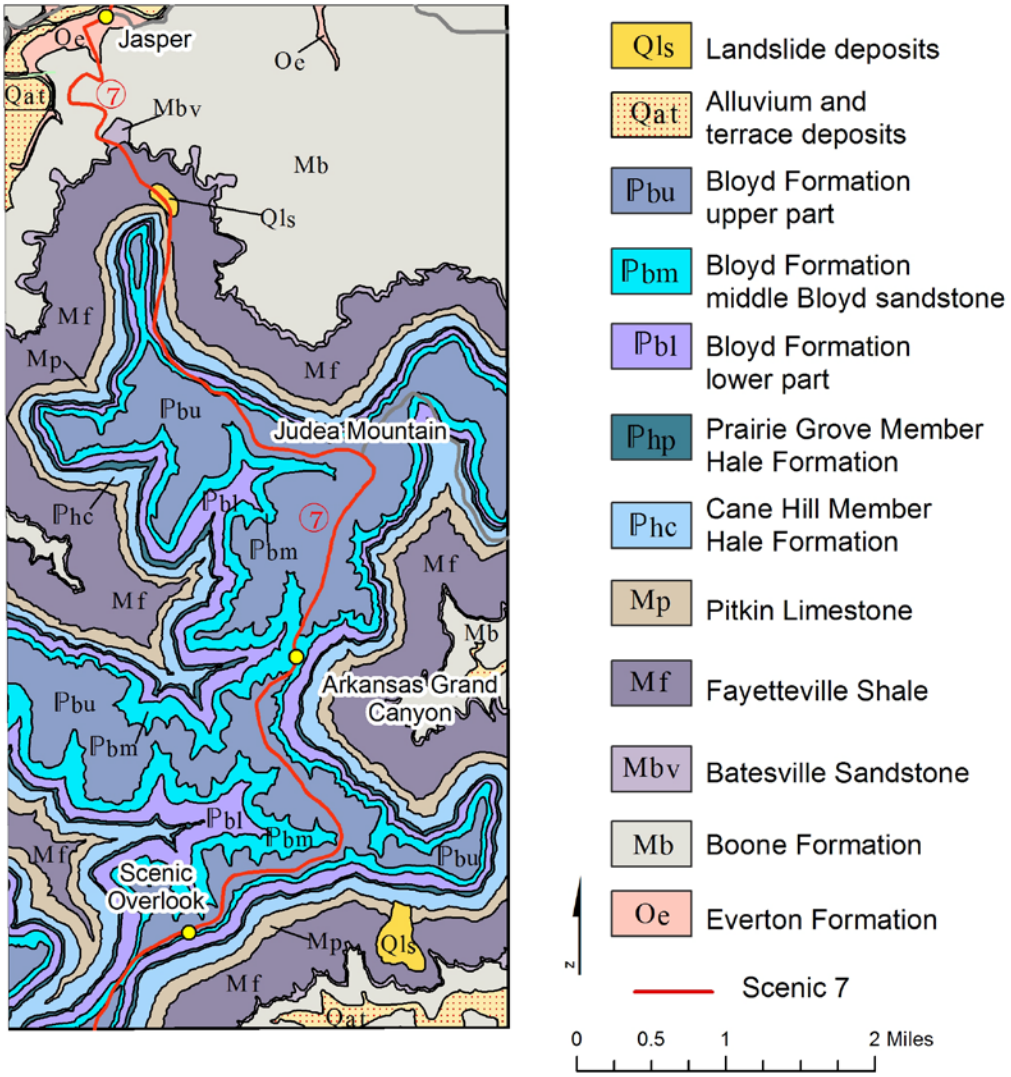


Figure 16. Geologic map from Jasper to Arkansas Grand Canyon
(from Geologic map of the Parthenon quadrangle, 1:24,000 scale)

Once you reach the summit of Judea Mountain, there are spectacular views of the surrounding landscape to the north, east, and southeast. Be sure to take advantage of these scenic opportunities by stopping at Scenic Point at the top of the uphill climb 3.6 miles south of Jasper and at Cliff House Inn 5.4 miles south from Scenic Point to view the Arkansas Grand Canyon (Fig. 17).

The valley between Judea Mountain and the highlands to the east was carved out by Big Creek and its tributaries. The valley floor elevation is about 800 feet while the mountain tops are generally 2,000 to 2,200 feet above sea level.

Figure 17. Arkansas Grand Canyon
(35°54′25″N 93°11′12″W)

If one were to hike from Big Creek to the summit of one of the surrounding mountain tops, you would cross six or seven geologic formations separated by about the same number of unconformities. The geologic ages encountered, in such a challenging climb, would range from the Middle Ordovician to the Middle Pennsylvanian Periods, spanning approximately 150 million years. These unconformities indicate that sea level fluctuated many times. When the Ozark Dome and its surrounding continental shelf were above sea level, erosion occurred. When sea level rose shallow-water marine limestone**,** sandstone, and shale were deposited.

Judea Mountain is capped by sandstone and shale of the upper and middle Bloyd Formation (Early Pennsylvanian Period, 312 to 318 million years ago). The Bloyd (Fig. 18) consists mostly of interbedded sandstone and shale that ranges from light-brown to gray on fresh surfaces, but weathers to a darker gray (Braden and Ausbrooks, 2003).

Trace fossils (feeding burrows and tracks of bottom-dwelling organisms) and lycopod (plant) fossils indicate that portions of the Bloyd were deposited in relatively shallow water in a non-marine setting. It should be noted that lycopod fossils are evidence of the first plant life on land in Arkansas rocks, and should be recognized as marking a significant step toward the development of more complex land-dwelling organisms. So far, all of the remains of life that we have encountered during our trip through time have been sea-dwelling creatures.

Figure 18. Bloyd Formation
(Judea Mountain Scenic Overlook, 35°55′10″N 93°10′31″W)

Road Log – Arkansas Grand Canyon Overlook to State Highway (SH) 16 (Road to Deer) Junction

Heading south again after stopping at the last scenic overlook, we pass through McElroy Gap where a side road winds downhill into the valley of the Left Fork of Big Creek flowing between Smith Mountain and Owens Mountain. One of the rare structural folds in rocks of the Boston Mountains Plateau is crossed 0.7 mile south of McElroy Gap. Red Rock Monocline, a step-like fold lying between Moss Mountain and Smith Mountain, trends northwest-southeast and dips toward the northeast (Fig. 19). The flexure is present probably because of normal faulting in deeper rocks. This type of structure is not caused by compressive mountain-building forces, it probably is a gravitational response of the sedimentary strata to normal faulting in the underlying igneous basement rock.

Continuing south, Scenic 7 leaves the upper Bloyd Formation and encounters the younger Atoka Formation 2.4 miles south of McElroy Gap. In this area, the Atoka consists of black to tan-colored shale, mica-bearing siltstone, and tan sandstone (Braden and Ausbrooks, 2003). Scenic 7 reaches an elevation of approximately 2,260 feet as it passes Crossroads Cemetery. The road continues south and the Bloyd Formation is exposed again as the hilly landscape makes a series of dips and rises. The Atoka is crossed again before reaching the intersection with SH 16.

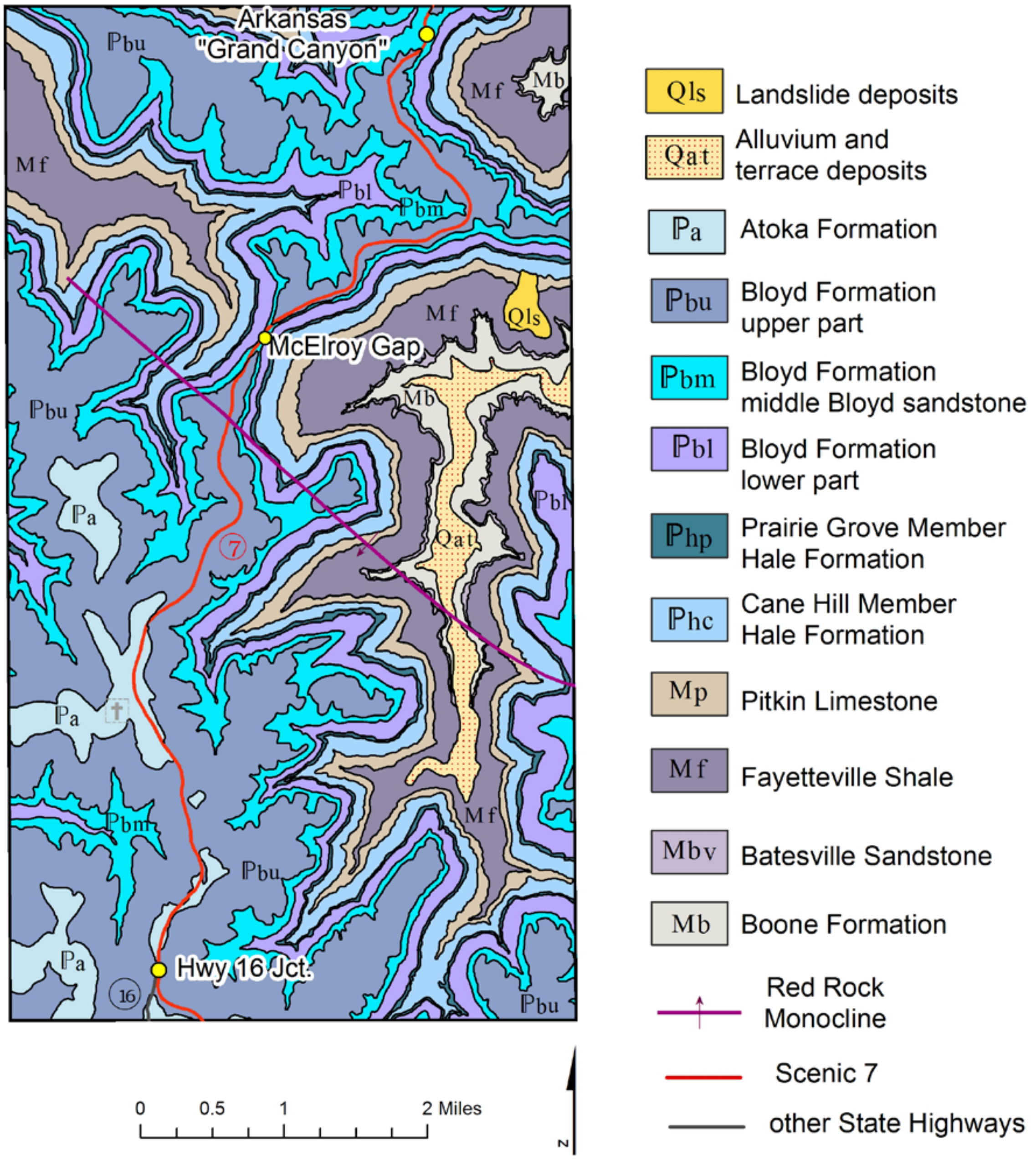


Figure 19. Geologic map from Arkansas Grand Canyon to State Highway 16
(from Geologic map of the Parthenon quadrangle, 1:24,000 scale)

Road Log – SH 16 Junction to Mulberry Fault

From the SH16 Junction to the Cowell community Scenic 7 remains on the Bloyd Formation, but in this area the Atoka caps the higher elevations, which may reach 2,230 feet above sea level.

Approximately 5 miles south of Cowell, Scenic 7 crosses a normal fault leading into a graben structure 0.3 mile wide at this point. The Atoka Formation is exposed between the normal faults that define the margins of the graben. The faults that bound the graben are the Limestone Fault on the north and the Confederate Fault on the south (Fig. 20). These two faults are considered to be major regional structures. Downward displacement of strata within the graben is approximately 200 feet (Braden and Smith, 2004). Faults are recognized in this area by the once nearly horizontal strata displaying dips up to 40 degrees near a fault. Also, faulting causes older strata to be brought into contact with younger strata at the surface and may cause offset in their outcrop patterns.

South of Muddy Gap, located 2 miles south of Sand Gap (Pelsor), the Atoka Formation is dipping an average of 5 degrees to the south. As you remember, this is unusual in the Ozark Plateaus since most of the strata are in a nearly horizontal position except where disturbed by faulting or folding. It is assumed that this monocline was caused by deeper normal faults in igneous basement rocks causing strata overlying the fault to fold due to the force of gravity. Between the Lurton area and Sand Gap (4.3 miles) the road remains on the Atoka Formation (Fig. 20).

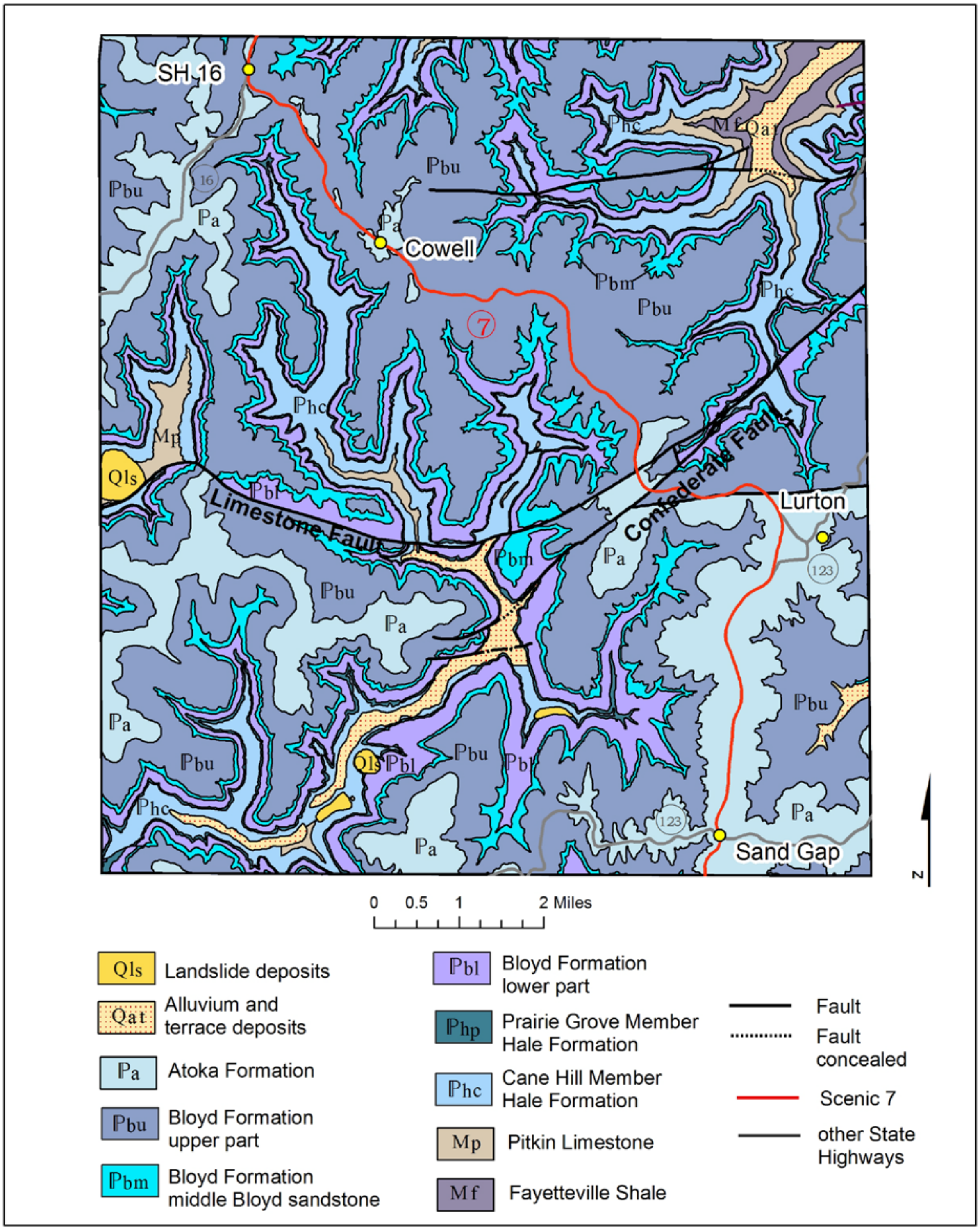


Figure 20. Geologic map from SH 16 Junction to Sand Gap
(from Geologic maps of the Deer, Lurton, and Sand Gap quadrangles, 1:24,000)

Figure 21. Rotary Ann Overlook
(Pope County, 35°40′10″N 93°05′56″W)

Rotary Ann Overlook, maintained by the U.S. Forest Service, is an excellent rest stop where we can view many square miles of the Boston Mountains which are actually a deeply-eroded plateau. Notice how the “knobs”, as the summits of the distant hill tops are labeled on the “Lay of the Land” signboard, are essentially at the same elevation (Fig. 21). The Boston Mountains Plateau is the highest part of the Arkansas Ozarks, reaching over 2,500 feet above sea level at some locations.

These higher elevations are topped by outcroppings of Pennsylvanian-aged sandstone of the Atoka and Bloyd Formations. The plateau has been eroded, as deeply as 500 to 1,500 feet, by numerous streams that have developed a dendritic (tree-like branching) drainage pattern over thousands of years because of the uniform hardness and mostly horizontal orientation of the sedimentary strata. However, some rectangular and trellis drainage patterns formed locally because of the presence of tilted strata due to minor folds and faults, especially along faults with a northeast-southwest trend.

After leaving Rotary Ann Overlook, Scenic 7 continues south (1.3 miles) to the Freeman Springs community. Two miles south of Freeman Springs, the road crosses the North Fork Monocline that trends northeast and dips toward the southeast (Fig. 22). Continuing south on the Atoka Formation, the road passes through the Simpson community and 1.8 miles farther is Moccasin Gap where we encounter the Treat Fault. A branch of this normal (gravity) fault is well exposed on the west side of the road - you can’t miss it (Fig. 23).

The Atoka Formation strata dip toward the south about 28 degrees, while the fault plane dips north 29 degrees. Along the outcrop the strata are offset approximately 46 feet to the north. The shales and siltstones in contact with the fault plane show drag. Drag is folding that indicates the direction of motion of the hanging wall (block above the fault plane) with respect to the footwall (block below the fault plane).

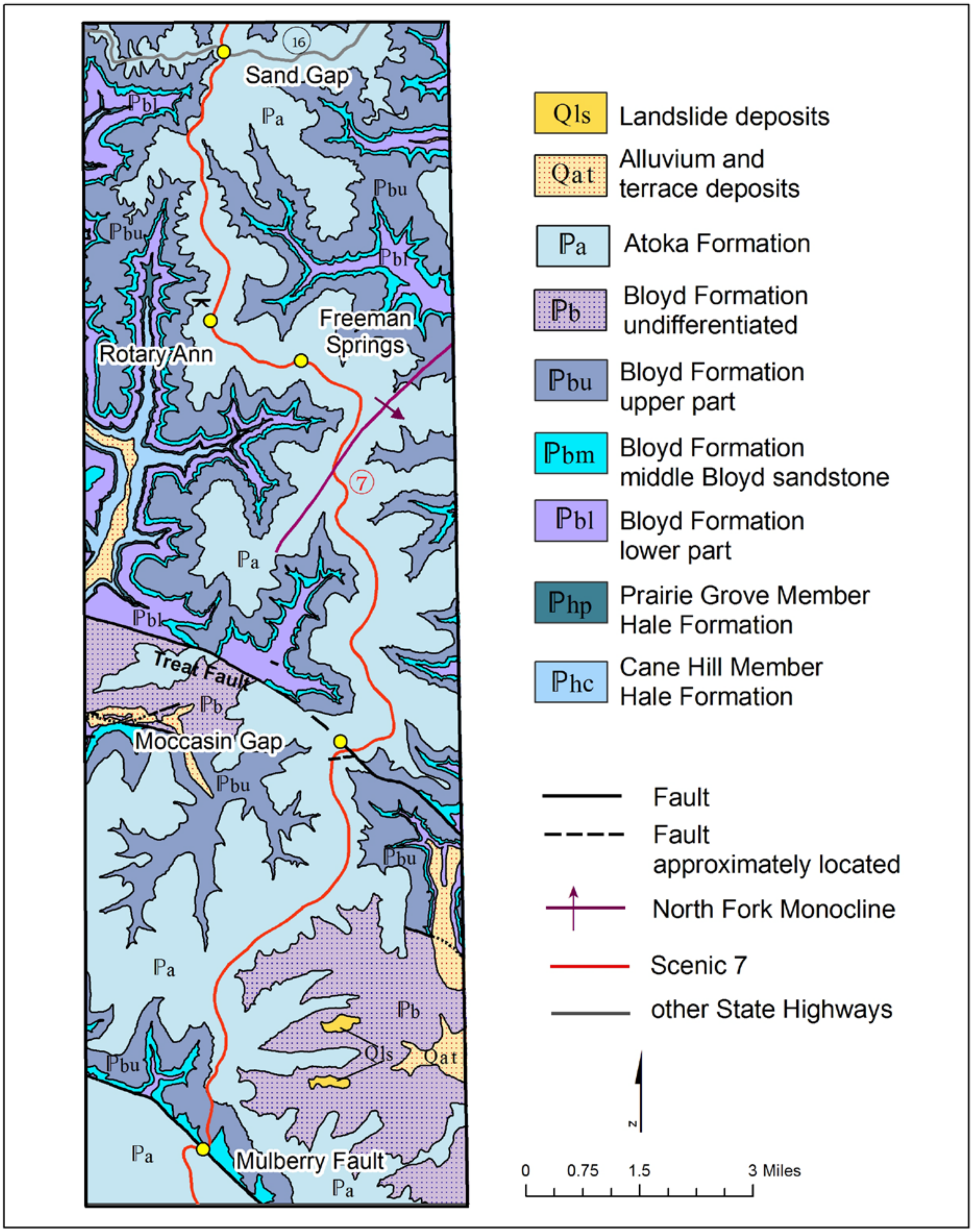


Figure 22. Geologic map from Sand Gap to the Mulberry Fault
(from Geologic maps of the Sand Gap and Simpson quadrangles, 1:24,000 scale)

From Moccasin Gap, Scenic 7 continues south on the Atoka Formation at an elevation over 1,400 feet above sea level. Approximately 4.9 miles from the fault, the road begins a downhill run and about 0.5 mile from the beginning of the descent we cross back onto the upper part of the Bloyd Formation. From this point Scenic 7 continues its descent and approximately 0.6 mile from the upper Bloyd contact, the middle Bloyd is crossed as the road curves sharply to the west and crosses the Mulberry Fault (35°29″32′N 93°06″14′W).

The Mulberry Fault is a major fault zone, forming the southern boundary of the Boston Mountains Plateau and the beginning of the Arkansas River Valley Physiographic Province (Fig. 24). Tensional forces in the Earth's crust caused the Mulberry and similar normal faults to develop in the igneous basement rocks and overlying sedimentary strata. Fault blocks (hanging walls), lying above the south-dipping fault surfaces, moved downward with respect to the blocks that underlie the fault (footwall). Most of the faults in this region are of this type and are known by oil and gas geologists as "down to the south" faults meaning that the hanging wall moved down on the south side of the fault surface.

Data gained from the drilling of natural gas wells indicate that the Mulberry Fault caused the Atoka and underlying strata to drop approximately 3,500 feet (Bill Cains, personal communication, 2011). Such displacements along major faults, like the Mulberry and associated cross-faults, caused numerous structural traps to form in the sedimentary strata, resulting in the natural gas accumulations characteristic of the Arkansas River Valley Province (aka Arkoma Basin).

Figure 23. Branch of the Treat Fault at Moccasin Gap
(Pope County, 35°35″04′N 93°04″13′W)

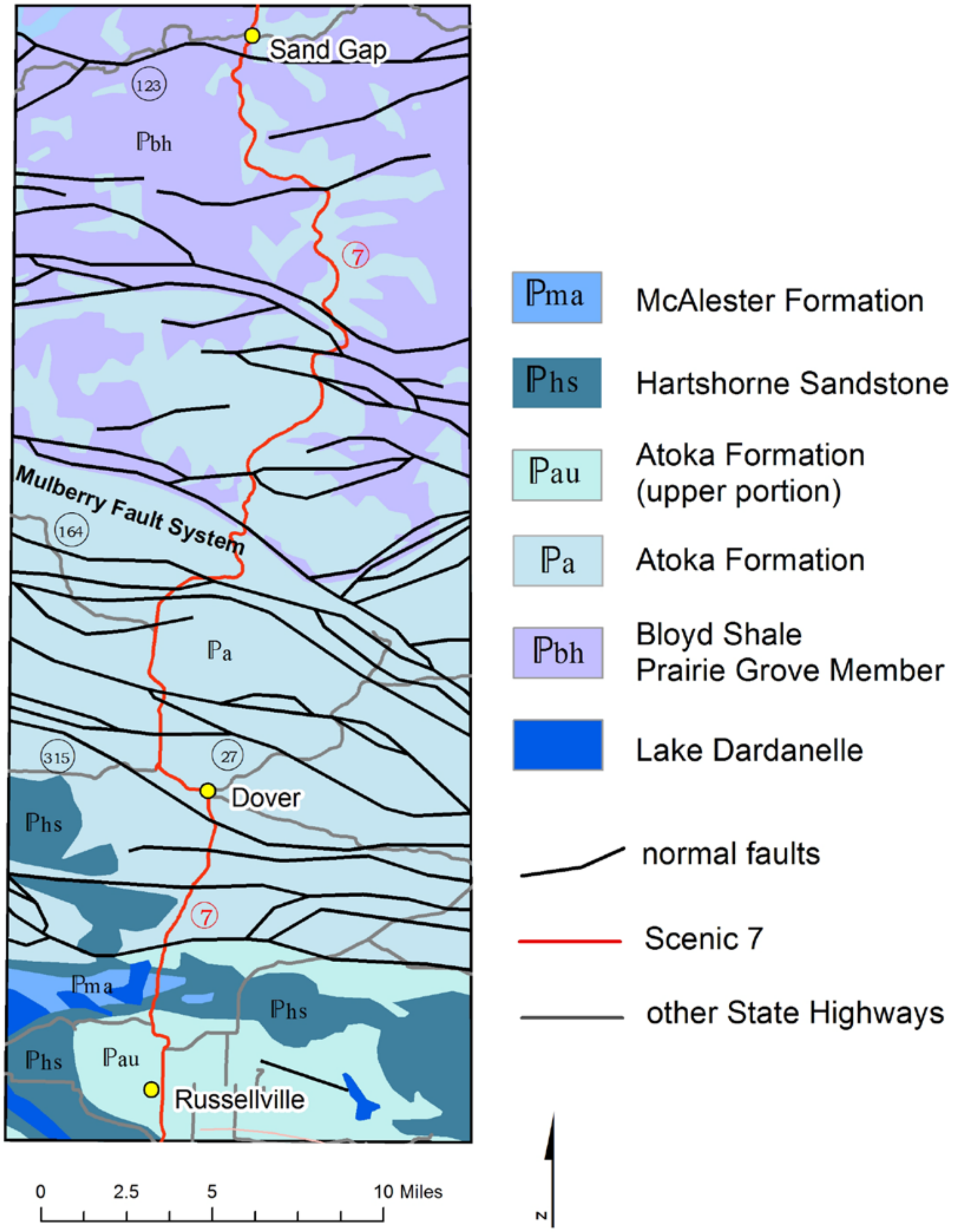


Figure 24. Geologic map of normal faults between Sand Gap and Russellville
(Source, Geologic Map of Arkansas, 1993)

Arkansas River Valley

Overview

This physiographic region lies between the Boston Mountains Plateau on the north and the Ouachita Mountains to the south. The Valley extends from the Oklahoma border on the west to the Mississippi River Alluvial Plain on the east, a distance of approximately 150 miles. The north to south width is approximately 30 miles along Scenic 7 (Fig.1).

The types of landforms present in the region, crossed by Scenic 7, range from broad floodplains and stream valleys to erosion-produced, mesa-like mountains (Crow Mountain, Mount Nebo) to ridges either narrow (Dardanelle Rock) or broad and rolling (Russellville Skyline Drive) (Fig. 25 and 26). The mountains and ridges are capped by erosion-resistant sandstone (Hartshorne Sandstone and sandstone of the Atoka Formation), while valleys are floored by softer shale and stream-deposited sediments (gravel, sand, silt, and clay). Almost all of the rocks are of sedimentary origin and are Pennsylvanian in age (approximately 300 million years ago). However, there are a few scattered, small igneous intrusions (Cretaceous Period, approximately 100 million years ago) in the Arkansas River Valley Province near the towns of Morrilton, Oppelo, Perry, and Blue Ball.

Rock Types Exposed Along Scenic 7 in the Arkansas River Valley

(Based on McFarland, 2004)

(Rock types are listed from youngest to oldest, map symbols follow the formation name.)

Alluvium (Qal)

Age: Quaternary, Holocene Epoch (Present to 11,700 years ago))

Description: These are unconsolidated sediments consisting of gravel, sand, silt, and clay. Fossils are rare and of modern life forms. Thicknesses are variable being dependent on the size of the stream or river.

Environment of deposition: alluvial deposits of streams and rivers.

Terrace Deposits (Qt)

Age: Quaternary, Pleistocene Epoch (11,700 years to 2.6 million years ago)

Description: These unconsolidated sediments are parts of former floodplains of major river systems. The sediments consist of gravel, sand, silt, and clay deposits that vary in thickness, are usually discontinuous and sometimes lens-shaped. Fossils are rare. Generally, terraces are several tens of feet above the level of the modern floodplain.

Environment of deposition: alluvial deposits of river systems.

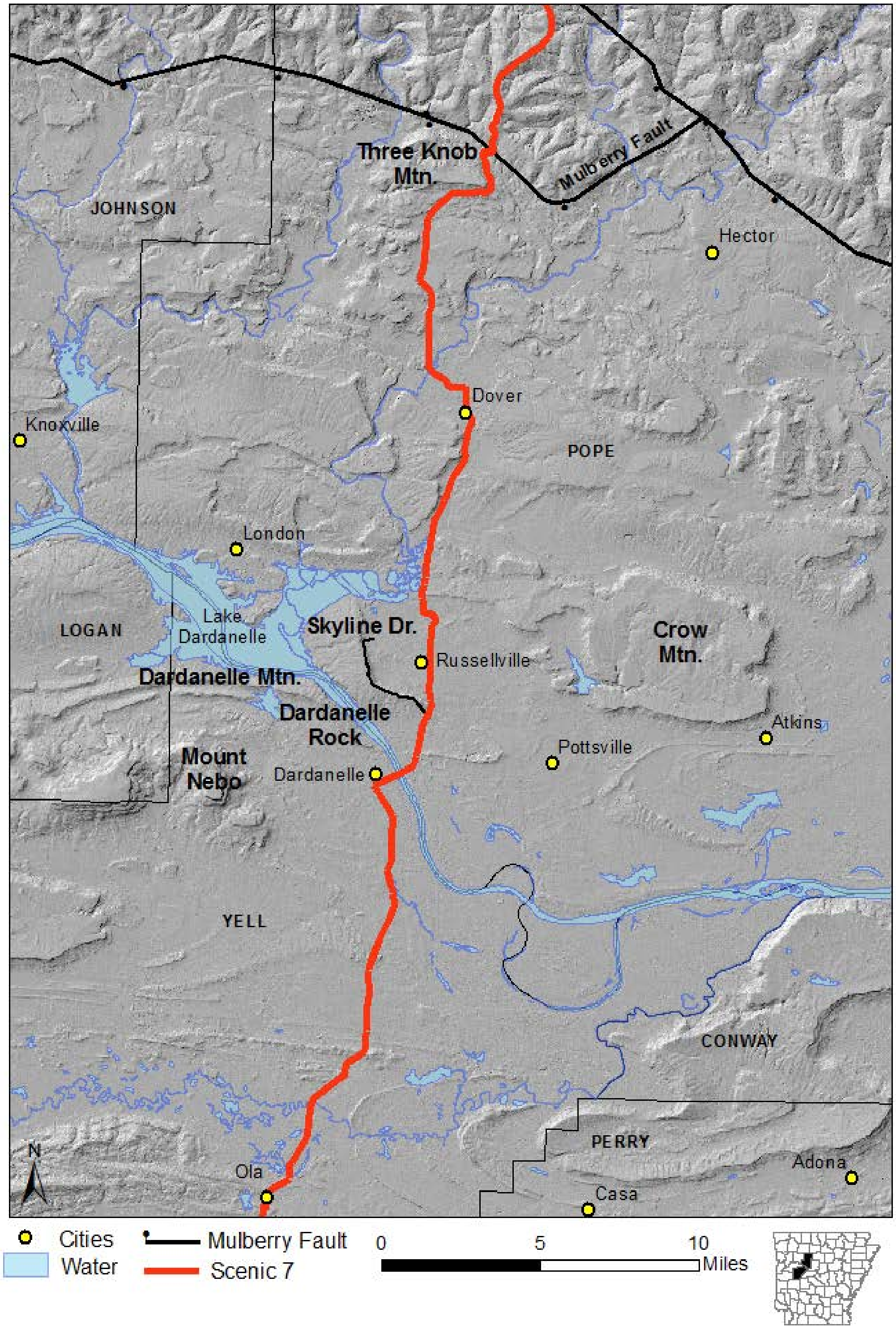


Figure 25. Shaded topographic relief map of the Arkansas River Valley (Ozark Mountains are located to the north of the Mulberry Fault and the Ouachita Mountains are located just to the south of Ola).

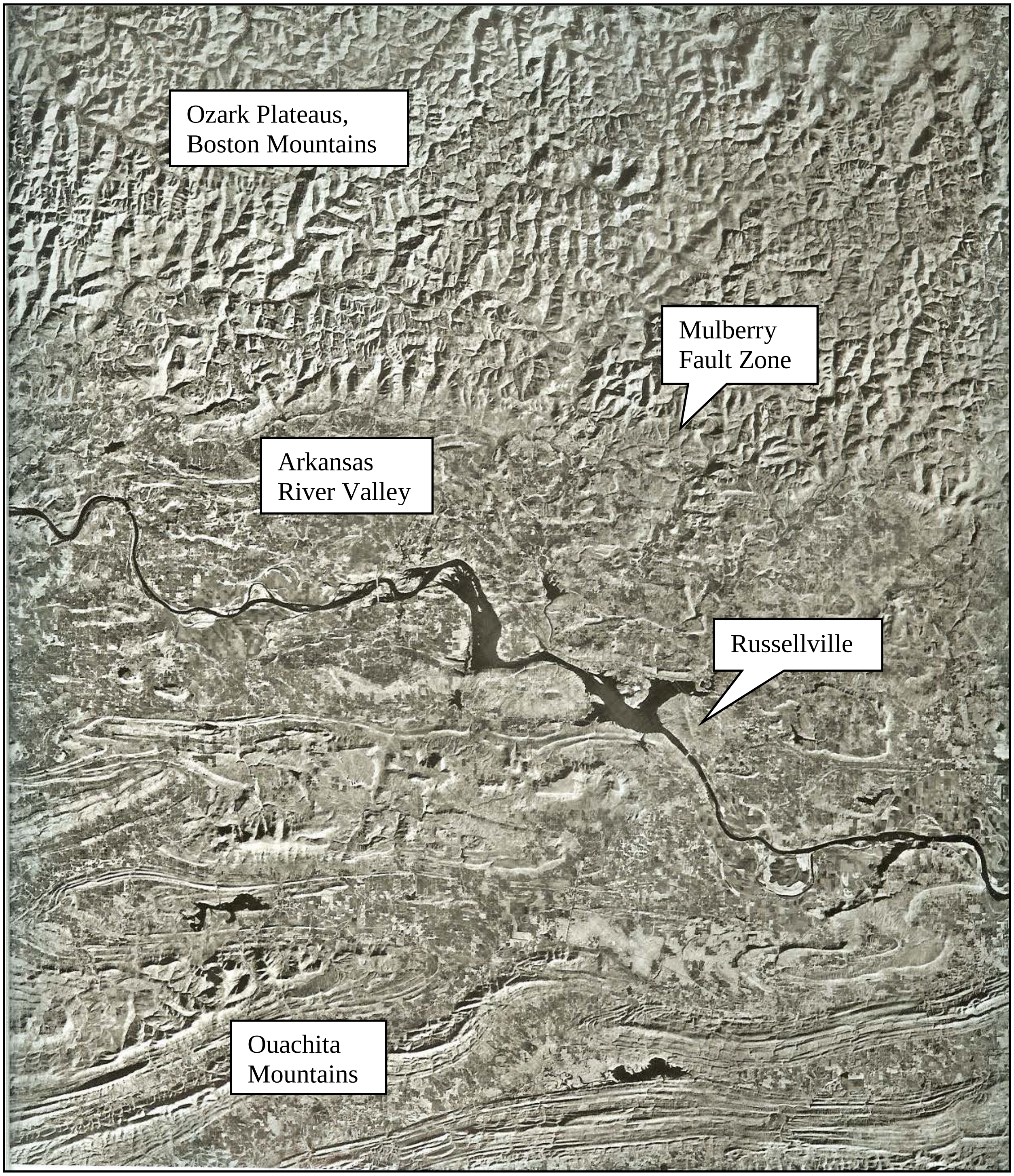


Figure 26. High altitude radar mosaic across the Arkansas River Valley
(source U.S. Geological Survey**)**

McAlester Formation (ℙma)

Age: Pennsylvanian (299 to 318 million years ago)
Description: The McAlester consists of shale, thin sandstones, and coal. The Lower Hartshorne Coal lies approximately 20 feet above the Hartshorne Sandstone in this region. The coal bed, which was mined extensively in the Russellville area, attained a maximum thickness of approximately 3 feet. The McAlester lies conformably above the Hartshorne Sandstone and ranges from approximately 500 to 800 feet thick in the local area. Between SH 7T junction (Bernice Avenue in Russellville) and the ridge approximately 0.6 mile north of the Arkansas River Bridge, the McAlester is exposed at the surface for a distance of approximately 1.1 miles along the axis of the Shinn Basin (syncline).
Environment of deposition: black shale and coal beds were deposited in marine coastal swamps and deltas, while the thicker shale and sandstone was formed in a deeper marine setting.

Hartshorne Sandstone (ℙhs)

Age**:** Pennsylvanian (299 to 318 million years ago)
Description: The Hartshorne is an erosion-resistant, brown to light-gray, massive to cross-bedded, sandstone that forms ridges (Russellville's Skyline Drive and Dardanelle Rock) and caps the flat-topped mountains (Crow Mountain and Mount Nebo) in the region. The Hartshorne ranges from approximately 10 to 300 feet in thickness in various parts of the Arkansas River Valley.
Environment of deposition: meandering stream channels, as indicted by cross-bedding of the sand layers and the exposure of channel-form deposits observed in road cuts and stream valleys.

Atoka Formation (ℙa)

Age: Pennsylvanian (299 to 318 million years ago)
Description: As you may recall (see page 7), the Atoka consists of gray to tan, silty sandstone and silty shale that is gray to black in color. It also contains irregularly distributed coal beds and black, organic-rich shale. The Atoka may be divided into lower (ℙal), middle (ℙam), and upper (ℙau) subdivisions in some areas.
Environment of deposition: shallow fresh to brackish water, coastal environment for some parts of the Atoka, while other parts, especially in the Ouachita Mountains were deposited in a deep-marine, continental slope setting, where turbidity current deposits formed submarine fans.

Rock and Mineral Resources

Pope County

Pope County has produced a number of mineral commodities including: coal, natural gas, dimension stone, crushed rock, sand, and gravel (Fig. 27). Coal mining began in 1873 west of Russellville and was a thriving industry by 1883. Initially, mining was of the down-dip type. Entry was at the surface outcrop of the coal and mining proceeded underground, as far as was commercially feasible. The deepest underground coal mine in the state (480 feet) was in the Shinn Basin south of Russellville.

Surface strip mining began in 1957 and continued until 1962 in the Shiloh Creek area north of Russellville. The mined area was reclaimed and developed into a public fishing area and softball park.

Sandstone has been quarried at a number of locations in the region, especially to produce crushed stone for construction of Interstate 40 and Dardanelle Dam on the Arkansas River. Also, sand and gravel are dredged from the Arkansas River to be used in the production of concrete and for general use.

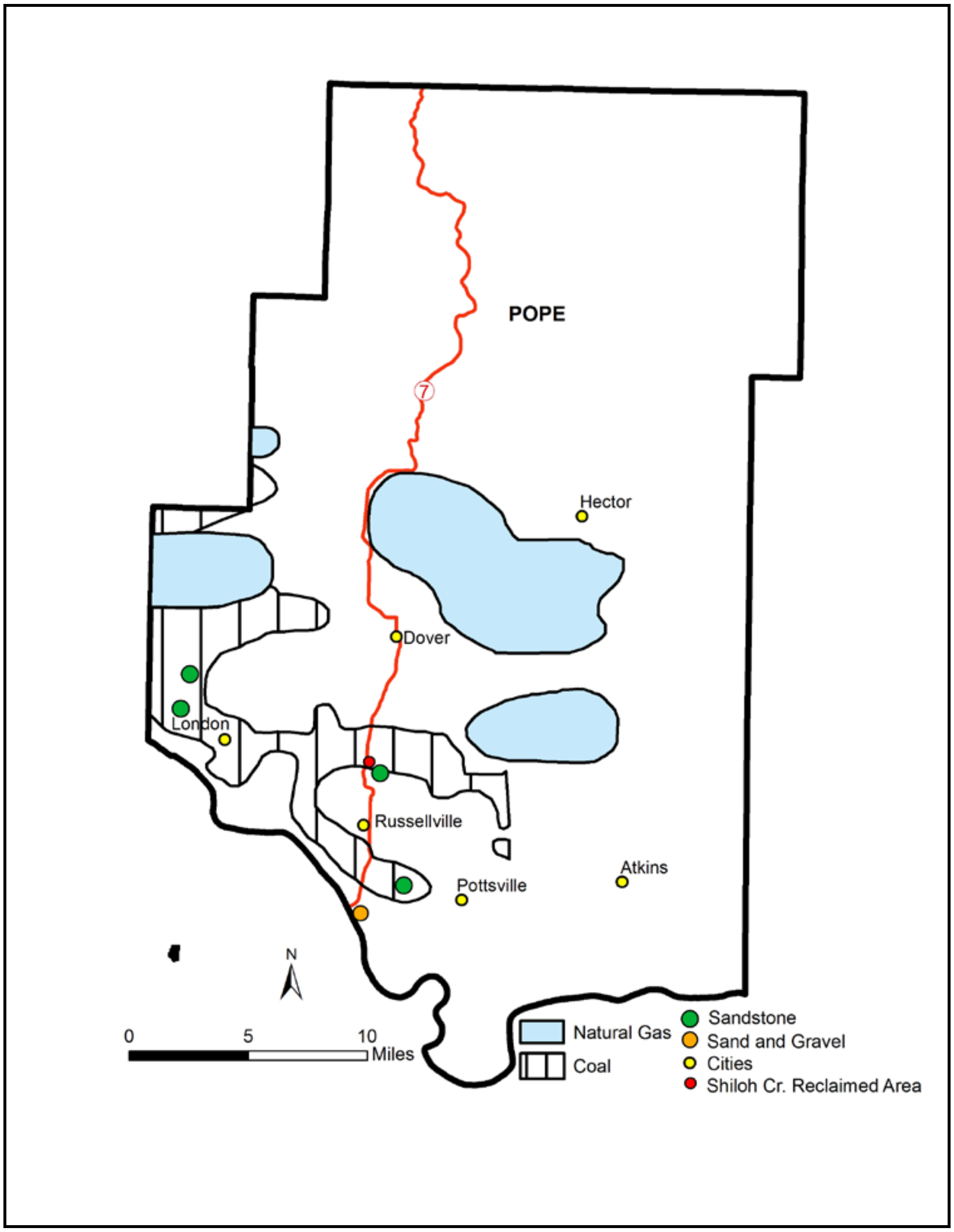


Figure 27. Mineral Resource Map of Pope County
(Natural gas and coal information, Arkansas Geological Commission, 2001; sandstone and sand/gravel information, U.S. Bureau of Mines, Bulletin 645, 1969)

Structural Geology and Natural Gas Production

As stated previously, the geologic boundary between the Boston Mountains Plateau and the Arkansas River Valley is the Mulberry Fault. Additionally, there are numerous parallel, east-west to southeast-northwest trending, normal faults present south of the Mulberry Fault (Fig. 24). Also, there are structural folds in the rock strata. These folds generally trend in an east-west direction with their limbs dipping from just a few degrees to nearly vertical. Many of the faults and folds are responsible for the accumulation (trapping) of natural gas several thousand feet below the surface.

Oil and gas exploration geologists refer to this region as part of the Arkoma Basin. A majority of the gas produced in the Arkoma Basin comes from sandstones in the Atoka Formation. The following gas fields are crossed by Scenic 7 before reaching Russellville: Dover, New Hope, and Furgeson (Fig. 28). In 2011 the wells in these fields produced 188,808,894 thousand cubic feet of gas from the Atoka Formation. At an average price of $4.00 per thousand cubic feet (forecastchart.com) gas production in the county was worth approximately $ 755 million.

Arkansas was ranked 8th in the U.S. among gas-producing states in 2011. Natural gas production, including that produced from the Fayetteville Shale and the central part of the Arkoma Basin, was 1,073,295,953 thousand cubic feet worth approximately $4.29 billion.

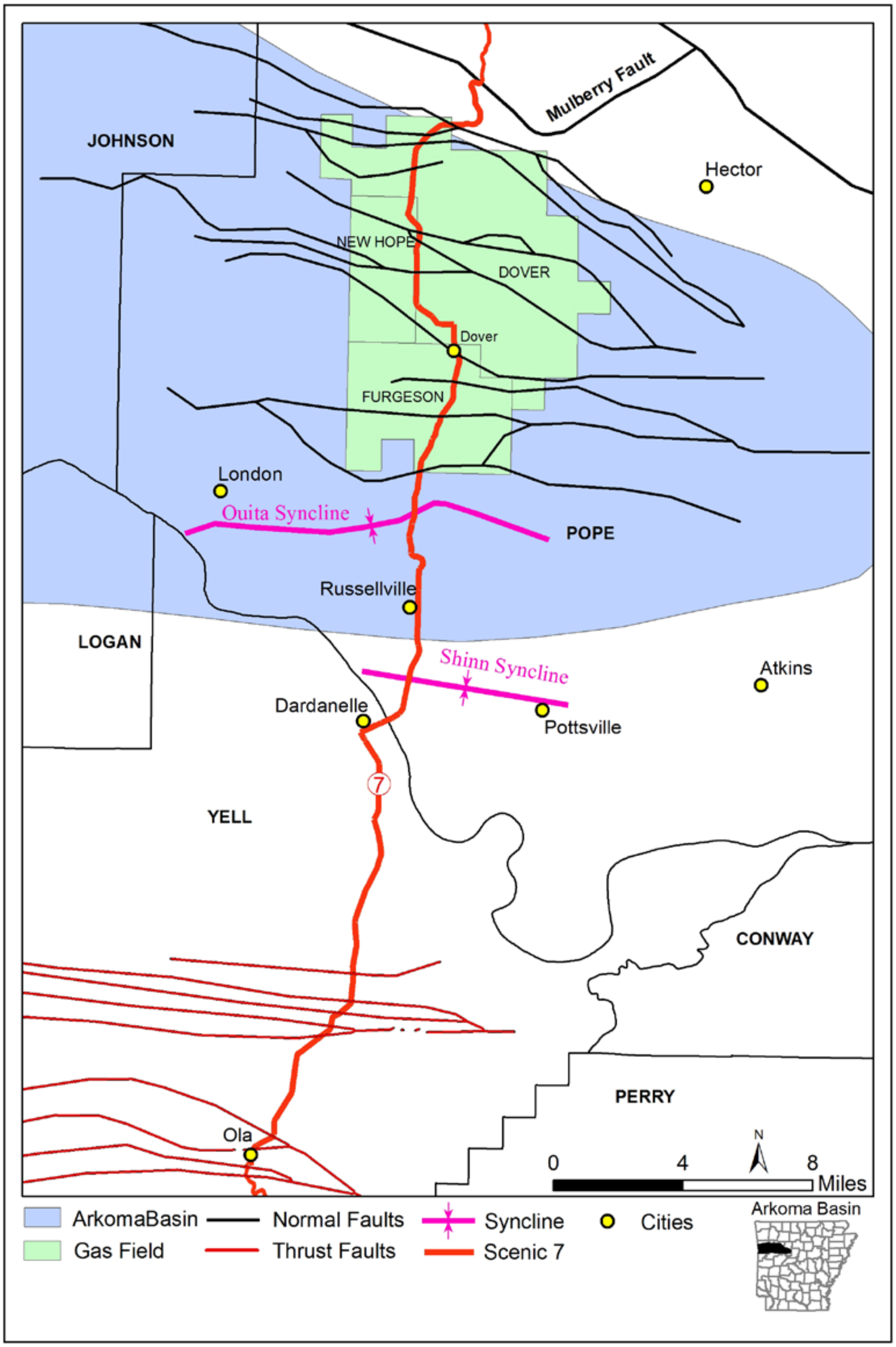


Figure 28. Arkoma Basin, gas fields, faults, and folds in portions of Pope and Yell Counties
(source, Arkansas Geological Survey)

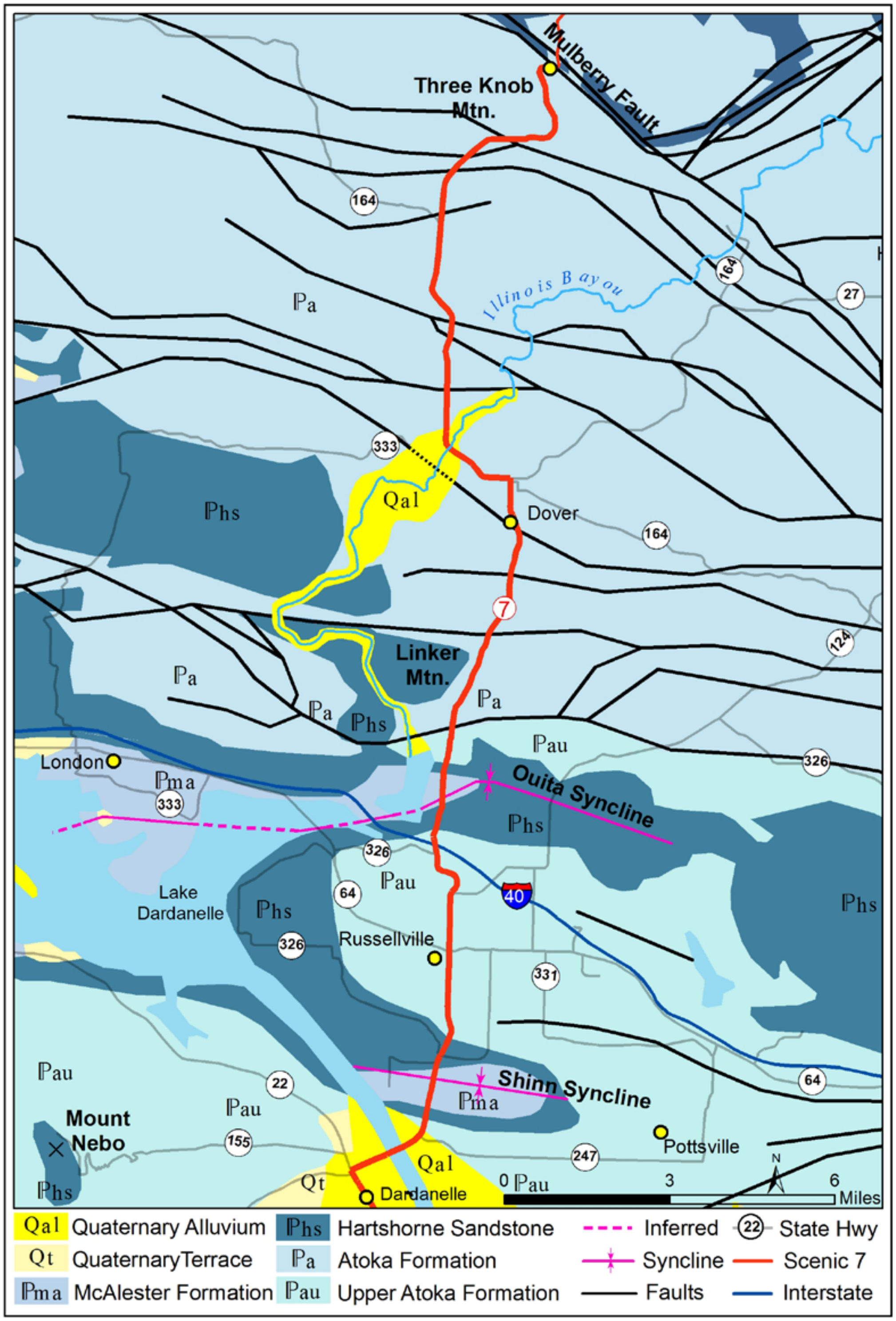


Figure 29. Geologic map Mulberry Fault to Dardanelle
(from Geologic Map of Arkansas, 1:500,000 scale).

Road Log – Mulberry Fault to Dardanelle

As Scenic 7 turns from south to west around Three Knob Mountain and then toward the south at the bottom of the hill, the elevation drops from 980 feet to 680 feet over a distance of 2.4 miles. The 300 foot drop in elevation across the Mulberry Fault marks the edge of the Boston Mountains Plateau and the beginning of the Arkansas River Valley Province. Between Three Knob Mountain and the town of Dover we cross seven normal faults that are not apparent in road cuts (Fig. 29). However, they were mapped by reference to aerial photographs and by geologic surface mapping methods. These structures are also detected during gas well drilling.

The Illinois Bayou is crossed approximately 0.8 mile north of Dover. Just before crossing the Bayou, SH 333 intersects Scenic 7 and heads west. Shale of the Atoka Formation is exposed in a cliff on the north side of SH 333. From the bridge toward Dover we are crossing alluvial deposits of the Illinois Bayou for approximately 0.5 mile.

From Dover to Russellville, four more normal faults are crossed. The rocks exposed adjacent to Scenic 7 are shale of the Atoka Formation. The Hartshorne Sandstone forms the caprock of Linker Mountain on the west (right) side of the road. Just south of the Russellville Golf and Country Club a portion of, nearly black, Atoka shale is exposed on the east (left) side of the road. Further south at Pleasant View and Shiloh Parks, on the west (right) side of the road, we can see reclaimed land where coal strip mining occurred (1957 to 1962) in the Lower Hartshorne Coal of the McAlester Formation. The McAlester is present in the Ouita syncline that plunges to the west under Dardanelle Reservoir.

The City of Russellville is located on the Atoka Formation (downtown area), the Hartshorne Sandstone (Skyline Drive area), and the McAlester Formation (Fig. 30). As we travel south on Scenic 7, the Hartshorne is crossed between West 21st Street and the intersection with SH 7T (Bernice Avenue). Beyond this intersection, the McAlester Formation is at the surface due to the presence of the Shinn Basin (syncline). Underground coal mines were operated in the Basin from 1887 until 1953, and as mentioned previously, this is the area where the deepest underground coal mine in Arkansas was located.

Approximately 1.1 miles south of Bernice Avenue, the south limb of the Shinn Basin is crossed. The McAlester Formation – Lower Hartshorne Coal, Hartshorne Sandstone, and the Atoka Formation are exposed in road cuts on both sides of the road (Fig. 31). The asymmetry of the Basin is displayed by the nearly vertical (89 degrees) north-dipping rock strata exposed in the southern limb, as compared to the 5 to 8 degrees south-dipping strata visible in the north limb.

Alluvial sediment begins approximately 0.4 mile after crossing the south limb of the Shinn Basin. As you cross the Arkansas River Bridge into Dardanelle, Dardanelle Dam can be seen to the northwest (right side of the bridge). Dardanelle Mountain and the famous Arkansas River landmark, Dardanelle Rock (Hartshorne Sandstone) (Fig. 32), also lie to the northwest. Excellent exposures of the Hartshorne are present in a quarry located southwest (left side) of the road to the dam overlook area.

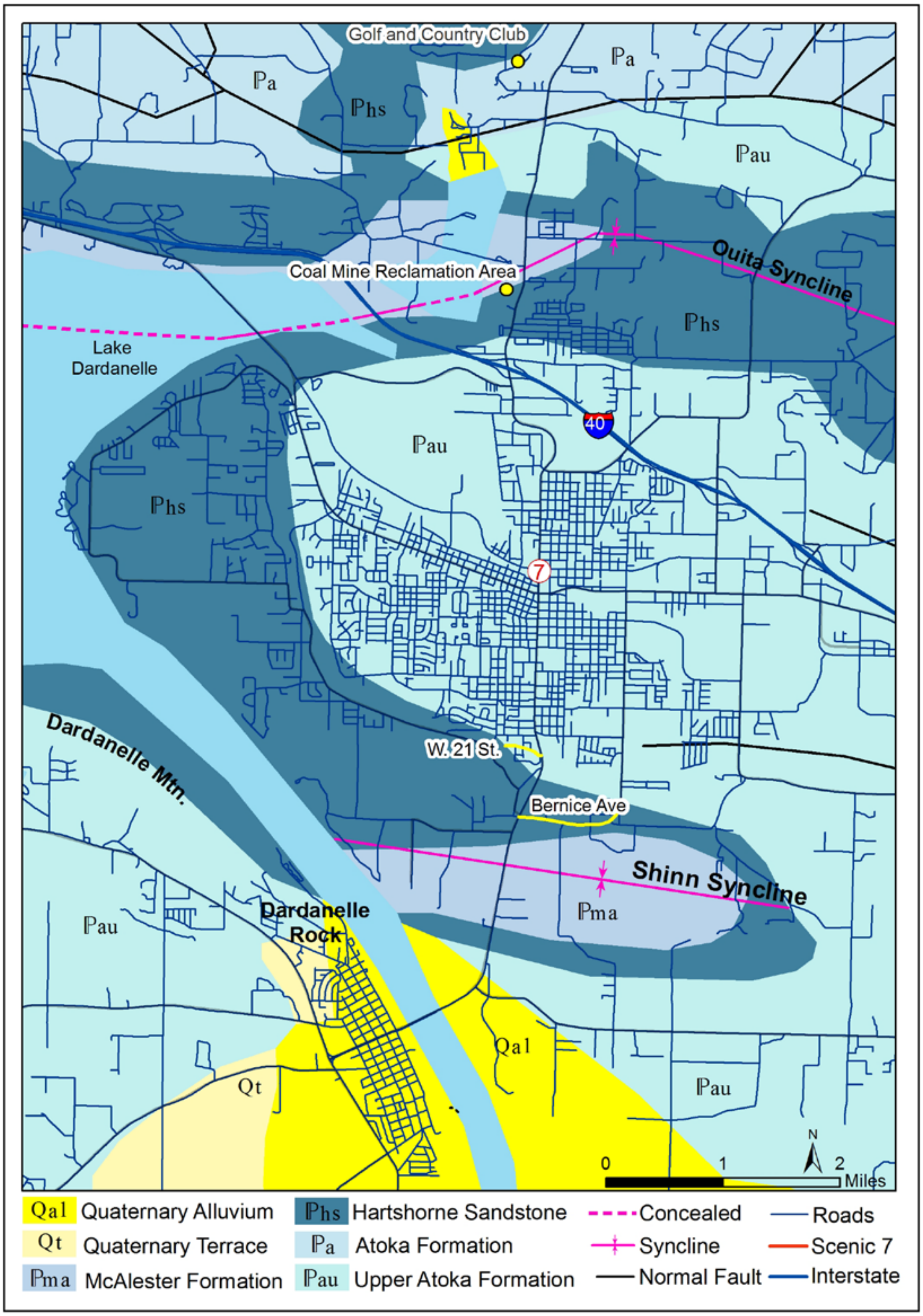


Figure 30. Geologic map of Russellville and Dardanelle
(from Geologic map of Arkansas, 1:500,000 scale)

Figure 31. Hartshorne Sandstone – Atoka Formation
(South Limb of Shinn Basin, 35°14’08”N 93°08’26”W)

Figure 32. Dardanelle Rock, Hartshorne Sandstone
(Arkansas River at Dardanelle, 35°14’10”N 93°09’43”W)

Dardanelle is located on Arkansas River alluvial (river) deposits. These deposits range in age from the Quaternary Period, Holocene Epoch (approximately 11,000 years ago) to the present time. The deposits narrow toward the northwest and widen southeast to approximately 6 miles in the Holla Bend National Wildlife Refuge. The sediment of the floodplain consists of gravel, sand, silt, and clay. The “bottomland” of this region is productive of soybeans, corn, cotton, and other row crops.

Figure 33. Mount Nebo
(West of Dardanelle 35°11'53"N 93°09'18"W)

Mount Nebo State Park lies due west of Dardanelle approximately 4.2 miles, "as the crow flies." Road distance to the summit is approximately 7 miles from the junction of Scenic 7 and SH 22. A side trip to the top of Nebo is well worth your time. At the intersection of Scenic 7 with SH 22 turn right and follow the signs to the State Park. The views are spectacular!

Mount Nebo is a prime example of the type of mesa-like, flat-topped mountains typical of the Arkansas River Valley Province (Fig. 33). Other prominent mountains of this "erosional-remnant" type include: Petit Jean, Spring, and Magazine. Each of these structures is capped by sandstone folded into shallow-dipping synclines. These sandstones are more resistant to erosion because compression of the rock, along the fold axis, closed most fractures and promoted recrystallization of the mineral grains. All of these mountains were part of a regional plateau that was eroded by the ancestral Arkansas River and its tributaries.

Road Trip Log -- Dardanelle to Ola

As you leave Dardanelle on Scenic 7, the agriculturally rich soil of the floodplain and terraces of the Arkansas River are seen. Also, excellent views of Mount Nebo and Jones Mountain are seen to the right (west) of Scenic 7 (Fig. 34). The road continues to cross alluvium for approximately 2 miles. At Smiley Bayou bridge we leave the alluvium behind and once again encounter the upper Atoka Formation. The Atoka sandstone and shale have dips generally less than 10 degrees in this area.

Approximately 0.3 mile south of the town of Centerville, the middle Atoka is exposed with dips up to 85 degrees, indicating the close proximity of a frontal thrust fault of the Ouachita Mountains. The fault is crossed by the highway about 0.9 miles south of Centerville. Over the next mile, four additional thrust faults in the middle and lower Atoka are crossed. However, there is little easily seen surface expression of these faults that were mapped through the use of aerial photographs and detailed field study. The road continues to cross the Atoka Formation for another 4 miles to the town of Ola where two more thrust faults are mapped, but which are not readily visible due to a lack of bedrock exposures near Scenic 7.

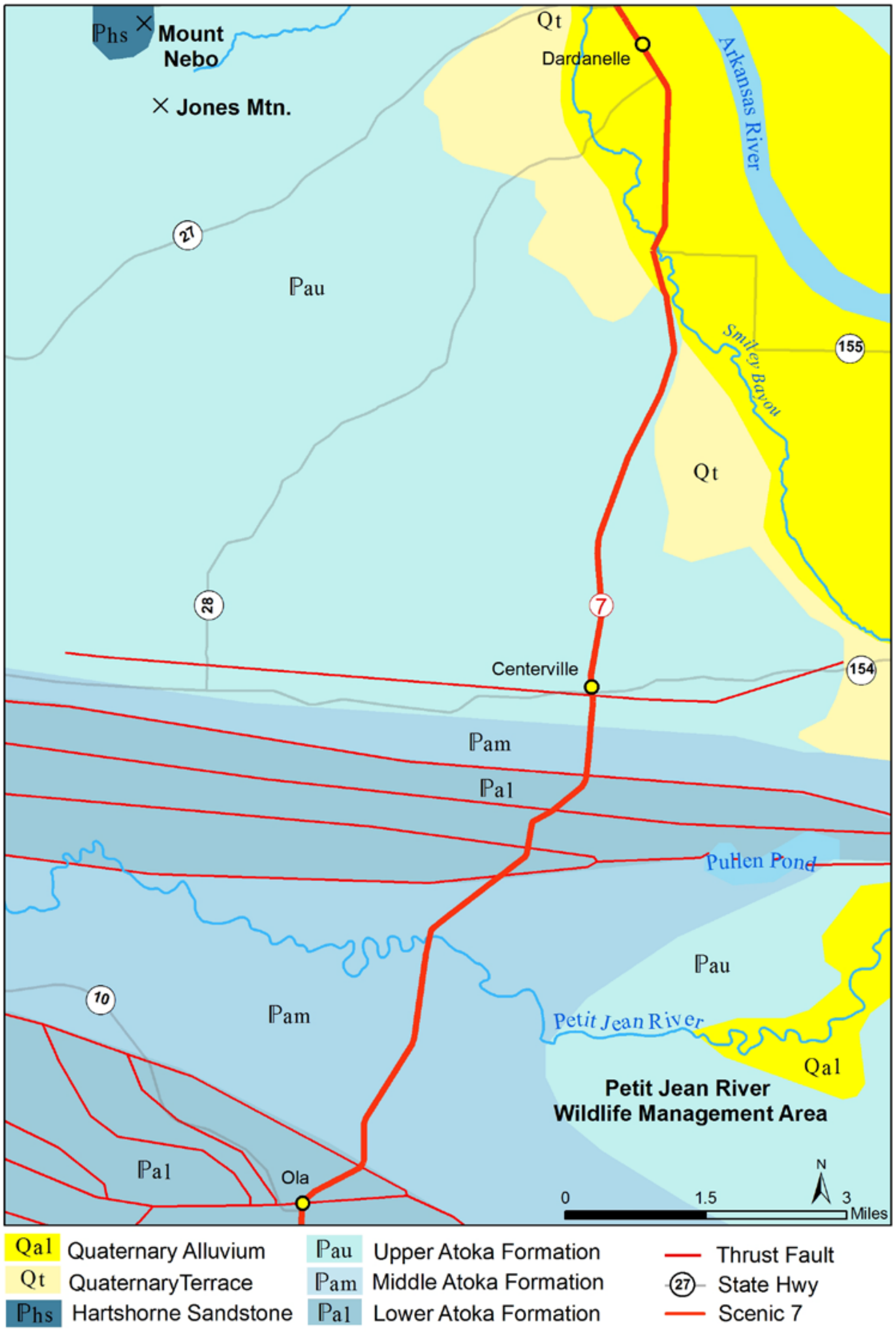


Figure 34. Geologic map from Dardanelle to Ola
(from Geologic Map of Arkansas 1:500,000)

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^{o} 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.

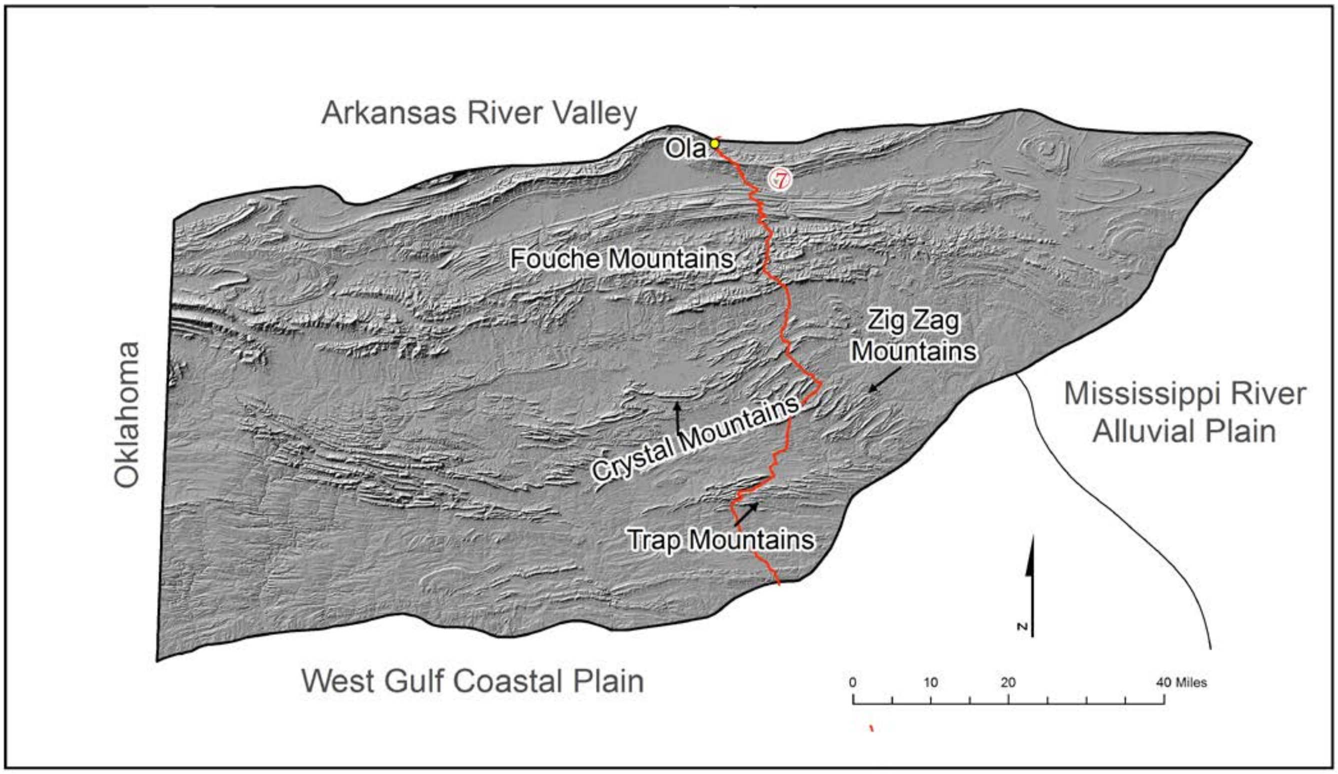


Figure 35. Shaded relief map of the Ouachita Mountains
(source, Arkansas Geological Survey)

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.

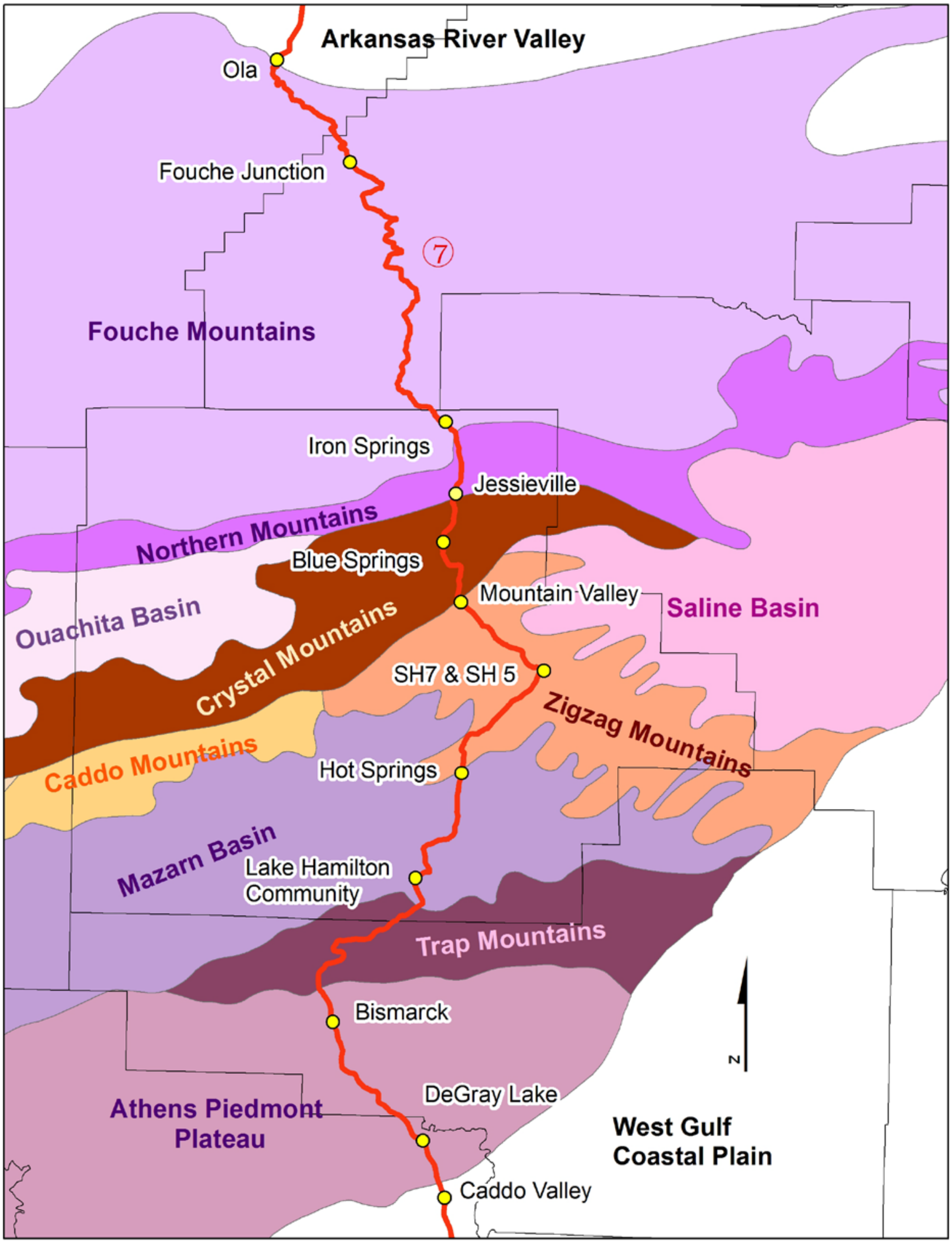


Figure. 36. Physiographic subdivisions of the Ouachita Mountains
(source, Arkansas Geological Survey)

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.

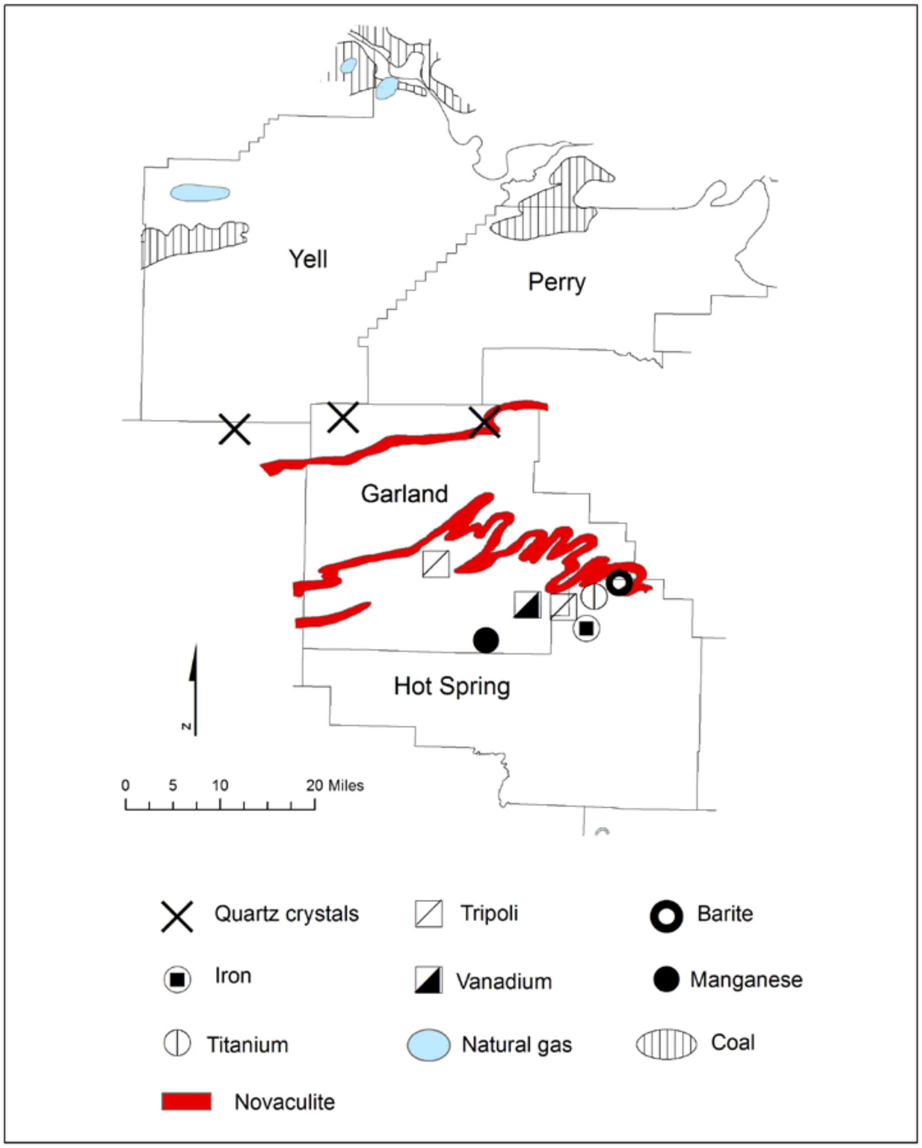


Figure 38. Location map of rock and mineral resources in Yell, Perry, Garland, and Hot Spring Counties
(from Arkansas Mineral Resources, page size map)

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.

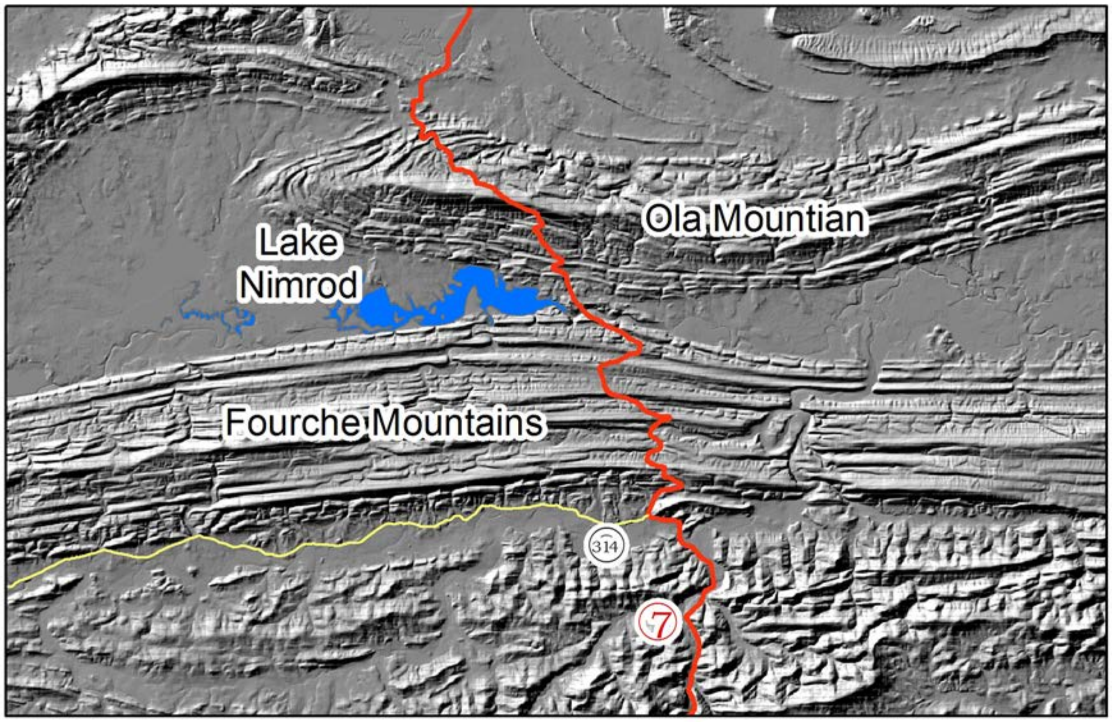


Figure 39. Fourche Mountains, Shaded Relief Map of Arkansas
(Source, Arkansas Geological Survey)

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”.

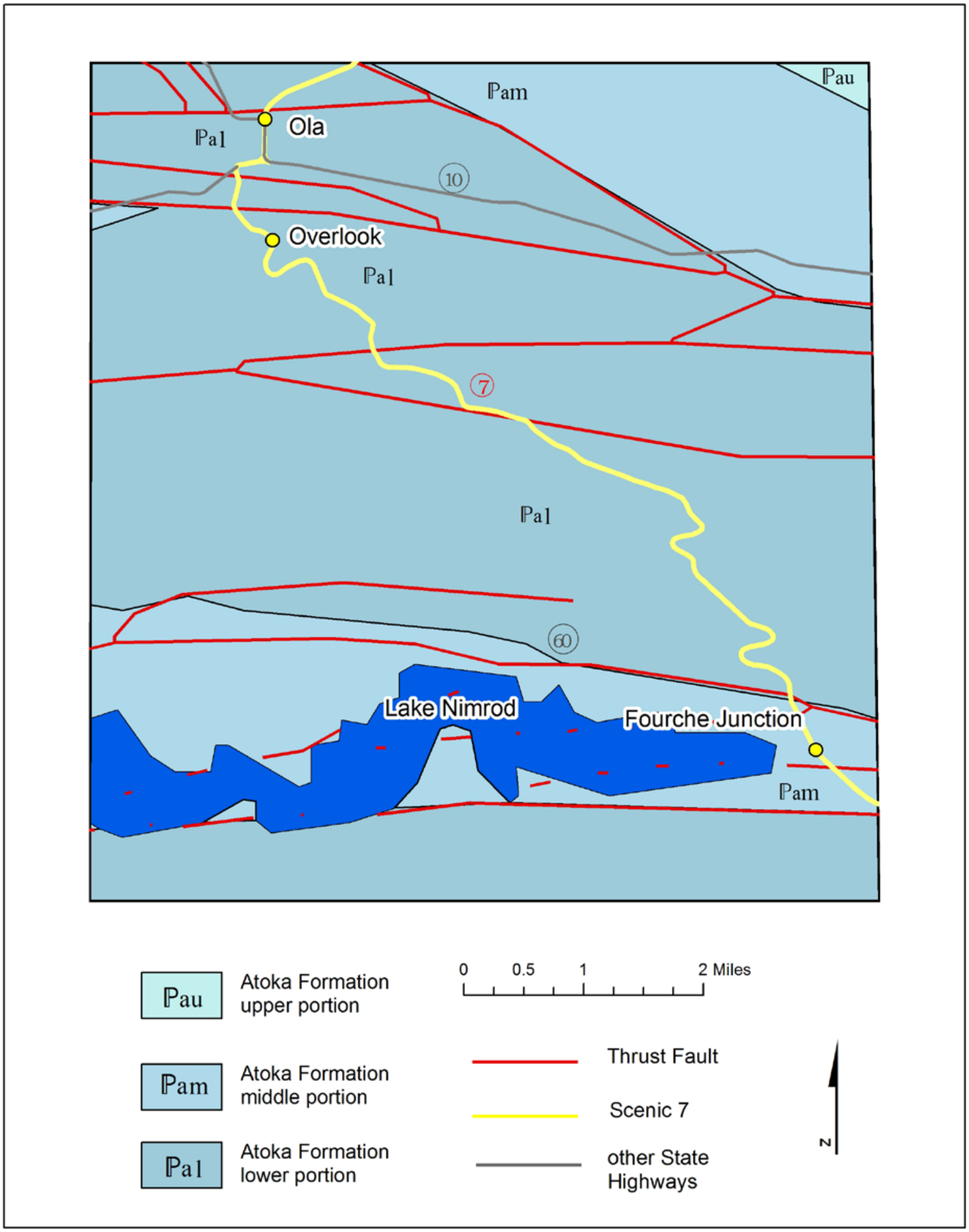


Figure 42. Geologic map from Ola to Fourche Junction
(from Geologic map of Arkansas, 1:500,000 scale)

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).

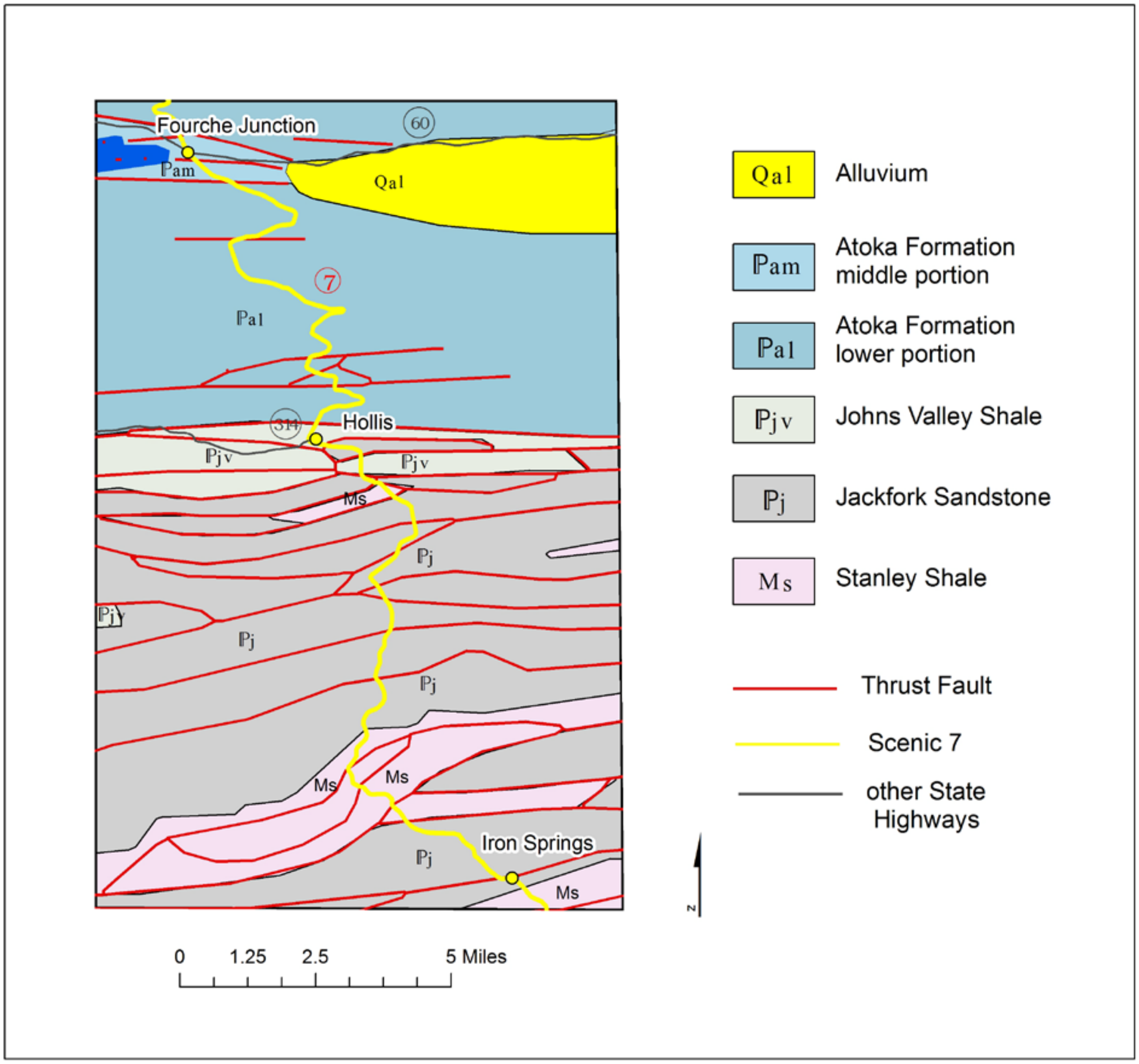


Figure 45. Geologic map from Fourche Junction to Iron Springs
(from Geologic map of Arkansas, 1:500,000 scale)

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.

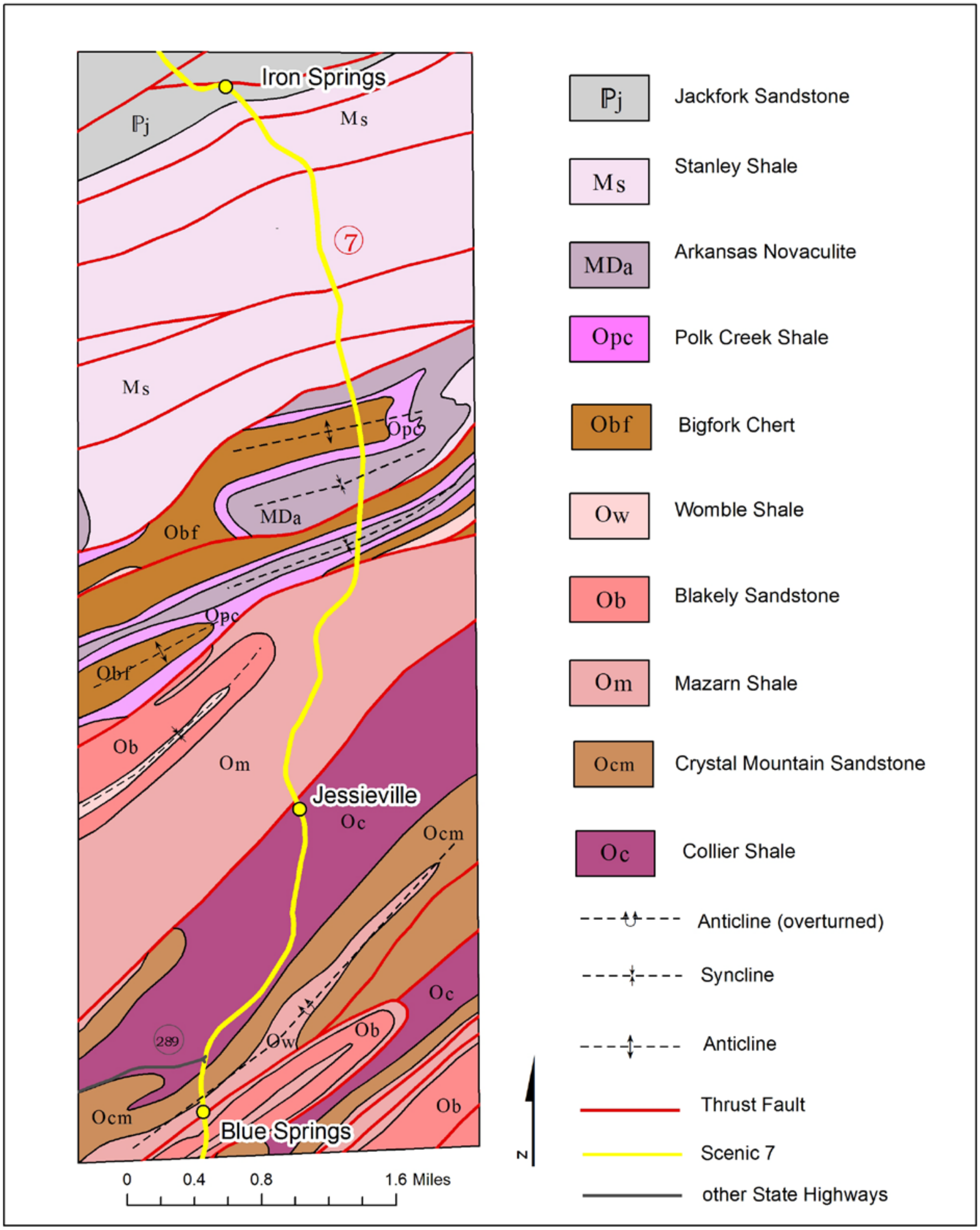


Figure 47. Geologic map from Iron Springs to Blue Springs
(from Geologic map of the Ouachita Mountain and a portion of the Arkansas River Valley regions, 1:100,000 scale)

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.

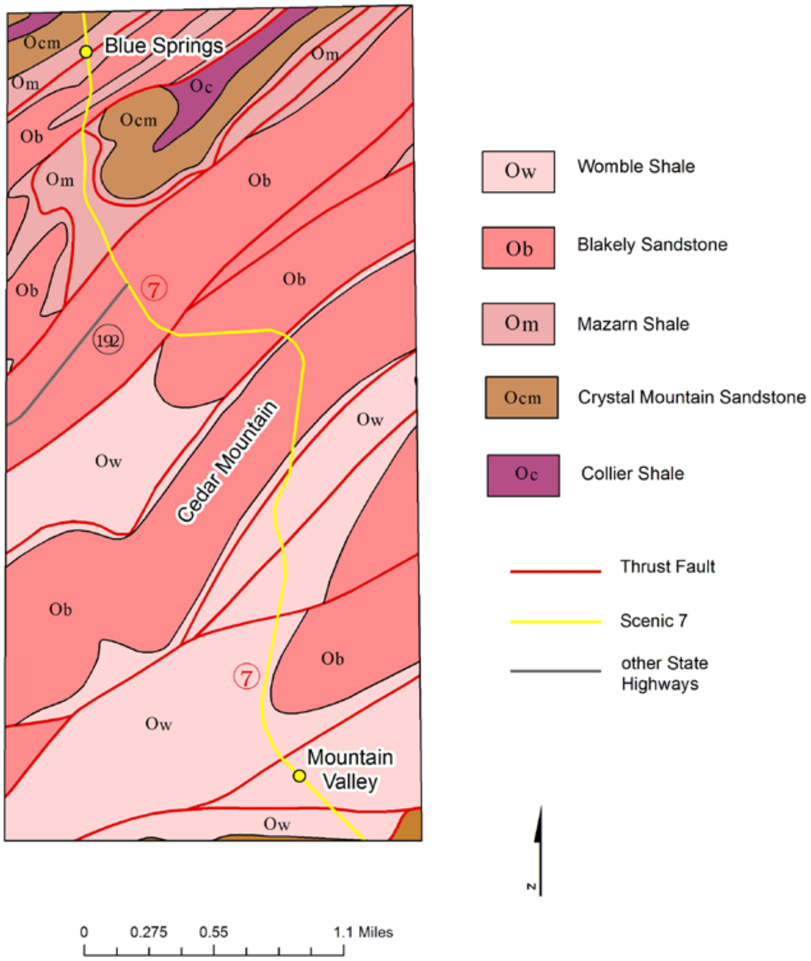


Figure 48. Geologic map from Blue Springs to Mountain Valley
(from Geologic map of the Ouachita Mountain and a portion of the Arkansas River Valley regions, 1:100,000 scale)

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.

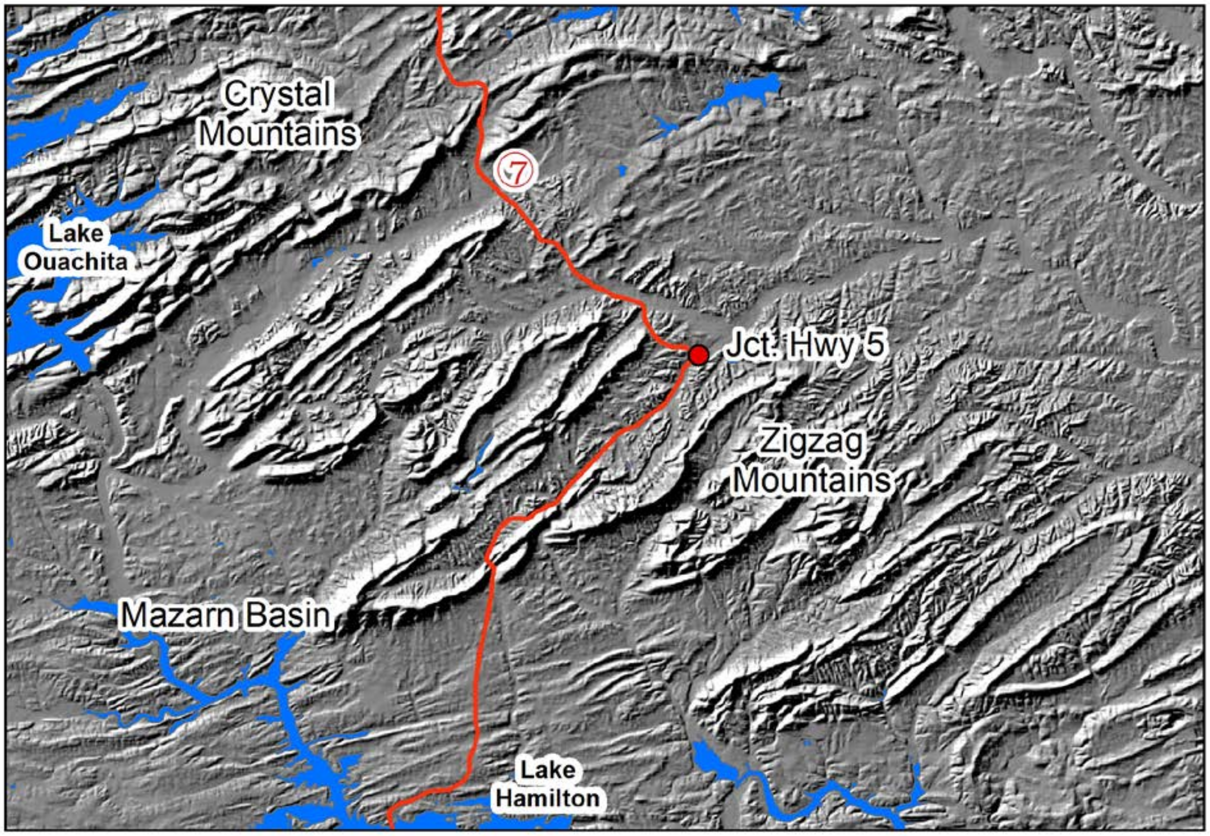


Figure 50. Zigzag Mountains, Shaded Relief Map of Arkansas
(Source, Arkansas Geological Survey)

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.

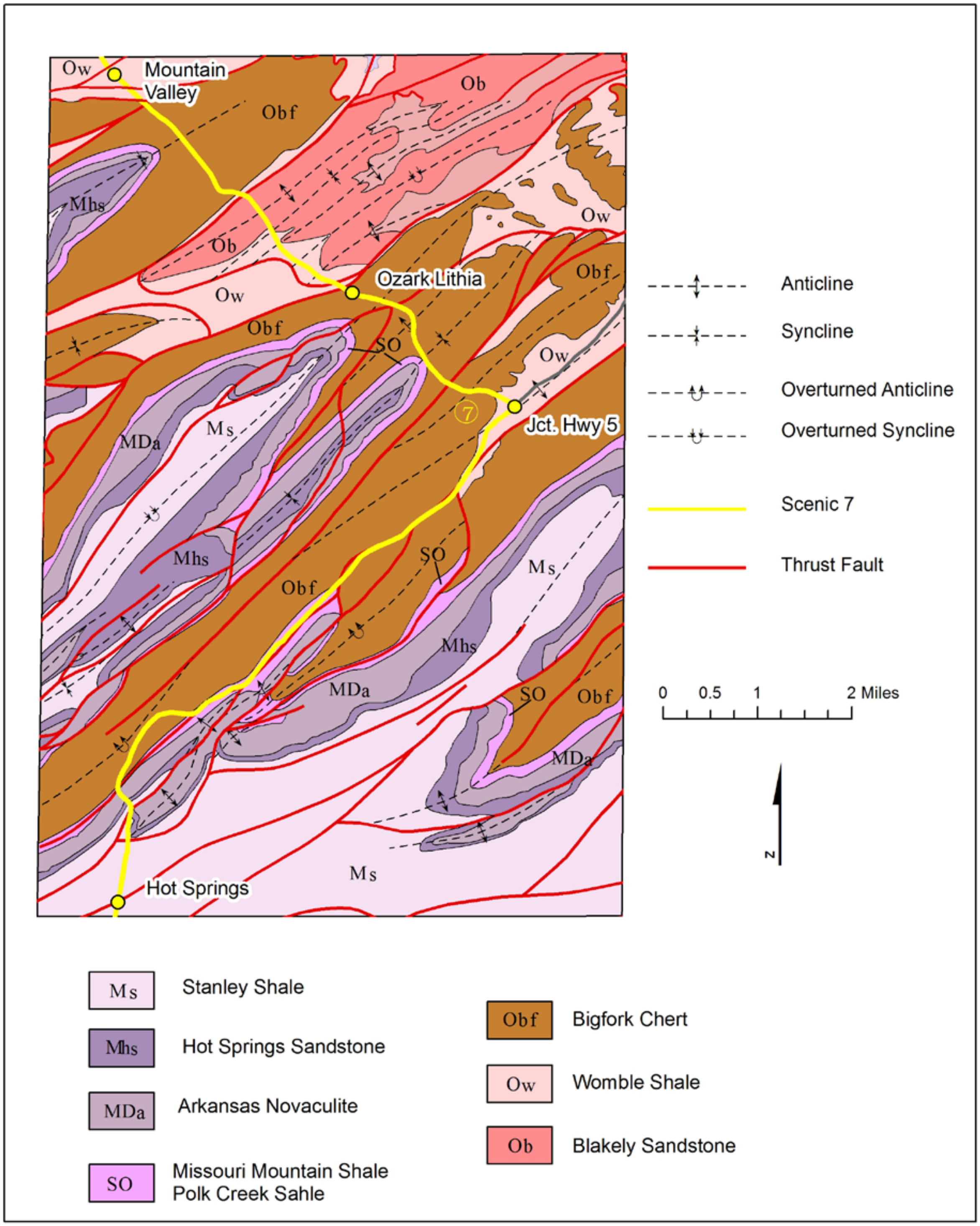


Figure 51. Geologic map from Mountain Valley to Hot Springs
(from Geologic map of Hot Springs North, Hot Springs South,
Fountain Lake, and Lake Catherine, 1:100,000)

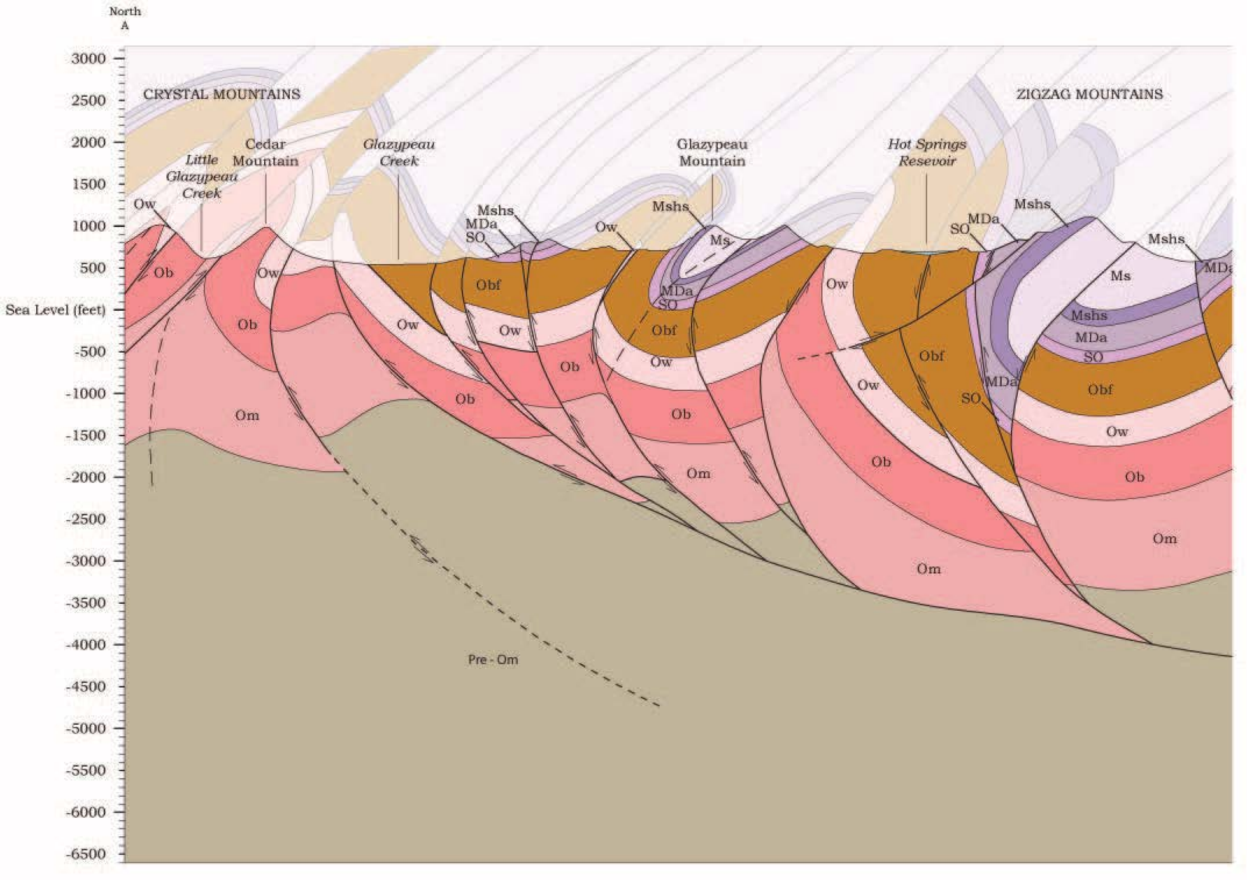


Figure 52. Zigzag Mountains Cross Section
(from Geologic map of Hot Springs North, Hot Springs South,
Fountain Lake, and Lake Catherine, 1:100,000)

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).

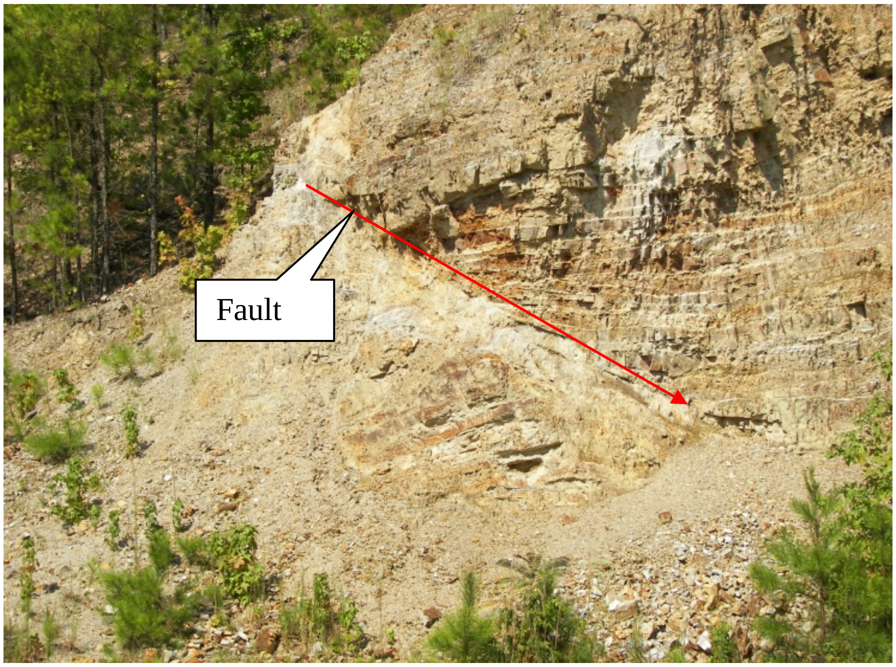


Figure 53. Womble Shale
(Fountain Lake Community, 34^{o}33′48″N 92^{o}59′43″W)

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).

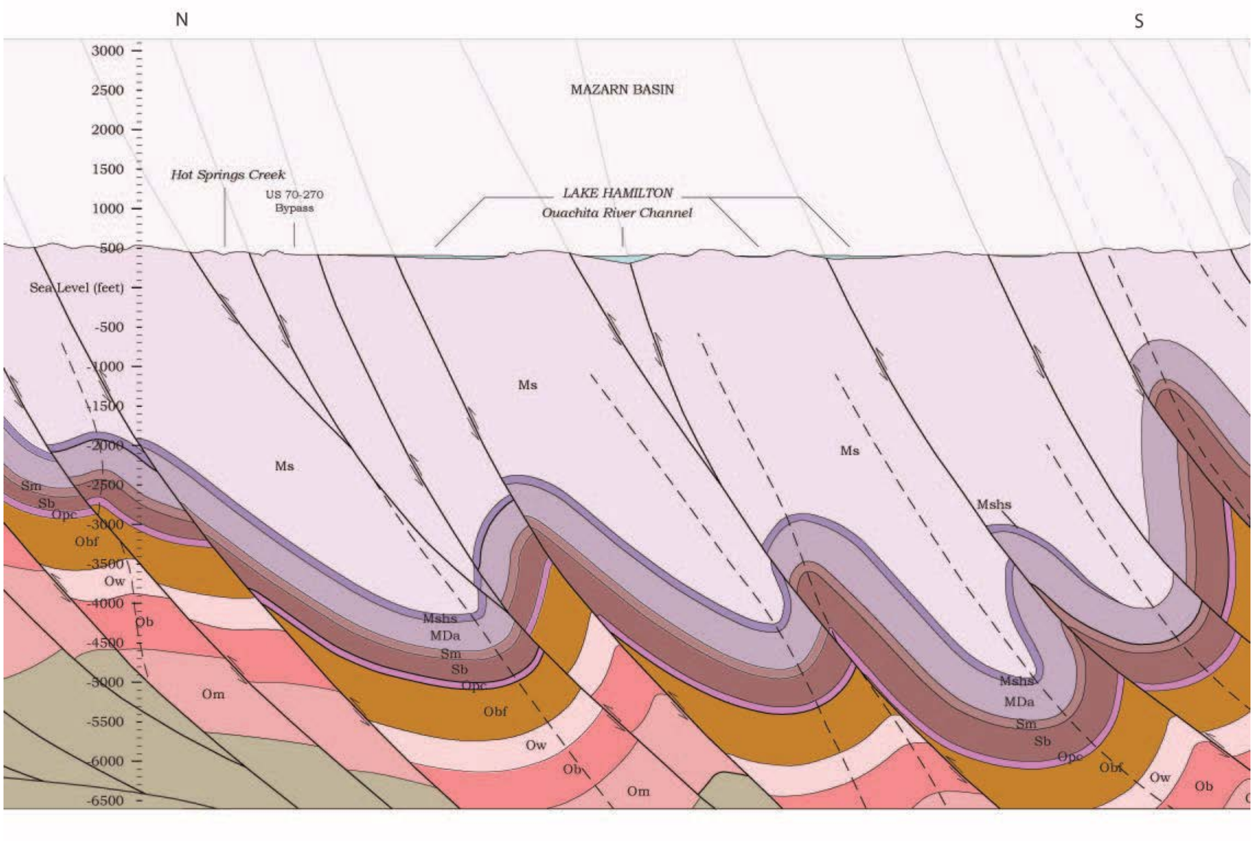


Figure 56. Mazarn Basin Cross Section
(from Geologic map of Hot Springs North, Hot Springs South,
Fountain Lake, and Lake Catherine, 1:100,000)

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).

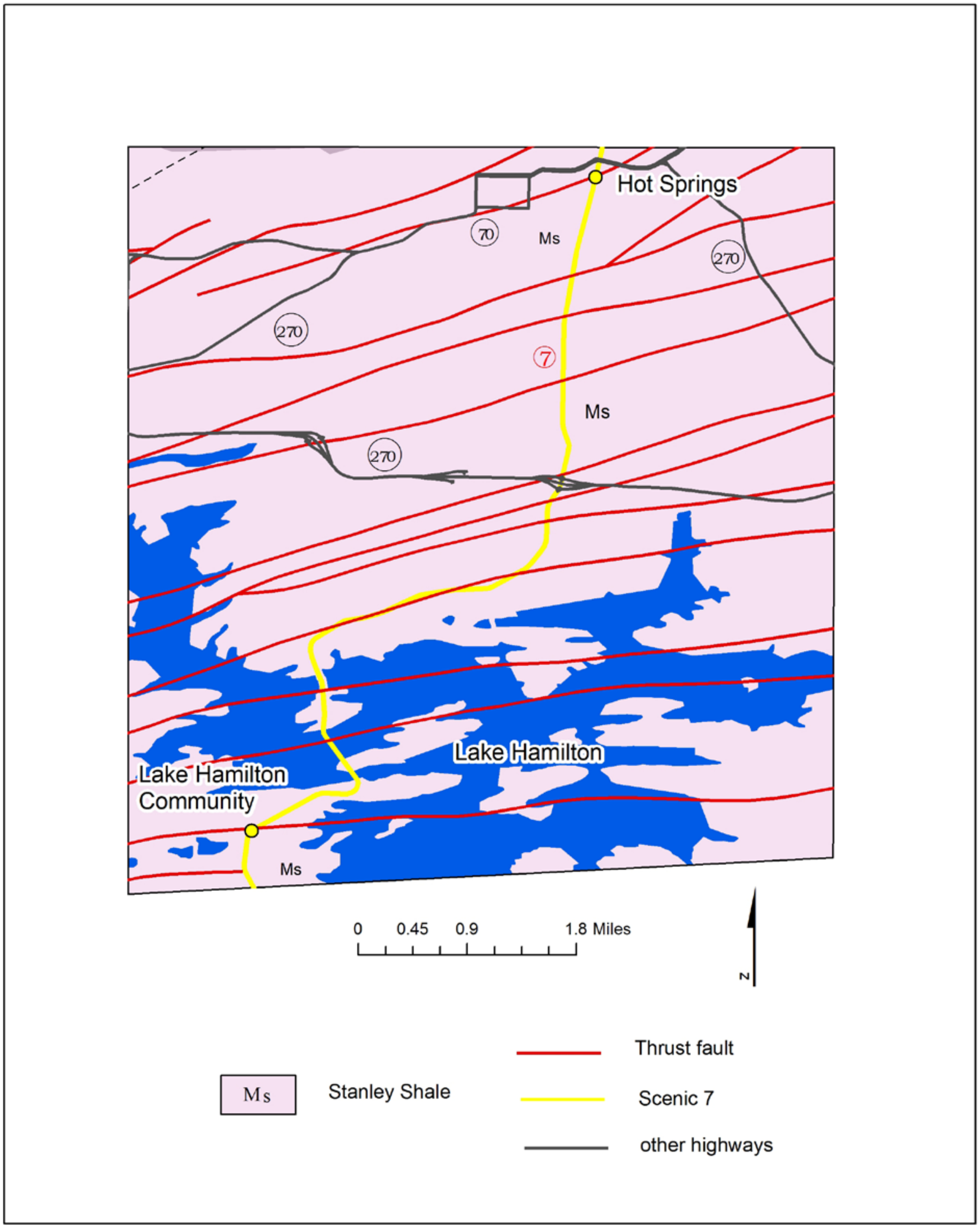


Figure 57. Geologic map from Hot Springs to Lake Hamilton Community
(from Geologic map of Arkansas, 1:500,000 scale)

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.

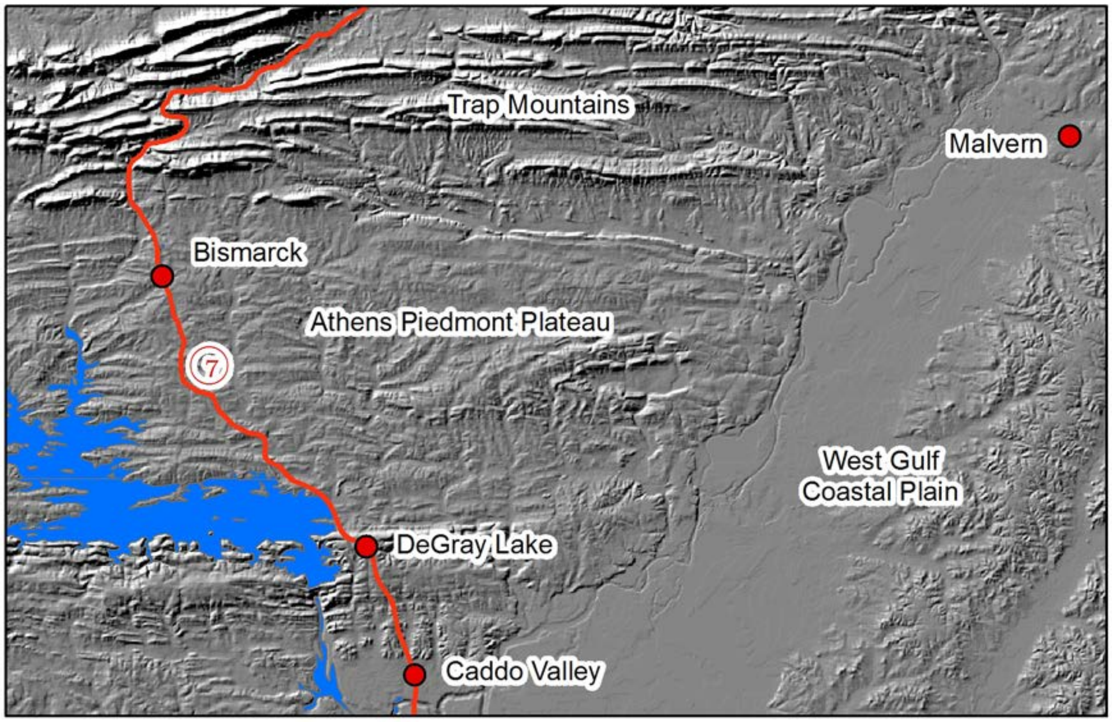


Figure 59. Shaded Relief Map of Arkansas
(Source, Arkansas Geologic Survey)

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.

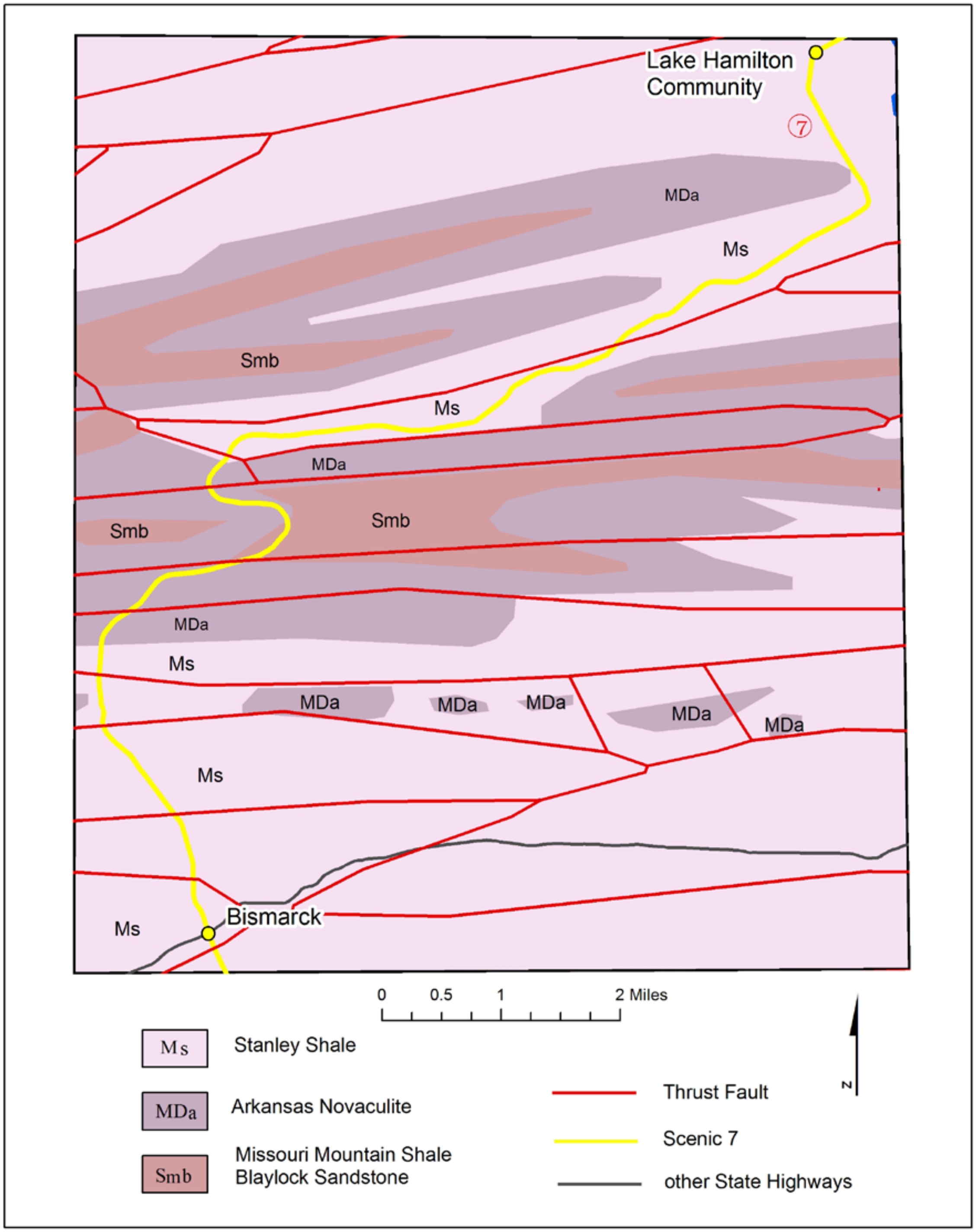


Figure 61. Geologic map from Lake Hamilton Community to Bismarck
(from Geologic map of Arkansas, 1:500,000 scale)

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.

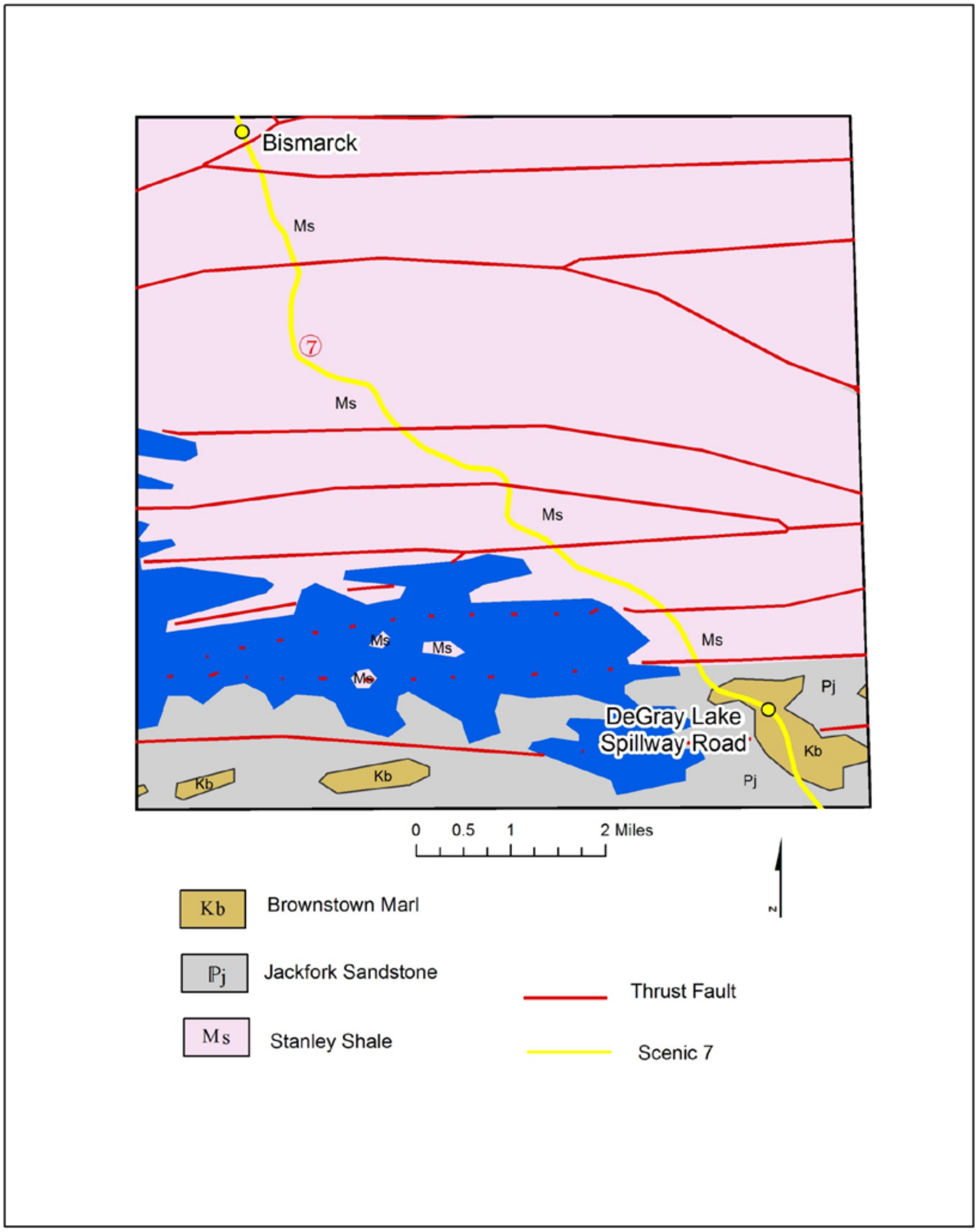


Figure 62. Geologic map from Bismarck to DeGray Lake
(from Geologic map of Arkansas, 1:500,000 scale)

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.

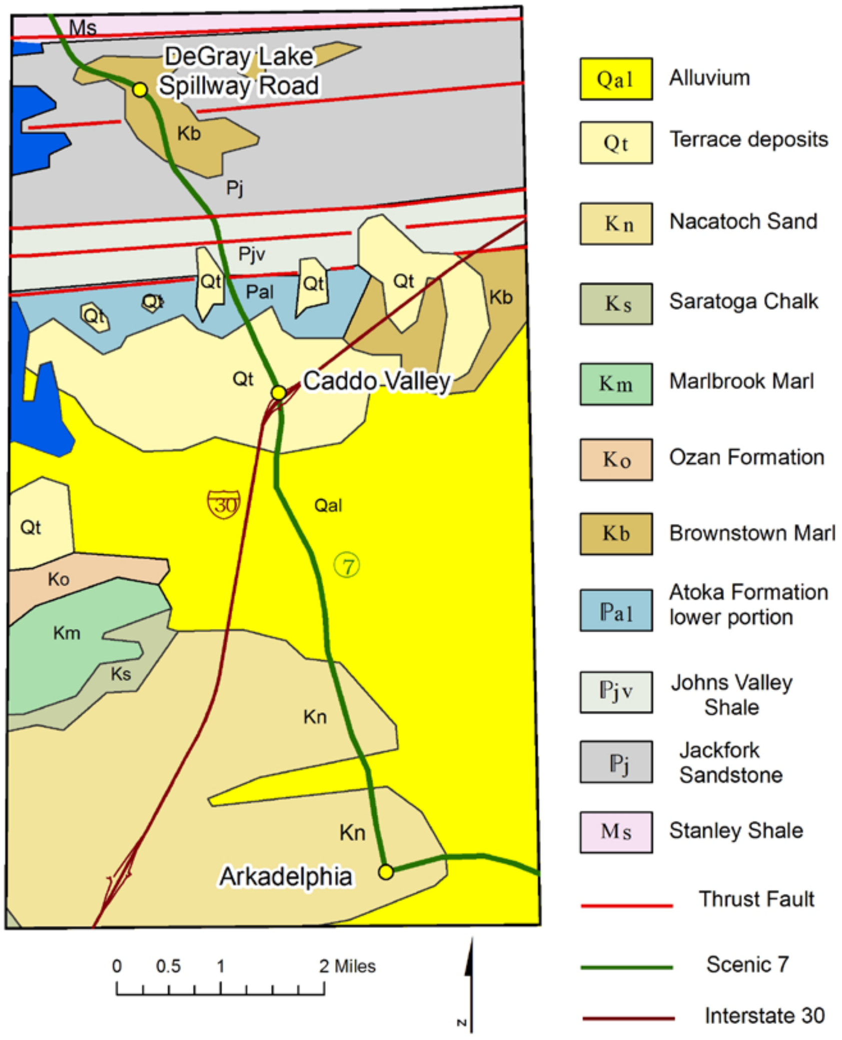


Figure 64. Geologic map from DeGray Lake to Arkadelphia
(from Geologic map of Arkansas, 1:500,000 scale)

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

West Gulf Coastal Plain

Overview

The West Gulf Coastal Plain, located in the southwestern quarter of the state, extends from the Oklahoma border on the west to the Bayou Bartholomew on the east (Fig. 1). It is approximately 100 miles wide (north to south) and 160 miles long (west to east). Elevations vary from 432 feet above sea level at DeQueen on the west to the floodplain of the Bayou Bartholomew on the east where the elevation is 184 feet. The landscape is especially hilly in the DeQueen area, near the Oklahoma border, and flat-lying near Monticello on the east. The region is crossed by four major river systems including the following: Red, Little Missouri, Ouachita, and Saline, all of which have well developed tributary networks. These drainage systems create a hilly, “rolling” landscape marked by numerous floodplains (Fig. 66).

At Caddo Valley, Scenic 7 leaves the Paleozoic-aged rock of the Ouachita Mountains and enters the younger sedimentary rocks and alluvial deposits of the West Gulf Coastal Plain. The sedimentary rocks and sediments exposed along Scenic 7 range in age from Early Cretaceous-age (145 million years ago) to Quaternary Period –Holocene Epoch-age sediments (recent to 11,700 years ago) (Fig. 67). The soft, fossil-bearing sedimentary rocks of the region are essentially flat-lying (dips less than one degree toward the south).

Rock Types Exposed Along Scenic 7 in the West Gulf Coast Plain

(Based on McFarland, 2004)

(Rock types are listed from youngest to oldest, map symbols follow formation names.)

Alluvium (Qal)
Age: Holocene Epoch (11,000 years ago to recent).
Description: modern stream-laid deposits, up to 25 feet thick, consisting of gravel of various sizes, usually overlain, by sand, silt, and a variety of clay types. None of these sediments are lithified. Usually, these “bottom-lands” contain significant amounts of organic matter (humus) making them excellent agricultural areas. Many of the gravel particles are novaculite and chert from the Ouachita Mountains and Cretaceous-age formations in the West Gulf Coastal Plain.
Environment of deposition: stream and river channels and flood plains.

Terrace deposits (Qt)
Age: Holocene Epoch (11,000 years ago to recent).
Description: The types of sediments just described as alluvium are also present in the terrace deposits. Most terraces are less than 50 feet thick and several ten’s of feet above the modern flood plain.
Environment of deposition: A terrace is an old flood plain that was “left behind” as the river or stream responsible for the original deposit shifted course and eroded a new, deeper channel.

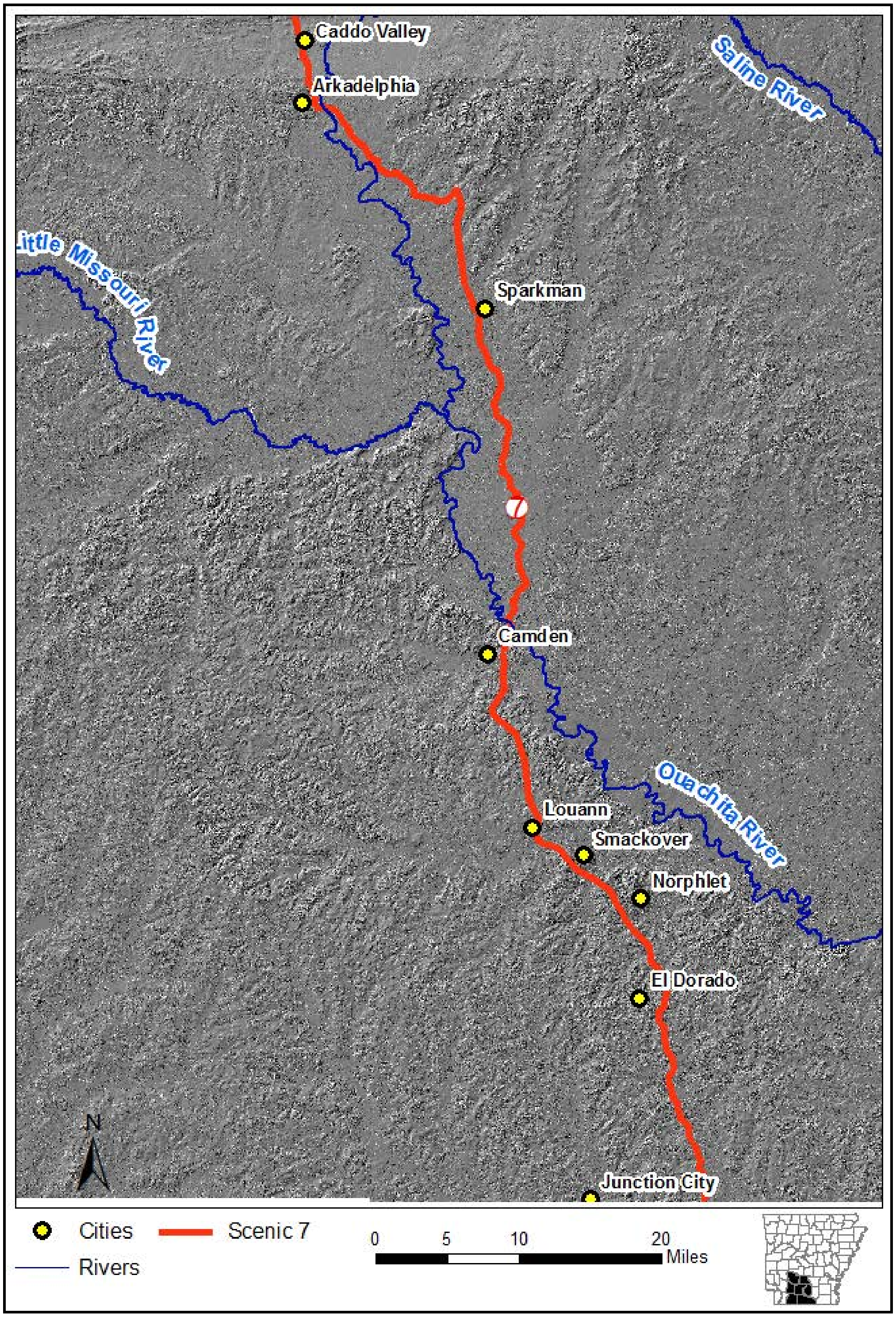


Figure 66. Shaded topographic relief map from Arkadelphia to El Dorado (source, Arkansas Geological Survey)

Claiborne Group (Tc)
Age: Tertiary Period, Eocene Epoch (56 to 34 million years ago).
Description: medium to fine sands, silts, and silty clays. Some zones (levels) contain a significant amount of plant-derived, carbon-rich deposits. Lignite (soft brown coal) deposits are present in areas that were originally coastal swamps. Fossils in the Claiborne include: leaf impressions, woody material in the lignite beds, and reptile and fish bones and teeth. The Claiborne's lower contact is unconformable and the thickness ranges from a few feet to 1,500 feet.
Environment of deposition: coastal swamps and embayments, where low-lying, land-derived sediments were intermixed with marine sediments.

Wilcox Group (Tw)
Age: Tertiary Period, Eocene Epoch (56 to 34 million years ago)
Description: fine sands, silty sands, light gray or brown clays, and gravels with several thick beds of lignite; plant fossils and trace fossils are present in some lignite deposits and clays associated with the lignite. The Wilcox's thickness ranges from very thin to over 1,000 feet, while the average thickness is reported to be 850 feet.
Environment of deposition: non-marine.

Nacatoch Sand Formation (Kn)
Age: Late Cretaceous Period (approximately 75 million years ago)
Description: unconsolidated sand, often yellow to gray in color that usually contains some of the following types of interbedded sedimentary materials: hard, fossil-bearing limestone; glauconite-bearing (an iron-bearing clay mineral, often called greensand) sandstone; clay-rich blue to black sand; light-gray clay; and calcite-bearing clay. The following types of fossils have been collected from the Nacatoch: corals, echinoderms, bryozoa, brachiopods, clams, cephalopods, gastropods, sea worm and crab parts, and shark teeth. The Nacatoch is separated from alluvium at its top and the underlying strata by unconformities. The Formation ranges from 150 to 400 feet in thickness.
Environment of deposition: shallow marine.

Brownstown Marl/Formation (Kb)
Age: Late Cretaceous (approximately 85 million years ago)
Description: clay-rich marl (a mixture of calcium carbonate and clay); some thin sandy limestone, sandy marl, and fine-grained sand. Colors are tan, brown, blue, green, red, yellow, gray and any combination depending on amount of weathering and iron content. Maximum thickness is about 250 feet, but thins east and west from the type locality in Howard County.
Environment of deposition: shallow marine.

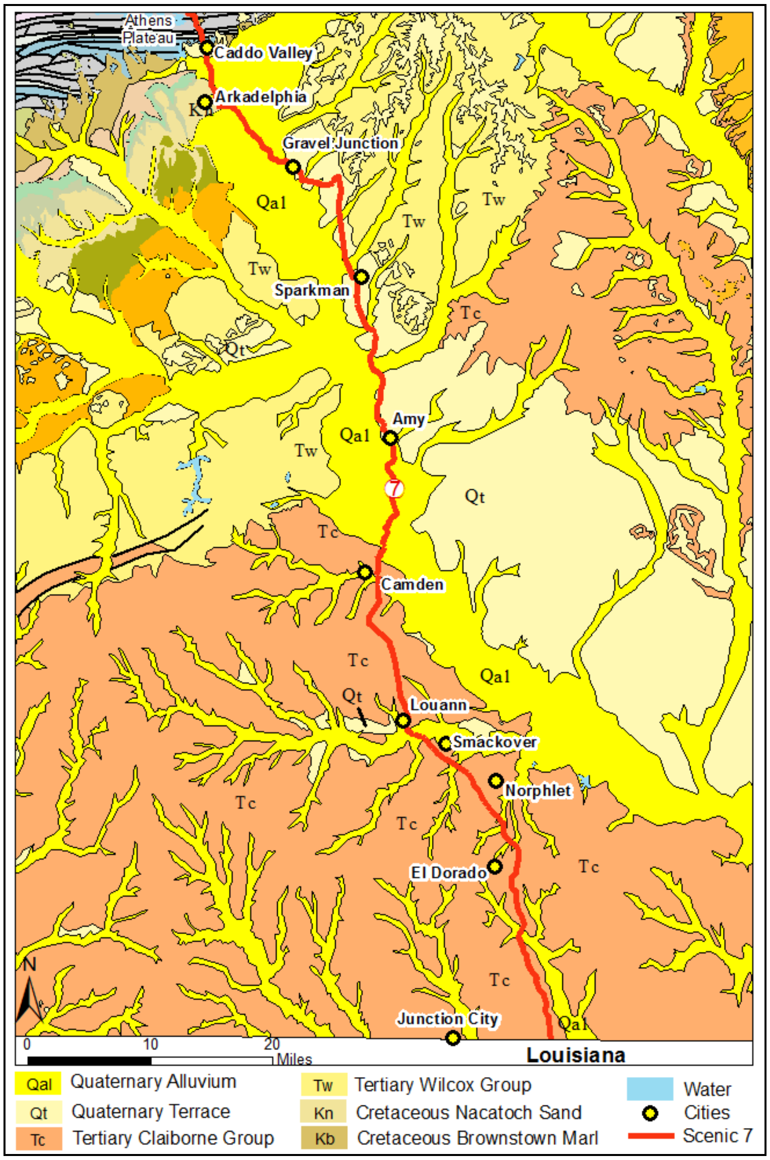


Figure 67. Geologic map of the West Gulf Coast Plain along Highway 7 from Arkadelphia to the Louisiana border
(from Geologic map of Arkansas, 1:500,000 scale)

West Gulf Coastal Plain Geologic History
(Based on Guccione, 1993)

During the Mesozoic Era (251 to 65 million years ago), the large continent formed by the collision of ancestral North America, South America, and Africa began to break apart due to sea-floor spreading (rifting). In the Jurassic Period (200 to 145 million years ago) rifting had progressed enough for the Gulf of Mexico to begin forming. The Gulf was relatively shallow and some areas became isolated enough to cause deposition of evaporate sediments: rock salt (halite) and calcium sulfates (gypsum and anhydrite). During the Cretaceous Period (145 to 65 million years ago) and the following Tertiary Period (65 to 2.6 million years ago), sea level continued to rise and sediments covered the southern edge of the Ouachitas forming the West Gulf Coastal Plain. The Ozark Plateaus and Ouachita Mountains remained above sea level and weathering and erosion of these exposed rocks produced sediments.

The fifth physiographic division of the state (Mississippi River Alluvial Plain) formed during the Tertiary Period. A billion-year-old graben structure in the basement igneous rock underlying the region (Reelfoot Rift, aka Mississippi River graben) was reactivated and extended northward from the ancestral Gulf of Mexico into North America creating what is known today as the Mississippi Embayment. The Embayment (Mississippi River Alluvial Plain) contains Tertiary and upper Cretaceous-aged sedimentary rocks, and alluvial sediments deposited by the Mississippi River.

Rock and Mineral Resources

Clark County

Sand and gravel are the most utilized mineral/rock resource in Clark County. However, the county has the following additional resources: crushed limestone, chalk, clay, and lignite (Fig. 68). Also, a mercury ore deposit was mined in the western part of the county south of the town of Amity. The mercury sulfide mineral (cinnabar) is present in fractures related to the thrust faults in the Jackfork Sandstone and Stanley Shale of the Athens Plateau. Mining of cinnabar began in Pike County in 1931, extended into western Clark County in 1939, and continued until 1946. Total production of refined mercury was over 950,000 pounds for the entire district over the 15 years of mining. The amount produced in Clark County was about 285,000 pounds. No commercial mining for mercury has occurred since 1946.

Dallas, Ouachita, and Union Counties

These counties have similar mineral/rock resources of clay, sand and gravel, and lignite (Fig. 69). Lignite is a soft brown-black coal that has about half of the heat production value of high-rank bituminous coal. Lignite has been blended with bituminous coal and used as a furnace fuel to generate electricity. However, it was recognized in the early 1900's that Arkansas lignite could be distilled to produce up to 38 gallons of crude oil per ton with an average yield of 25 gallons per ton (AGS Website, 2012). It is estimated by the Arkansas Geological Survey that the state contains about 4.3 billion tons of lignite in the Wilcox Group (Tertiary Period, Eocene Epoch) within 150 feet of the surface. This amount of lignite could produce approximately 2.6 billion barrels of liquid petroleum products. Such an amount is estimated to be about 14 percent of the crude oil reserves in the North Slope Field in Alaska.

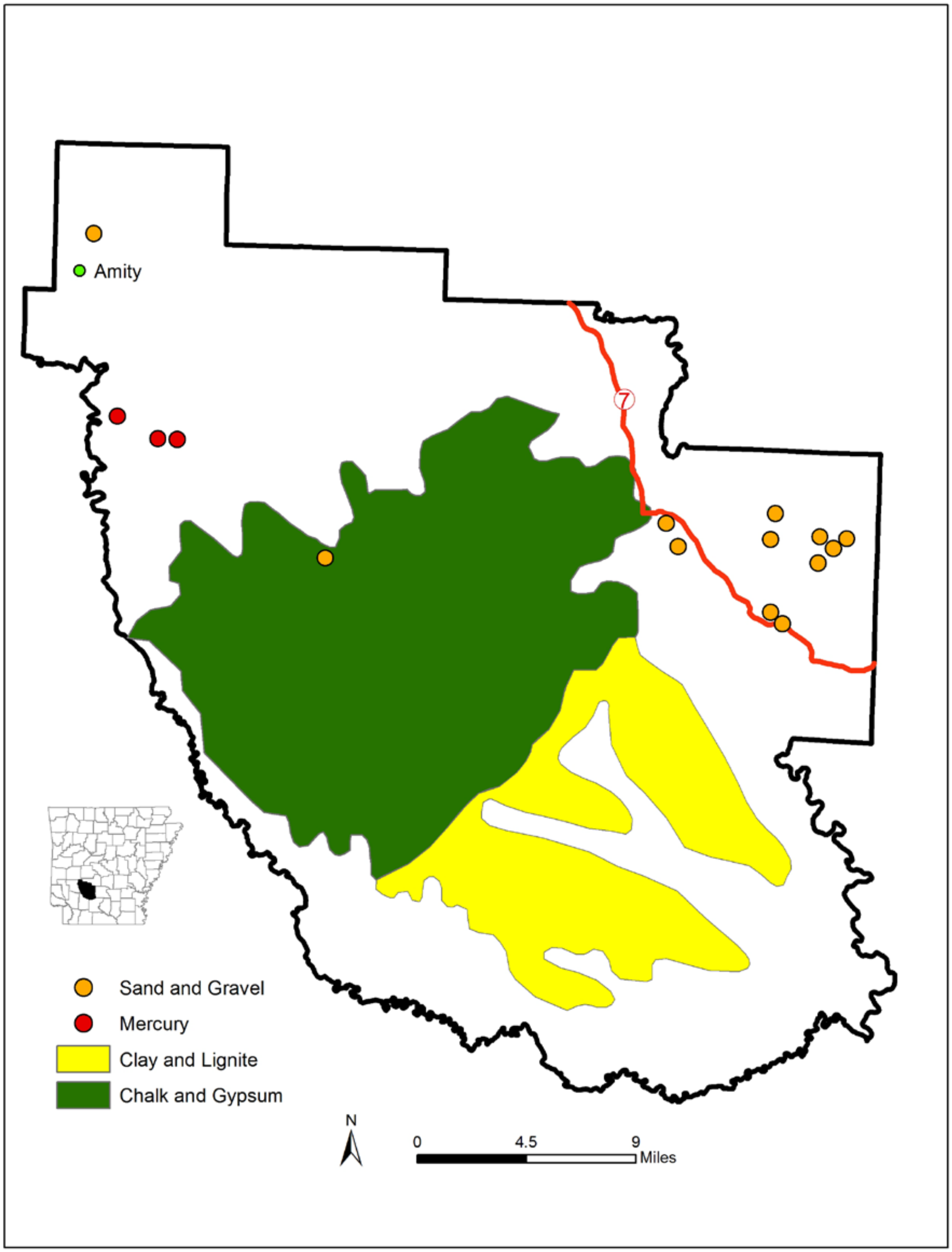


Figure 68. Rock and mineral resources of Clark County
(from Arkansas Mineral Resources, page size map**)**

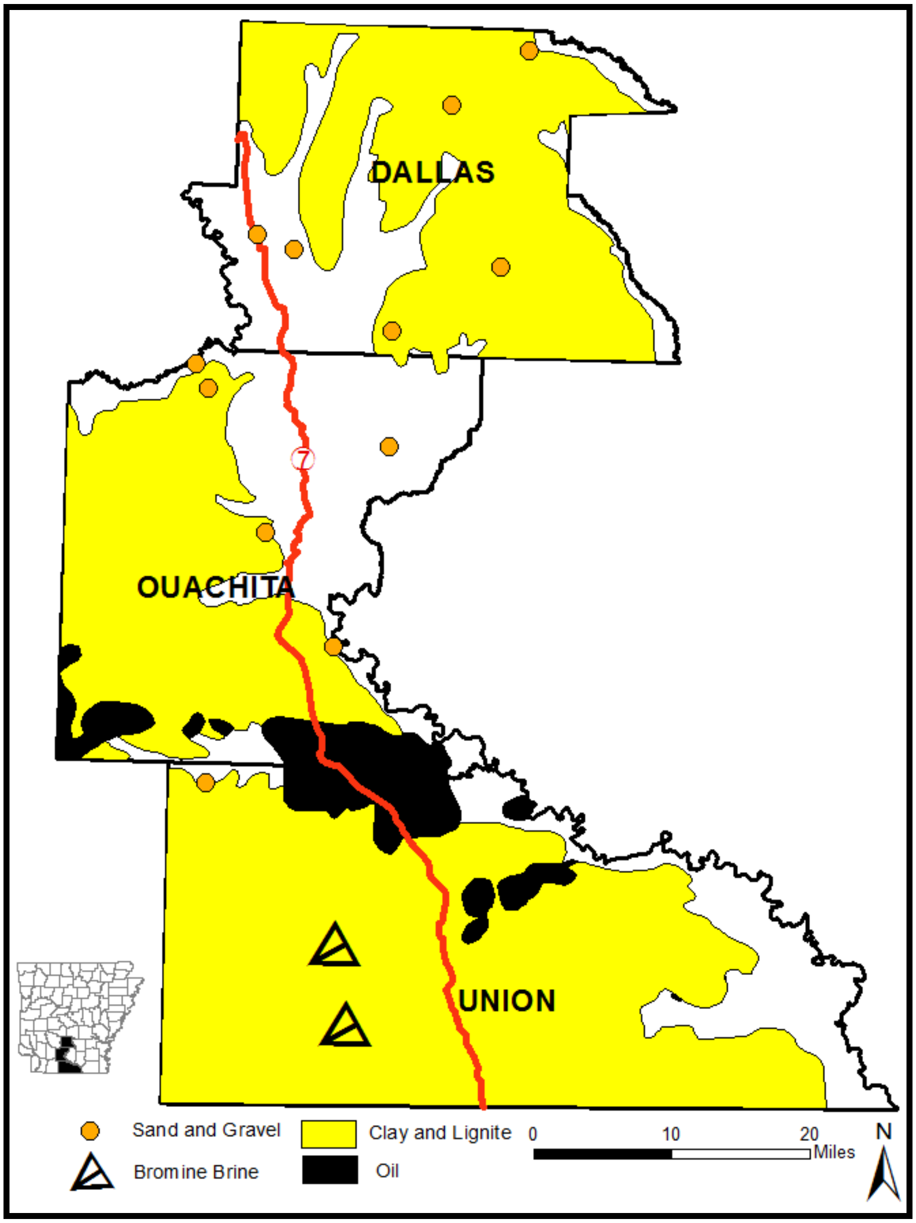


Figure 69. Rock and mineral resources of Dallas, Ouachita, and Union Counties (from Arkansas Mineral Resources, page size map)

South Arkansas Oil

Ouachita and Union Counties

Scenic 7 passes through Arkansas' oil boom area of the 1920's. The towns of Smackover and El Dorado lie in the center of a ten county oil/gas-rich region. Eighty-five percent of the oil production has come from the following four counties: Union, Lafayette, Columbia, and Ouachita. If you have seen the movie “Boom Town” starring Clark Gable and Spencer Tracy you have seen Hollywood’s version of what that era was like. However, the real story is more interesting, amazing, and colorful than Hollywood’s.

After the discovery of oil in 1901 near Beaumont, Texas, interest in oil prospecting in surrounding states grew at a feverish pace. By 1910 there had been 47 wells drilled in Arkansas. Thirty-seven of these wells produced gas for which there was no market, but none produced oil. There were unsuccessful wells drilled in 1914 and 1916 near the Union-Columbia county line. Many of these early prospects were drilled where there were gas seeps at the surface. The Hunter No. 1 wildcat well was drilled in Ouachita County in 1920 with some oil being found, but not in commercial quantities.

The real oil boom in Arkansas began January 10, 1921 with the successful completion of a well a mile southwest of the town of El Dorado, a name that means “the Golden One”. The well, known as the Busey No.1, tapped into the Nacatoch sand at a depth of 2,233 feet. It began producing a mixture of gas, oil, and salt water with a roar that was heard over 2 miles away. The gusher spewed several hundred feet into the air and oil landed downwind as much as a mile away. Busey No. 1 produced as much as 10,000 barrels (a barrel equals 42 gallons) of oil per day. At 50 cents per barrel, the price in 1921, that works out to $5,000 per day, not bad. At today’s price, averaging about $100 per barrel, that amount of crude oil would be worth $1 million per day, now that is real money! However, the flow only lasted 45 days. But, that didn’t matter to speculators and wildcat oil prospectors.

About a year after the Busey No. 1 discovery, a geologic structure known as the Norphlet Dome was drilled about 8 miles north of El Dorado. The gas cap above the oil sand in the dome was penetrated and the gas pressure was so great the well blew out forming a surface crater 500 feet wide and 150 feet deep which swallowed the rig and all of the drilling equipment. The Smackover Field had been discovered with a bang!

Rapid expansion of the area took place and in three years it covered 40 square miles. By the end of 1922 there were over 900 wells in operation in Arkansas and production was 10,560,841 barrels for the year. In 1925 the Smackover Field was the largest oil producing area in the world! Some of its wells produced over 50,000 barrels per day! The peak of the oil boom in south Arkansas occurred in 1925 with 3,483 wells in production. That year the area produced 73 million barrels of oil. There was so much oil being produced it could not be hauled or piped away fast enough, so “crude” storage facilities were constructed. Pits were dug and earthen dams were piled up. Crude oil was stored in open lakes until it could be pumped into tankers and transported to refineries. Many personal fortunes were made and two well-known oil companies were founded, Murphy Oil Company and Lion Oil Company.

To see a graphic portrayal of the Arkansas Oil Boom, please visit the Arkansas Museum of Natural Resources in Smackover on Scenic 7 (Fig. 70). It is free and well worth your time.

Since 1970 annual oil production in Arkansas has declined from approximately 20 million barrels to 5.8 million barrels in 2011 placing the state 17th among the 31 oil-producing states. Using traditional drilling methods crude oil reserves are estimated to be 31 million barrels. However, horizontal drilling and advanced well completion methods could significantly increase crude oil production and reserves.


(A) (B)

Figure 70. Modern pumper (A) and oil well (B) on display at the Arkansas Museum of Natural Resources

South Arkansas Brine Production

In the 1920's oil producers in Arkansas had a problem disposing of all of the salt water that accompanied oil production, especially the brines produced from the Smackover Formation (Late Jurassic age, 144 to 206 million years old). These brines contain approximately 70 times more bromine than is present in modern sea water. The bromine was considered to be "worthless" and difficult to manage. Today, it is recognized that bromine has significant value.

The commercial recovery of bromine began in 1957 from oil wells in Union County. Bromine is a reddish-brown liquid chemical element that gives off poisonous, corrosive fumes at room temperature. This dangerous chemical requires specialized equipment and well-trained personnel for its successful recovery and marketing.

Arkansas leads in production of bromine and supplies 40 percent of the world's need. Bromine is used in the manufacture of medicines, herbicides, pesticides, disinfectants, anti-knock motor fuel additive, and numerous other chemical applications. In 2011 the production was 289,818,680 barrels valued at approximately $400 million.

Road Log – Arkadelphia to Camden

As we leave Arkadelphia, the Ouachita River is crossed and the landscape becomes one of broad, flat fields. These excellent croplands are the result of the modern Ouachita River and its ancestor depositing vast amounts of alluvial sediment (gravel, sand, silt, and clay) over the past several thousand years. Scenic 7 roughly parallels the river, crossing the alluvium of the floodplain, until the road climbs onto the river terrace near the Gravel Junction community (Fig. 71). From this location the road remains on the higher elevations of the river terrace to avoid periodic flooding on the river alluvial plain. Scenic 7 remains on this "high ground" until the Amy community is reached.

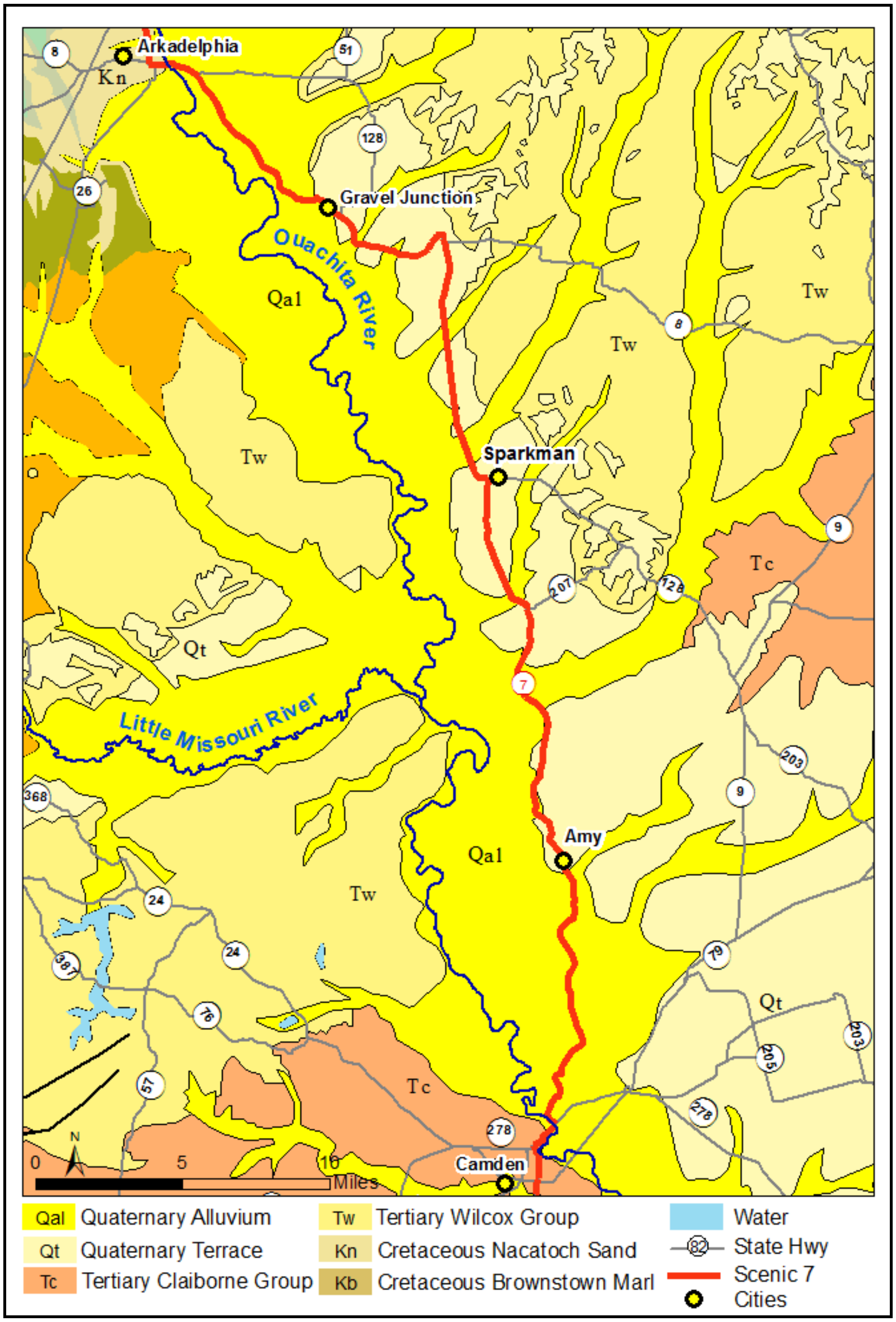


Figure 71. Geologic map from Arkadelphia to Camden
(from Geologic map of Arkansas, 1:500,000 scale)

Approximately 0.5 mile south of Amy, Scenic 7 once again crosses the river alluvium. The "rolling" character of the landscape is due to erosion caused by modern streams, as they cut away at the soft alluvium. The road remains on alluvium the rest of the way to Camden, where we will once again cross the Ouachita River (Fig. 72).

Figure 72. Ouachita River at Camden (33°35′49″N 92°49′05″W)

Road Log – Camden to Louisiana State Line

From Camden to the Louisiana State Line Scenic 7 traverses the Claiborne Group of Tertiary-Eocene Epoch-aged (56 to 34 million years ago) sediment (Fig. 73). This Group is composed of mostly unconsolidated, non-marine sediment (gravel, sand, silt, and clay) (Fig. 74). In some localities the Claiborne contains beds of lignite. Since the Claiborne is unconsolidated few outcrops exist along the road; vegetation covers most of the road right of way along this last 40 miles of Scenic 7.

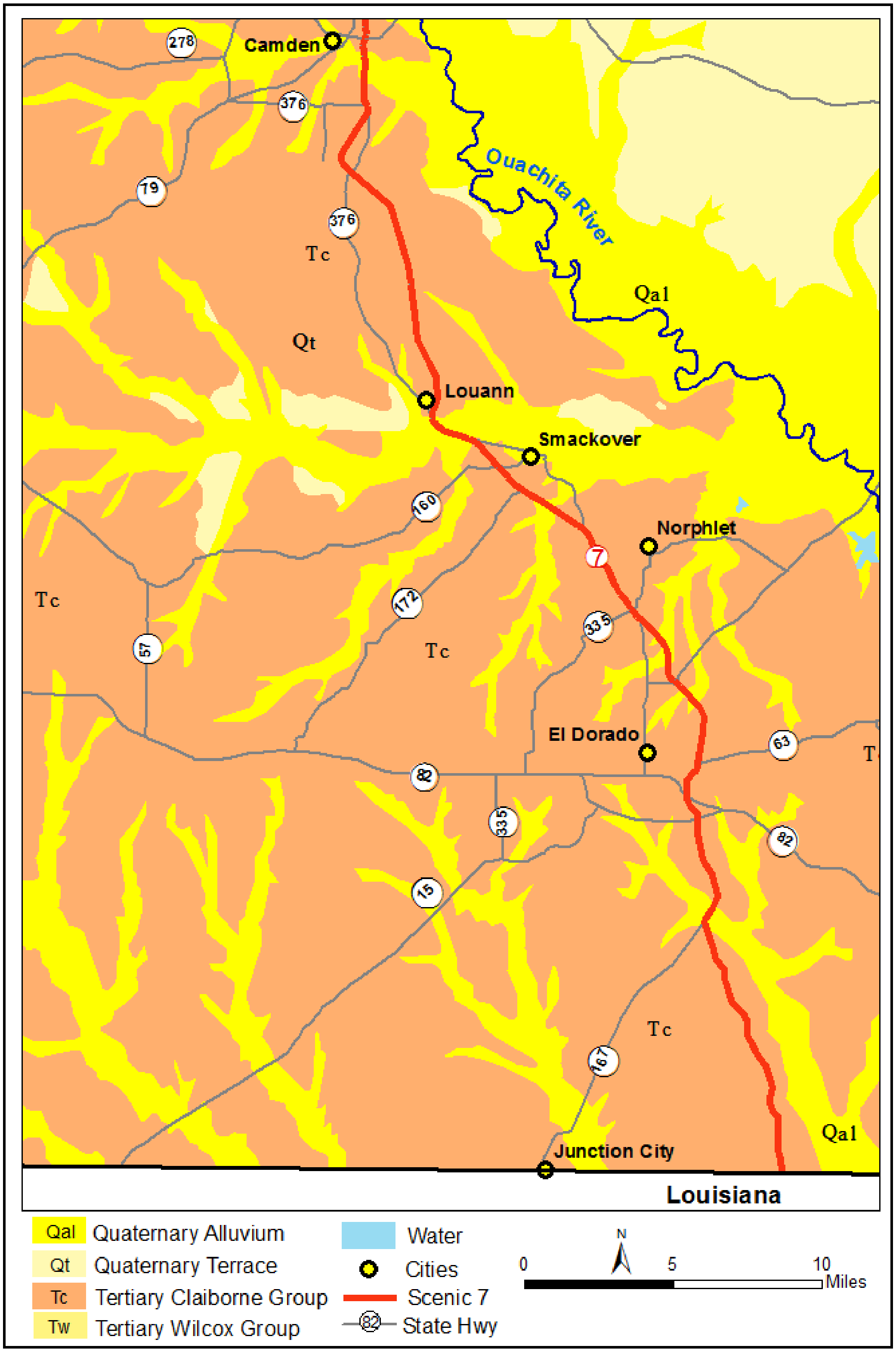


Figure 73. Geologic map from Camden to Louisiana state line
(from Geologic map of Arkansas, 1:500,000 scale)

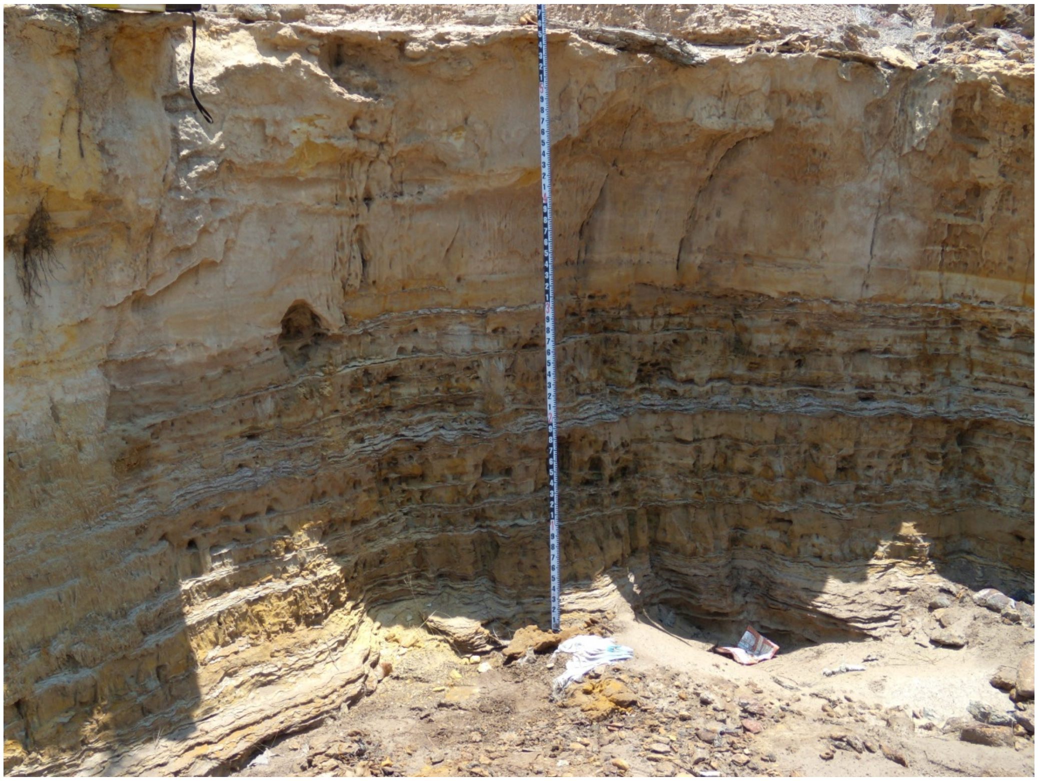


Figure 74. Tertiary Sparta Sand, Claiborne Group, taken near Camden, AR
(courtesy of Doug Hanson, AGS)

Conclusion

Since we began the trip on Scenic 7 at Diamond City on the shore of Bull Shoals Lake and are now crossing into Louisiana, we have traveled almost 300 miles over some of the most varied and complex geologic structures to be found anywhere. As stated at the beginning of the trip, not only has it been a trip across landscapes and sedimentary rocks, it has been a trip through almost 500 million years of time.

We have seen evidence that millions of years ago the Ozark Plateaus were part of a continental shelf covered by shallow sea water that was repeatedly raised above sea level and then submerged. As we approached the Arkansas River Valley, we saw rocks that were deposited in a deepening trough along the edge of the ancient North American Continent. Then farther south in the Ouachita Mountains, we viewed some of the most complex geologic structures in North America. We have seen the results of the process geologists call plate tectonics. The massive folding and faulting of sedimentary strata was caused by compressive forces resulting from the collision of ancestral South America-Africa with ancestral North America.

According to current theory, the energy for such plate tectonic activity is derived from the interior heat of the Earth. The core temperature is estimated to be 12,000^{o} F (6,700^{o} C) and it is postulated that core heat is transferred to the cooler exterior of the Earth by conduction and flow of material in convection currents. A similar phenomenon can be observed in a pan of water as it nears the boiling temperature. Convection currents in the mantle and lower crust could create tension and compression in the rock of the crust and drive plate tectonic movements.

After leaving Caddo Valley, just north of Arkadelphia, we entered another geologic province, the West Gulf Coastal Plain. After the Ouachita mountain-building episode reached its climax the processes of weathering and erosion began their slow actions that cause, even the most durable rocks, to become sediments. However slow the processes, they are very effective when operating over millions of years. The time gap between rocks of the Ouachitas and the overlapping Cretaceous-age sediments of the Coastal Plain is approximately 150 million years.

That time gap was filled with the processes of weathering and erosion of the Ozarks and Ouachitas and deposition of sediments into a newly developing basin on the southern flank of the continent. The heat of the Earth's interior continued to drive the processes of plate tectonics and the Gulf of Mexico developed. Ultimately, the reactivation of the Reelfoot Rift (Mississippi River graben), the one billion years old underlying structure of the Mississippi River Alluvial Plain, caused subsidence of the area and deposition of Cretaceous, Tertiary, and Quaternary-aged sediments (145 million years ago to recent time)to form the West Gulf Coastal Plain.

Today, the details of the processes may be obscured by the vastness of geologic time and the physical dimensions of the problem. However, reasonable explanations have been developed and are continually improved through the careful observation of minerals, rocks, fossils, and stratigraphic and structural relationships using the tools of modern science. That is the job of a geologist.

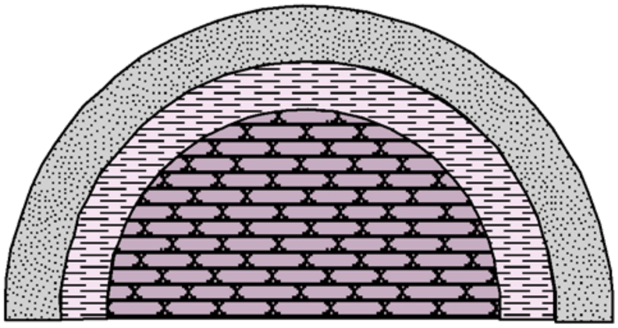
Additional information concerning the geology of Arkansas can be found by accessing the Arkansas Geological Survey's website at www.geology.ar.gov.

Glossary of Terms

Abyssal – a term applied to an ocean environment below 6,000 feet deep

Artesian – a natural flow of well or spring water to a height above the surface

Anticline – an upfold (arch) in sedimentary strata



Cross section view

Barite – a mineral composed of barium sulfate

Basement rock – igneous or metamorphic rock that underlies a sedimentary rock sequence

Basin – a structural (bowl-like) depression in the Earth's crust

Bedrock – solid rock that underlies the superficial covering of soil or alluvial deposits

Boxwork concretion – an accumulation of weathering-resistant mineral matter, usually an iron oxide, along fractures, resulting in a geometric pattern of ridges and hollows in rock outcrops, often in sandstones

Brackish water – mixed fresh and sea water

Calcite – a mineral composed of calcium carbonate, the principle mineral in limestone; also numerous types of fossils have this composition since numerous organisms have the ability to convert calcium, carbon, and oxygen present in sea water into shells and other types of structural framework

Carpet rock – a rock, usually sandstone, with a geometric pattern of ridges and "hollowed-out" depressions which were formed due to weathering of intersecting mineralized (hardened) fractures

Coal – a combustible, brown to black sedimentary or metamorphic rock

Ranks of coal arranged in increasing heat value per pound:

Lignite > Bituminous > Semi-anthracite > Anthracite (metamorphic)

Chaotic structure – a complex jumble of folded and faulted sedimentary rocks resulting from extreme tectonic forces

Chert – a microcrystalline variety of quartz (silicon dioxide)

Clastic – a term applied to sediment composed of weathered (broken) fragments of minerals or rocks, for example: gravel, sand, silt

Clay - a group of very fine-grained minerals produced by the weathering of igneous and metamorphic rocks, especially those containing feldspars, which are transported by rivers to basins of deposition where the clay is compacted and converted into shale by the heating and pressure provided by deep burial

Conglomerate – a sedimentary rock composed of large (greater than 2 millimeters in diameter) rounded mineral or rock fragments and finer sediment held together by a mineral cement

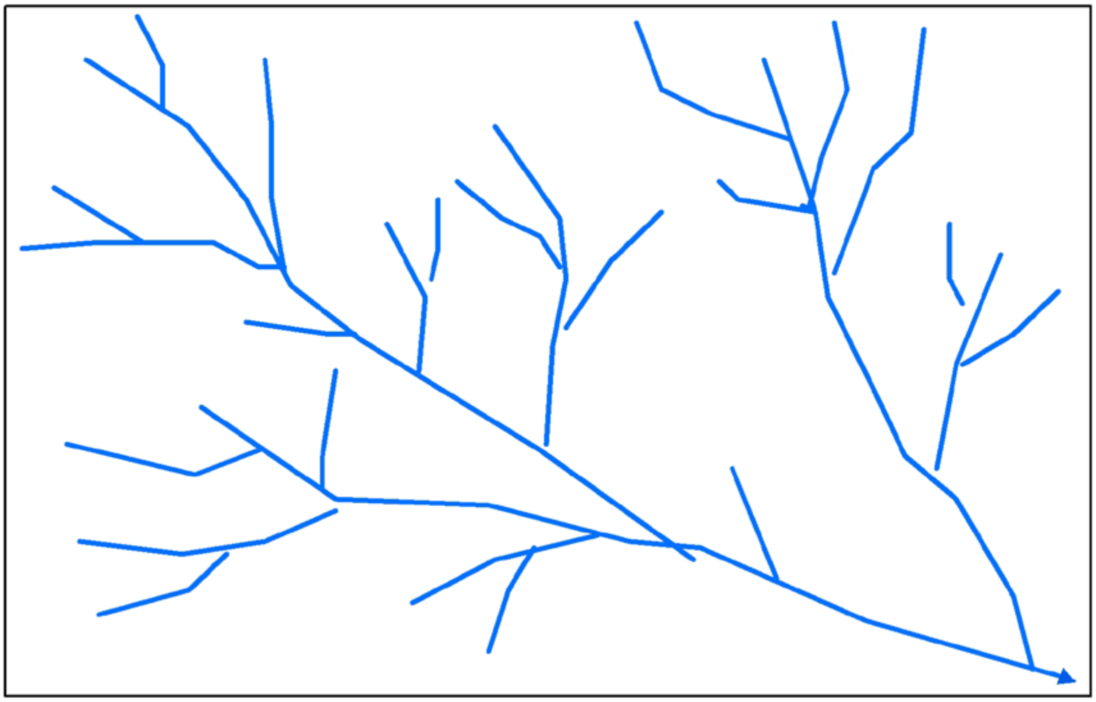
Continental shelf – a portion of a continent covered by shallow sea water (maximum depth of 600 feet)

Core – the intermost zone of the Earth's internal structure

Crust – the outermost rocky zone of the Earth's internal structure, thickness from 3 to 43 miles (5 to 70 km)

Delta – a deposit of sediment formed at the mouth of a river upon entry to the ocean or a lake

Dendritic drainage pattern – streams that are arranged in a pattern that resembles the branching of a tree, usually developed across a rock or soil surface that is uniformly resistant to erosion, such as horizontal sedimentary rocks



Map view

Dickite – a clay mineral often present along fault surfaces; it is considered to indicate that hydrothermal fluids were present along the fault surface

Dike – an igneous intrusion (pluton) that has a tabular shape that cuts across surrounding rock structures

Dip – the angle of inclination (tilt) of a bed of sedimentary rock as measured from a horizontal plane to the surface of the bed; the positions of other geologic features (fault planes, veins of mineral matter, etc.) may also be described in the same manner

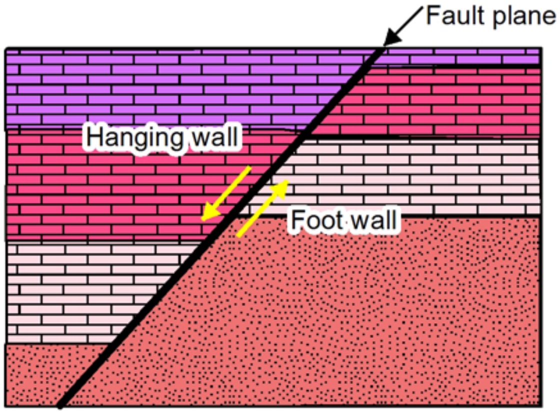
Dolostone – a sedimentary rock composed of dolomite (calcium-magnesium carbonate)

Dome – an upfold (inverted bowl) in the Earth's crust

Drag fold – a minor fold in sedimentary strata produced by friction as a result of faulting

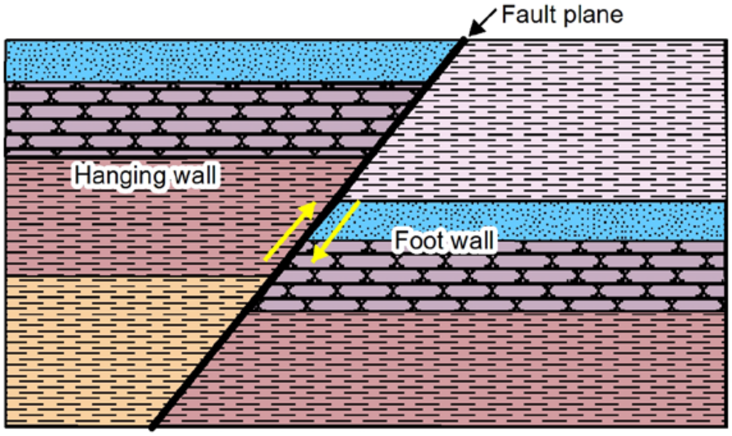
Faults –

Normal or Gravity fault – a rupture in rock material caused by tension and gravity, resulting in the rocks above the fault break (hanging wall) moving downwards



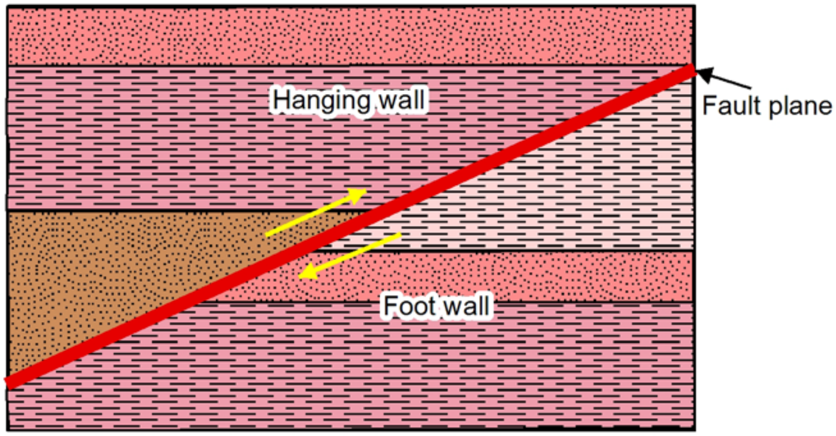
Cross section view

Reverse fault – a rupture in rock material caused by compression, resulting in rocks above the fault break (hanging wall) moving upwards along the break at an angle greater that 45 degrees to the horizon



Cross section view

Thrust fault – a rupture in rock material caused by extreme compression, resulting in movement (at an angle less than 45 degrees) of rock masses over once adjacent rocks, perhaps for many miles



Cross section view

Feldspar – the most abundant mineral family in igneous and metamorphic rocks; including: orthoclase – albite (potassium – sodium aluminosilicate) and plagioclase (sodium – calcium aluminosilicate)

Fissile -- thin-bedded rock, usually shale, that splits into layers less than 2 mm thick

Flysch – a sequence of thinly-bedded marine sediments (clay-rich limestone, calcite-rich shale, conglomerate, coarse sandstone, and a "dirty" sandstone (greywacke) containing a wide variety of mineral types characteristic of igneous and metamorphic rocks); formed as a result of erosion of a rising landmass, prior to the main stage of mountain building activity

Footwall – the rocks below a fault plane

Formation – a term that is applied to a group of sedimentary strata (sandstone, shales, etc.) that form at approximately the same time

Fossils:

Algae – an aquatic nonvascular plant (seaweed, pond scum, stoneworts)
Annelid – marine worm
Brachiopod – "lampshells", a marine invertebrate with two unequal shells that are symmetrical on either side of a mid-dividing line
Bryozoa - "moss animals", small invertebrate marine animals (less than 1 mm in length) that live in colonies and build calcareous skeletons of many, often branching forms
Cephalopod – a marine mollusk with an external calcareous straight or coiled shell that is divided into successively larger chambers as the animal grows

Coral – a large, varied group of colony-forming, bottom-dwelling marine organisms that secrete a calcareous external skeleton

Crinoid – "sea lily", a bottom-dwelling marine organism of the phylum Echinodermata, class Crinodia, commonly-found fossils are of the column or stem of the organism which supported a calyx (head)

Conodont – small, tooth-like in appearance, but of uncertain function or type of parent organism; however they are very distinctive and useful as geologic time markers from Cambrian to Upper Triassic

Echinoderms – marine invertebrates with radial symmetry like "starfish"; that do not form colonies; crinoids are a member of this group

Gastropods – "snail**";** mollusks that form a single spiral-form shell that is not divided into chambers

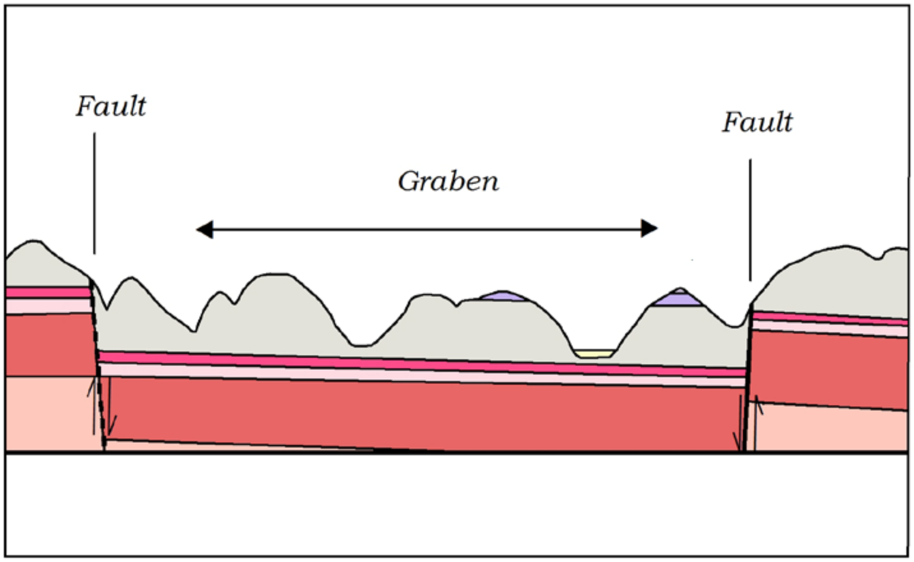
Lycopod – a land plant related to modern "club moss"

Trilobite – a marine arthropod with a three-lobed outer shell (head, mid-section, tail) that is divided lengthwise into central (axial) and side regions; became extinct in the Permian Period

Geosyncline – a very large downwarp in the basement rock into which extremely thick masses of sediments (several tens of thousands feet) may accumulate, formed in subduction zones where ocean crust is downwarped adjacent to a continent

Glauconite – a green-colored mica-like mineral, containing iron and potassium, that forms in a marine environment, sometimes called "greensand"

Graben – a down-dropped block of the Earth's crust between two normal faults



Cross section view

Granite – a coarse-grained (phaneritic) igneous rock composed of quartz and alkali feldspars (orthoclase, microcline, and albite); that cooled (solidified) in a deep plutonic setting

Hanging wall – the rocks above a fault plane

Hematite – a mineral composed of iron oxide, usually formed by the weathering (oxidization) of iron-bearing rocks and minerals

Hornfels – a dark gray to black, brittle, hard, non-foliated metamorphic rock, often formed due to heat promoting recrystallization of shale at the contact between the shale and an intruding magma

Igneous – rocks that crystallize from a molten material (magma in the subsurface or lava on the surface) upon cooling

Inlier – an outcropping of younger rock strata surrounding an exposure of older rocks; often caused by erosion of an anticline or thrust fault resulting in an exposure of the underlying core of older strata

Joint – a fracture in rocks along which there is no significant movement, except a "pull-apart" of a few inches or less

Karst topography – a type of landscape that develops in an area with soluble bedrock (limestone, dolostone, gypsum, halite) causing the formation of caves, sinkholes, springs, and other unique features

Limestone – a chemically-precipitated sedimentary rock composed of calcite (calcium carbonate)

Limonite – a non-crystalline variety of hydrous iron oxide that may form during the weathering of iron-rich rocks and minerals

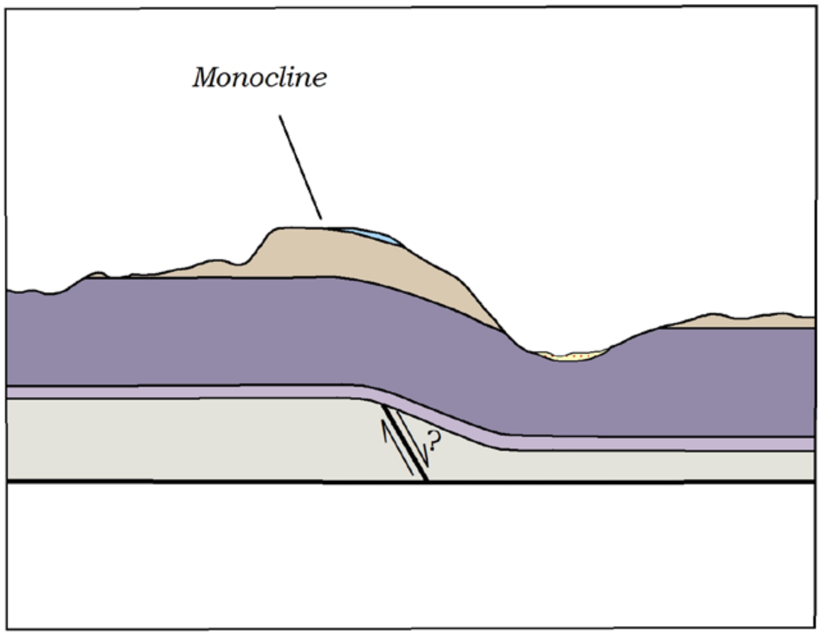
Liesengang banding – rings or bands of color developed in rocks due to the rhythmic precipitation of iron oxides or other minerals during weathering

Magma – molten rock material below the Earth's surface that when cooled and crystallized becomes igneous rock

Mantle – the intermediate zone of the Earth's internal structure from 43 to 1,800 miles (70 to 2,900 km) below the surface, composed of silicate rock, comprises 82 percent of the Earth's volume

Metamorphic – a family of rocks that develops after earlier-formed rock is exposed to increased heat, pressure, and/or chemically active fluids, and as a result undergo changes in composition, texture, and structure

Monocline – a step-like fold in sedimentary strata



Cross section view

Nappe – a large mass of rock moved forward one mile or more by thrust faulting or overturned folding

Nodule – an irregularly-shaped mass of mineral matter of different composition than the surrounding rock material

Novaculite – a massively-bedded sedimentary rock composed of microcrystalline chert (silicon dioxide)

Orogeny – the process, usually involving intense compressive forces being applied to thick masses sediment, leading to the formation of folded and thrust-faulted mountains

Outcrop – a surface exposure of bedrock; not soil or alluvium

Peneplain – a low-elevation large area land surface lacking significant topographic relief, formed by long-term weathering and erosion nearly to sea level, that later was uplifted as a unit to form a plateau, thus allowing streams to begin another erosion cycle

Physiographic – relating to the landform features of the Earth's surface

Plate – a continental-size, solid portion of the Earth's crust that can move across the semi-solid material below the crust

Plate tectonics – a theory developed in the 1960's that explains the structure of the Earth's crust and phenomena such as earthquakes, volcanoes, and mountains, as the result of the crust being divided into solid-rock plates that move across hotter, less rigid underlying rock (mantle)

Plunging folds – since folds are three-dimensional structures their crests or troughs do not always remain the same in respect to the horizon, so plunging folds tilt down or up when compared to an imaginary horizontal plane

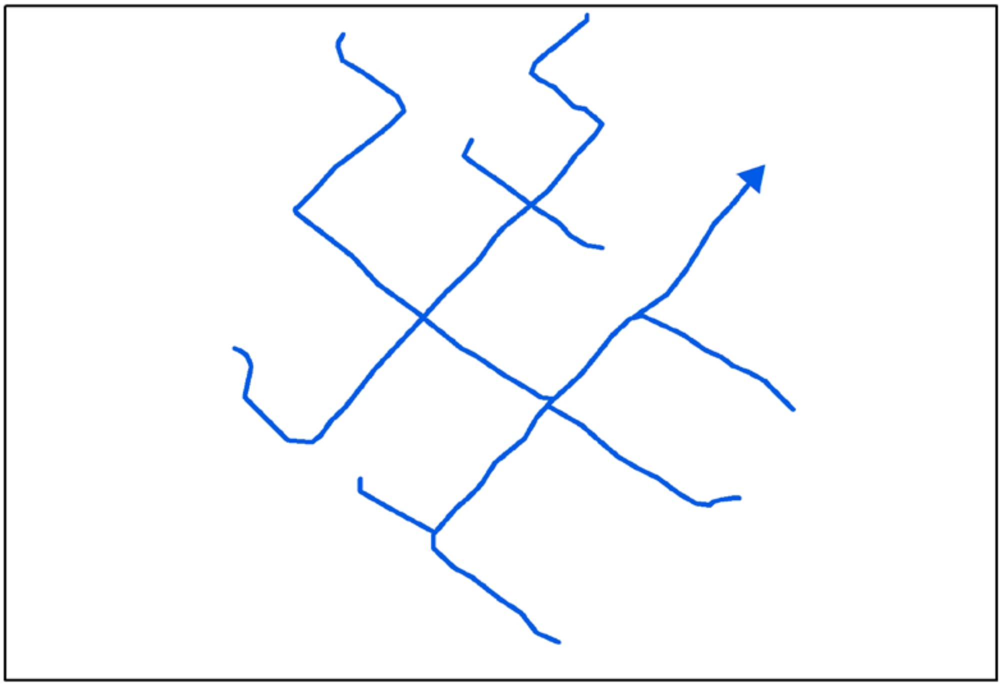
Pluton – a general term applied to any size or shape of igneous rock mass within the Earth's crust, for example: dike, sill, stock, etc.

Plutonic – a type of igneous rock that forms when magma cools deep underground allowing crystals to form that can be seen without magnification

Quartz – a mineral composed of silicon dioxide, varieties include: chalcedony (agate), chert, flint, jasper, novaculite, smoky, and crystal

Recrystallize – a process whereby a mineral may resume the crystallization process because of being placed in a higher temperature, or higher pressure, often fluid-rich environment; resulting in the growth of some minerals at the expense of others

Rectangular drainage – a stream pattern controlled by fractures or faults that intersect at nearly a right angle



Map view

Rifting – a tectonic process caused by tension in the Earth's crust that results in the formation of rift valleys (grabens) on continents and the sea floor

Rhyolite – a fine-grained (aphanitic) igneous rock that cooled quickly at or near the surface of the Earth and is the volcanic equivalent of granite (quartz and alkali feldspars)

Rock cleavage – a regular fracture pattern in rocks due to tectonic forces, not related to cleavage in minerals

Sand – refers to the size of sediment having grains between 2 and 1/16 millimeters in diameter

Sandstone – a sedimentary rock composed of sand-sized (2–1/16 millimeters) mineral grains

Sediment – loose mineral grains that are weathered from rocks, transported by wind, water, and/or glacial ice, and deposited a distance from their source

Sedimentary – a family of rocks that form from weathered rock residue or are chemically precipitated from water, which characteristically display bedding or layering

Shale – a very fine-grained sedimentary rock often with thin laminations resulting in a flaky habit

Sill – a tabular-shaped, igneous intrusion (pluton) that is parallel to the enclosing sedimentary rocks

Silt – sediment that is finer grained than sand

Siltstone – a clastic sedimentary rock composed of silt-size particles (less than 1/16 millimeter in diameter)

Slate – a platy, fine-grained, hard metamorphic rock that often breaks into plate-like pieces

Slickensides – a polished surface, often with ridges and grooves, on a fault plane indicating the direction of movement of the adjacent rock masses

Sole thrust fault – the lowest thrust fault in a shingle-like stack of faults

Strata – layers of sedimentary rock

Stratigraphy – the study of sedimentary rock layers, including: composition and size of mineral and rock grains, cementing material, bedding plane patterns, fossil content, regional distribution, bed succession, and age of deposition

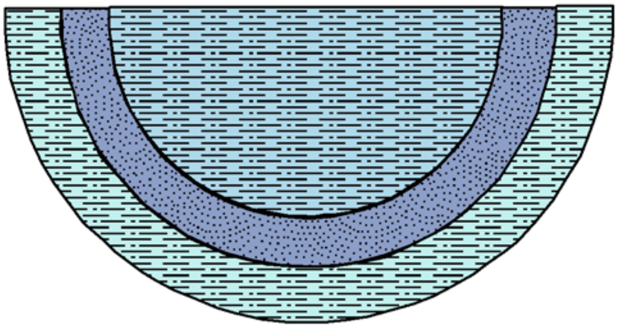
Strike – the compass direction a sedimentary bed or fault makes upon intersecting the horizontal plane

Subduction – a process that results in a plate of the Earth's crust, usually ocean basin crust, being drawn below another plate of the crust, usually continental crust

Submarine fan – a fan-shaped marine deposit of sediment carried down a continental slope by turbidity flow of water and sediment of mixed grain sizes

Syenite – a coarse-grained (plutonic) igneous rock composed of alkali feldspar (orthoclase and albite) and a minor amount of dark minerals (hornblende or biotite), similar to granite in texture and mineral content except for the absence of quartz since the parent magma was deficient in silica. It is the most common plutonic rock exposed in Arkansas.

Syncline – a downfold (trough) in sedimentary strata

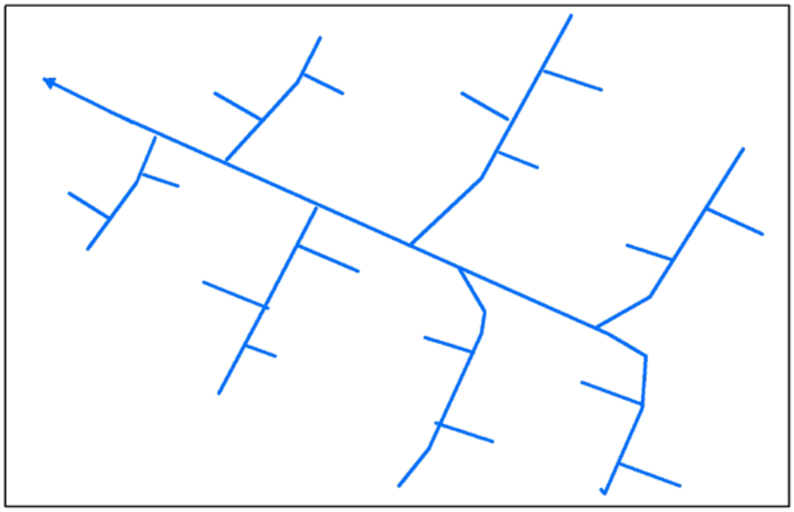


Cross section view

Tectonic – forces or processes that change the structure of the Earth's crust

Terrace – an elevated flat area of alluvium situated above the present-day floodplain, formed as a previous floodplain prior to the river eroding its channel to a lower level

Trellis drainage – a stream drainage pattern consisting of a main channel with numerous tributary channels that enter at nearly right angles, resulting from stream erosion of strata with alternating resistant and non-resistant characteristics



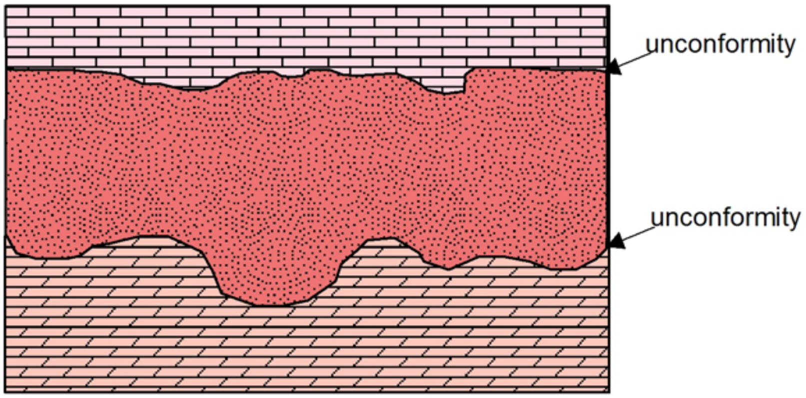
Map view

Tuff – a rock composed of compacted volcanic ash

Turbidite – a sedimentary deposit (submarine fan) formed because of a turbidity current down the continental slope

Turbidity current – a flow of mixed sizes of sediment and water as a “slurry” (like fresh cement) that, due to its higher density than water, will stay in contact with the bottom and not significantly mix with water being displaced by the flow

Unconformity – a zone of erosion or non-deposition in a sedimentary sequence of strata, marking a gap (missing sediments, thus a time gap) in the sedimentary record



Cross section view

Vein – a mineral-filled fracture

Water gap – a stream valley that cuts across a ridge of resistant rock strata

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