THE GEOLOGY OF THE BROKEN BOW UPLIFT

AN INTRODUCTION AND FIELD-TRIP GUIDE

Oklahoma Geological Survey
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THE GEOLOGY OF THE BROKEN BOW UPLIFT

AN INTRODUCTION AND FIELD-TRIP GUIDE

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OKLAHOMA GEOLOGICAL SURVEY
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INTRODUCTION

The Ouachita Mountains extend from near Little Rock, Arkansas, to near Atoka, Oklahoma. Broken Bow, Oklahoma, is at the southern edge of the mountains. The Ouachita Mountains are one of the few east-west trending mountain ranges in the country; the only others are the Uinta Mountains in northeastern Utah and the Transverse Ranges northwest of Los Angeles.

Although the Ouachita Mountains appear to be a rather small mountain range, they are, in fact, part of a very long mountain range that extends from eastern Mississippi to west Texas and probably into Sonora, Mexico. This is called the Ouachita tectonic belt (Fig. 1). Most of this tectonic belt is buried by younger rocks so we don't see it at the surface. However, geologists know where it is because they've drilled into it in the course of exploring for oil and gas. In addition to the Ouachita Mountains in Oklahoma and Arkansas, one place where the tectonic belt comes to the surface is the Marathon Mountains in Texas.

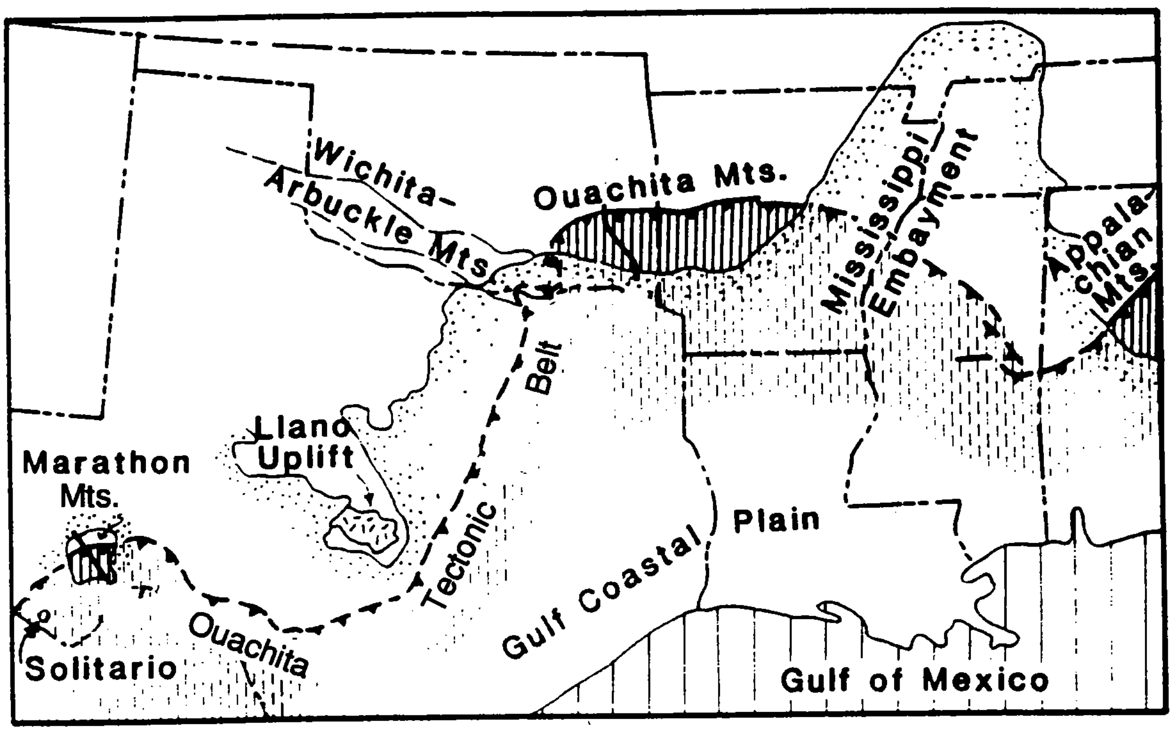


Figure 1. Map showing the location of the Ouachita tectonic belt. The tectonic belt is exposed in the Ouachita Mountains of Oklahoma and Arkansas and Marathon Mountains of Texas. Most of it is buried beneath younger sedimentary rocks of the Gulf Coastal Plain and Mississippi Embayment. The dashed line with sawteeth marks the northern or western edge of the tectonic belt where it is buried.

In some respects, the Ouachitas can be thought of as a continuation of the Appalachian Mountains, which extend from eastern Canada to Georgia. Where the two mountain ranges meet, in Mississippi, is buried by younger rocks (Fig 1). Therefore, geologists aren't really sure exactly how one mountain range intersects the other. However, there are a number of similarites between the two. The most important similarity is that both the Appalachians and

Ouachitas are what geologists call fold-and-thrust belts (Fig. 2). Fold-and-thrust belts are mountain ranges that form as a result of compression; in terms of plate tectonics, they form when two of the earth's plates collide. When this occurs, horizontal rock layers are folded into anticlines (upfolds) and synclines (downfolds) (Fig. 2). In addition, one mass of rocks can be shoved or faulted over another, forming a thrust fault (Fig. 2).

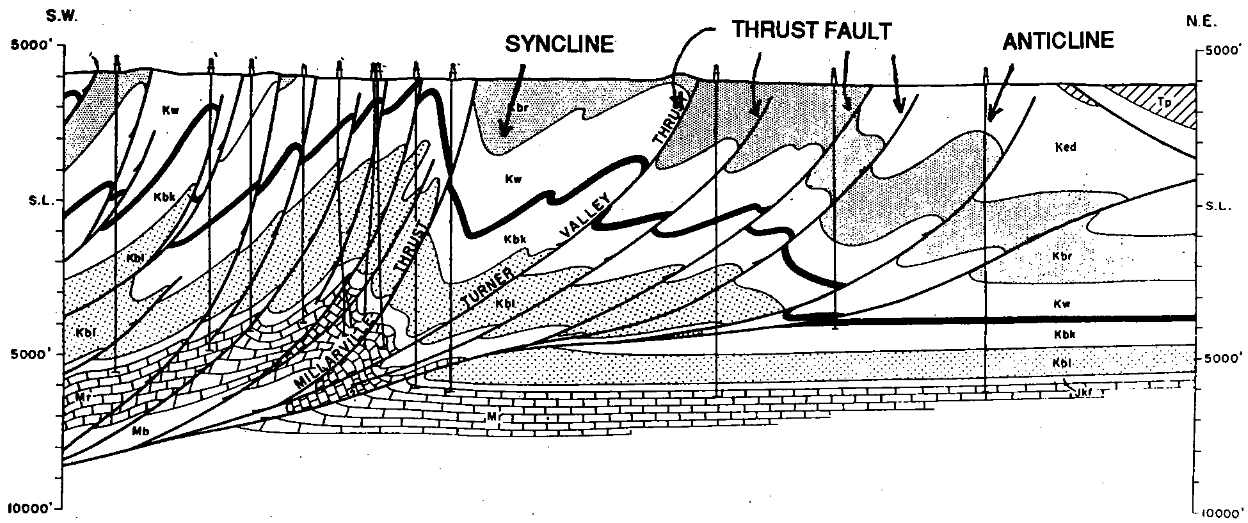


Figure 2. Example of a fold-and-thrust belt from the Rocky Mountains in Alberta, Canada. Vertical lines are oil wells that geologists have used to prove the existence and location of the folds and faults.

GENERAL GEOLOGY OF THE OUACHITA MOUNTAINS

The Ouachita Mountains geologic province is surrounded by other geologic provinces that have their own distinctive geology (Fig. 3). To the north is the Arkoma Basin, which includes the San Bois Mountains and Poteau Mountain. To the east are the flatlands of the Mississippi Embayment, an area of relatively young rocks. South of the Ouachitas is the Gulf Coastal Plain. These rocks, which were deposited during the age of the dinosaurs, are the ones that are largely responsible for burying much of the Ouachitas in Texas (Fig. 1).

The Ouachita Mountains in Oklahoma and Arkansas are usually divided into several "belts" that are characterized by the way the rocks are folded and thrust-faulted and by the age and kinds of rocks present. In Oklahoma, the Ouachitas are divided into three belts; these are, from north to south, the frontal belt, the central belt, and the Broken Bow uplift (Fig. 3). The northern boundary of the frontal belt (and northern edge of the Ouachita Mountains) is the Choctaw fault. The Choctaw fault is extremely difficult to identify on the ground, but geologists know it extends from just south of Hodgen, to just south of Wilburton, to just southeast of Hartshorne, through Pittsburg, and through Atoka. The southern boundary of the frontal belt (and northern boundary of the central belt) is called the Windingstair fault. It is a bit easier to find on the ground, but you still can't put your hand on it. The Windingstair fault is located just north of Big Cedar and extends from there west to just north of Talihina, behind Buffalo Mountain, to northwest of Redden, and to just east of Atoka. The edge of the Broken Bow uplift is a bit harder to define, but it generally includes the area that is characterized by steep hills similar to those around Broken Bow Lake.

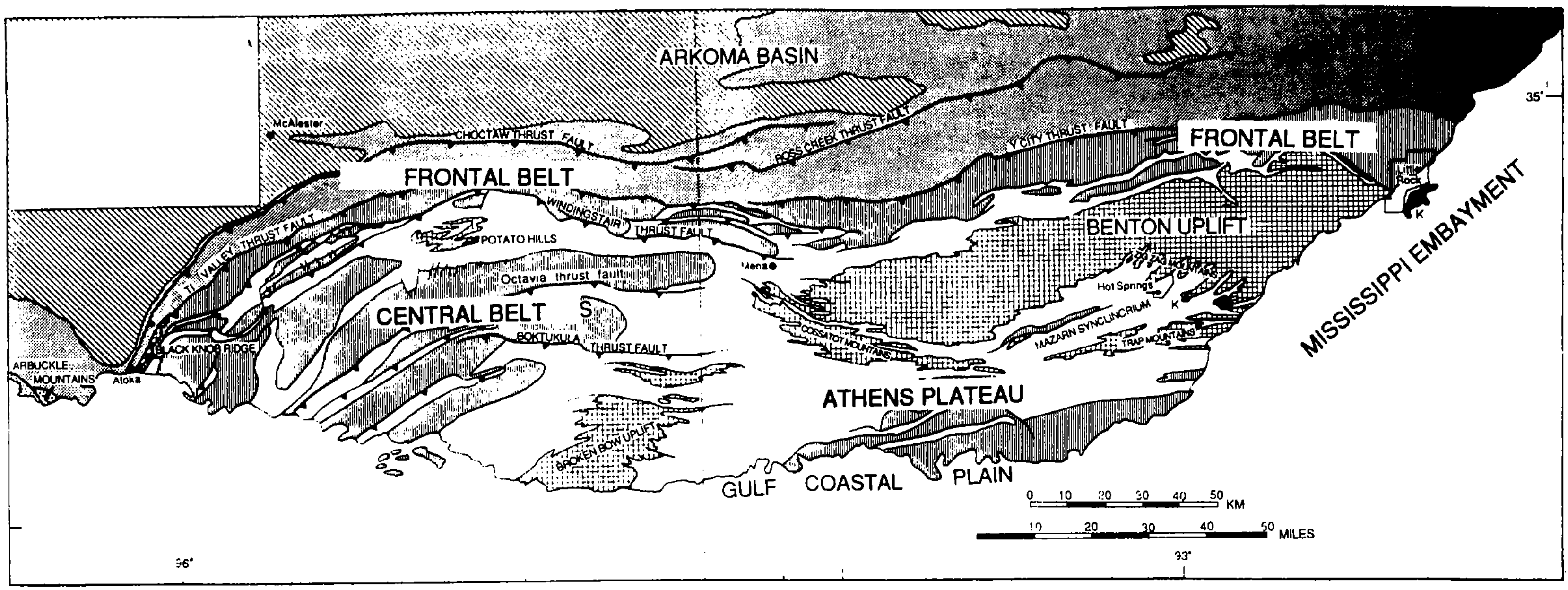


Figure 3. General geologic map of the Ouachita Mountains showing the surrounding geologic provinces and different belts within the mountains. The Arkoma Basin is north of the Ouachita Mountains; the Mississippi Embayment to the east, and Gulf Coastal Plain to the south. In Oklahoma, the Ouachita Mountains include the frontal belt, central belt, and Broken Bow uplift.

In Arkansas, the Ouachitas are also divided into three belts (Fig. 3), but these are somewhat different from those in Oklahoma. The northernmost belt is also called the frontal belt. The central belt of Oklahoma narrows near the state line; as a result, there is no central belt in Arkansas. Instead, the frontal belt of Arkansas is bordered immediately to the south by the Benton uplift. In many respects, the Benton uplift of Arkansas is similar to the Broken Bow uplift of Oklahoma and the two are often combined and called the Benton - Broken Bow uplift. South of the Benton uplift in Arkansas is the Athens Plateau, which is not present in Oklahoma. We will confine ourselves in this discussion to the different belts as they are recognized in the Oklahoma Ouachitas.

The different belts (frontal, central, and Broken Bow uplift) are characterized by different styles of folding and thrust-faulting and by different formations (ages and kinds of rocks). In the frontal belt, there are many closely spaced thrust faults (couple of miles) and the rocks are highly folded. Most of the rocks in the frontal belt are early Pennsylvanian in age and were deposited about 330 to 310 million years ago. (This is over 50 million years before the first dinosaurs roamed the earth.) Most of the rocks are sandstone and shale and were deposited in a relatively deep ocean (e.g., Atoka Formation, Jackfork Group; Fig. 4); some of the rocks, particularly along the northern edge of the frontal belt, are limestone that was deposited in shallow seas (e.g., Wapanucka Limestone).

In the central belt, thrust faults are widely spaced (tens of miles) and the folds are mostly relatively open. Like the frontal belt, most of the rocks (with the exception of the Potato Hills) are sandstone and shale (e.g., Stanley Shale, Jackfork Group, Atoka Formation; Fig. 4), but some are slightly older. Most were deposited during late Mississippian and early Pennsylvanian time about 350 to 310 million years ago.

The Broken Bow uplift consists of tightly folded rocks; the folds are, in some ways, similar to those in the frontal belt. But the rocks in the Broken Bow uplift (e.g., Collier Shale to Arkansas Novaculite; Fig. 4) are much older than those in the frontal belt; in fact, the rocks in the Broken Bow uplift (and Benton uplift in Arkansas) are among the oldest in the Ouachita Mountains and range in age from about half a billion years old (500 million) to about 350 million years old.

THE BROKEN BOW UPLIFT

This field guide focusses on the geology of the Broken Bow uplift and the immediately overlying Gulf Coastal Plain rocks (Fig. 3). The rocks of the uplift are early and middle Paleozoic in age (about 500 to 350 million years old); the sedimentary rocks of the Gulf Coastal Plain are Cretaceous (about 125 million to 80 million years old) (Fig. 5). The contact between the two groups of rocks is known as an unconformity; unconformities represent "missing" pieces of the Earth's history. The unconformity between the Ouachita and Gulf Coastal Plain rocks represents about 225 million years of the Earth's history that is not recorded in the rocks of the area. The rocks of the uplift are strongly folded and faulted; those of the Gulf Coastal Plain are nearly horizontal. Therefore, geologists believe that somewhere in that missing 225 million years, there was a period of mountain building (folding and thrust faulting of the Ouachita rocks), followed by erosion and later deposition of the flat-lying Gulf Coastal Plain rocks. But more about that below.

THE OKLAHOMA BASIN

The history of the Broken Bow uplift begins about 500 million years ago. At that time, nearly all of Oklahoma was covered by a broad shallow sea. Limestone was the most common rock deposited; sandstone and shale were minor additions. This broad sea was known as the Oklahoma Basin (Fig. 6). The rocks that were deposited in this basin are presently exposed in

Age	System	Series	Arkoma Basin		Ouachita Mountains
	PENNSYLVANIAN	Desmoinesian	Krebs Gp.	Boggy Fm.	
				Savanna Fm.	
				McAlester Fm.	
				Hartshorne Fm. Upper / Lower	
		Atokan	Atoka Fm.		Atoka Formation
		Morrowan	Wapanucka Ls.		Johns Valley Shale
			Union Valley Ls. Cromwell ss.		Jackfork Group
330 MY	MISSISSIPPIAN	Chesterian	"Caney" Sh.		Stanley Shale
		Meramecian			
		Osagean			Arkansas Novaculite
		Kinderhookian			
365 MY	DEVONIAN	Upper	Woodford Sh.		
		Lower	Hunton Gp.	Frisco Ls. Bois d'Arc Ls. Haragan Ls.	Pinetop Chert
405 MY	SILURIAN	Upper		Henryhouse Fm.	Missouri Mountain Shale
		Lower		Chimneyhill Subgroup	Blaylock Sandstone
425 MY	ORDOVICIAN	Upper	Sylvan Sh.		Polk Creek Shale
			Viola Gp.	Welling Fm. Viola Springs Fm.	Bigfork Chert
		Middle	Simpson Gp.	Bromide Fm. Tulip Creek Fm. McLish Fm. Oil Creek Fm.	Womble Shale
				Joins Fm.	Blakely Sandstone
		Lower	Arbuckle Gp.	West Spring Creek Fm.	Mazarn Shale
				Kindblade Fm. Cool Creek Fm.	Crystal Mountain Ss.
				McKenzie Hill Fm. Butterly Dol.	Collier Shale
500 MY	CAMBRIAN	Upper		Signal Mountain Ls. Royer Dol. Fort Sill Ls.	? ?
			Timbered Hills Gp.	Honey Creek Ls. Reagan Ss.	
570 MY	PRECAMBRIAN		Granite and rhyolite		

Figure 4. Chart showing the names and ages of major formations in the Ouachita Mountains compared to those in the Arkoma Basin. The rocks in the Arkoma Basin are similar to those in the Arbuckle Mountains exposed along Interstate 35.

the Arbuckle Mountains (especially along I-35), however, we know they are present in the subsurface beneath the Ouachita Mountains because they've been drilled by geologists looking for oil and gas. Several wells have penetrated these old limestones in the Arkoma Basin in Latimer and Atoka Counties; more important is the discovery of these limestones (albeit metamorphosed) about 12,000 deep beneath the Broken Bow uplift by the Sohio 1-22 Weyerhaeuser well which was drilled in 1987. (This well is located about six miles northwest of Broken Bow.)

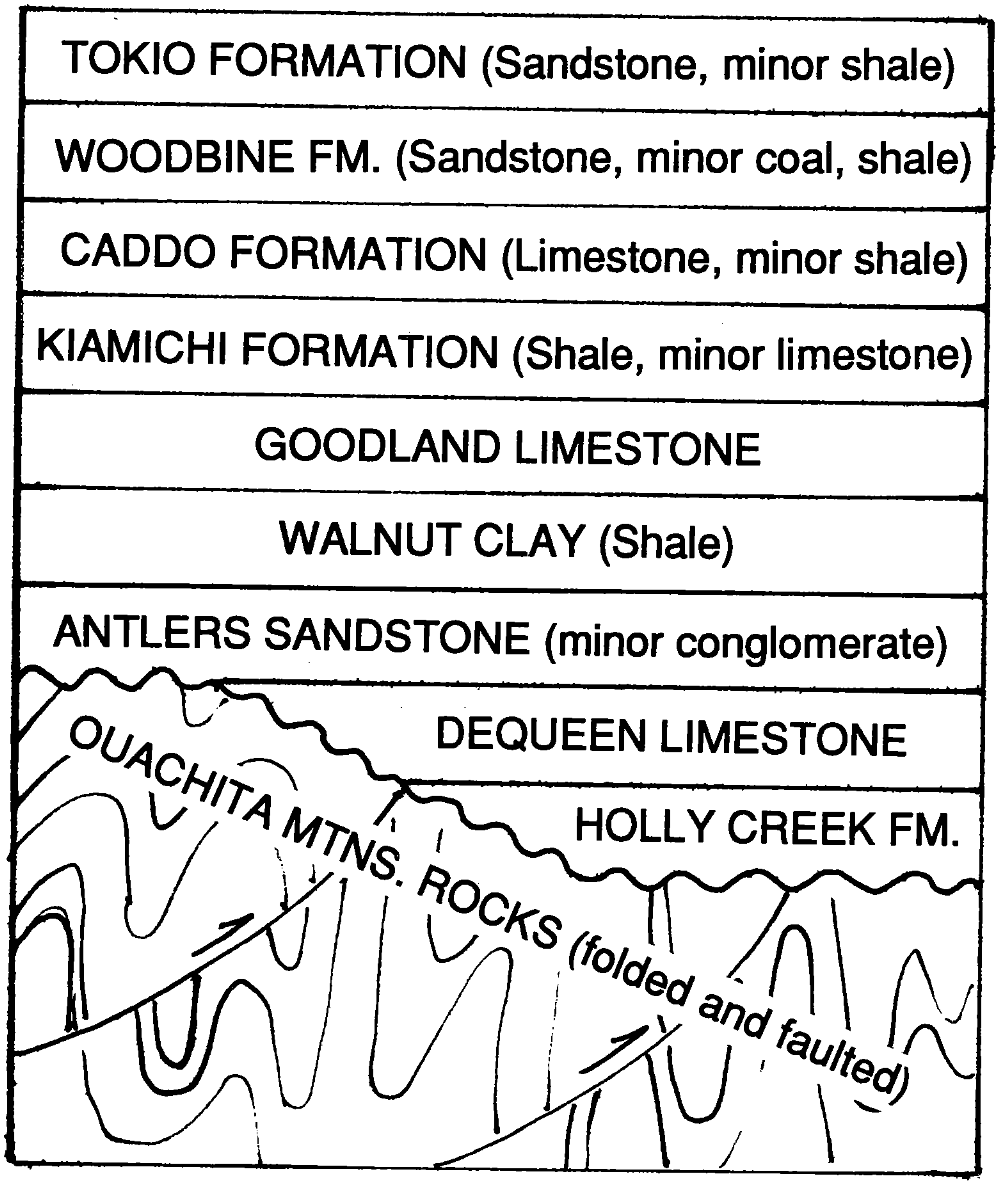


Figure 5. Chart showing the names of major formations in the Gulf Coastal Plain near Broken Bow. These formations are much younger than the folded and faulted rocks of the Ouachita Mountains. The contact between the two groups of rocks is known as an unconformity and represents a missing piece of the Earth's history.

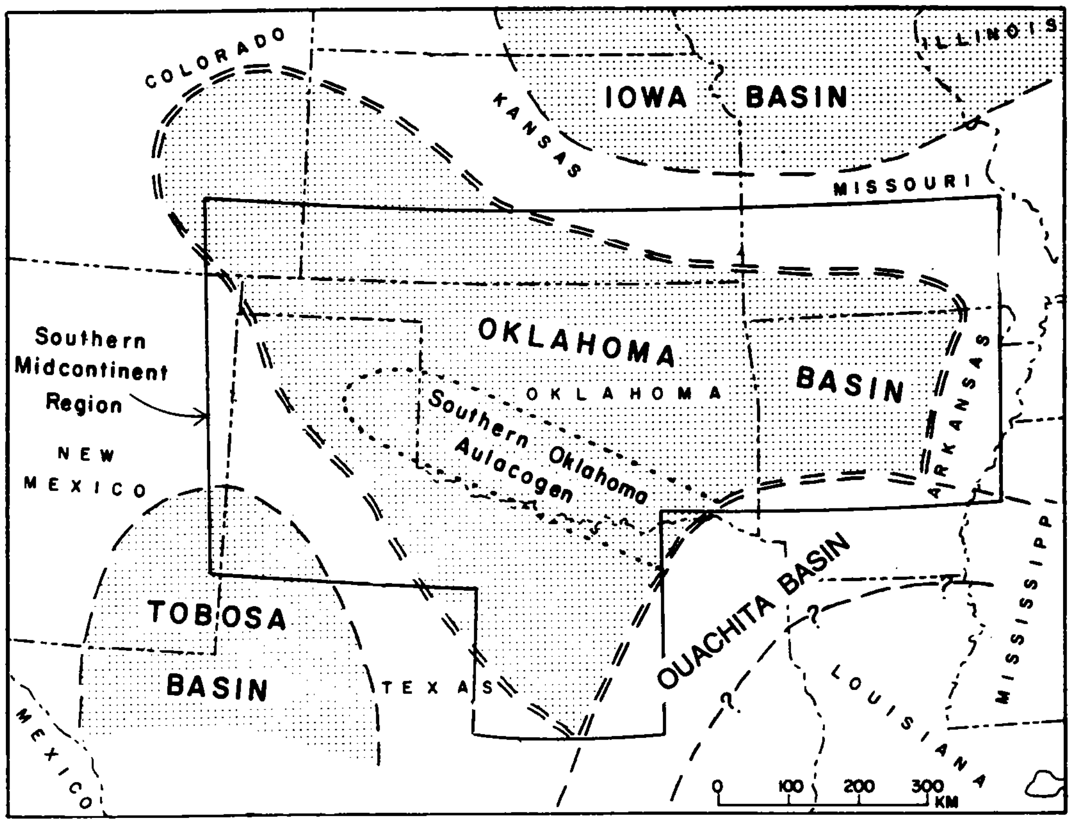


Figure 6. Map showing the location of the shallow-marine Oklahoma Basin and deep-marine Ouachita Basin. The "Southern Oklahoma Aulacogen" is an area of unusually thick Paleozoic sedimentary rocks, parts of which were uplifted to form the Arbuckle and Wichita Mountains.

The rocks of the Broken Bow uplift, although approximately the same age as those in the Arbuckle Mountains and the Arkoma Basin (Fig. 4), are very different. Instead of limestone with minor sandstone and shale, the rocks of the uplift are mostly shale and chert, with minor sandstone and limestone (Fig. 7). Geologists generally agree that relatively fine-grained rocks, like shale and chert, were deposited under quiet marine conditions, although the presence of minor sandstone and limestone indicates land and/or shallow ocean conditions were occasionally close.

The different rocks (but of the same age) tell geologists that at the same time the shallow-water limestones were being deposited over most, if not all, of Oklahoma, deeper ocean conditions existed some distance to the south. This deep ocean basin is known as the Ouachita Basin (Fig. 8A). Starting about 500 million years ago, a series of formations were deposited in the basin most likely in a moderately deep-ocean environment. What these rock are doing in Oklahoma is the subject of the next section.

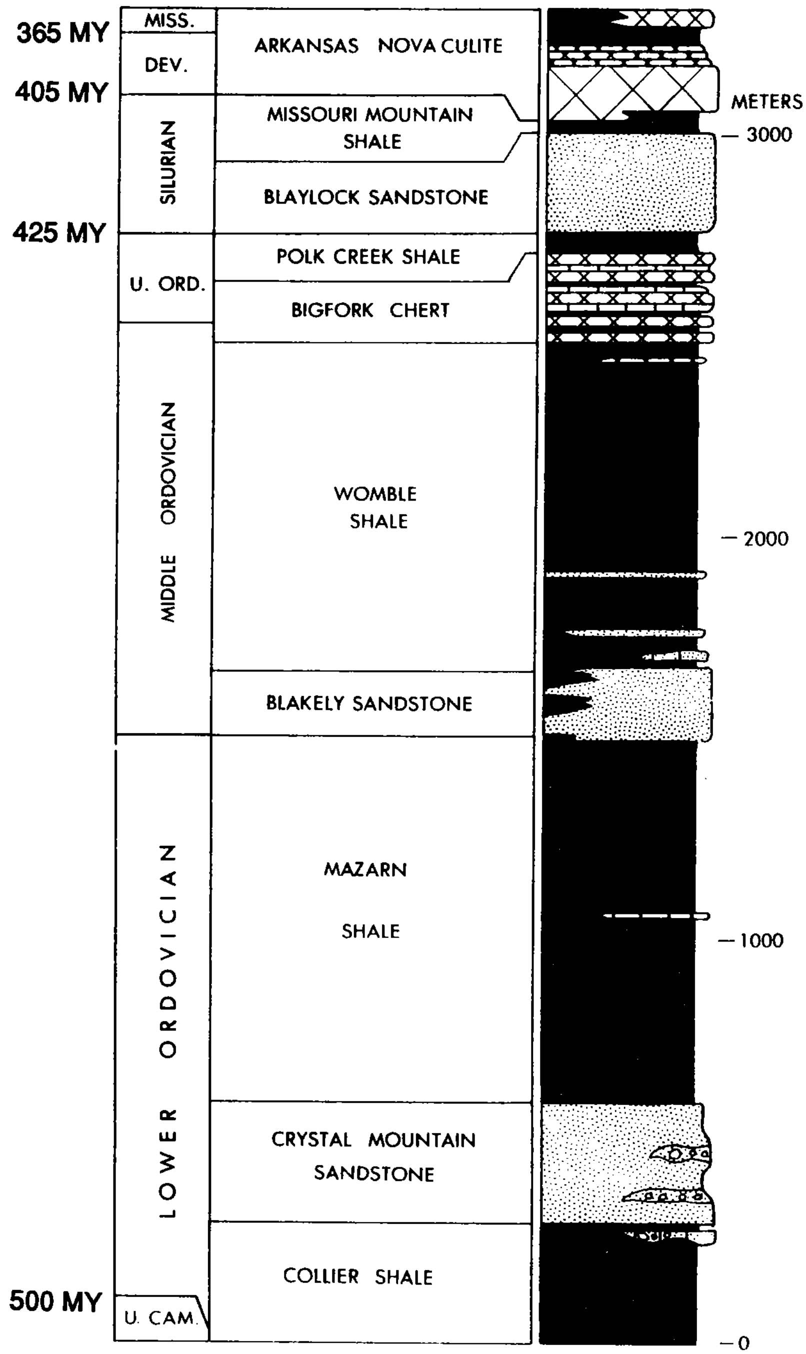


Figure 7. Chart showing the formations exposed in the Broken Bow uplift, the age of the formations, and the dominant rock type. Solid black - shale (including slate, phyllite); stippled pattern - sandstone; crossed pattern - chert and siliceous shale; vertical pattern - limestone; circles - conglomerate.

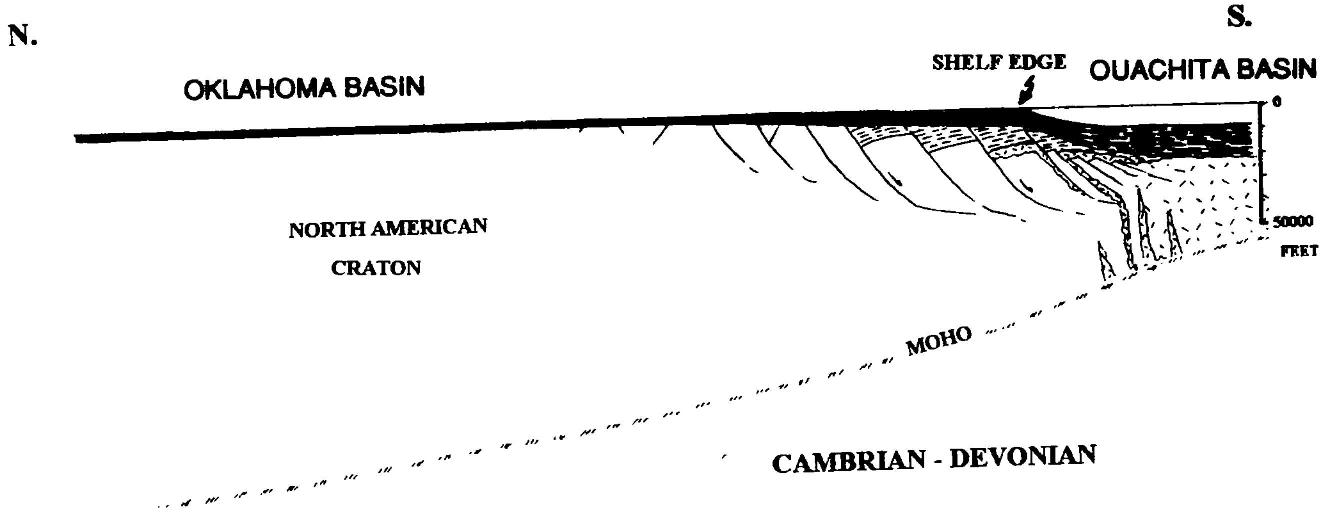


Figure 8. Cross section through the future location of the Ouachita Mountains in Cambrian to Devonian times. The Oklahoma Basin is the site of a shallow ocean in which mostly limestone is being deposited. The Ouachita Basin is the site of relatively deeper-water deposition, mostly shale and chert. The location of the shelf edge, the boundary between the Oklahoma and Ouachita Basins, is unknown, but is south of Broken Bow.

THE OUACHITA OROGENY - MAIN PHASE

(Orogeny = Mountain Building)

Starting about 350 million years ago, this serene picture began to change. Somewhere to the south, a microcontinent some geologists call Llanoria began to collide with the North American continent. At first, this collision produced a deep ocean basin (Ouachita Trough) and tremendous volumes and sandstone and shale began to flood into the basin (Fig. 9). (These sandstones and shales are exposed in the central and frontal belts of the Ouachita Mountains.) Some of the sandstone was eroded from the high Appalachian Mountains, some from the interior of the North American continent, and some from Llanoria, but all contributed to filling the basin. There is good evidence that volcanoes existed to the south, because minor amounts of volcanic ash (called tuff) is found in some places in the sandstone and shale.

As Llanoria and North America continued to collide, downwarping of the Ouachita Trough kept pace with the sandstone and shale that were trying to fill it. With time, the deepest part of the trough migrated to the north; geologists know this because successively younger trough-filling formations thicken northwards. At the same time the deep ocean trough formed and migrated northwards, the rocks of the old Ouachita Basin began to be compressed and, like any rocks that are compressed sufficiently, they began to fold and fault (Fig. 10). However, the rocks of the old Ouachita Basin were not the only rocks to suffer; the sandstones and shales in the deep ocean trough were also involved in the folding and thrust-faulting. It is these folded and faulted rocks that form the Ouachita Mountains (Fig. 11).

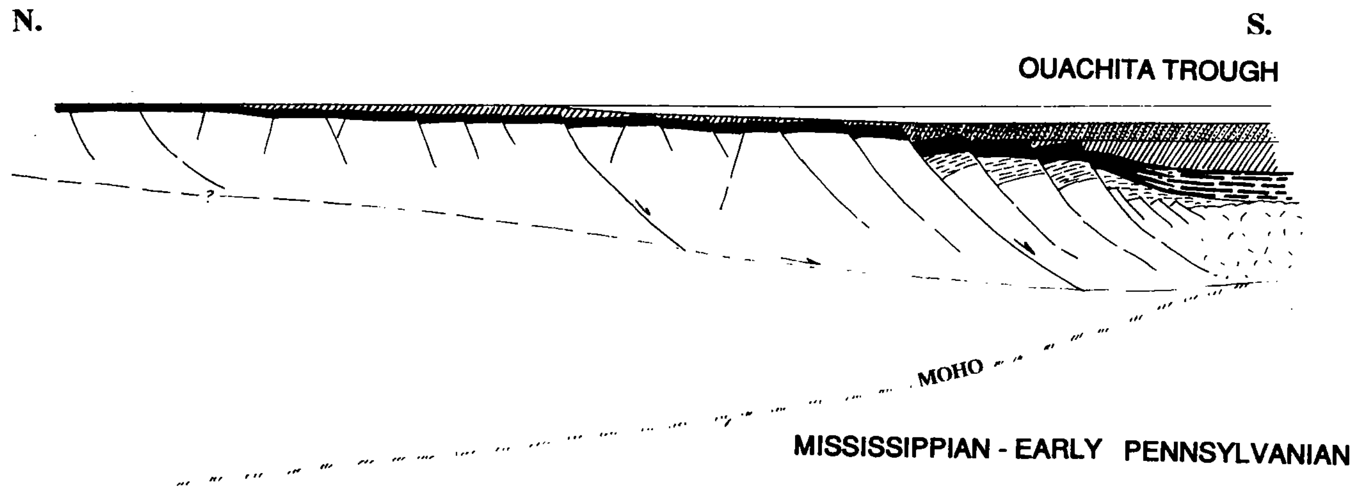


Figure 9. Cross section through the future site of the Ouachita Mountains in Mississippian to early Pennsylvanian time. The deep Ouachita Trough has formed over the site of the older Ouachita Basin and a thick sequence of sandstones and shales (represented by the cross-hatched and stippled/cross-hatched formations) is deposited in the trough.

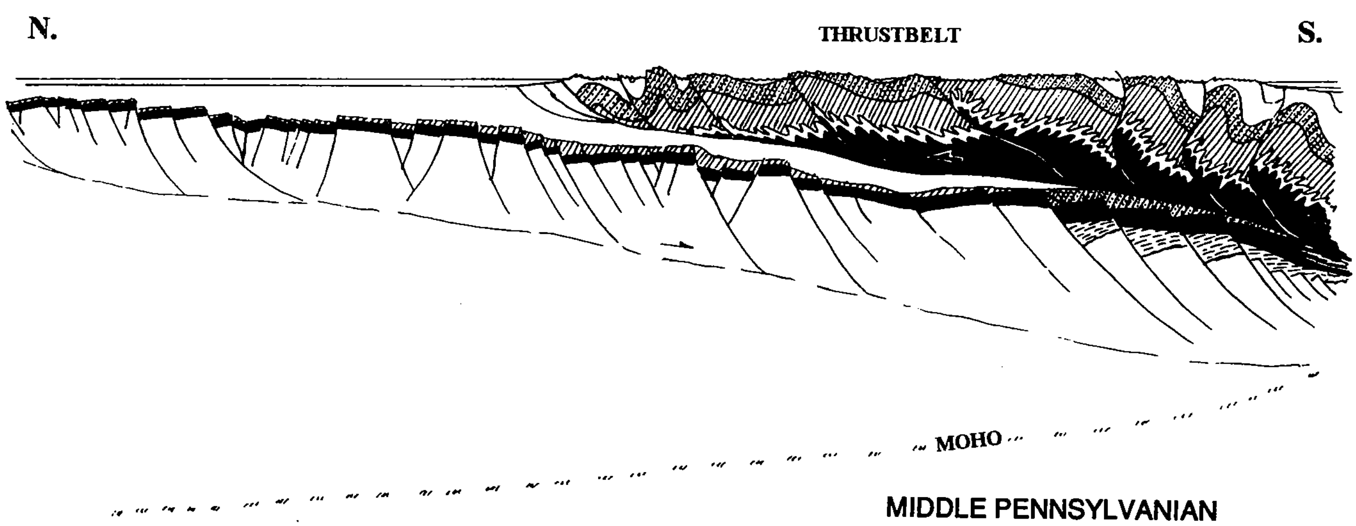


Figure 10. Cross section through the Ouachita Mountains in middle Pennsylvanian time. Despite the fact that folding and thrust faulting has occurred, the mountains are just barely above water and erosion is minimal. The Ouachita Basin rocks have been thrust over the Oklahoma Basin rocks.

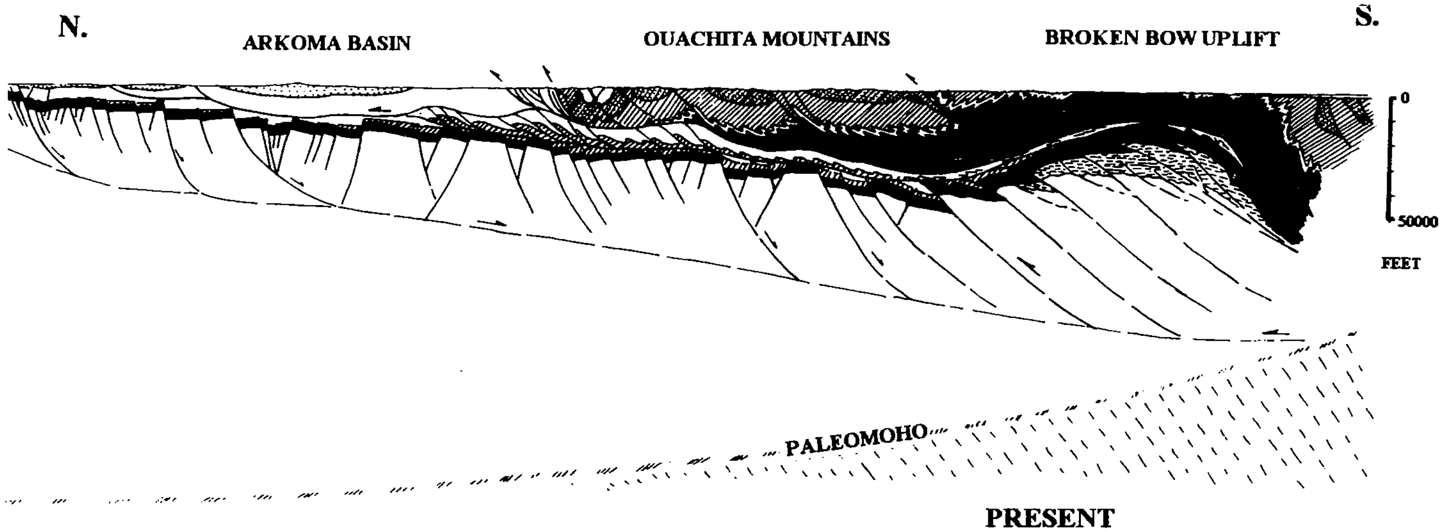


Figure 11. Cross section through the Ouachita Mountains fold and thrust belt at the present time. The late-stage Broken Bow uplift has been raised and subjected to more erosion than the surrounding area.

Geologists continue to argue about exactly how much the rocks of the Ouachita Mountains were compressed; in other words, exactly how much shortening occurred as a result of the
continental collision. One way to answer this question would be to determine how much movement occurred on each and every thrust fault in the Ouachitas. Except for a few well-studied faults in the far northern part of the mountains, the amount of movement on the thrust faults in the Ouachita Mountains is unknown. Thus, the total amount of shortening is also unknown. Some of the faults clearly have a lot of movement across them. One was encountered in the Sohio well about 12,000 feet below the surface. Here, rocks of the Ouachita Basin that were deposited in the deep ocean are thrust over shallow-water rocks of the Oklahoma Basin.

Geologists also know that the rocks exposed in the Potato Hills, which are similar to those of the Broken Bow uplift, must have been deposited well south of the Sohio well and subsequently thrust-faulted to their present position. This means that, at a minimum, the Ouachitas have been shortened by about 50 miles. In all likelihood, the actual amount of shortening is much greater.

Of all the aspects of the geology of the Broken Bow uplift that have been studied, one is particularly interesting and little studied. Most of the rocks surrounding Broken Bow Lake are highly folded and steeply tilted. This is also true about the same age rocks along the west side of the uplift along the Glover River. These rocks include all the formations of the Broken Bow uplift except the two oldest, the Crystal Mountain Sandstone and the Collier Shale (Figs. 4, 7). These two formations are exposed in the "core" of the uplift southwest of Broken Bow Lake, for example, along Lukfata Creek and its tributaries. Nearly everywhere these formations are observed, they are slightly metamorphosed and gently tilted. Careful examination of these oldest formations shows that even though they are gently tilted, they are highly folded and faulted, only the folds appear to have been knocked over on their sides and the faults are nearly horizontal.

There appears to be a major fault separating the gently tilted, but highly deformed, and slightly metamorphosed older rocks ("lower level") from the steeply tilted, also highly deformed, but less metamorphosed, younger rocks ("upper level") (Fig. 12). This feature has been called the Hochatown fault and separates the hilly country of the younger rocks from the flatter country of the older rocks. It may be one of the larger thrust faults that formed during the Ouachita orogeny, but its origin is unknown. In fact, it has received so little attention from geologists that even it's exact location is, in many places, unclear.

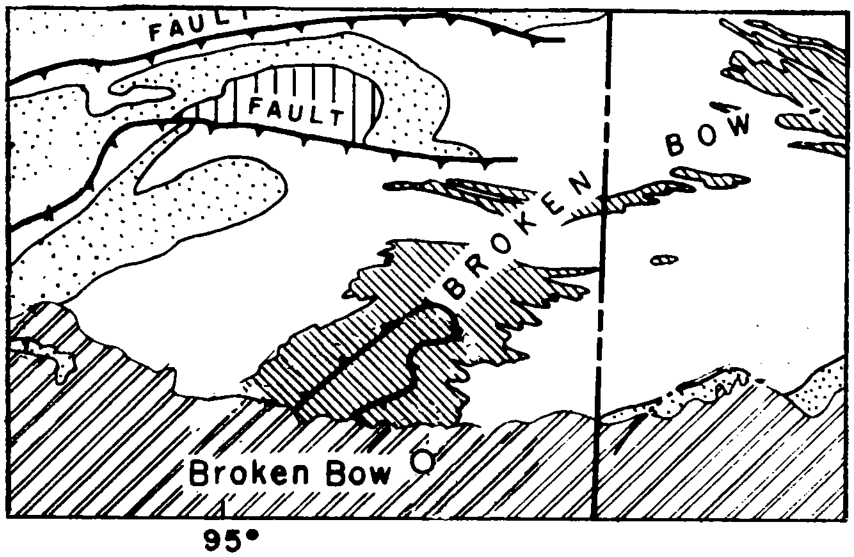


Figure 12. Generalized geologic map of the area near the Broken Bow uplift. Note the heavy, solid line surrounding the "core" of the uplift. This probably represents a major fault separating an "upper level" of mostly steeply tilted rocks from a "lower level" of mostly nearly horizontal, but still very deformed, older rocks.

The main phase of the Ouachita orogeny ended about 310 million years ago. This date is well-known from work done just north of the Ouachitas in Latimer and Pittsburg Counties. Although the time of its beginning is poorly known, it appears that most of the complex geology that we see in the Ouachita Mountains formed over about 40 million years, from about 350 to 310 million years ago. Interestingly, although geologists can show that a tremendous amount of deformation and shortening occurred during this time, they cannot show that the mountains were ever very high; in fact, it appears that during most of this time period, the evolving Ouachita mountain range was below sea level. It was not until somewhat later, after most of the folding and faulting had ceased, that the Ouachitas were raised to form what most of us would recognize as a mountain range.

THE OUACHITA OROGENY - FINAL PULSE

The Ouachita orogeny is generally believed to have formed as a result of the collision of a microcontinent called Llanoria with the North American continent. This collision formed a series of east-west oriented folds and faults. The general orientation of the Broken Bow uplift, however, is northeast-southwest. The origin of this oblique orientation of the Broken Bow uplift compared to the general orientation of most of the geologic features in the Ouachitas is debated among geologists. An additional question is why are the old rocks of the Ouachita Basin exposed at all, when they are surrounded on three sides by the folded and faulted sandstones and shales of the Ouachita Trough?

Most geologists believe that although most of the folding and thrusting associated with the Ouachita orogeny ended about 310 million years ago, things didn't stop entirely. Between about 310 and 270 million years ago (late Pennsylvanian to early Permian), the Ouachitas were raised above sea level to form a major mountain chain. As they rose, they were eroded. (The material eroded from the Ouachitas forms much of the red sandstone so common throughout much of central Oklahoma.) Near the end of this period of uplift, it appears that the area of the Broken Bow uplift was raised higher than the surrounding countryside. Later erosion caused some of the older, originally more deeply buried (and therefore more metamorphosed) rocks to be exposed at the surface (Fig. 11). This uplift of the Broken Bow area appears to have been the final pulse of mountain building in the Ouachita Mountains area.

THE GULF COASTAL PLAIN

The youngest rocks in the Broken Bow area, in fact, the rocks that the town of Broken Bow is built on, are much younger than those of the mountains just to the north. The youngest rocks of the Broken Bow uplift are about 350 million years old; the oldest rocks that are part of what geologists call the Gulf Coastal Plain are about 125 million years old. Geologists are pretty sure the Ouachitas were a high mountain range until about 270 million years ago because most of the rocks of that age (the Permian red rocks of much of central Oklahoma) appear to have come from the eroding Ouachitas. However, exactly what the Ouachita Mountains area of Oklahoma looked like between about 270 and 125 million years ago is unknown. There are no rocks that age around to give geologists any clues. However, the history of southeastern Oklahoma after about 125 million years ago is relatively well-known.

The Gulf Coastal Plain sedimentary rocks in southeastern Oklahoma consist of repeating sandstone, shale, limestone, and thin lignite coal beds (Fig. 5). Most of the sandstone beds were deposited above sea level or under very nearshore conditions. The same is true of the coals - clearly, they were deposited in swamps and lagoons. The limestones were mostly deposited under shallow marine conditions, as the abundance of shells testifies. The shales contain marine shells, but also a significant porportion of land-derived material (clay), thus, they are transitional between the sandstones and the limestones.

The Cretaceous history of southeastern Oklahoma thus consists of a series of advances and retreats of an ancient sea. When the sea was at its maximum advance, limestone was deposited throughout the region. Periodically, the sea retreated and the low hills of the Ouachita "Mountains" to the north supplied sand and silt to a low coastal area and shoreline. In places, swamps existed that later formed coal beds. Over time, the sea withdrew to the south to its present location, but always with minor attempts to regain its former territory.

ROAD LOG

Start field trip in parking lot on southeast side of Broken Bow Lake dam. Drive north across dam, then another 1 1/2 miles to the smaller emergency spillway dam. Drive across it a couple tenths of a mile and turn sharply left to the parking lot at the bottom of the dam. Park at the end of the parking lot. After looking at the rocks in the creek, we will walk along the old haul road (watch out for poison ivy and snakes!) to the quarry.

Stop 1. Polk Creek Shale in creek, Blaylock Sandstone in Riprap Quarry.

Our first stop is to look at two of the formations in the upper level of the Broken Bow uplift.

At the end of the parking lot are excellent exposures of the Polk Creek Shale, which is about 445 to 438 million years old (late Ordovician). Throughout most of the Ouachitas, the Polk Creek Shale is about 115 to 200 feet thick. The most common fossils in the Polk Creek Shale are graptolites, which are black and look like thin hacksaw blades with big teeth (Fig. 13). (Unfortunately, the Polk Creek Shale in this area is slightly metamorphosed and the graptolites have been "baked out" of the rocks. Graptolites are common in the formation along Black Knob Ridge near Atoka and Stringtown and in the Potato Hills southwest of Talihina.)

Most of the Polk Creek consists of black, papery, highly carbonaceous shale with less common thin layers of black chert. In many places it is a good source rock for petroleum. Like many fine-grained rocks, the Polk Creek shale was deposited as fine clay and organic matter under quiet, probably relatively deep marine conditions. In the Broken Bow uplift area, the Polk Creek has been slightly metamorphosed and has a slight sheen to it.

Cross the small creek at the end of the parking lot, follow it downstream to the main creek, and walk along the trail that follows the main creek. After about 100 yards, turn right and walk along the old haul road to the quarry. The rocks taken from the quarry were used to build the emergency spillway dam and the main reservoir dam. As we walk to the quarry, we are walking generally south. We are also walking from older rocks (Ordovician Polk Creek Shale) to younger rocks (Silurian Blaylock Sandstone) and into the center of a large syncline (downfold).

Spectacular outcrops of Blaylock Sandstone are exposed in the riprap quarry. The Blaylock Sandstone is early Silurian in age (about 438 to 425 million years old). A more detailed description of the Blaylock Sandstone is given at Stop 3. However, certain features of the Blaylock Sandstone and the folding history of the Broken Bow uplift are well-displayed here.

The thick sandstone beds in the Blaylock are the first feature that catches your eye. If you look closely at the sandstone beds on the south quarry wall (to your right as you walk in), you'll notice some V-shaped bulbous features. Geologists call these "flute casts" and they can be used to determined what direction the current was flowing when the sandstone was deposited (Fig. 14A). The point of the V points up-current. They are similar to "groove casts" (Fig. 14B)(see Stop 3) and the two are often found togehter.

The second feature to notice are the folded beds of sandstone on some of the quarry walls. One question that has intrigued geologists is the origin of those folds in relation to the very large folds similar to the syncline that we are walking into. Now walk to the end of the quarry and look at the thin shale beds between the thicker sandstone beds. Do you see a faint planar fabric in the shale? Geologists call this feature cleavage and, depending on where you look, it may or may not be parallel to the sandstone layers surrounding the shale (Fig. 15).

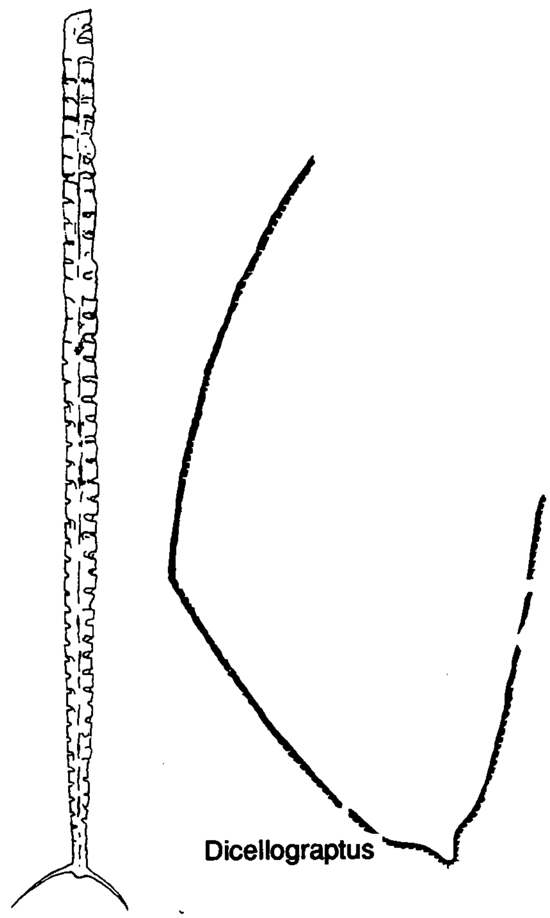


Figure 13. Two species of graptolites common in the Polk Creek Shale along Black Knob Ridge near Atoka and in the Potato Hills near Talihina.

Typically, cleavage in shale forms at the same time the shale is folded and it develops parallel to a plane that would divide the fold in half.

Dr. Kent Nielsen, a geologist from the University of Texas at Dallas, has mapped the orientation of cleavages at many, many localities near here. He discovered that the cleavage itself is folded. This means that the cleavage in the shale beds formed in response to an early period of folding, and that the cleavage was folded (and the shale beds refolded) during a second period of folding. Elsewhere, Dr. Nielsen has shown that some of the thrust faults in the Broken Bow uplift are folded. Obviously, the history of folding and faulting in the rocks of the Broken Bow uplift is very complicated.

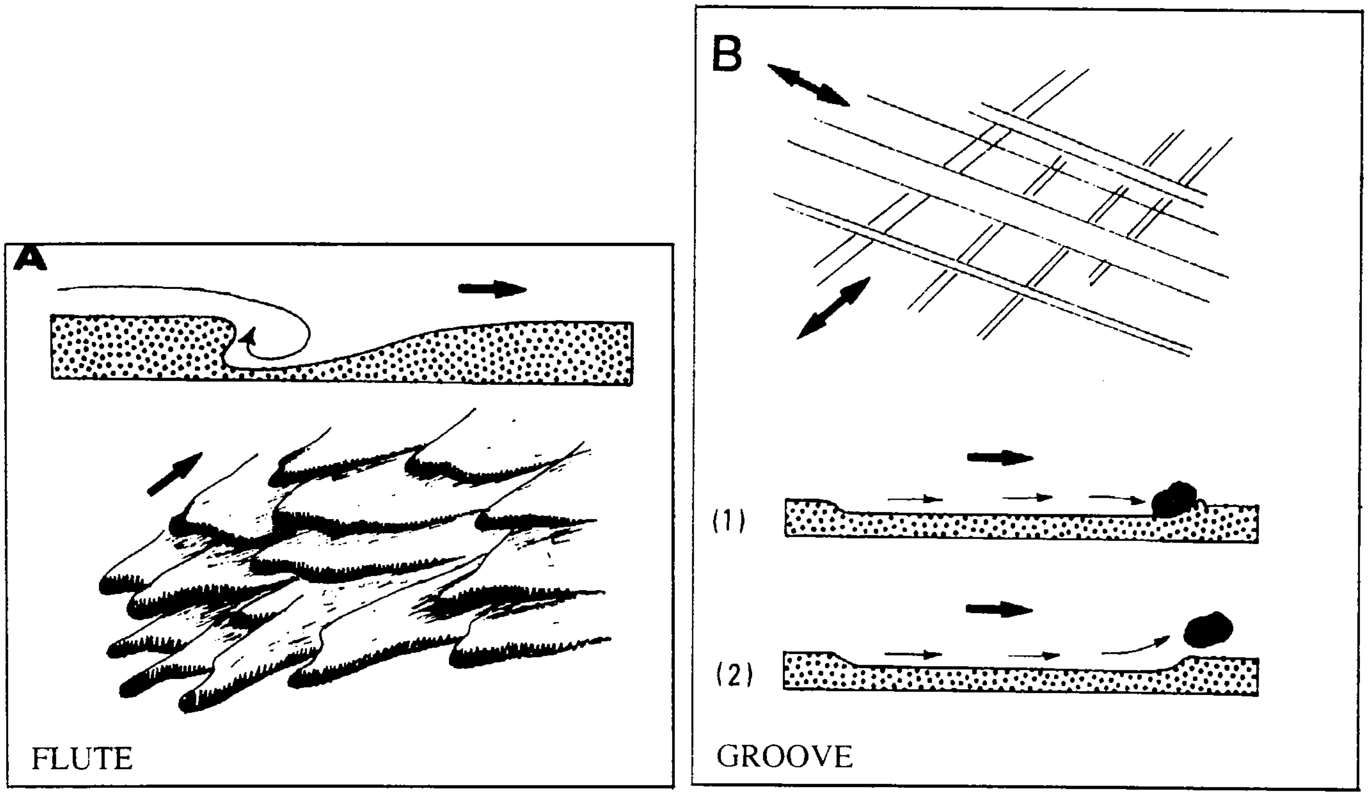


Figure 14. Diagram of flute casts and grooves casts on the bottoms of sandstone beds deposited by turbidity currents. Also shown are cross sections showing how the casts are formed: flute casts by current scouring, groove casts by a solid object scouring. Note that current directions as indicated by flute and groove casts are sometimes variable.

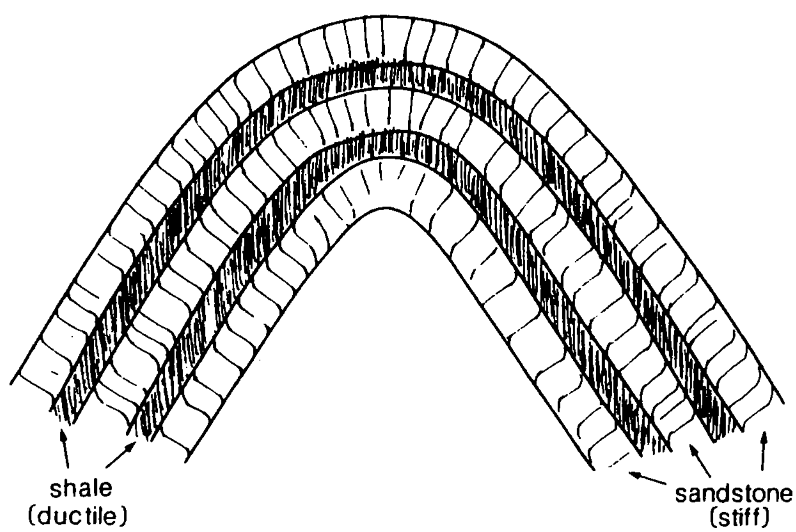


Figure 15. Fold (anticline) showing cleavage in shale beds. In the Broken Bow uplift, this planar feature has been folded by later folding events.

Return to parking lot and cars.

Note: Our next stop is at the end of a short dirt road. The road is not suitable for motor homes. If is has just rained, it may not be suitable for 2-wheel drive vehicles. Four-wheel drive vehicles can negotiate it at all times. In any event, there are several moderately deep hogwallows along the road, so take care going through them. If you want to leave your vehicle along the main highway and jump into somebody else's car, we'll do that.

Continue west along Highway A259 out of park. Turn right and drive north on Highway 259 2.6 miles to an unmarked dirt road that is barely visible on the right. Turn right onto it. It quickly joins a better dirt road; turn right onto it. This road twists and turns for about .6 miles when it is joined by a dirt road coming in from the right. Continue straight ahead for a hundred yards or so and turn left. Drive about .9 miles or so to the end of this road.

Stop 2. Quartz Crystals in the Ouachita Mountains

(Note: The following description of quartz crystals in the Ouachita Mountains is taken almost verbatim from an excellent flyer written by J. Michael Howard and distributed by the Arkansas Geological Commission. The Arkansas Geological Commission has studied the quartz crystals in Arkansas and has several publications that are invaluable to the interested individual.)

INTRODUCTION

Quartz, or silica (SiO_2), is a hard, brittle, durable mineral that exhibits considerable resistance to weathering. It occurs in nature in many varieties, but is best known from Arkansas as prismatic, elongate, clear or colorless vitreous crystals. In the mineralogical profession, Arkansas is known worldwide for its quartz crystals. Because of this, and the popularity of quartz with the many tourists who visit Arkansas each year, the Arkansas General Assembly of 1967 established Act 128, which designated quartz crystal as the official State Mineral.

HISTORY

The existence of quartz crystal in the Ouachita Mountains has been known since humans first occupied the area. According to H.D. Miser, Desoto's men in 1541 found that the Indians had been chipping arrowheads from quartz crystal. Nearly 300 years later, in 1819, H.R. Schoolcraft, a naturalist, described Arkansas quartz crystals. The major early source of crystal appears to have been the Crystal Mountains in Montgomery County. By 1890, crystals were also being mined from deposits in Garland County and the western part of Saline County.

Few restrictions or legal problems hindered the early miners, although most crystal deposits were on land owned by the Federal Government and by timber companies. Patented claims or leases were rarely obtained. As long as the timber was left undamaged and the openings did not become pitfalls for livestock, a miner was free to dig where he dropped his pick and scratcher (an iron rod, commonly 1 to 2 feet long and bent into a right angle several inches from the point, used to scratch out the crystals). During World War II, the critical need for oscillator grade quartz, used in communication equipment, brought about a rapid expansion in prospecting and mining. With Federal agencies and private mining companies participating, mining rights received more careful scrutiny and free-for-all operations dwindled.

Following World War II, techniques were developed for growing quartz crystals artificially and the demand for Arkansas quartz was mostly limited to the expanding tourist and museum markets. Some crystals were cut into semi-precious "Hot Springs diamonds" for jewelry purposes. The present major commercial use of quartz is as a high purity feedstock (lasca) for the growth of synthetic quartz crystals. These man-made crystals have many chemical, thermal, and electrical applications.

With the increased demand by tourists, museums, and the fused glass market, the price for quartz crystals has continued to rise in recent years. Some exquisitely developed quartz clusters are reportedly valued at thousands of dollars.

GENERAL GEOLOGY

Most of the quartz veins and crystals are restricted to a belt about 30 to 40 miles wide that extends a distance of about 170 miles in a west-southwest direction from Little Rock, Arkansas to eastern Oklahoma (Fig. 16).

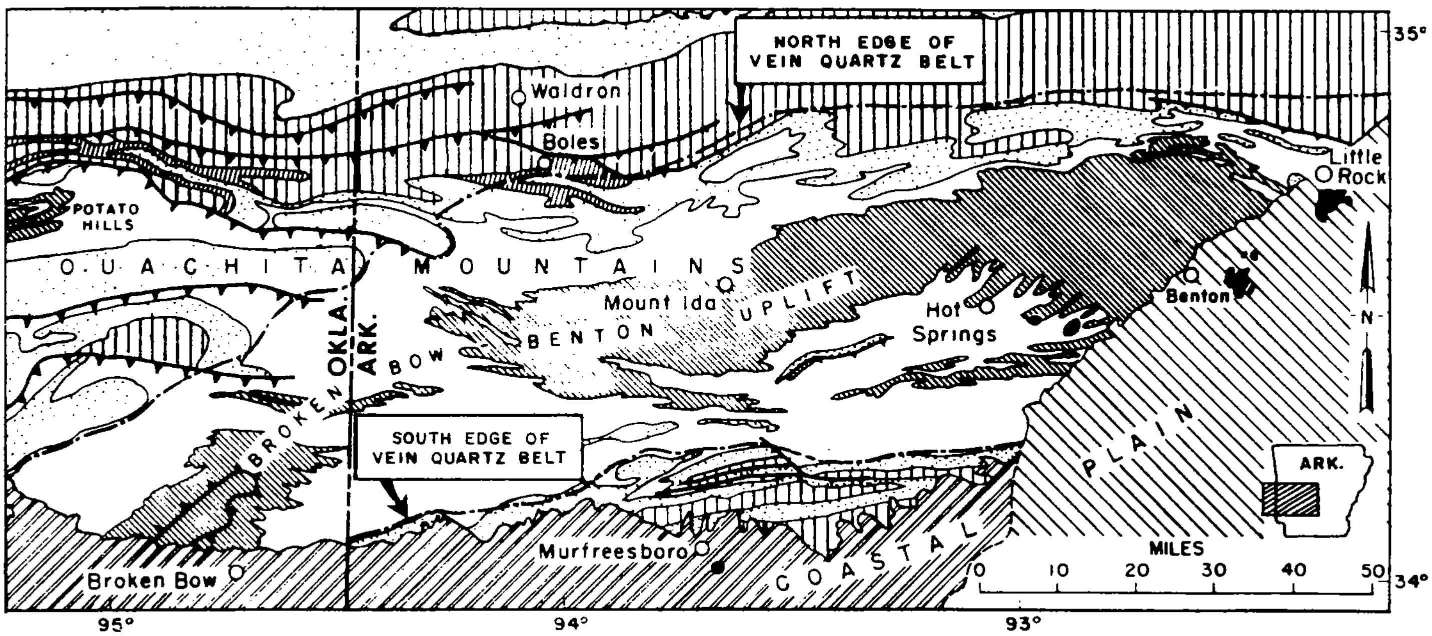


Figure 16. Generalized geologic map of the Ouachita Mountains showing the location of the vein quartz belt.

The quartz veins occur in both Paleozoic sandstones and shales, but those enclosed in shales typically are massive milky vein deposits. Deposits in sandstone units may be in the form of veins, sheeted zones, and/or stockworks. Although these forms may contain much less quartz volumetrically when compared to deposits in shales, they often yield a higher proportion of clear crystals in cavities or pockets (Figs. 17, 18). Many of the crystal-bearing pockets were distorted or crushed by structural adjustments in the Ouachita Mountains that occurred after initial quartz deposition. This deformation commonly causes the veins to show complex fabrics.

The quartz veins were formed by the filling of open fissures and show little evidence of significant replacement of wall rock. Milky quartz crystals and associated vein minerals of the Ouachita Mountains were deposited from hot waters during the closing stages of mountain building, about 280-245 million years ago. The veins attain a width of as much as 60 feet in Arkansas and nearly 100 feet in Oklahoma. They are most numerous along the central core of the Ouachita Mountains, where they occur in shale, slate, sandstone and other rocks. Along and near the borders of this region, the veins are usually confined to sandstone beds lying between thick beds of shale.

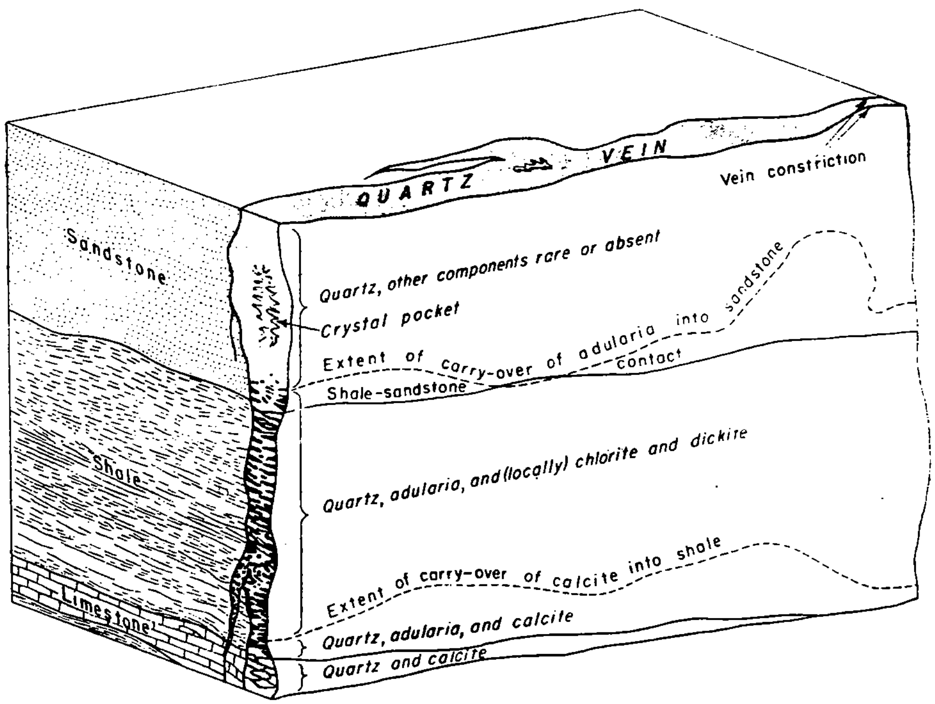


Figure 17. Block diagram showing the kinds of quartz veins and accessory minerals that occur relative to the kind of rock surrounding the vein.

Most of the collectible quartz crystal is obtained from deposits in the Blakely (Ordovician) and Crystal Mountain (Ordovician) Sandstones, but attractive quartz crystal may occasionally be collected from any of the Paleozoic units. These strata total more tha 25,000 feet in thickness and have been deformed into complex, gently plunging folds that trend nearly east-west. Steeply dipping fractures closely related to the major folds controlled the location of deposition of most of the quartz.

[The quartz crystal deposit at this locality is located in the Collier Shale. Weathered shale is visible in the small pit at the top of the hill. Note how the quartz vein cuts obliquely across the bedding in the shale. It is also important to note that the Hochatown fault, which may be a major thrust fault in the Ouachita Mountains, is located only about 1/2 mile northwest of here.]

TYPES

Most of the quartz in the Ouachita Mountains occurs as white or milky veins. The principal difference between milky quartz and clear rock crystal is the presence of innumerable microscopic bubbles or fluid-filled cavities in the former. These cavities scatter the light that otherwise would pass through as in clear crystal. In addition to clear crystal and milky quartz, other varieties of quartz are present. Smoky quartz occurs adjacent to Cretaceous igneous rocks near Magnet Cove in Hot Spring County. The dark color is due to defects in the crystal lattice caused by radioactivity that was present when the quartz was deposited. Banding or growth zoning is not uncommon in well formed crystals from this area. Quartz with fluid inclusions and negative crystal quartz are found near the edges or fringes of the area of major quartz deposition. Generally, these types resemble quartz from near Herkimer, New York and formed in calcite veins which are commonly weathered to clay, leaving the crystals suspended where they wash out in loose soil. Phantom or zoned quartz is caused by temporary interruption of the growth process. Phantoms may be caused by small bubbles or inclusions of minerals adhering to the crystal faces. Amethyst (purple or bluish-violet quartz) occurs associated with Cretaceous igneous intrusive rocks, particularly with calcite veins at the Crater of Diamonds State Park and as veins associated with serpentine bodies in northern Saline County. Across the northern limits of vein quartz deposition, a type of quartz termed "solution quartz" by local collectors occurs. This quartz is unusual because much of it has grown as suspended or unattached crystals or clusters (burrs) in a clay mineral called rectorite. Specimens of these more unusual varieties are prized by collectors because of their beauty and scarcity.

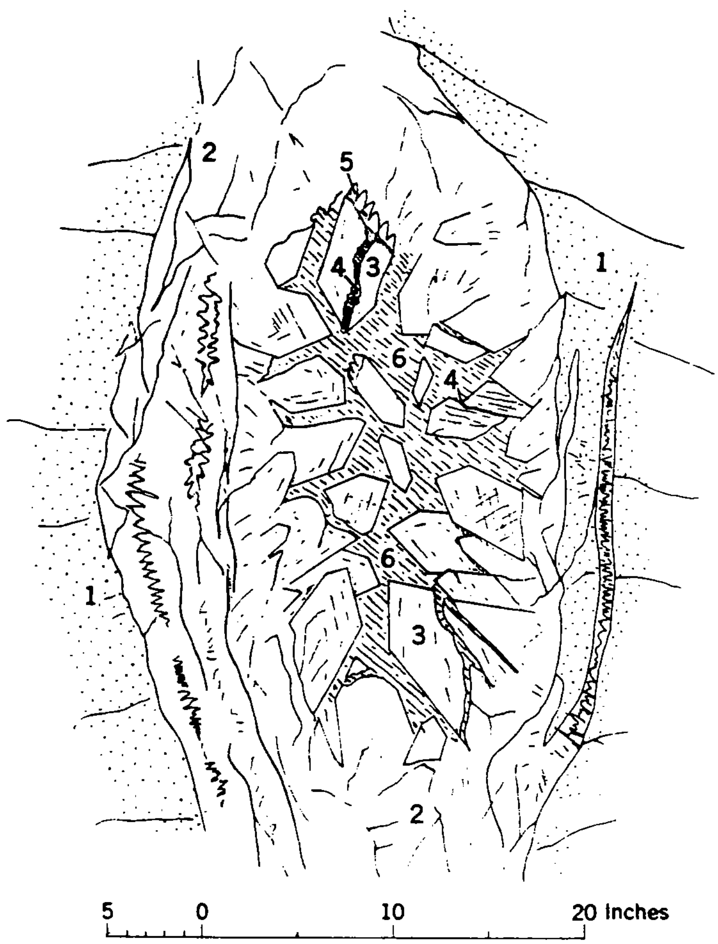


Figure 18. Example of quartz crystal pocket. 1 - sandstone; 2 - massive, milky vein quartz; 3 - fractured quartz crystal; 4 - healed fracture; 5 - part of crystal grown after fracture; 6 - red clay filling around crystals.

Several minerals are associated with the quartz, which usually constitutes 90 percent or more of the cavity fillings (Fig. 18). Clay minerals, including dickite and nontronite, are widespread. Calcite is a common associate, especially in veins cutting limestone or calcareous siltstone. Adularia and chlorite are found in veins cutting certain shales (Fig. 17). Carbonaceous material also is common. Less common accessory minerals are brookite, rectorite, the sulfides of lead, zinc, antimony and mercury, the lithium mica cookeite, and the carbonates ankerite and siderite.

Retrace route back to Highway 259 and turn north (right). Drive 5.4 miles to dirt road to Carter Mountain Lookout Tower on right. Turn right on lookout tower road and park. Be careful crossing the highway. The traffic moves fast and isn't expecting pedestrians!

Stop 3. Blaylock Sandstone, Missouri Mountain Shale, and Arkansas Novaculite.

The outcrop on the west side of the highway just north of here and the outcrop on the east side of the highway just south of here exposes three formations that make up many of the hills of the Broken Bow uplift. These formations were deposited over a time span of about 75 million years, from the early Silurian to the early Mississippian time periods (Figs. 4, 7). These formations also represent a variety of different rock types and therefore, a variety of conditions under which they were deposited. Many professional geological field trips have stopped at this exposure and the rocks here are well-studied.

The oldest formation exposed here, the early Silurian Blaylock Sandstone (Figs. 4, 7), are the sandstone and shale beds north of the turnoff and best-exposed on the west side of Highway 259. About 225 feet of the formation is present here. This is the same formation that is exposed in the riprap quarry at Stop 1, but the highway roadcuts here give us a better opportunity to examine the rocks.

Wherever the Blaylock Sandstone is exposed throughout the Ouachita Mountains, it is composed of sandstone and shale. In some places, the sandstone beds are thicker and there is proportionately more sandstone; in other places, shale predominates. For the most part, the sandstone is brownish to slightly olive-colored and is fine-grained, which means that individual sand grains are barely visible with the naked eye, but easily seen with a hand lens. Under the microscope, it can be seen that the sandstone is mostly made up of quartz grains; small feldspar and rock fragments make up the remainder of the rocks. The shale between the sandstone beds is mostly pale green, though a few beds are reddish. The shale has been very slightly metamorphosed and has a distinct platy appearance (cleavage - see Stop 1 for more discussion of cleavage); when this occurs in shale, geologists sometimes call the rock "argillite".

Close examination of the sandstone reveals that some of the sandstone beds are "graded", which means that the sand grains at the bottom of the bed (towards the north) are slightly larger than those at the top of the bed (towards the south). Can you find any examples of graded bedding in the sandstone beds? Some of the sandstone beds show faint parallel lines or planes towards the top of the bed. And some show unusual parallel lines or "grooves" on the very bottoms of the beds. These "grooves" indicate which way the current was coming from when the sandstone was deposited (Fig. 14B). Geologists who have looked at the Blaylock Sandstone throughout the Ouachitas know that the currents that deposited the sandstone was flowing to the west.

These characteristics of the Blaylock Sandstone: the alternating beds of sandstone and shale, graded bedding and faint parallel bedding in the sandstone, and "bottom marks" suggest that the Blaylock was deposited by deep marine currents called turbidity currents. These can be thought of as a "submarine sand-and-mud clouds"; the closest analogy that most people can visualize is the volcanic ash cloud associated with the eruption of Mt. St. Helens in 1980. In that eruption, a huge cloud of volcanic ash blew out of the volcano, hugged the ground, and traveled laterally at great speeds for large distances. Imagine a similar situation deep under the ocean, with a bottom-hugging cloud of sand and mud, traveling at great speeds for hundreds of miles, and finally coming to rest. Repeated turbidity currents, each depositing a layer of sand, and separated by intervals of quiet deposition of mud, describes the conditions under which the Blaylock Sandstone was deposited.

The next youngest formation exposed at this stop is the late Silurian Missouri Mountain Shale (Figs. 4, 7). The shale is poorly exposed because it is not a hard rock and erodes easily. However, it is exposed in the bar ditch along the side of the road to the lookout tower.

The Missouri Mountain Shale at this location is about 95 feet thick, although much less is actually exposed. It is composed mostly of argillite (like the Blaylock) and a few thin sandstone beds. Like the Blaylock Sandstone, the Missouri Mountain Shale was probably deposited under relatively deep ocean conditions by turbidity currents, but the rarity of sandstone beds indicate that those currents were much less frequent and/or weaker.

Perhaps the most interesting formation in the Ouachita Mountains is the Devonian to early Mississippian Arkansas Novaculite (Figs. 4, 7). It is made up mostly of a variety of relatively hard rocks and is resistant to erosion; therefore, it forms many of the high hills in the Broken Bow uplift area. It is interesting to geologists because it is a relatively thin formation yet took about 55 million years to be deposited and because there is no general agreement on the origin of all the silica (quartz) in the formation (see discussion below). At this location, the novaculite is exposed in the high roadcuts south of the lookout tower road on the east side of Highway 259. About 440 feet of Arkansas Novaculite has been measured here. In Pike and Garland Counties, Arkansas, the novaculite has been quarried and made into some of the world's finest-quality whetstones. A calcareous variety of novaculite near Hot Springs has weathered into a material known as tripoli, which is mined as an abrasive.

The Arkansas Novaculite consists of a variety of somewhat similar rock types; these are argillite (discussed under the Blaylock Sandstone, above), siliceous shale (a hard variety of shale), chert (an extremely fine-grained rock that is nearly 100% silica and shatters when hit with a hammer), and novaculite. Novaculite is a variety of chert that is characterized by fracture surfaces that are gritty, in contrast to fracture surfaces in chert that are smooth. Obviously, chert and novaculite can grade imperceptably into one another - what is gritty to one person may be smooth to another. In fact, all the rock types found in the Arkansas Novaculite grade into one another, and it is sometimes difficult for a geologist to distinguish between, for example, a siliceous shale and an argillite.

There are several geological problems surrounding the Arkansas Novaculite. One is the issue of where all the silica that makes up the formation came from. Some geologists believe that there must have been a tremendous amount of volcanism during the Devonian. The silica-rich volcanic ash would settle out in the ocean where it would dissolve, only to be redeposited on the sea floor by organisms or by non-organic processes. Other geologists believe that much of the silica in the Arkansas Novaculite is secondary, that is, was originally deposited as a different mineral, and later replaced by silica. By looking at the novaculite microscopically, they see evidence for original (but now gone) carbonate (limestone). The origin of all the silica is unanswered. The possibility of an ultimately volcanic origin may never be proved because there is no evidence for volcanic ash in the Arkansas Novaculite. Similarly, if all the silica is secondary, where did that silica come from?

Another geological problem is under what conditions was the Arkansas Novaculite deposited. The absence of sandstone indicates that there were very few currents active when it was deposited, and the fact that the formation was deposited over a very long period of time indicates that whatever process is invoked, it must be slow. In the past, the Arkansas Novaculite was used as an example of very slow accumulation of siliceous mud in a quiet, deep marine environment. Recent research, which has focused on the very rare sandstone and conglomerate beds in the novaculite (there is one 1-foot-thick conglomerate bed in this outcrop about 1/3 of the way from the bottom of the formation; can you find it?), has challenged this view. Some geologists point to many features that indicate the novaculite originally contained a greater amount of carbonate (limestone) than it does now and that this is evidence for deposition in shallow water. They also suggest that some of the microscopic sand particles found in the chert represents wind-blown sand, which would probably indicate being relatively close to land. Some geologists even go so far as to suggest there is evidence that the Arkansas Novaculite suffered the ultimate in shallow-water deposition, that is, that is was exposed to the air and locally eroded.

Most geologists agree that a substantial part of the Arkansas Novaculite was deposited under quiet, relatively deep marine conditions. But substantial disagreement exists over the origin of other parts of the formation, and ideas range from deep marine to above water!

Return to cars and head south on Highway 259 for about 5.2 miles. At that point, there is a major graded gravel road to the right (west). Turn right on that road. Dirve 1.2 miles to large excavation on north (right) side of road. This road approximately parallels the Hochatown fault, which lies 1/4 to 1 mile northwest of the road. The outcrop we will look at and others along the road allow one to look at some of the rocks in the "lower level" of the Broken Bow uplift.

Stop 4. Collier Shale.

The Collier Shale at this outcrop is not really a shale, rather, it is a phyllite. Phyllite is the slightly metamorphosed equivalent of shale and is distinguished from shale by a conspicuous "sheen"; this "sheen" is caused by parallel mica flakes which grew when the shale was metamorphosed.

The Collier is the oldest formation in the Broken Bow uplift. Trilobites from the Collier in Arkansas are late Cambrian, but the most common fossils in the Collier are microscopic conodonts, and these indicate most of the Collier is Ordovician. In the Broken Bow uplift, most of the Collier is too metamorphosed to find any fossils, but conodonts have been found, in places.

The Collier Shale consists mostly of black to dark gray shale, phyllite, and slate. Although it looks like it is well-bedded, most of the layers in the Collier are cleavage planes (see discussion of cleavage at Stop 1). Dark gray limestone, bedded sandstone made up largely of limestone grains, and coarse-grained sandstone and conglomerate are less-common rock types. It is the limestone in which Collier fossils have been found. Careful study of the Collier has lead some geologists to suggest that it was deposited by turbidity currents, much like the Blaylock Sandstone (see Stop 3). However, the limestone beds are unusual. It is possible that the turbidity currents that formed the Collier originated in an area that was mostly limestone, unlike, for example, the Blaylock turbidity currents that originated in an area that was mostly sand. Interpretation of exactly how the Collier was deposited is difficult because much of the evidence that geologists would like to see has been obscured (at best) or destroyed (at worst) by the metamorphism that has occurred.

Perhaps some of the most "poetic" descriptions of the Collier is by C.W. Honess, the first geologist to map this area in the area from 1917 to 1919. He described the Collier Shale as follows:

"The oldest formation which comes to the surface in the area ... is a mass of much contorted and metamorphosed ... black shales."

"... The outcroppings are blue-black slates and soft unctuous shales, cut by thin stringers and veins of milky quartz ..."

"That the series has been subjected to very severe regional metamorphism is evident ... The shales have suffered pronounced twisting and crushing, not only as shown by microscopic examination, but as revealed by the sandy more resistant layers, whose presence indicates the complexity of these contortions."

"... Only the upper portion of the formation is exposed and this is so badly mashed that it cannot be measured."

Return back along same road to Highway 259. Turn right (south on Highway 259. As we drive south, look at some of the low roadcuts along the highway, particularly the east side. At first, you'll continue to see dark shaly-looking rocks similar to those at Stop 4. These are mostly rocks of the lower level of the Broken Bow uplift. Then we'll encounter some hills - we're back into the upper level. After that, you'll notice some reddish-colored gravelly-looking rocks. These are part of the Holly Creek Formation that is Cretaceous in age (Fig. 5). We're now out of the Ouachita Mountains geologic province and into the Gulf Coastal Plain. A couple miles north of Broken Bow we cross a poorly exposed De Queen Limestone, also Cretaceous. The town of Broken Bow is located on the Antlers Sandstone, which is probably the most extensive Cretaceous formation in southeastern Oklahoma; to the west, the Antlers Sandstone lies directly on the Ouachita Mountains rocks and the Holly Creek Formation and De Queen Limestone are absent.

Continue south through town of Broken Bow towards Idabel. About 6 miles south of Broken Bow, cross the Little River. 0.8 miles south of the bridge, turn right (west) into the Meridian Aggregates Company Idabel quarry. NOTE - Please be sure you've signed and returned to the field-trip leader a hold-harmless waiver before entering the quarry.

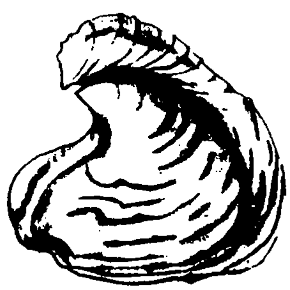
Stop 5. GOODLAND LIMESTONE

This formation should strike you as much different from all the other rocks we've seen on the field trip. First of all, it is nearly horizontal; nowhere in the Ouachita Mountains do we see rocks as flat-lying as this. Secondly, it is soft, in fact, it goes "thud" when you hit it with a hammer. This contrasts with the limestone beds in the Collier Shale that are hard and "ring" when you hit them. This difference in hardness indicates that the Goodland was probably never buried very deeply, whereas the Collier was. Thirdly, the Goodland Limestone is loaded with fossils; none of the formations in the entire Ouachita Mountains is as richly fossiliferous as the Goodland.

We have left the Ouachita Mountains geologic province to the north and entered what geologists call the Gulf Coastal Plain (Fig. 3). The Ouachita Mountains are buried beneath these rocks; geologists aren't sure exactly how far south you have to go before this buried mountain range is no longer present. The Gulf Coastal Plain, which extends all the way to the Gulf of Mexico, is composed of nearly horizontal rocks (all sedimentary) that get younger towards the south. In other words, the oldest rocks of the Gulf Coastal Plain are farthest to the north, right next to the Ouachita Mountains. These oldest rocks are about 125 million years old, whereas the ones they cover are as young as about 350 million years. Thus, we have no geologic record of about 225 million years in this area. We suspect that the Ouachita were a high mountain range as late as about 270 million years ago, which means we can narrow our mystery chapter in geologic history of this area down to about 150 million years. That's still a long time.

The Goodland Limestone in this area is about 50 feet thick. It is white to grayish-white to gray on fresh surfaces and buff-colored where weathered. Most of it consists of a chalky, fine-grained limestone, but beds of dense, coarse-grained limestone are also present. The formation contain abundant fossils, including pelecypods (clams, oysters, and scallops), gastropods (snails), echinoids (sea urchins, sand dollars), and ammonites ("uncoiled" snails) (Fig. 19). Some beds in the limestone are nearly 100% fossils. From the kinds of fossils in the Goodland, it is obviously marine. Based on where we find similar kinds of marine animals today, the water depth was less than 120 feet. The fact that most of the fossil shells in the Goodland are broken suggests some wave or current action, possibly during storms. This supports the shallow water origin of the Goodland.

Fossil... *Pelecypod*
Scientific name.............................. *Gryphaea navia*



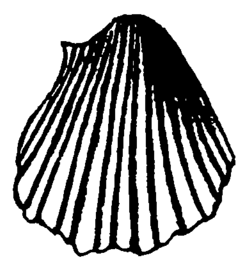
exterior of left valve

Fossil... *Pelecypod*
Scientific name.......................... *Gryphaea corrugata*

exterior of right valve

interior of right valve

Fossil... *Pelecypod*
Scientific name.............................. *Pecten texanus*



exterior of right valve

anterior view

Fossil... *Gastropod*
Scientific name......................... *Turritella vertebroides*

Fossil... *Gastropod*
Scientific name........................... *Tylostoma elevata*

Figure 19. Common fossils from the Goodland Limestone.

The Goodland Limestone represents a shallow marine environment. Beneath it is a thin deposit of clay known as the Walnut Clay. Beneath the Walnut Clay is the Antlers Sandstone, which contains abundant conglomerate beds in places and locally, petrified wood. The presence of conglomerate and wood and extreme scarcity of shells indicates the Antlers was deposited by streams, thus, above sea level. The Walnut Clay contains marine shells but is mostly clay, therefore, can be thought of as a mixed marine-terrestrial deposit, or possibly a very near shore deposit. The Goodland, as we've discussed in clearly marine. Thus, the Antlers - Walnut - Goodland succession represents the advance of an early Cretaceous ocean across this part of Oklahoma. How far that ocean extended to the north is unknown because all we're left with is the eroded northern edge of the Gulf Coastal Plain. Is it possible that the Cretaceous ocean once covered all the Ouachita Mountains and the deposits it left behind are now eroded off?

This is the last stop of this field trip, co-sponsored by the Oklahoma Academy of Science and the Oklahoma Geological Survey. We hope you have enjoyed yourselves, collected some good specimens, and learned a bit about the geology of this beautiful and geologically fascinating part of the State. Two individuals deserve special mention and my sincere thanks. Steve Due, of Eagletown, knows the Broken Bow area far better than I and showed me around prior to this trip. John Hogan, of the Geology and Geophysics Department at OU, was instrumental is setting up the trip.

Please drive safely on your way home.

Most of the figures used in this report are copied from existing publications. The following section lists those publications.

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Fig. 19. from James, B.W., 1977, Fossil Collecting in the Ardmore Area: Ardmore, Oklahoma, Ardmore Geological Society, 20p.