GUIDEBOOK 84-2

STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

Norman F. Williams, State Geologist

A GUIDEBOOK TO THE GEOLOGY OF THE CENTRAL AND SOUTHERN OUAСHITA MOUNTAINS, ARKANSAS

By

Charles G. Stone and Boyd R. Haley

With Contributions

By

J. Kaspar Arbenz, Samuel A. Bowring, William V. Bush, R. L. Ethington, Dwight T. Jenkins, Rufus J. LeBlanc, Robert J. Lillie, A. Wallace Mitchell, Michael R. Owen, Douglas L. Smith, Jay Zimmerman, and others

Little Rock, Arkansas
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FOREWORD

This guidebook on the Paleozoic rocks, primarily in the central and southern Ouachita Mountains of Arkansas, is prepared at the request of Mr. Gary Boland of Arkla Exploration Company and Mr. Arthur Trowbridge, consulting geologist for the Gulf Coast Association of Geological Societies. The field trip follows their 34th Annual Meeting held in Shreveport, Louisiana, October 24–26, 1984.

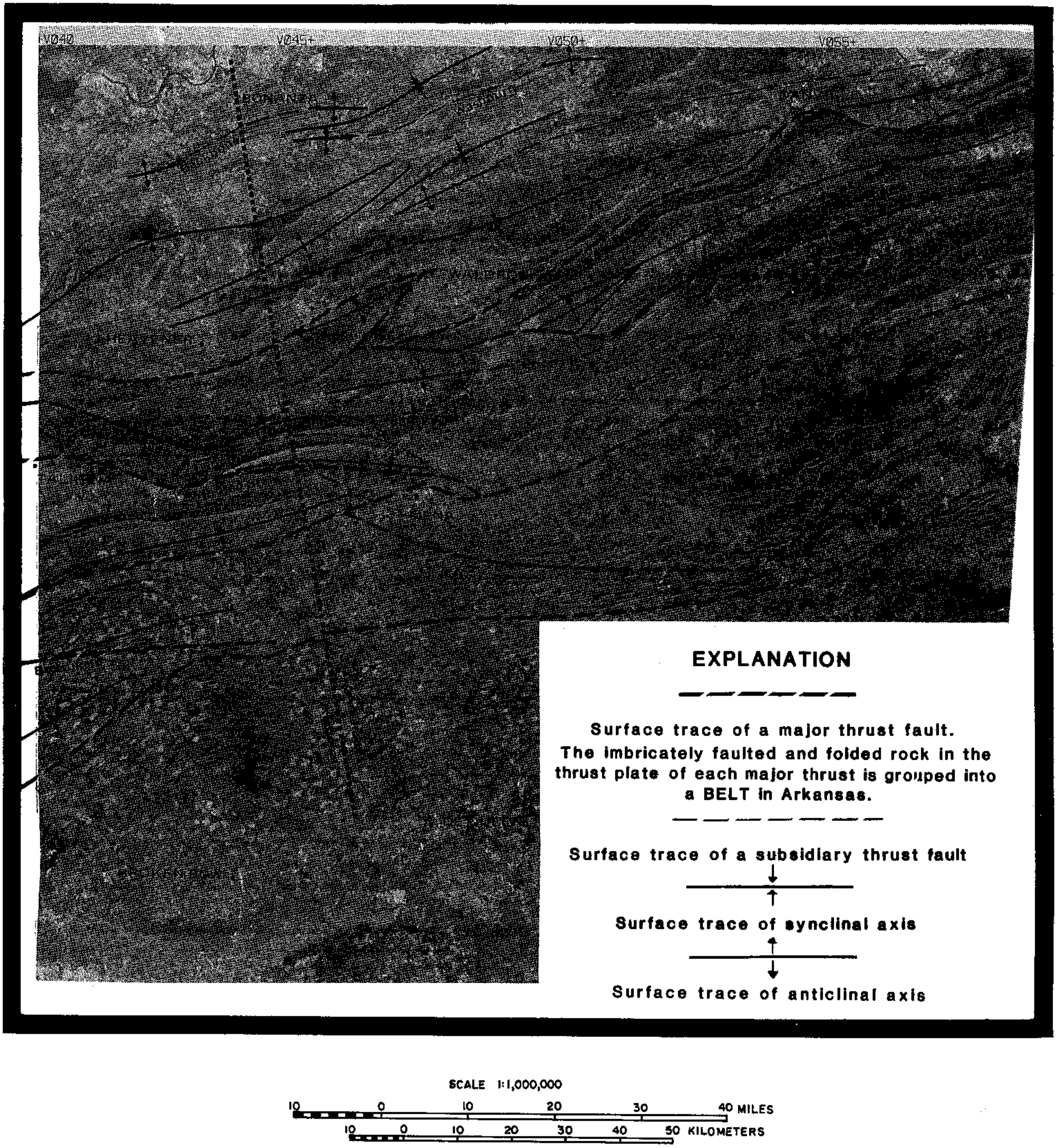
The emphasis of the three-day field trip is on the major thrust faults and the various styles and intensities of deformation in the respective structural belts. The depositional environments and the oil and gas potential of the Early Ordovician to Middle Pennsylvanian formations are also highlighted on the tour.

We wish to acknowledge the important contributions of J. Kaspar Arbenz, Samuel A. Bowring, William V. Bush, Raymond L. Ethington, Dwight T. Jenkins, Rufus J. LeBlanc, Robert J. Lillie, A. Wallace Mitchell, Michael R. Owen, Douglas L. Smith, Jay Zimmerman, and other authors. A deep depth of gratitude is also expressed to Loretta Chase, George Colton, Adrian Hunter, Patrick Kelone, Anthony Rushing, Oleta Sproul, Susan Young and other personnel who worked so diligently on the speedy compilation of this guidebook.

Charles G. Stone

Boyd R. Haley

October 5, 1984

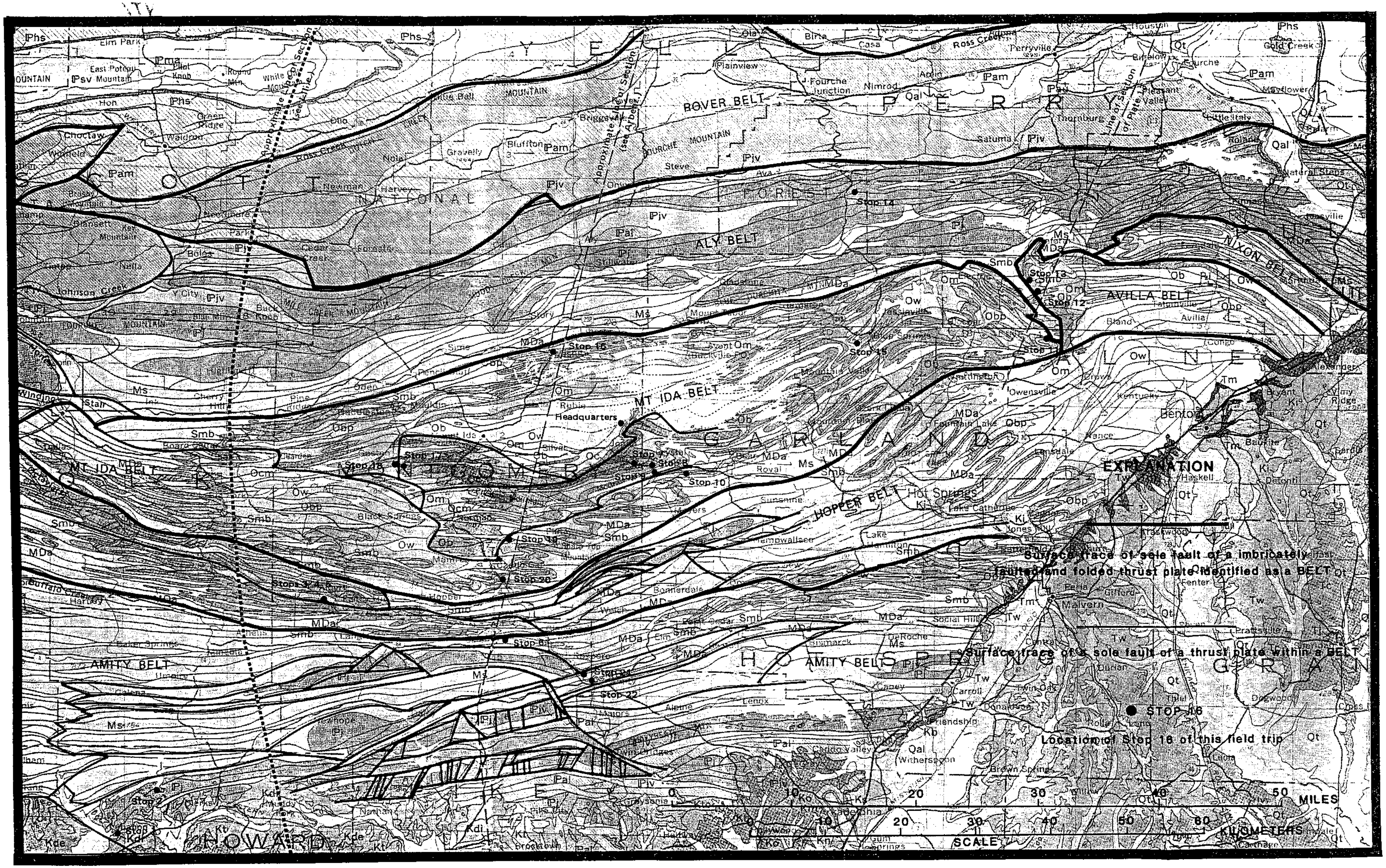


SELECTED STRUCTURAL FEATURES IN A PART OF THE OUACHITA MOUNTAINS AND VICINITY, ARKANSAS-OKLAHOMA

Landsat imagery provided by Gary Boland, ARKLA Exploration Co.

Geology of Oklahoma from Marcher and Bergman, 1983;
Geology of Arkansas from Haley and others, 1976.

PLATE 1



SELECTED STRUCTURAL FEATURES IN THE OUACHITA MOUNTAINS, ARKANSAS

Geology modified from Haley and others, 1976.

PLATE 2

CORRELATION OF PALEOZOIC ROCKS IN THE OZARK, ARKANSAS VALLEY, AND OUACHITA MOUNTAIN REGIONS, ARK.

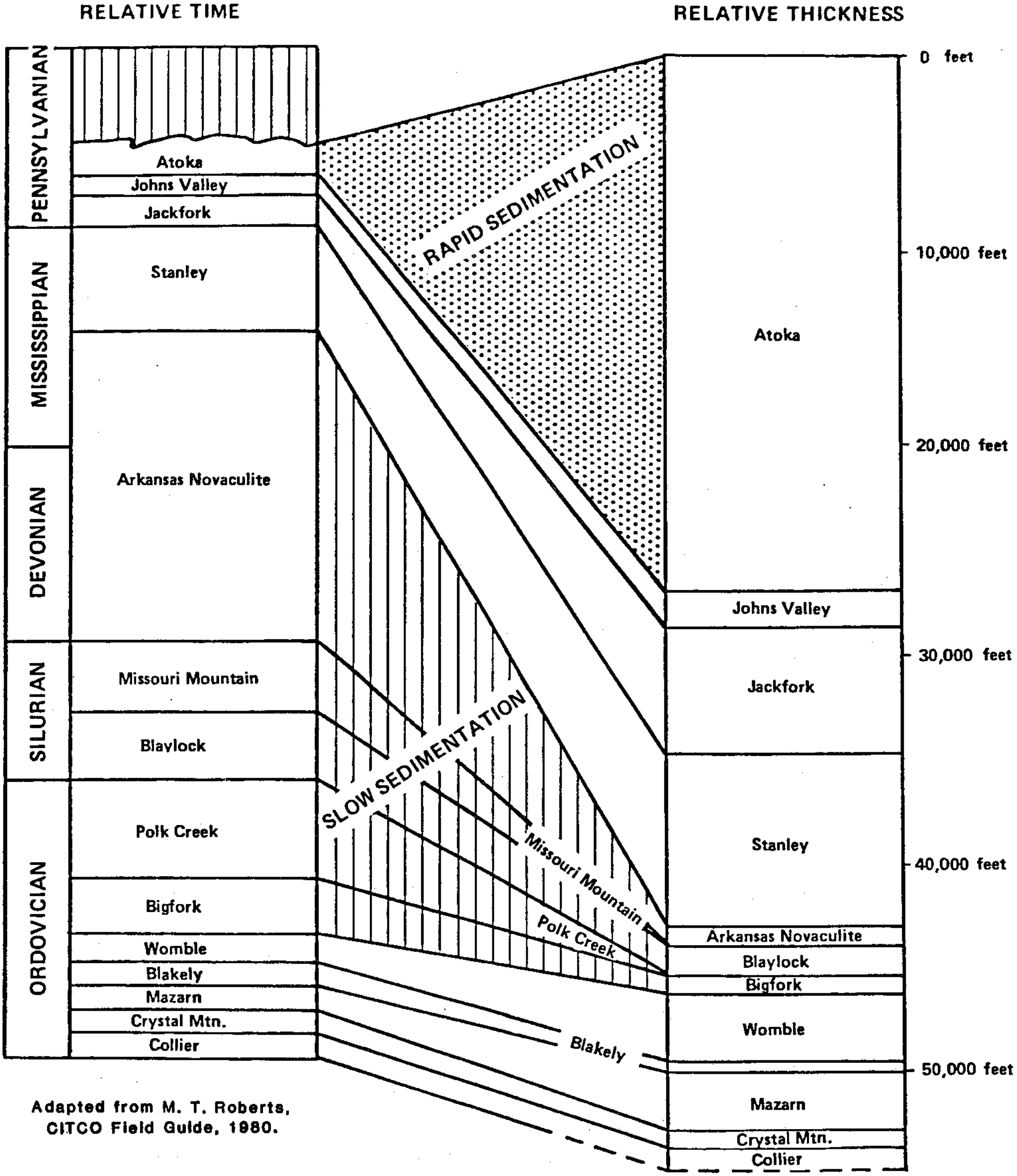
AGE			OZARK – ARKANSAS VALLEY SECTION		MAP SYM.		OUACHITA MTN. SECTION		MAP SYM.	
CARBONIFEROUS SYSTEM	PENNSYLVANIAN	DES MOINES	Boggy Fm.			₽by	Missing			
			Savanna Fm.			₽sv				
			Mc Alester Fm.			₽ma				
			Hartshorne Sandstone			₽hs				
		ATOKA	Atoka Fm.			₽a	Atoka Fm.			₽a
		MORROW	Bloyd Shale.	Kessler Ls Mbr.	₽bh	₽pk	Johns Valley Shale			₽jv
				Woolsey Mbr.		₽bw				
				Brentwood Ls Mbr.		₽bb	Jackfork Fm.			₽j
			Hale Fm.	Prairie Grove Mbr.		₽hp				
				Cane Hill Mbr.		₽hc				
	MISSISSIPPIAN	UPPER	Pitkin Limestone		Mpfb	Mp	Stanley Shale	Chickasaw Creek Mbr.		Ms
			Fayetteville Shale	Wedington SS Mbr.		Mf				
			Batesville Sandstone	Hindsville Ls. Mbr.		Mbh				
			Ruddell Shale			Mr				
			Moorefield Fm.			Mm		Hatton Tuff		
			Boone Fm.	Short Creek Oolite Mbr.		Mb		Hot Springs SS Mbr.		
		LOWER		St. Joe Ls. Mbr.			Arkansas Novaculite	Upper Div.		MDa
DEVONIAN		UPPER	Chattanooga Shale	Sylamore SS		MDcp		Middle Div.		
		MIDDLE	Clifty Limestone					Lower Div.		
		LOWER	Penters Chert							
SILURIAN		UPPER	Missing				Missouri Mountain Shale		SmOpc	Smb
			Lafferty Limestone			Slsb	Blaylock Sandstone			
			St. Clair Limestone							
		LOWER	Brassfield Limestone							
ORDOVICIAN		UPPER	Cason Shale		Ocj		Polk Creek Shale			Opc
			Fernvale Limestone			Of	Bigfork Chert			Obf
		MIDDLE	Kimmswick Limestone							
			Plattin Limestone				Womble Shale			Ow
			Joachim Dolomite							
			St. Peter Sandstone			Ose				
			Everton Fm.	Jasper Ls. Mbr.			Blakely Sandstone			Ob
				Newton SS Mbr.						
				King River SS Mbr.						
		LOWER	Powell Dolomite			Op	Mazarn Shale			Om
			Cotter Dolomite			Ocjc				
			Jefferson City Dolomite				Crystal Mountain Sandstone			Ocm
			Roubidoux Fm.			Not exposed				Oc
			Gasconade-VanBuren Fm	Gunter Mbr.						
CAMBRIAN		UPPER	Eminence Dolomite				Older rocks not exposed			
			Potosi Dolomite							
			Derby-Doerun-Davis Fm.							
			Bonneterre Dolomite							
			Lamotte Sandstone							
PRE-C			Igneous Rocks							

PLATE 3

Stratigraphic section of rocks exposed in the Ouachita Mountains and Arkansas Valley Provinces, Arkansas.

	MAXIMUM THICKNESS
Quaternary	
Alluvium – clay, silt, sand, and gravel	90′
Terrace Deposits – gravel, sand, clay	40′
Cretaceous System	
Tokio Formation – gravel, sand, clay	300′
Brownstown Marl – gravel, sand, marl, and clay	250′
Igneous Rocks – peridotite, kimberlite, and tuff	---
Trinity Group – gravel, sand, clay, gypsum, and minor limestone	150-1,000
Pennsylvanian System	
Des Moinesian Series	
Savanna Formation - sandstone and sandy shale	850
McAlester Formation - shale, sandstone, and coal	1,000
Hartshorne Sandstone - massive sandstone	325
Atokan Series	
Atoka Formation - shale and sandstone	27,500+
Morrowan Series	
Johns Valley Shale - shale, minor sandstone and limestone, and erratic boulders	1,500+
Jackfork Sandstone - sandstone and shale	6,000
Mississippian System	
Stanley Shale - shale, sandstone, and some chert	11,000
Devonian and Mississippian Systems	
Arkansas Novaculite - novaculite, shale, and conglomerate	950
Silurian System	
Missouri Mountain Shale - shale with minor sandstone	250
Blaylock Sandstone - sandstone, siltstone, and shale	1,500
Ordovician System	
Polk Creek Shale - shale	175
Bigfork Chert - chert, limestone, and shale	800
Womble Shale - shale with some thin limestone and sandstone	1,900
Blakely Sandstone - shale and sandstone	450
Mazarn Shale - shale with some sandstone and limestone	3,000
Crystal Mountain Sandstone - sandstone	850
Collier Shale - shale and limestone	1,000

PLATE 4



Adapted from M. T. Roberts, CITCO Field Guide, 1980.

PLATE 5 CHART SHOWING SEDIMENTATION RATES OF THE PALEOZOIC ROCKS IN THE OUACHITA MOUNTAINS, ARKANSAS.

STOP DESCRIPTIONS – FIRST DAY

SOUTHWESTERN OUACHITA MOUNTAINS
DIERKS – ALBERT PIKE – GLENWOOD – MT. IDA

STOP 1 – ASPHALT IN UPPER JACKFORK SANDSTONE AT H M B QUARRY

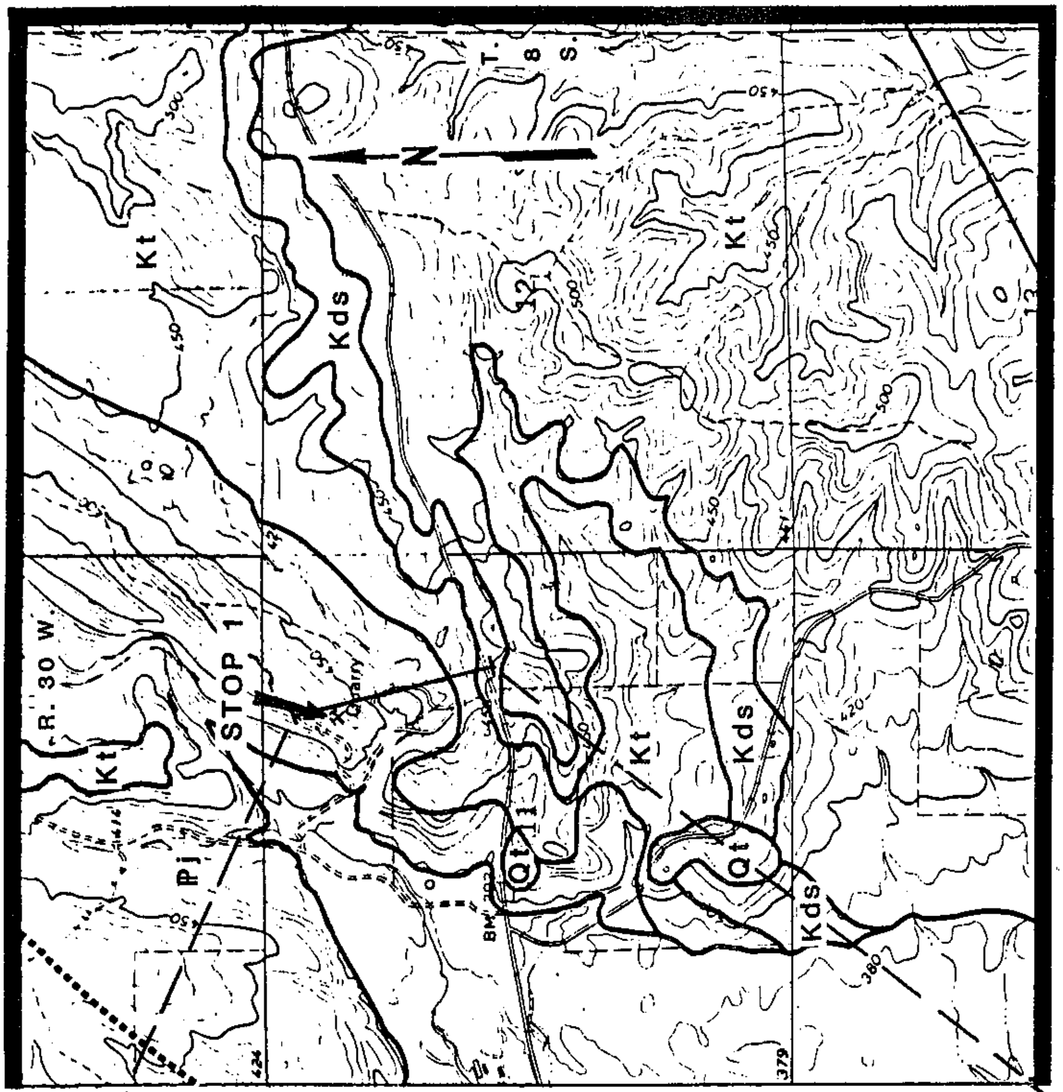
We wish to offer our sincere thanks to Bill Muse and Leda Roberts of the HMB Construction Company for their gracious assistance and permission to visit the quarry site (Plate 6).

Sandstones in the steeply southeastward dipping upper Jackfork Sandstone (Lower Pennsylvanian) are quarried for road materials and other construction stone by the HMB Construction Company. Some fault associated fractures in the sandstone beds in this quarry contain irregularly shaped accumulations of pyritic viscous oil. Some of the oil is in the more friable sandstone next to the fractures and also along some of the bedding planes. Miser and Purdue (1929) reported an outcrop of asphaltic sand in the lower part of the Trinity Group (Lower Cretaceous) about one-fourth mile south of this quarry. This asphaltic sand and a deeper asphaltic sand were penetrated by exploration holes drilled recently by the Arkansas Geological Commission.

We have not determined whether this is Paleozoic oil that has seeped into the Cretaceous sands or that it is Cretaceous oil that has seeped into the fractures of the Jackfork sandstones or other possibilities.

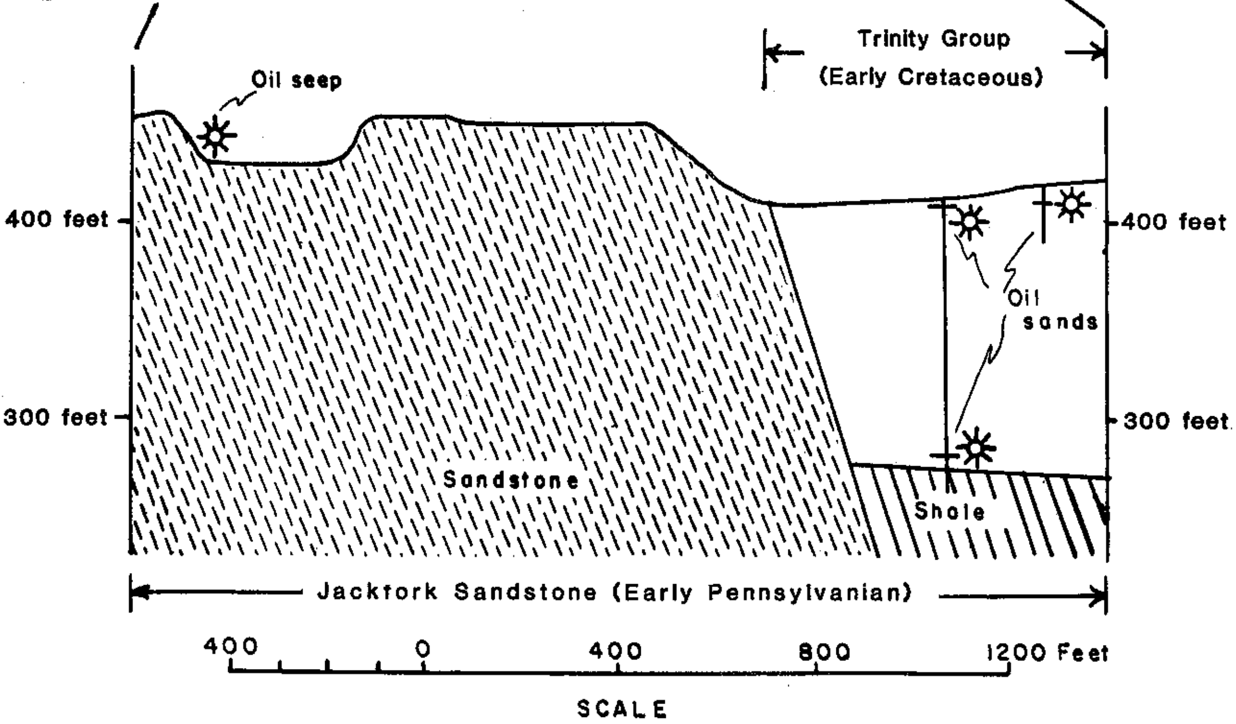
At this Stop we are in the Athens Plateau subprovince of the southernmost Ouachita Mountains. Typically the rocks in this subprovince are folded less intensely than they are to the north. There are broad synclines and narrow, tight, often slightly inclined anticlines, all of which are cut by major thrust faults and smaller tear faults. Until quite recently this basic description fit the geology for all of this region. However in the antimony district immediately northwest of this area, Haley and Stone (geologic map in Howard, 1979) mapped a major decollement with the upper Stanley Sahle being thrust northward many miles over tightly folded and highly faulted sequences of middle and lower Stanley Shale.

These massive upper Jackfork sandstones are thought to represent a very large submarine fan channel sequence (probably midfan) that was derived from postulated sources to the southeast. Numerous small granule or "grit" bearing beds occur in several of the more massive sandstone intervals. Abundant westward directed paleocurrent features occur at the base of many of the beds. Ripple marks and trace fossils are present on the tops of many of the thinner sandstones. Some late Paleozoic hydrothermal quartz veinlets fill a few of the fractures and are more numerous in the small faulted intervals.



Geology modified from Miser 1929

PLATE 6. JACKFORK QUARRY – STOP I.



Datum is mean sea level

STRUCTURAL SECTION AT STOP 1

PLATE 6

STOP 2 — LOWER JACKFORK SANDSTONE AT DIERKS LAKE SPILLWAY

By Rufus J. Le Blanc, Sr., Shell Oil Company, Houston, Texas

In 1945, when I was employed by the Mississippi River Commission and the Corps of Engineers, I conducted some geological field studies in southwestern Arkansas for the purpose of selecting sites to construct dams across several rivers as part of the overall, long-range flood control program within the Mississippi Valley and its tributaries.

One of the sites that I studied was located where the Saline River crosses the Jackfork Sandstone about five miles northwest of Dierks, Arkansas. In about 1946 the Mississippi River Commission decided to build a dam at that site. However, Congress did not appropriate funds for the construction of this dam until about 20 years later.

In 1976 Boyd Haley (U. S. Geological Survey) and Charlie Stone (Arkansas Geological Commission) informed me that the Dierks dam was completed and the black top road to the dam was open. Within a week I visited the Dierks Dam and spillway area with a Shell film crew (Plate 7). All of the lower Jackfork exposed on the west side of the spillway, and along the highway just east of the spillway was filmed with a 16 mm movie camera. In addition, many "still" color photographs were taken. Many of these photographs are being made available for Boyd and Charlie to use as they see fit in their guidebook for this fieldtrip. Using the Mutti and Ricci Lucchi deep sea-fan model, sequences and concepts I interpreted the Jackfork deposits in the Dierks Dam area to be of deep-sea fan origin. My interpretations are indicated on the photographs included in this guidebook.

The 1,200 feet of lower Jackfork sediments exposed along the west wall of the spillway consist of an overall, thick regressive sequence of deep-sea fan origin. The lower part of this section consists mainly of deep-fan lobe deposits. The middle part of the section consists of deep-sea fan channel and fan lobe sediments. The upper part of the section at the south end of the spillway consists of deep-sea fan channel sequences. The Jackfork section exposed on the north side of the road cut just east of the spillway is interpreted to be a very thick deep-sea fan channel sequence which is characterized by a series of sandstone beds that thin upwards.

During the past 8 years I have conducted Shell field trips to the Dierks Dam area for over 250 Shell geologists and geophysicists. There is seldom complete agreement on the depositional environments of ancient clastics, however — there has been good general agreement amongst Shell geologists that the interpretations indicated on the photographs are reasonable.

I am sorry that I can not accompany Charlie and Boyd on this field trip. These two geologists have devoted a considerable amount of time helping me out in the Ouachitas, Arkansas Valley and the Boston Mountains during the past 9 years. I am deeply indebted to both of these two good friends.

"Rufus, you rascal, the whole experience, your friendship, and the sedimentological education have truly been our pleasure! ! ! " Boyd and Charlie

"Several small thrust faults of late Paleozoic age are present in the exposures. These faults are usually marked by a thin gouge and slickenside interval filled wtih rock fragments, dickite, milky quartz veins with some small clear crystals, and minor other minerals. Small drag folds and tear faults occur in a thrust fault zone exposed in the roadcut."

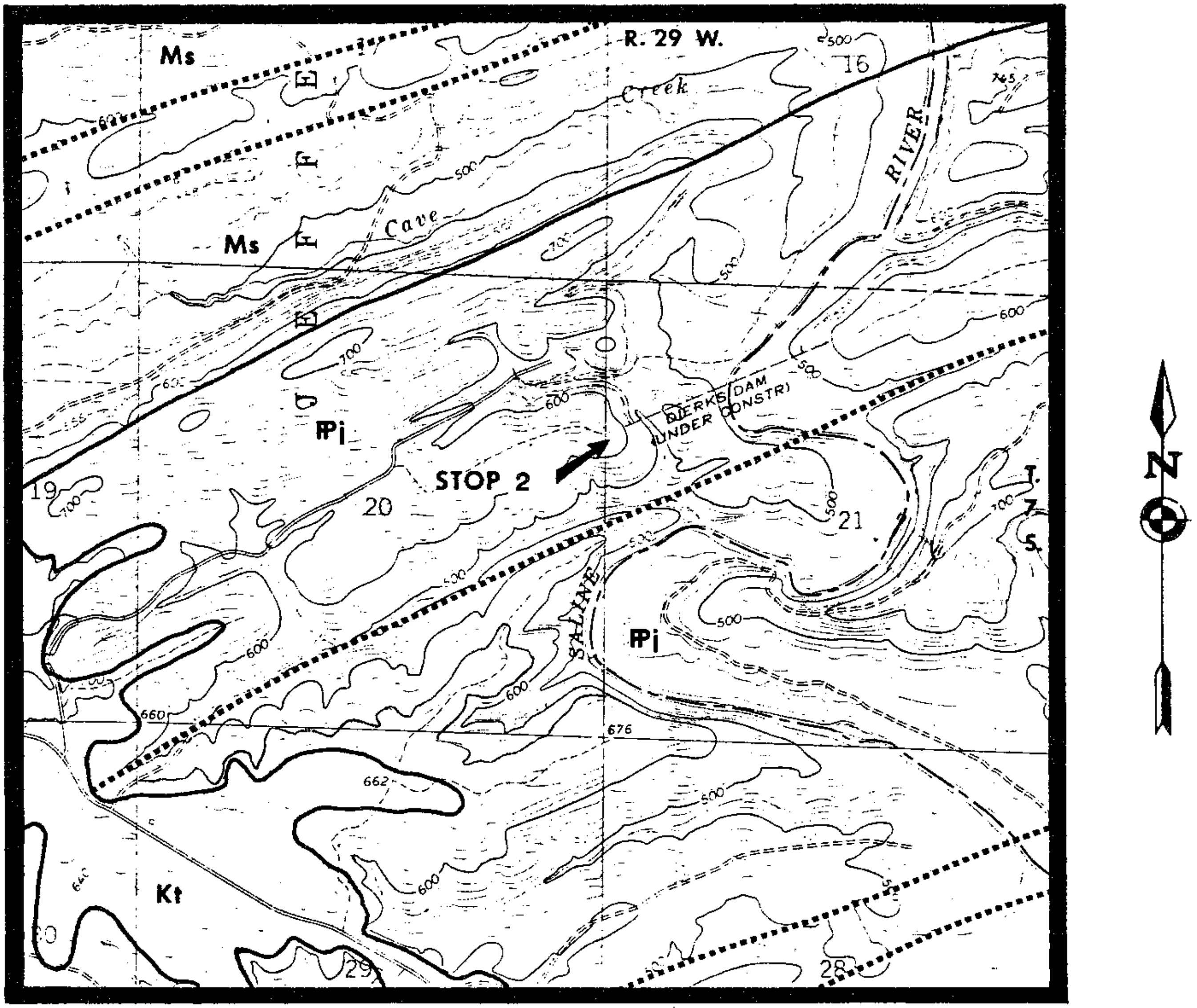
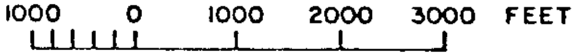


PLATE 7. GEOLOGIC MAP OF THE DIERKS LAKE SPILLWAY AREA-STOP 2.



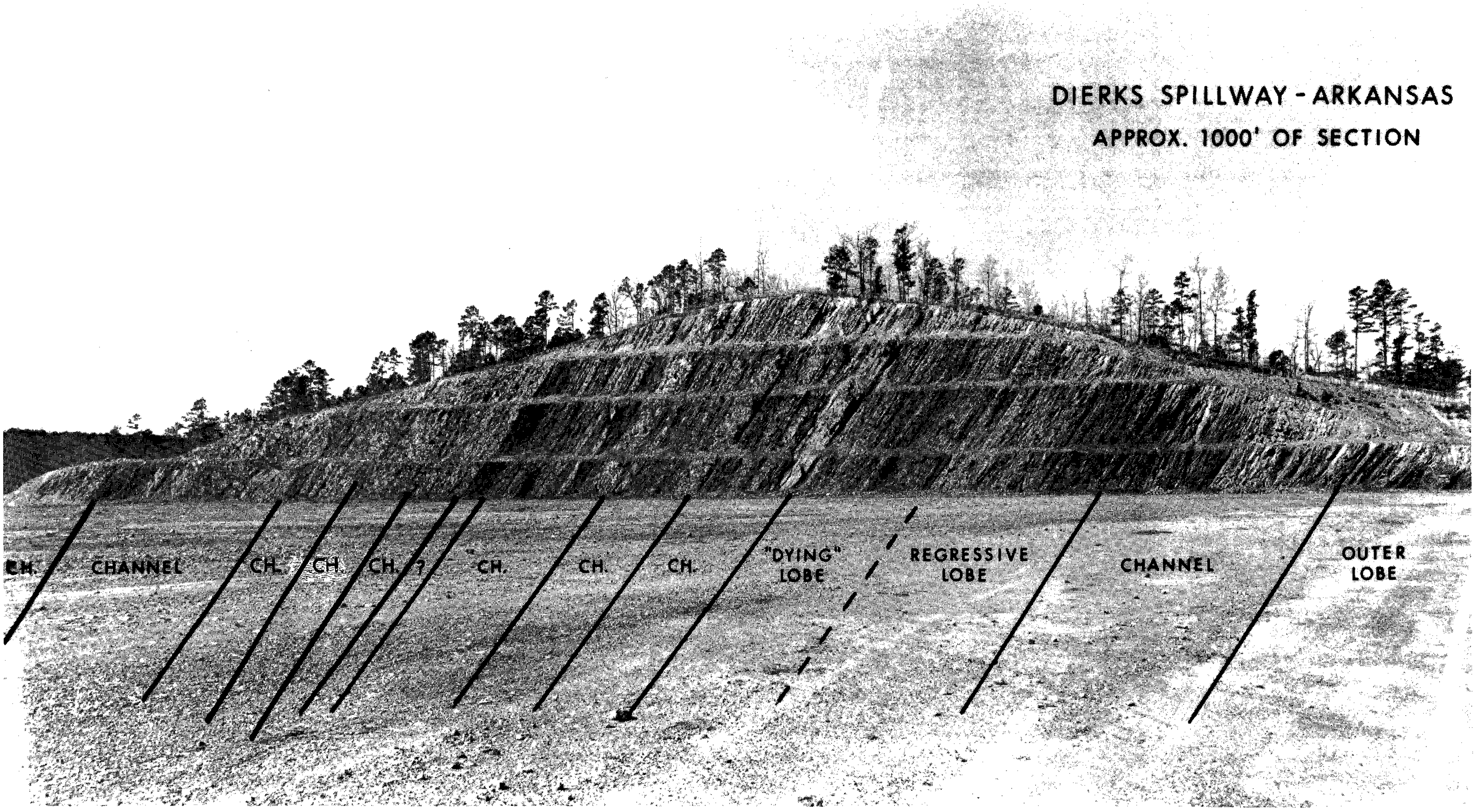
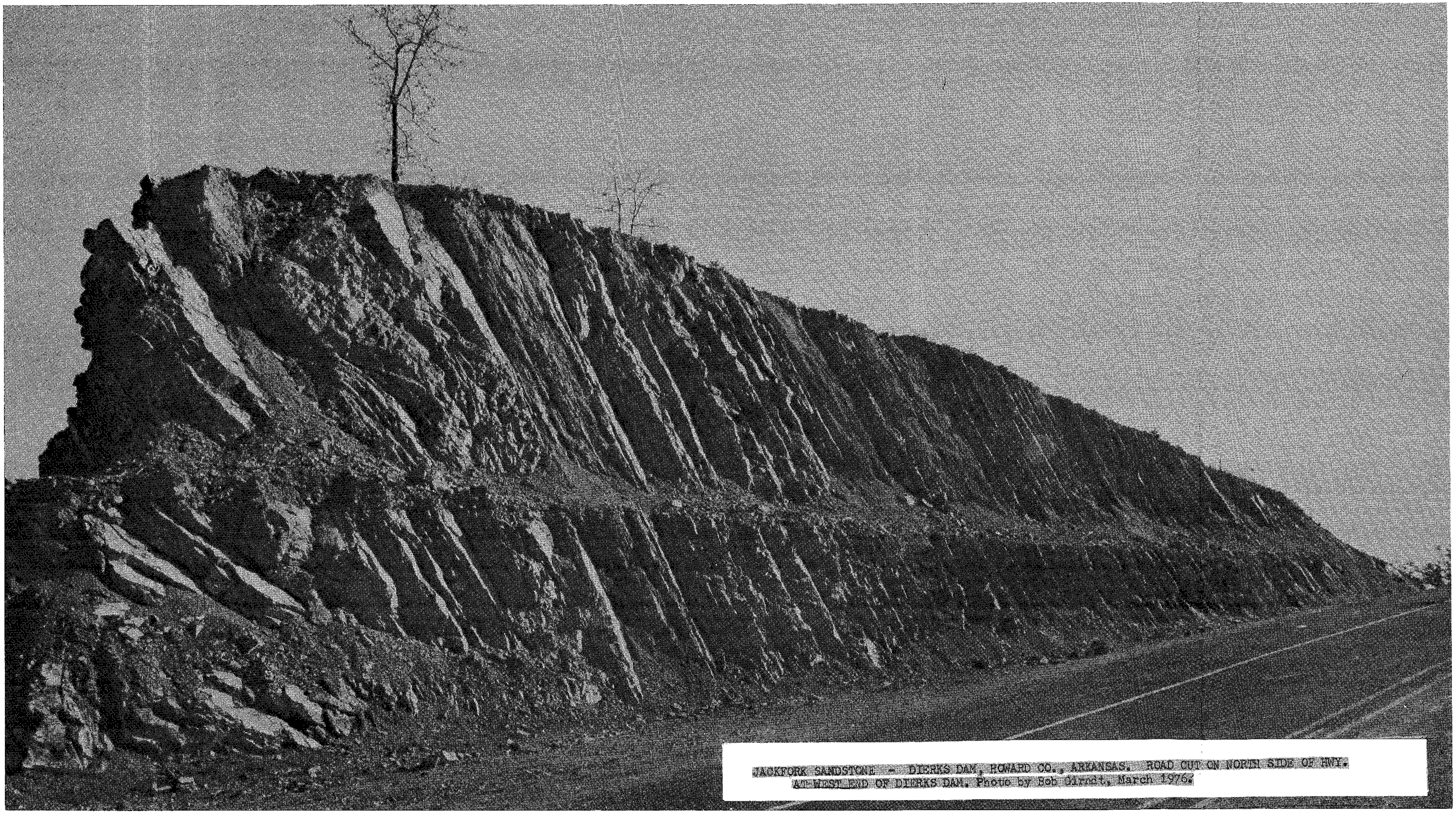

DIERKS SPILLWAY - ARKANSAS
APPROX. 1000' OF SECTION
CH.
CHANNEL
CH.
CH.
CH. ?
CH.
CH.
CH.
"DYING" LOBE
REGRESSIVE LOBE
CHANNEL
OUTER LOBE

FIGURE 1



JACKFORK SANDSTONE - DIERKS DAM, HOWARD CO., ARKANSAS. ROAD CUT ON NORTH SIDE OF HWY.
AT WEST END OF DIERKS DAM. Photo by Bob Girndt, March 1976.

FIGURE 2

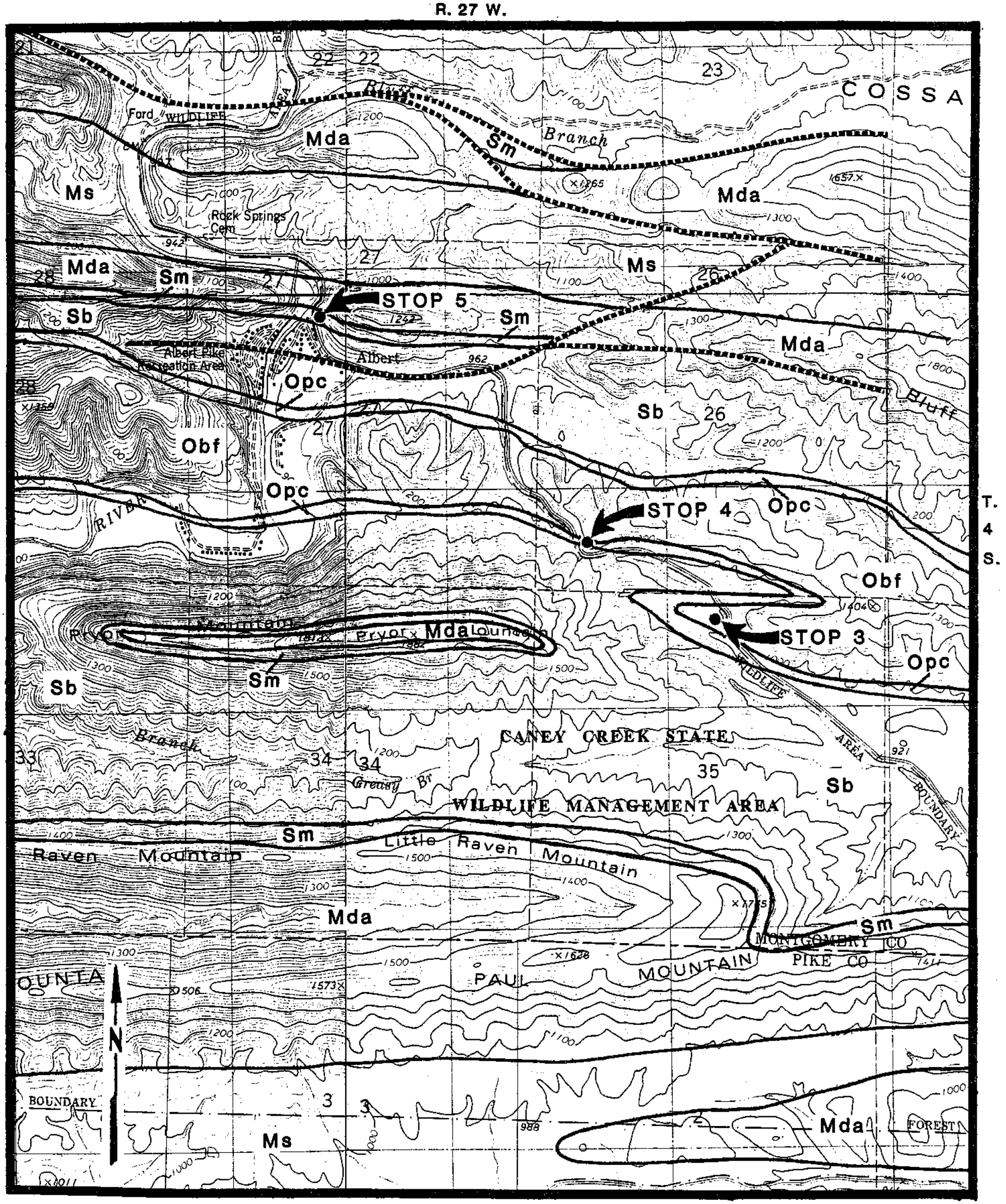
STOP 3. – ASPHALTITE (BITUMEN) IN UPPER BIGFORK CHERT IN THE COSSATOT MOUNTAINS

This recently excavated exposure on the U. S. Forest Service side road has revealed a significant outcrop of probable fresh black upper Bigfork chert, siltstone and shale at the eastern base of Pyror Mountain (Plate 8). Miser and Purdue (1929) also considered this sequence as being in the upper Bigfork Chert, but it is possible that it belongs in the overlying Polk Creek Shale. The problem in reality is that the contact between the two formations is transitional, that is, from more cherty layers below to more shaly sequences above.

The uniqueness of this outcrop is that there appears to be sapropelic unweathered black siltstone, silty chert and shale that have yielded liquid hydrocarbons which have filled many fractures and bedding layers with veinlets of later matured and degraded "solid" asphaltite (bitumen). This asphaltite also often appears to be slickensided along various sheared, slightly cleaved and small faulted intervals. The asphaltite impregnations appear to have also enhanced some of the deformational processes. Tarnish upon the asphaltite is evident and reflects, in part, the presence of sulfides within both it and the rock. Traces of smeared graptolites have been found in the shales but no attempt has been made to correlate them.

A chemical analysis was performed on a selected asphaltite-rich specimen with the following results: Gold – nil; silver – 0.0002%; lead – 0.0002%; zinc – 0.006%; copper – 0.005%; cobalt – 0.001%; nickel – 0.008%; and vanadium – 0.018%. There has been no attempt to determine the exact variety of asphaltite.

Honess (1923) and Miser and Purdue (1929) and others note thin conglomerates in the Bigfork Chert and Polk Creek Shale that contain some granitic granules. These and several of the other very slowly deposited and highly reduced rock sequences were evidently interrupted at times by either active slurries from submarine scarps or there were minor spasms of igneous and volcanic activity in the proto-Ouachita trough that in some cases may have created possible submarine exhalative mineral occurrences.



GEOLOGIC MAP IN THE VICINITY OF STOPS 3,4, AND 5

Geology modified from Miser (1929)

STOP 4. — ISOCLINAL FOLDING IN SILURIAN AND ORDOVICIAN ROCKS IN THE COSSATOT MOUNTAINS

This exposure occurs along the U. S. Forest Service road east of Pryor Mountain (Plate 8). The rocks outcropping are the Bigfork Chert, Polk Creek Shale and Blaylock Sandstone. The Bigfork is composed of hard gray chert and interbedded somewhat leached brown, often calcareous cherty siltstone in beds from 1 inch to 2 feet in thickness. Some minor black shales are also present. Because of the tight, but upright, folding in the formation, it is difficult to estimate its thickness, but it is likely about 750 feet. This entire sequence of rock when unweathered is dark gray to black in color. The Polk Creek Shale which is about 125 feet thick overlies the Bigfork Chert and is nicely exposed along the southern end of the roadcut in several tightly digitated folds. It is typically a slightly cleaved, black, graphitic, graptolite-bearing shale with minor, thin gray cherty layers. Except in creeks the Polk Creek Shale is rarely seen in outcrop, usually being covered by surrounding more resistant formations.

Honess (1923) and Miser and Purdue (1929) noted conglomerates containing granitic gravel at both the top of the Polk Creek Shale and/or the base of the overlying lower Silurian Blaylock Sandstone. There is considerable speculation as to the origin of these occurrences.

As one proceeds downhill there are mostly steeply dipping, tightly folded and somewhat faulted sequences of the Bigfork Chert along the crest of an anticline; then a small east-west valley is underlain by a covered Polk Creek Shale; and finally there are partial exposures of the Blaylock Sandstone of Lower Silurian age. In the Cossatot Mountains the Blaylock Sandstone is about 1000 feet thick and consists of thin interbedded fine-grained subgraywacke sandstones, some siltstones and gray to olive gray shales. These rocks have many flysch-like characteristics and contain some deep-water Nereites trace fossils. The Blaylock is either not present or does not constitute a mappable unit in the central and northern Ouachita Mountains of Arkansas. A probable source area to the southeast is indicated by the lithologic types, thickness of beds, paleocurrent data and other features. The source for most of the clastic fractions in the other pre-Stanley strata in the Ouachita Mountains was probably the North American craton.

STOP 5. — ARKANSAS NOVACULITE AT ALBERT PIKE

This highly scenic stop is situated on a roadcut directly above the Albert Pike Recreational Area and the Little Missouri River (Plate 8). This exposure of nearly vertical strata with minor faults illustrates the massive, grayish-white, dense homogeneous character of the Lower Division and the thin black to rarely olive chert and black shale of the Middle Division of the Arkansas Novaculite. The top of the Lower Division contains a coarse, mostly novaculite, breccia that is about 5 feet thick with abundant incorporated pyrite. Considerable discussion has been invoked in recent years concerning the origin of this breccia, since it is present in much of the Ouachita Mountains. It is our belief that the breccia represents a deposit derived from along extensionally faulted submarine scarps during a time of some rather active Middle Devonian volcanic and igneous activity. Indeed Honess (1923) in the Broken Bow area of Oklahoma and Stone and Haley (1977) near Hot Springs in Arkansas have identified granitic and/or volcanic fragments in this and associated breccias. Denison et al. (1977) notably describes several Devonian along with the predominant late Paleozoic age dates in the rocks of the foldbelt. Conodonts are abundant in the Middle Division shales with the Devonian-Mississippian boundary being placed by Hass (1951) in the upper part of the unit at Caddo Gap (Stop 20).

Practically all the structures in the rocks in the area are exceptionally tight and the sequences are generally upright although there are locally beds overturned both to the north and south. The plunge of the fold hinges are usually at or near horizontal but a few have attitudes that are rather steeply inclined. Haley et al. (1976) indicates that the Cossatot Mountains are flanked both to the north and south by major thrust faults and that significant thrusts or splays of these thrusts dissect the rocks in this area.

The spectacular, tall, jagged peaks and hogbacks, the narrow rocky gaps, and the spiny cataracts and small waterfalls are formed primarily as a result of the resistant 300-450 feet thick generally steeply dipping novaculites of the Lower Division of the Arkansas Novaculite. Modern generations now use this dense novaculite as a whetstone and for other silica products, but earlier the Caddo and other Indian cultures mined and worked the novaculite in very large quantities throughout this region for various artifacts.

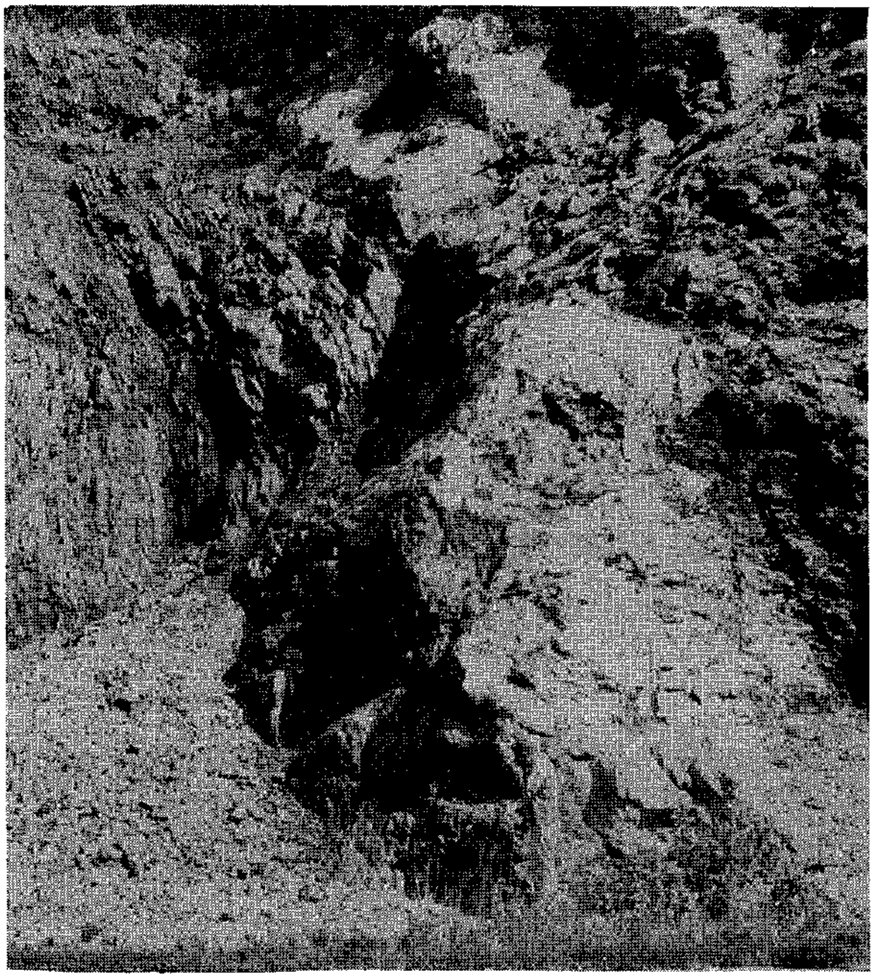
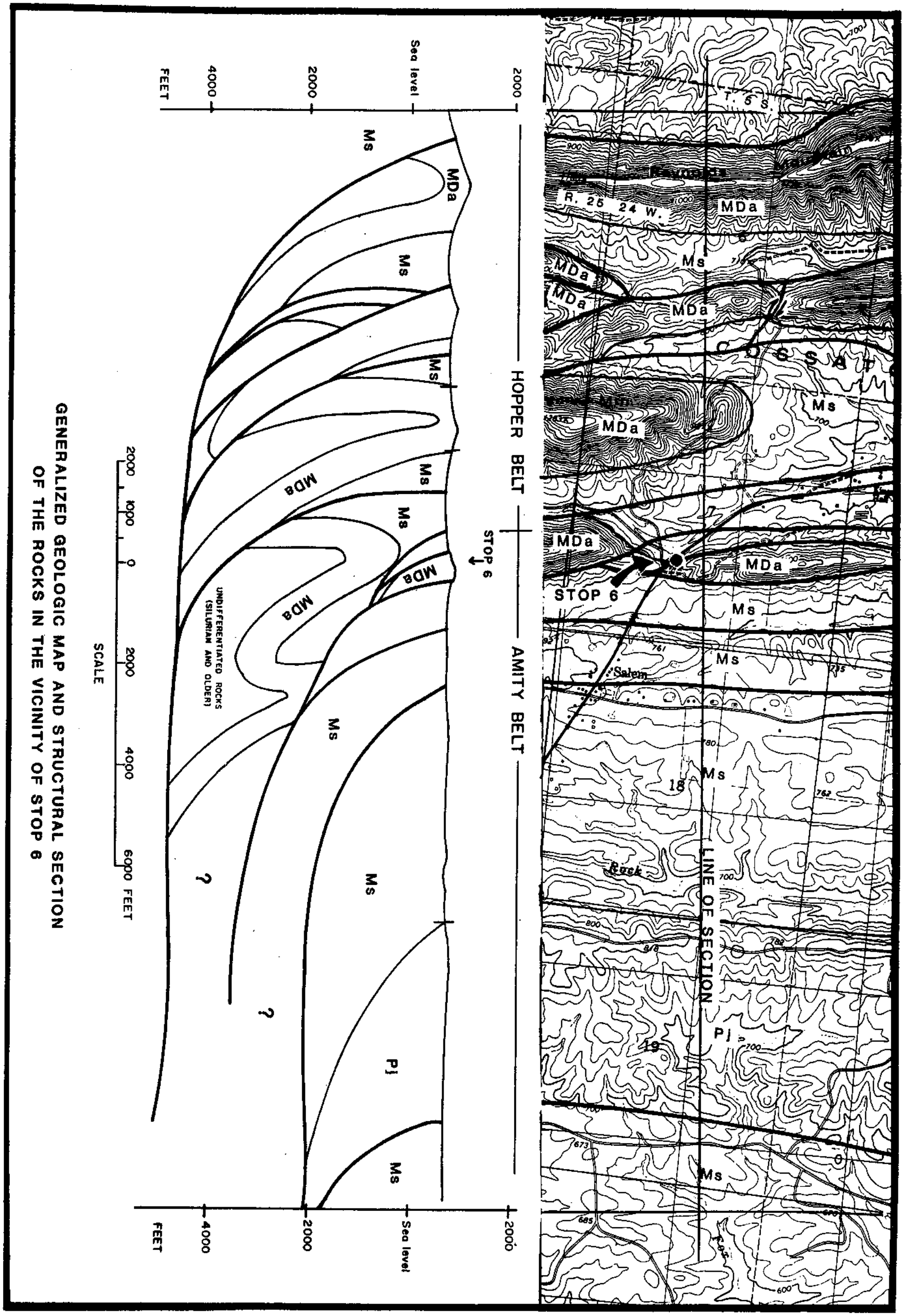


Figure 3. — Stop 5. Vertical beds of massive, dense, white to light gray novaculite, with a breccia interval at the top, in the Lower Division (on right) with thin gray chert and black shale of the Middle Division of the Arkansas Novaculite (on left). Note that there are several small generally northward dipping thrust faults.



GENERALIZED GEOLOGIC MAP AND STRUCTURAL SECTION OF THE ROCKS IN THE VICINITY OF STOP 6

PLATE 9

STOP 6. — THRUST FAULT IN STANLEY SHALE AND ARKANSAS NOVACULITE NEAR SALEM

This exposure on the east side of U. S. Hwy. 70 and Arkansas Hwy. 27 displays from north to south; shale, tuffaceous (?) siltstone, chert and minor conglomerate with some minor faulting in the lowermost Stanley Shale; weathered intervals of thin-bedded tripolitic novaculite of the Upper Division of the Arkansas Novaculite; black conodont-bearing siliceous shale and chert of the Middle Division of the Arkansas Novaculite; a fault zone; and, at the south end, graywacke and shales of the lower Stanley Shale (Plate 9). It is thought that this sequence in the eastern Cossatot Mountains shows the transition from the earlier thin trough deposits to the later thick turbidite-flysch facies. These rocks contain folds that are very tight and upright or slightly inclined to the north and fault planes that dip to the south. The lower Stanley sandstones are often tuffaceous, but the acidic volcaniclastic beds of the Hatton Tuff lentil which are prominent to the west and southwest have not been identified in this area. The thin tuffaceous (?) siltstone of the lower Stanley Shale likely represents outer submarine fan or basin plain facies. The following abstract by Niem presents some of the present concepts on the lower Stanley deposition.

Niem, Alan R., 1976, **PATTERNS OF FLYSCH DEPOSITION AND DEEP—SEA FANS IN THE LOWER STANLEY GROUP (MISSISSIPPIAN), OUACHITA MOUNTAINS, OKLAHOMA AND ARKANSAS:** Jour. Sed. Petrology, v. 46, no. 3, p. 633—646.

A southern proximal and northern distal flysch facies are recognized in Mississippian lower Stanley strata over an area of 5000 sq. mi. in the Ouachita Mountains of Oklahoma and Arkansas. Four widespread tuffs, each with distinctive lithologies, are interbedded with deep-marine turbidite sandstones and shales and serve as key units for detailed correlation of eight sections 500 to 1500 thick.

The lower Stanley flysch is an ancient analog to one or more modern deep-sea fans and adjacent basin deposits. The lithologic character, sedimentary structures, bedding styles, fan-like geometry, ratio of sandstones to shale, and stratigraphic relationships of proximal and distal facies of the lower Stanley Group are similar to middle and outer margins of modern deep-sea fans and associated basin sediments off the coast of western North America.

A proximal turbidite facies (probably a channeled suprafan) was deposited in the Hot Springs area of Arkansas at the same time a deep-water shale-rich facies accumulated in the southern and central Ouachitas of Oklahoma. During later Stanley time a proximal flysch facies prograded over the shale-rich facies of the southern Ouachitas of Oklahoma and represents deposition of a middle fan facies over an outer fan and basin plain facies. This proximal facies laterally changes to a distal flysch facies of apparent outer fan and basin plain deposition in the central Ouachitas of Oklahoma. The source area for lower Stanley strata was to the south-southeast, probably a northeastern continuation of the buried upper plate of the Luling thrust of Texas.

Hass (1950, p. 1578; 1953, p. 52) describes a collection of conodonts 75—145 feet about the base of the Stanley in shales at several locations and stated that they were Meramecian in age. These same conodonts were examined by J. W. Huddle (in Gordon and Stone, 1977, p. 77) and he recognized them as an early Chesterian assemblage. The Hatton Tuff lentil and some bedded barite deposits were associated with these shales in some instances. The basal Stanley Shale (sandstone, conglomerates and shales of the Hot Springs Sandstone Member) is late Meramecian age according to Gordon and Stone (1977, p. 76—77).

STOP DESCRIPTIONS — SECOND DAY

CENTRAL AND NORTHERN OUACHITA MOUNTAINS
CRYSTAL SPRINGS–HOT SPRINGS–CROWS–JESSIEVILLE
FANNIE–STORY–WASHITA–MT. IDA

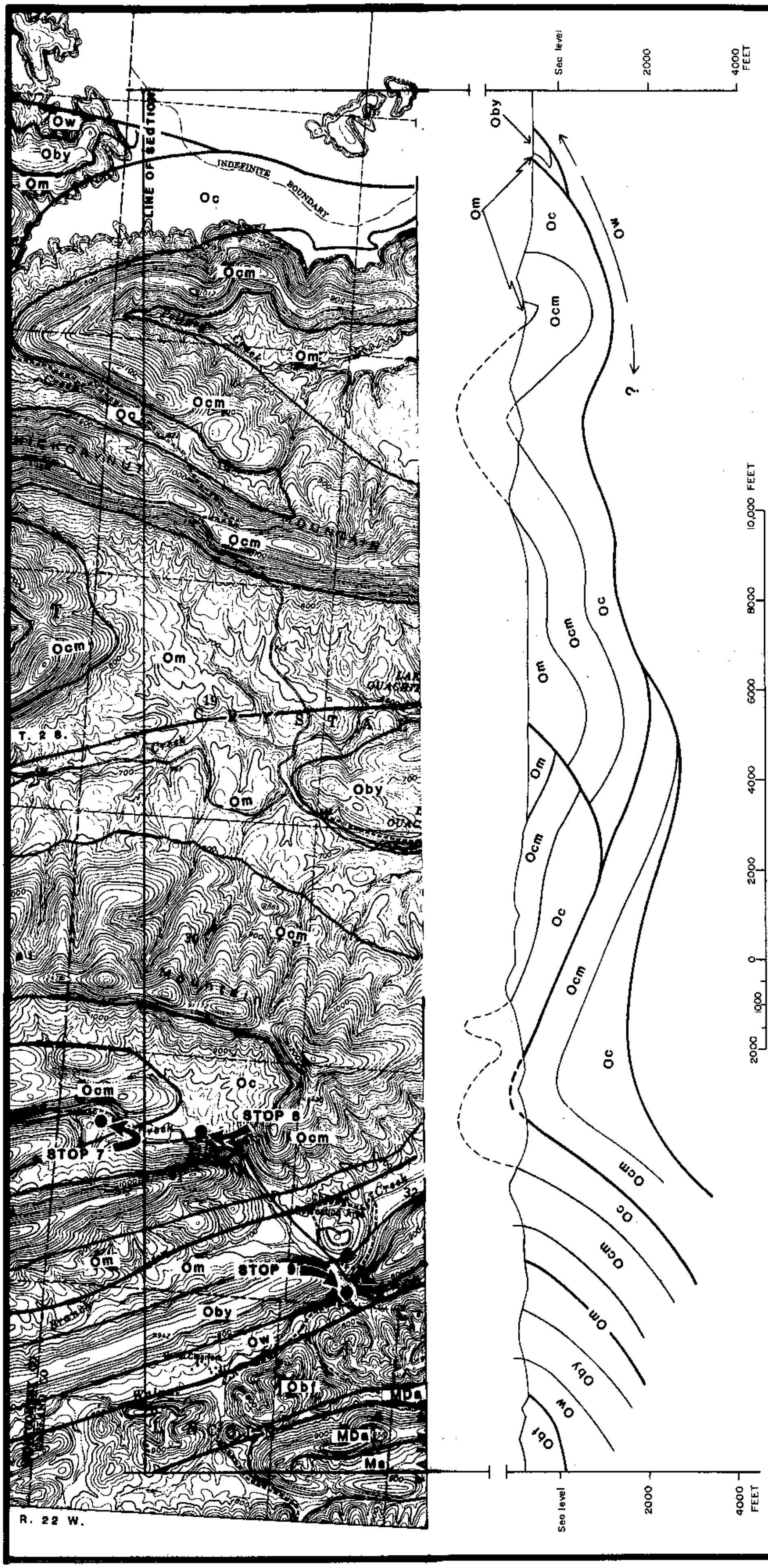
STOP 7. – STRUCTURAL WINDOW IN THE LOWER ORDOVICIAN CRYSTAL MOUNTAIN SANDSTONE

A series of nearly flat-lying interbedded orthoquartzites and buff to gray banded shales of the Crystal Mountain Sandstone are exposed on the south roadcut of U. S. Hwy. 270 northwest of the Crystal Mountain Rock and Gift Shop (Plate 10). The surrounding hills are formed by massive sandstones of the Crystal Mountain. Near the base of the Crystal Mountain in this area are intervals of thin-bedded, gray micritic limestone and thin-to thick-bedded conglomerate composed of clasts of limestone, sandstone, and chert. Hydrothermal quartz veins in cavities and joints are common in the Crystal Mountain.

Small cross-laminations and graded bedding indicate that the rocks are upright. These rocks appear to be near the center of an anticlinal flexure,but they dip under the Collier in all directions. The contact between the two formations is a low-angle thrust fault that has been folded. The Crystal Mountain is being seen through a structural window.

Sequences of upward bed thinning and grain fining suggest that the sandstone at this stop was deposited in a submarine fan channel. The sediments were derived from submarine ridges, slopes, scarps, and possibly foreland facies to the north and northeast, and deposited as turbidites and fluxoturbidites in middle and upper submarine fan deposits. Davies and Williamson (1977) state that the Crystal Mountain and Blakely formations were deposited in a shallow-marine basin with most of the sandstones derived from a southern provenance.

No diagnostic fossils have been collected from the Crystal Mountain Sandstone, but it is likely that conodonts will be found in the thin limestones. The Crystal Mountain Sandstone is placed in the lower Ordovician as a result of its stratigraphic position.



GENERALIZED GEOLOGIC MAP AND STRUCTURAL SECTION OF THE ROCKS NEAR AND NORTH OF STOPS 7, 8, AND 9

PLATE 10

STOP 8. — COLLIER LIMESTONE AT MURPHY CREEK

The upper Collier Shale crops out 0.2 miles east of the Crystal Mountain Rock and Gift Shop on Murphy Creek (Plate 10). Mr. Garland Milholen owner of the shop has graciously given us permission to examine the exposures in the stream to the north of the road-right-of-way. It would be courteous and proper for anyone wishing to gain access to this property to contact Mr. Milholen! The outcrop consists of micritic to pelletoidal, very thin to massive bedded limestone, gray shale, and black chert. Small pellets and oolites are present in the more massive limestone south of the bridge, which forms a good marker in the Collier throughout the region. Some of these massive limestones contain clasts of chert, limestone, and sandstone.

Graded bedding and cross laminations indicate the beds are upright and inclined to the south. The isoclinal folds are overturned or recumbent to the south. Strain has caused well-developed cleavage, flowage of shale in the fold hinge line, and boudinage in some beds. Small hydrothermal quartz-calcite veins fill fractures in the Collier. The folds appear to be relatively straightforward, but detailed studies in the area by Stone and Haley in 1980 and a thesis by Paul Soustek (SIU 1979) have proved otherwise. There are several epochs of folding, the earliest probably caused by soft-sediment deformation. The faulting is equally complex.

Wise (1963) reported biologic features in thin limestones of the Collier south of Mount Ida (Stop 17). These were thought to represent algal structures but now are considered trace fossils. Repetski and Ethington (1977) obtained conodonts from Collier limestone intervals in Arkansas and Oklahoma that confirmed an Early Ordovician (Tremadocian) rather than a Cambrian age. They stated that the presence of *Cordylodus angulatus* Pander established the Early Ordovician age. They further stated that this species joined by other distinctive elements includes both simple cones and multidenticulate forms. These include: *Paldotus bassleri* Furnish; *Loxodus bransoni* Furnish; *Ancanthodus lineatus* Furnish; *"Oistodus" triangularis* Furnish; and *Chosondina herfurthi* Muller. This fauna was designated "Fauna C" in North American studies, thus making the Collier correlative with the McKenzie Hill Formation of the Arbuckle Mountains and Oneota Dolomite of the Upper Mississippi Valley.

In the Broken Bow area of Oklahoma, Pitt (1955) applied the name Lukfata Sandstone to a sequence of shales, thin bedded limestones, and sandstones that he considered older than the Collier Shale. Repetski and Ethington (1977), on the basis of conodonts, showed that the Lukfata is younger than the Collier and can be correlated with the Crystal Mountain Sandstone or possibly the Mazarn Shale.

Our opinions on the deposition of the Ordovician rocks in the Ouachita Mountains are summarized in the following abstract.

Stone, Charles G., and Haley, Boyd R., 1981, **DEEP—WATER DEPOSITION OF ORDOVICIAN STRATA IN THE OUACHITA MOUNTAINS, ARKANSAS AND OKLAHOMA:** South Central GSA Meeting, San Antonio, Texas.

Early workers in the Ouachita Mountains placed the Ordovician strata in deltaic and restricted shallow-water marine depositional environments. Subsequent investigators generally followed this regime until the early 1950's when concepts of deep-water marine depositional environments were

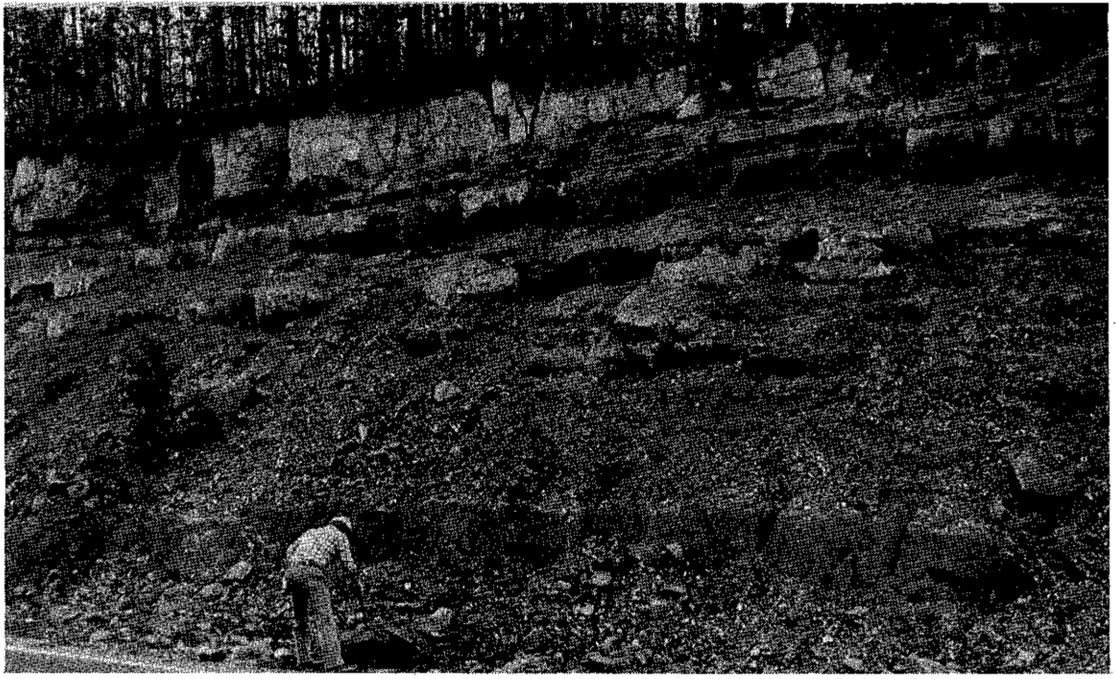


Figure 4. — Stop 7. Upright weathered quartzitic sandstones and shales with dissecting hydrothermal quartz veins in the Crystal Mountain Sandstone on U. S. Hwy. 270.

Figure 5. — Stop 8. Isoclinal recumbent folds in thin beds of micritic limestone and shale of the Collier Shale a short distance north of Murphy Creek bridge on U. S. Hwy. 270.

applied to portions of the Ordovician through middle Pennsylvanian rocks. Recent workers in the Ouachita Mountains may be grouped into two general categories concerning models for Ordovician deposition: (1) all the rocks were deposited in deep-water marine environment; or (2) all or most of the rocks were deposited in deltaic or shallow-water marine environments.

During our studies over the past decade we have not found any indigenous shallow-water marine sedimentary structures, invertebrate fossils, or trace fossils in Ordovician rocks of the Ouachita Mountains. However, there are lithic units with bottom marks, trace fossils, and other features considered to be of deep-water marine origin. Numerous thin-bedded, dense, blue-gray limestones are thought to represent **in situ** *deep-water marine deposits formed above the carbonate compensation depth. Lithologies and features that have been misinterpreted as being shallow-water marine origin include: (a) cross-laminations; (b) cleavage refraction in sandstones; (c) slump and slurry intervals containing flowage structures and superposed erratic blocks; and (d) transported bioclastic, oolitic and pelletoidal limestones.*

We conclude that all Ordovician strata in the Ouachita Mountains from the early Ordovician Collier through the late Ordovician Polk Creek formations are proto-Ouachita bathyal platform or trough deposits and represent either: (1) indigenous pelagic or hemipelagic deposits; or (2) turbidity or bottom current submarine fan and related facies, combined with episodes of slump and slurry detachments all derived from "northerly" flanking shelf, slope and submarine ridge sources.

STOP 9 — MAZARN SHALE, BLAKELY SANDSTONE AND WOMBLE SHALE AT THE CHARLTON AREA

The upper Mazarn Shale, Blakely Sandstone, and lower Womble Shale are exposed along Murphy Creek and in the roadcuts on both sides of U. S. Hwy. 270 south of the Charlton Recreation Area (Plate 10). A trail leads northward along the east bank of Murphy Creek to an abandoned "gold-silver" exploration tunnel.

Mazarn Shale

The upper part of the Mazarn is poorly exposed in the creek and consists of greenish-black banded shale, thin gray siltstone, light gray fine-grained sandstone, and dark gray micritic limestone. Nereites and possibly other trace fossils are rather abundant in some beds and are considered indicative of bathyal to abyssal water depths.

Blakely Sandstone

West along the creek are outcrops of the lower and middle parts of the Blakely. The lower part consists of thin-bedded quartzitic sandstone and shale. The middle part consists of tan-black banded shale and thin-to thick-bedded quartzitic sandstone. The thicker bedded sandstones are well exposed at the east end of the bridge.

East of the bridge in the roadcut is an outcrop of thin bedded quartzitic sandstone and gray-black banded shale in the upper part of the Blakely. In this outcrop the Blakely is cut by two partially weathered lamprophyre igneous dikes (monchiquite), probably early Late Cretaceous in age.

Bottom marks, cross laminations, graded bedding, and the position of the Womble indicate the top of the complexly folded sequences is to the south. Discontinuous sandstone masses, sedimentary pull-aparts, structural boudinage and well-developed northward dipping cleavage are present in the Blakely. Buthman (1982) determined that paleocurrents were dominantly south-southeast to southwest in the Blakely Sandstone in this area.

The Blakely often contains two prominent divisions of sandstone, thus has often been referred to as the "double Blakely Sandstone". Several of the sandstone sequences are thinning upward and could have been deposited in a midfan submarine channel with a source area to the northeast.

Womble Shale

The lower part of the Womble is exposed above the upper Blakely in the roadcut. The rocks consist of black shale and thin lenses and beds of medium grained, slightly phosphatic sandy limestone. The shale weathers to a brown color and the limestone contains sponge spicules and other bioclastics. The bioclastic limestone lenses may have been deposited by submarine sediment slurries from local and, in part, extrabasinal sources that existed along the northern flank of the Ouachita trough. J. Keith Rigby of Brigham Young University examined the Womble limestone containing sponge spicules from this site and stated:

"The long monactines all clustered together are typical of root tuffs in the hexactinellids. The spicules were originally opaline silica and have been replaced in part by calcium carbonate and chalcedony. I suspect that the tuffs were probably formed in place and may represent deep-water sponges. Had the tuffs been transported far, I think they would have been broken apart."

Recent studies by Repetski (in Ketner, 1980) indicate that the lower Womble is Middle Ordovician in age. Markham (1972) has shown that the Womble contains bioclastic limestone intervals and slurried masses at several places in the region. Indeed there are intervals of olistostromes or sedimentary melange in the Womble throughout much of the Ouachita region. In the eastern core area near Benton the upper Womble contains some lenticular channel-like layers of phosphatic subgraywacke and conglomerate. These beds become finer grained to the south suggesting a northern source. Honess (1923) described some similar argillaceous brownish-green sandstones in the Broken Bow area of Oklahoma.

Figure 6. — Stop 9. Southward verging folds (top to right) in thin bedded sandstones and shales of the Blakely Sandstone on the north side of U. S. Hwy. 270.

Figure 7. — Stop 10. Southward verging chevron and box folds (top to left) in the weathered Bigfork Chert at a rock aggregate quarry south of Crystal Springs.

STOP 10. – FOLDED BIGFORK CHERT AT CRYSTAL SPRINGS QUARRIES

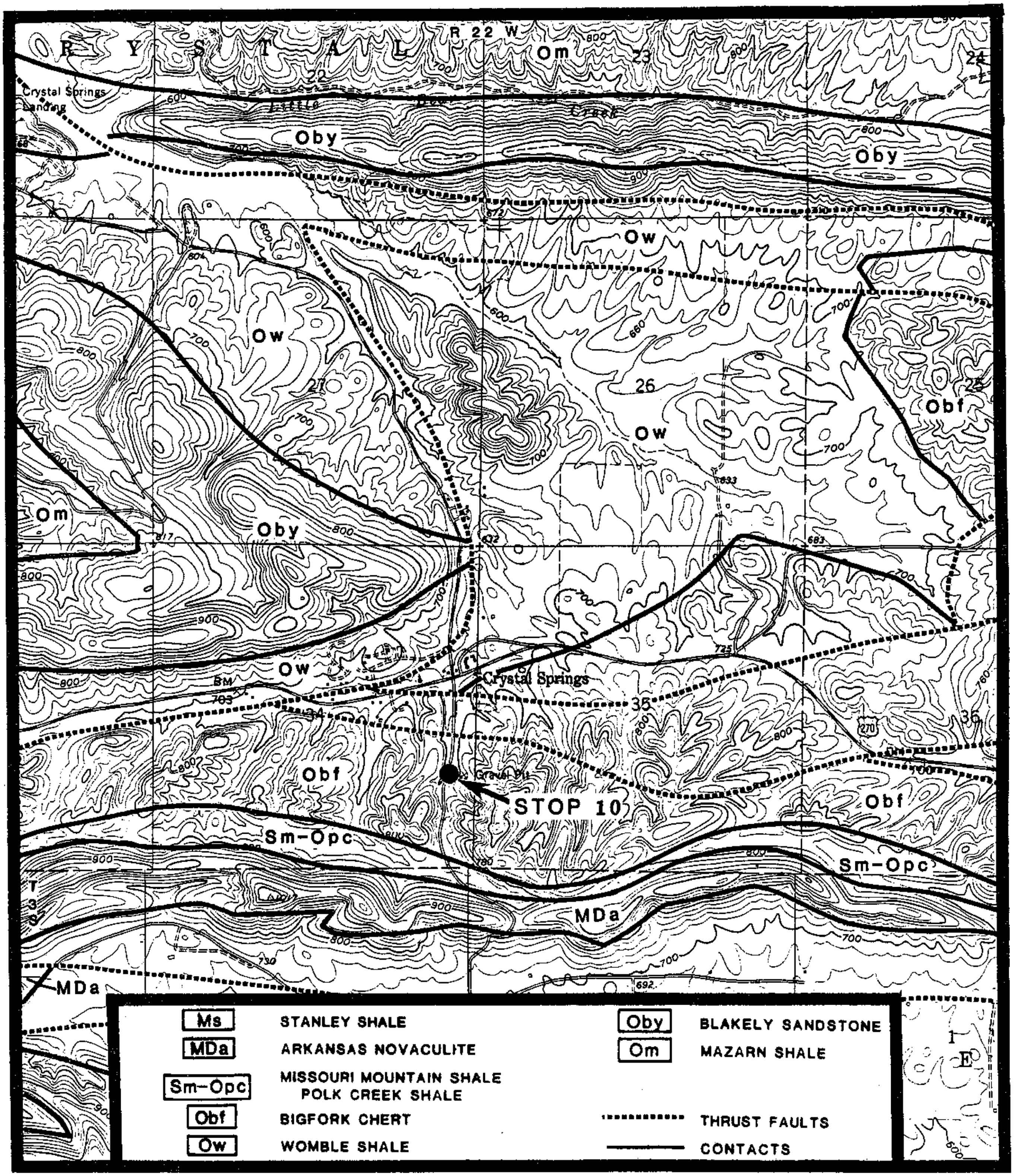
These two quarries are operated by Mr. Ralph Harrison in the Middle and Upper Ordovician age Bigfork Chert south of Crystal Springs (Plate 11) and are worked with little equipment for rock aggregate. We wish to acknowledge the kindness of Mr. Harrison and Mr. Garfield Lewis, owner of the property, for letting us have access to the site.

The Bigfork Chert commonly forms low hummocky hills ("Potato Hills") with rather large talus slopes composed of small angular fragments. In this area the Arkansas Novaculite is quite massive and forms the high ridges to the south. The less resistant Womble Shale underlies the valley to the north.

The Bigfork is complexly folded with both chevron and box folds inclined to the south. The strata dips gently to steeply to the north. The sequence is composed of many thin interbedded and often graded, calcareous (often decalcified), rather punky, silty chert (brown), light gray chert and siliceous shale. It is thought that the basal silty part of these interbedded sequences represent many minor influxes of fine clastics brought into the Ouachita trough by turbidity and bottom currents with each chert and siliceous shale representing the normal deep-water pelagic accumulations. Near the north end of the west pit there are a few thin intervals of weathered coarse sandstone and fine conglomerate that contain some feldspar, granite(?), and other fragments. It is not known whether these lithologies represent submarine slurries from postulated Precambrian submarine scarps or a concurrent volcanic-igneous event, but we suspicion the latter is correct. Some traces of asphaltite and highly carbonaceous intervals were also encountered at the base of the pit in this same general area. Partial chemical analysis was performed on some of the purplish-red oxides permeating several of the intervals with the following results: Fe_20_3 – 5.98%, Mn0 – 0.031%, Cu0 – nil, Zn0 – 0.008 and Pb0 – nil.

There is a low-angle northward dipping cleavage in some intervals and it refracts across the more massive chert. There is also some flowage of the rock into the hinges of the folds. Several small thrust faults cut the sequences at places along the south end of the west pit. It would be most interesting to determine when these faults were formed!

In the proper geologic conditions the Bigfork Chert should afford considerable hydrocarbon potential as both a source rock and for reservoir capacities.



– GEOLOGIC MAP OF CRYSTAL SPRINGS AREA –

1000 0 1000 2000 3000 FEET

Geology from Haley and others (1976)

STOP 11. — THRUST FAULT BETWEEN WOMBLE LIMESTONE AND STANLEY SHALE NEAR STEINER MOUNTAIN

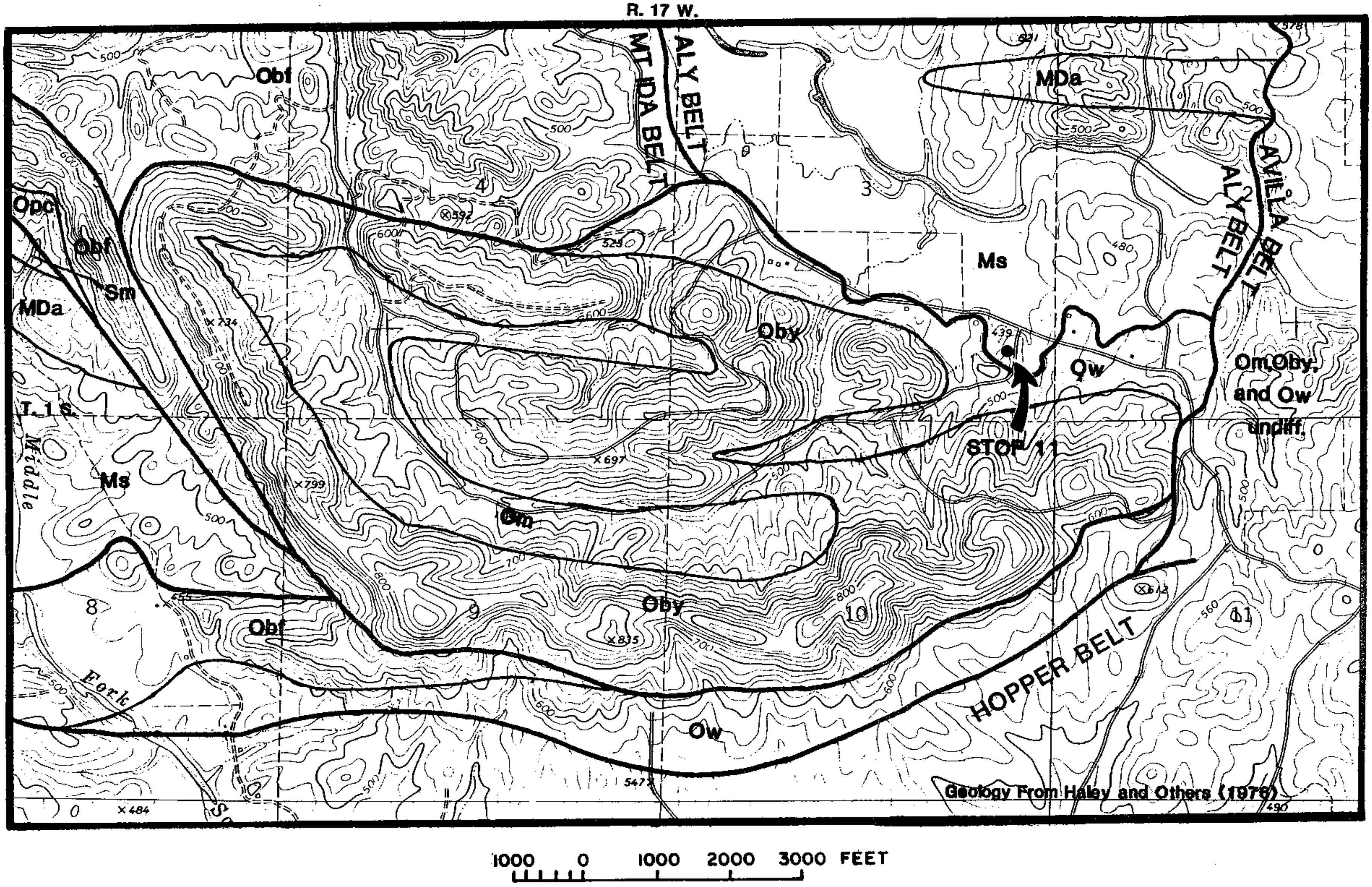
This partial exposure at the northeast end of Steiner Mountain illustrates a significant low-angle thrust fault (at this locality) near the eastern terminus of the Mt. Ida belt (Plate 12). Shales and thin micritic to locally, rather thick intervals of conglomeratic limestones of the Middle Ordovician lower Womble Shale (Mt. Ida belt) are thrust over shales and minor siltstones of the Mississippian Stanley Shale (Aly belt). Recently, Ray Ethington of the University of Missouri obtained conodonts from limestones that were submitted by Stone from this locality that colloborate the lower Womble Shale determination.

The prominent structural indentation comprising Stanley Shale and some older rocks of the Aly belt along the Alum Fork of the Saline River is named the Alum Fork re-entrant. Immediately to the east and southeast of this area the rocks of both the Aly and Mt. Ida belts are overthrusted by the Mazarn and other Ordovician rocks that belong to the Hopper and Avilla belts and this major thrust fault has been named the Alum Fork decollement. Along the surface trace of the Alum Fork decollement displacement, of at least, 8 miles can be measured in this area.

The Mt. Ida belt in the vicinity of Steiner Mountain also contains several other structural plates and thrust faults that, in part, through erosion have left a series of windows, klippen and other complex features. Several of these thrust faults are estimated to have several miles of displacement. Some typically small milky quartz veins of hydrothermal origin are present in the rocks comprising the Mt. Ida and Aly belts in this area, but they are significantly more abundant and larger in the Hopper and Avilla belts.

There have been numerous investigations in recent years to unravel the complex geology in this eastern Benton Uplift of the Ouachita Mountains. A partial list of this work includes: the basic field mapping in the late 1950's and early 1960's by Sterling, Stone and Holbrook; somewhat later the initial structural analysis mostly by Viele; later the definitive regional and detailed mapping by Haley and Stone; following are the studies by Viele and students; and concurrently the work by Haley and Stone, Ethington and others. Several publications have been accomplished by Viele to explain the origin of the complex structure in these rocks. We have offered alternative proposals but rather little of apparent significance has been published. Presented here is a nearly north-south cross section through this region (Plate 13), previously open-filed that we suggest represents a logical interpretation of the structure of these rocks. Major decollements are shown as flooring the strata in the Avilla and Hopper belts and overriding the more northerly facies of the Mt. Ida and parts of the Aly belts. We also show the Maumelle chaotic zone as a tectonically imprinted, mostly slope facies, of the Jackfork Sandstone and other formations; whereas Viele (i.e. 1973) illustrates it as a structural melange.

The trip proceeds from this area to a scenic Lunch Stop on Weyerhaeuser Company road No. 24530 about ½ mile to the north on the Alum Fork of the Saline River where there is an opportunity to examine lower Stanley Shale in the Alum Fork re-entrant. A side trip can also be made into another drainage about ¼ mile to the northeast where there is an exposure of a 5 — 15 foot thick calcite-bearing, mylonized breccia that represents the Alum Fork decollement zone. At this locality micritic, silty limestones and black shales of the Lower Ordovician Mazarn Shale overlie shales with locally some very thin graywackes and cone-in-cone concretions of the



Geology From Haley and Others (1976)

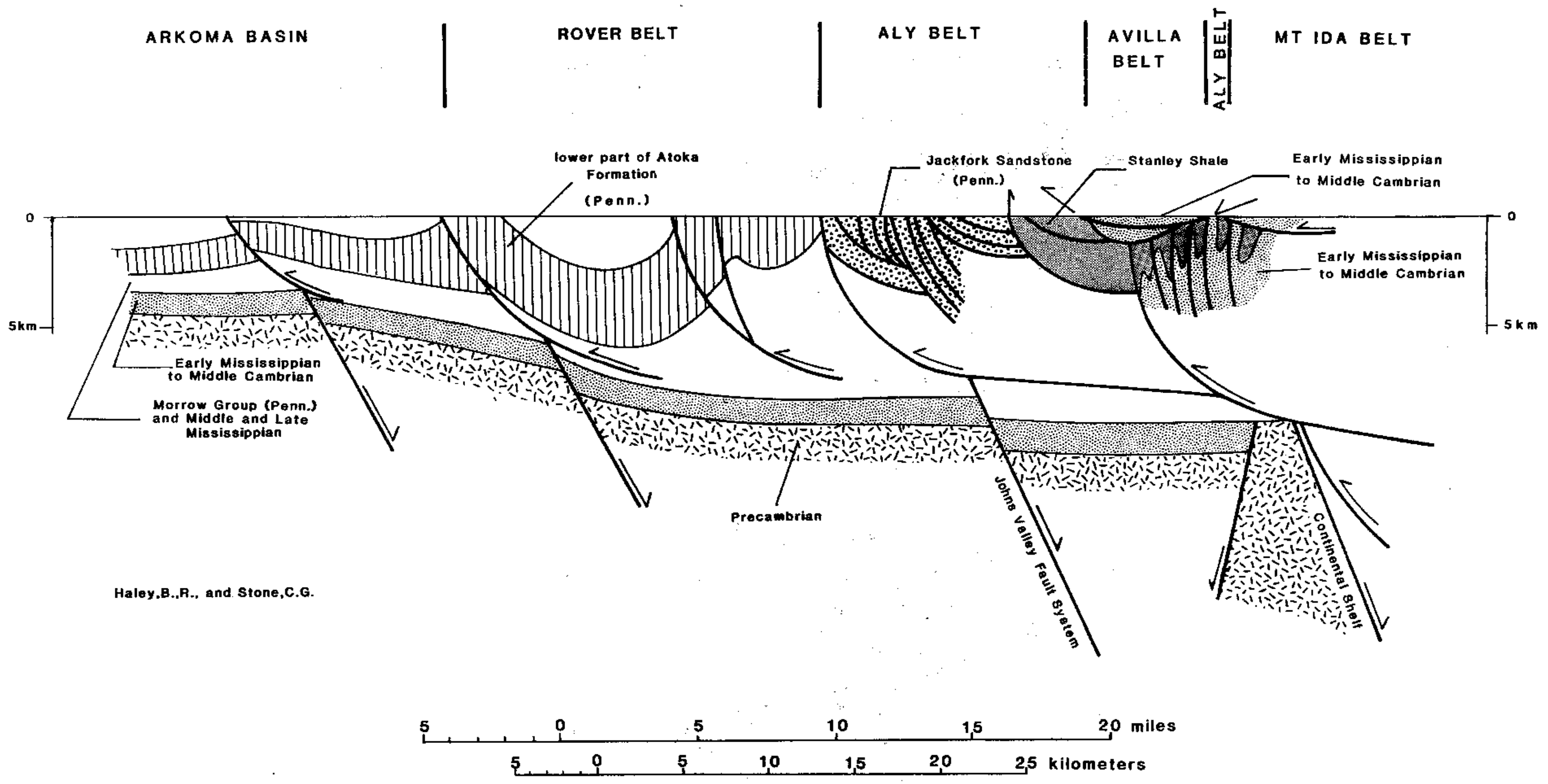
PLATE 12. GEOLOGIC MAP IN VICINITY OF STOP 11

Mississippian lower Stanley Shale.

For about the next 20 miles we will be travelling primarily on Weyerhaeuser Company roads and we wish to extend our sincere thanks to Mr. Bob Bearden and Mr. William Willis of Weyerhaeuser for their kind assistance and for obtaining permission to use the roads.

IN THE RESOUNDING WORDS OF THE LATE HUGH D. MISER ---"BOYS, ARE WE GEOLOGISTS OR ARE WE FISHERMEN" ????

Figure 8. — Stop 11. This is the Lunch Stop at the low-water bridge on the scenic Alum Fork of the Saline River situated within the Alum Fork re-entrant in the lower Stanley Shale.



Haley,B.,R., and Stone,C.G.

STRUCTURAL CROSS SECTION OF THE EASTERN OUACHITA MOUNTAINS

PLATE 13

STOP 12. — ALUM FORK DECOLLEMENT WITH BLAKELY SANDSTONE AND MAZARN SHALE IN FAULT CONTACT WITH STANLEY SHALE AND ARKANSAS NOVACULITE

This stop is scheduled to examine the rather poor exposure along a Weyerhaeuser road that illustrates some clean quartzose sandstone lenses of the Blakely Sandstone belonging to the Avilla belt (Plate 14). Locally there are some erratic granite and meta-arkose boulders and cobbles in the formation. As we proceed down the hill, to the west, there are some weathered limestones, calcareous siltstones and shales of the Mazarn Shale. Near the base of the hill is a thin sheared interval representing the fault plane of the Alum Fork decollement. Below the fault are some exposures of the lower Stanley Shale of the Aly belt. The northern facies of the Arkansas Novaculite is present immediately to the south and is partially exposed in an adjoining roadcut.

Large milky quartz veins with abundant accumulations of residuum are present in the older overthrusted rocks but are significantly less common in the underlying strata. As previously stated, at least 8 miles of displacement can be measured along this fault contact in this area. However the rocks on either side of the re-entrant do not, then, in most ways, lithically and otherwise resemble. In all likelihood this fault has a displacement of 20 to 40 miles; this is further illustrated by the southern facies of the Arkansas Novaculite present in the Avilla belt a few miles northeast of this area. It is interesting to note that most, if not all, of the numerous thrust faults and related splays of the underlying plate (Aly belt) are also covered by the overlying plate (Avilla belt).

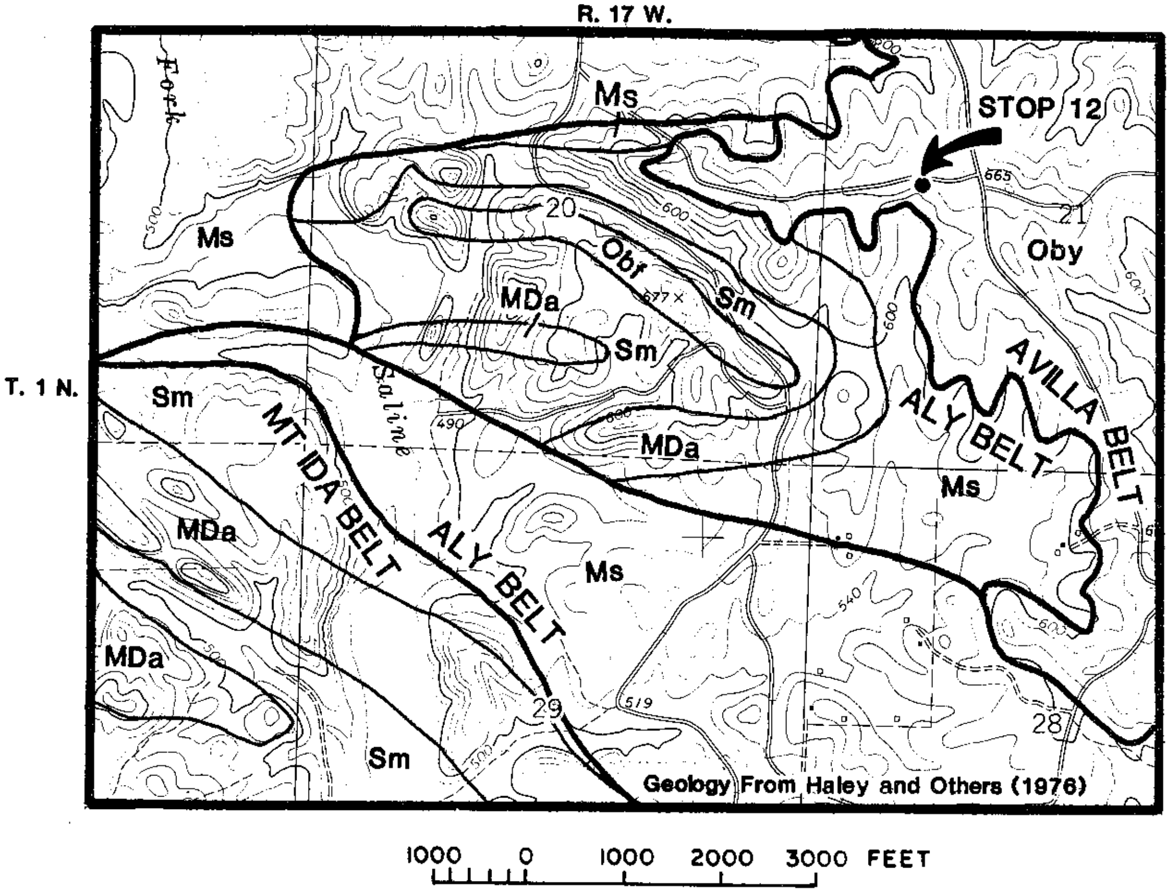


PLATE 14. GEOLOGIC MAP IN VICINITY OF STOP 12

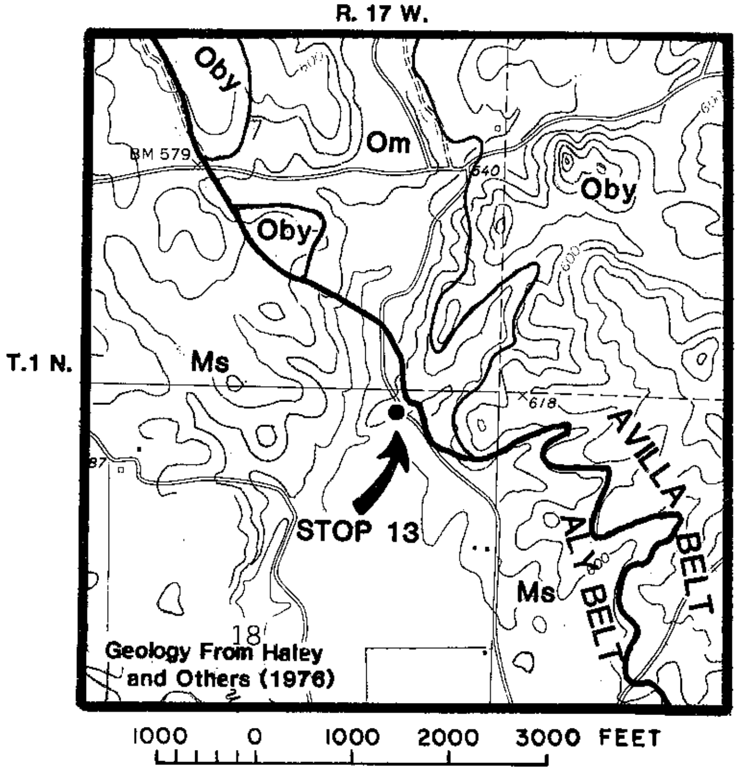


PLATE 15. GEOLOGIC MAP IN VICINITY OF STOP 13

STOP 13. — ALUM FORK DECOLLEMENT WITH MAZARN LIMESTONE IN FAULT CONTACT WITH STANLEY SHALE

This is another opportunity to view the rocks on both sides of the Alum Fork decollement (Plate 15). At the road tightly folded, crinkled and cleaved shales of the lower Stanley Shale (Aly belt) are poorly exposed, to the north about 25 yards is a mostly covered, thin brecciated, mylonized interval that represents the fault zone, and directly above this are very tightly buckled, often recumbent, thin, dense, micritic limestones and some black shales of the Mazarn Shale (Avilla belt). Samples of limestone from this location submitted to Ray Ethington of the University of Missouri did not yield conodonts, but at Hester Chapel about 1½ miles to the north, a conodont of Lower Ordovician Mazarn affinities was obtained. As stated at the previous two stops, the structural displacement of the Alum Fork decollement is likely 20 to 40 miles. We have also mapped other major low-angle thrust faults in the Avilla belt structurally above the Alum Fork decollement that have unknown but sizable displacements.

In the late 1950's when the work in this region was instigated, in part by the suggestion of the late Hugh D. Miser of the U.S. Geological Survey, it was the prevailing opinion of several geologists working primarily in Oklahoma, that the rocks in the Ouachita foldbelt were, generally, very simply folded and not appreciably thrust faulted. One notable investigation described all the Ouachita strata as being autochthonous (in place). This thesis was also strongly contradicted by a number of geologists. There are many long and heart rendering (but generally friendly) discussions about these complexly rucked sequences of Paleozoic rocks. But it seems that most investigators are presently in agreement on several critical observations: the rocks are mostly of deep water origin; they are allochtonous; there are major thrust faults; and there are structural belts. The real "burning" question that remains is how or why these rocks get here and why they are the way they are!

In conclusion one of the earliest and certainly the foremost truly definitive field determination of major low-angle folded thrust faults in the Ouachita Mountains was made here in this area!

STOP 14. – LOWER JACKFORK SANDSTONE AT THE SPILLWAY ON LITTLE BEAR CREEK LAKE NEAR HOLLIS

During recent investigations to re-evaluate the rocks in this area for the field trip, we did observe two sizable black bears!

More than 100 feet of rather severely fractured and quartz veined quartzose sandstone, siltstone and shale of the lower Jackfork Sandstone are exposed along the east wall of the spillway for the lake on Little Bear Creek south of Hollis, Arkansas (Plate 16). This section occurs about 900–1000 feet above the base of the formation. Thr rocks are gently dipping and near the crest of a slightly vergent (southward) anticline in the Aly belt of the frontal Ouachita Mountains. Most outcrops elsewhere in this area have very steep inclinations. A major east-west thrust fault is present in the lake and dam area to the south. These rocks are likely representative of slightly incised channel-fill sequences on the upper part of a submarine fan. Five distinct and possibly more channels or channel migrations and reactivations are exposed. The base of the sequence contains sedimentary slump and large pull-a-part features that are further disturbed by structural flowage and small bedding plane and other thrust faults. Paleocurrent data appear to indicate a source to the northeast and east. In recent years, rocks exposed in the spillway and in other sites in the Jackfork Sandstone in Arkansas have served as models for depositional training programs. The following abstract by Thompson and LeBlanc represents one of the first and foremost interpretations derived from these studies.

Thompson, Alan, and LeBlanc, R. J., 1975 **CARBONIFEROUS DEEP–SEA FAN FACIES OF ARKANSAS AND OKLAHOMA:** Geological Society of America Abs. with Programs, v. 7, p. 1298–1299.

The Carboniferous flysch facies in the Ouachita Mountains of Arkansas and Oklahoma consists of over 20,000 feet of turbidites and related sediments. The section in Oklahoma is mainly shaly flysch, but Morris recently described several sections in Arkansas which contain thicker-bedded and coarser-grained rocks than those encountered in Oklahoma. More recently Graham, et al., suggested that the Ouachita flysch originated as a submarine fan system, similar to the Bengal fan. The writers recently studied exposures of Stanley, Jackfork, Johns Valley, and Atoka strata in Arkansas and Oklahoma in an attempt to classify these strata according to the submarine fan-channel model of Mutti and Ricci–Lucchi.

Sequences in which sandstones thin upward and thicken upward, indicative of channel and fan-lobe, respectively, are common in all units studied. Sequences in which sands thicken upward and then reverse themselves to continue thinning upward are thought to represent lobes which are gradually abandoned. Examples which best fit the submarine fan-channel model occur in the Jackfork. The section in Big Rock Quarry at North Little Rock consists of at least eleven distinct channel-fill sequences. Along Route I–30 between Arkadelphia and Malvern five distinct channel-fill sequences can be seen. Deposits at both of these localities are interpreted as inner fan, with the former being most proximal. Midfan deposits are present farther to the west in the vicinity of DeGray Dam, and outer fan deposits occur in eastern Oklahoma. The submarine canyon which fed this deep-sea fan complex was located to the east near Memphis.

We agree that a major source area for the Jackfork Sandstone in this region was to the east or northeast. But as indicated by Michael Owen (in this guidebook) and others, much of the Jackfork in the southern Ouachita Mountains was probably derived from terrane (metasedimentary) to the southeast. Plate 17 is a general depositional model for the Jackfork. With minor revisions, it is published through the kind permission of M. T. Roberts, from the Cities Service Company, 1980, Field Guide to Carboniferous deep-water clastics, Ouachita Mountains.

The rocks in this portion of the Aly belt are intensely thrust faulted and display prominent shearing, small fracture-filling quartz veins and slickensides coated with yellowish-white splotches or groove-fillings of dickite. Stone and Milton (1976) showed that two major generations of quartz veins are present in this portion of the frontal Ouachita Mountains. The first containing dickite and the latter rectorite and cookeite, both associated with minor ore minerals and other minerals. These types of veins are probably present at this site. Some of the quartz veins are crinkled or rotated, suggesting a change in the axis of compression during the very late episodes of Ouachita tectonism.

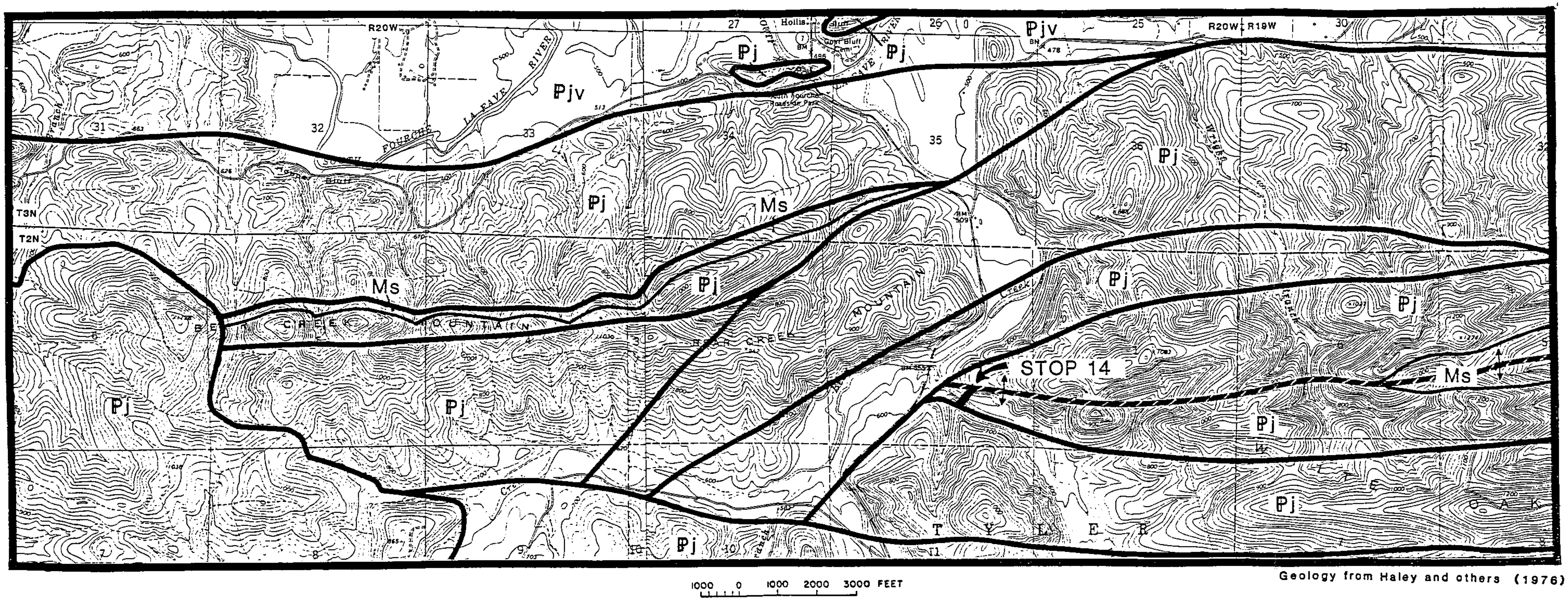
The major stratigraphic and structural boundary in the frontal Ouachita Mountains is along the northern limits of the Aly belt near the community of Hollis, about two miles north of here. The major thrust faults present in this area (by some interpretations) may represent the Winding Stair, Honess, Briery, Y City, and Ti Valley of western Arkansas and eastern Oklahoma. The various sequences of Stanley Shale, Jackfork Sandstone, Johns Valley Shale and lower Atoka Formation are significantly displaced. Interestingly, these units locally contain olistoliths derived from foreland facies that was to the north (e.g., Gordon and Stone, 1977). This belt of structurally complex rocks has been identified by Viele (1973) as the Maumelle chaotic zone and as the suture between the North American and South American plates. The overall tectonic intensity caused by the multiple stacking of rocks by several large thrust faults, the probability of significant differences in configuration and structural involvement of the basement; the later deformational effects of a probable subsurface triangle zone (see Arbenz in this guidebook), and other factors constitute a more plausible explanation for the structural complexities of this belt (see Plate 13).

Northward from the Aly belt for about 20 miles more gently deformed and imbricately thrust faulted sequences of mostly thick flysch facies of the lower Atoka Formation comprise the Rover belt. At Danville and Ola the Ross Creek thrust fault is recognized as the boundary between the frontal Ouachita Mountains and the Arkoma basin.

There has been considerable evaluation of the mostly platform and deltaic facies in the Arkoma basin and environs in recent years as a result of the intensive search for natural gas and coal resources. An abstract and schematic cross section (Plate 18) are from Haley and illustrate the geology of the Arkoma basin and its relationship to the Ouachita Mountains and the Ozark dome at the end of Atokan time.

Haley, Boyd R., 1982, **GEOLOGY AND ENERGY RESOURCES OF THE ARKOMA BASIN, OKLAHOMA AND ARKANSAS:** Univ. of Missouri: – Rolla Journal, No. 3, p. 43–53.

The Arkoma basin is a structurally defined basin that underlies an area of about 13,000 sq. mi. It extends from Little Rock, Arkansas, to Atoka, Oklahoma. The rocks in the basin grade upward from dolomite, some limestone, sandstone (Upper Cambrian to Upper Devonian) to shale and limestone (Upper Devonian to Lower Pennsylvanian) to shale, limestone, and sandstone (Lower Pennsylvanian) to shale and sandstone (Middle Pennsylvanian). The sediments that formed rocks in the lower part of the Atoka Formation on the south side of the basin were deposited in a deep-water environment. All other sediments in the basin were deposited in shallow-water, littoral, or deltaic environments. Growth faults were restricted to the south side of the basin during Late Mississippian and Morrowan time but became common throughout the basin during Atokan time.



Geology from Haley and others (1976)

PLATE 16 GEOLOGIC MAP IN THE VICINITY OF STOP 14

Figure 9. — Stop 14. Little Bear Creek Lake spillway, near Hollis, Arkansas. This exposure in the lower Jackfork Sandstone consists of several apparently entrenched and, in part, slumped thick sandstone intervals product of a large upper submarine fan channel sequence.

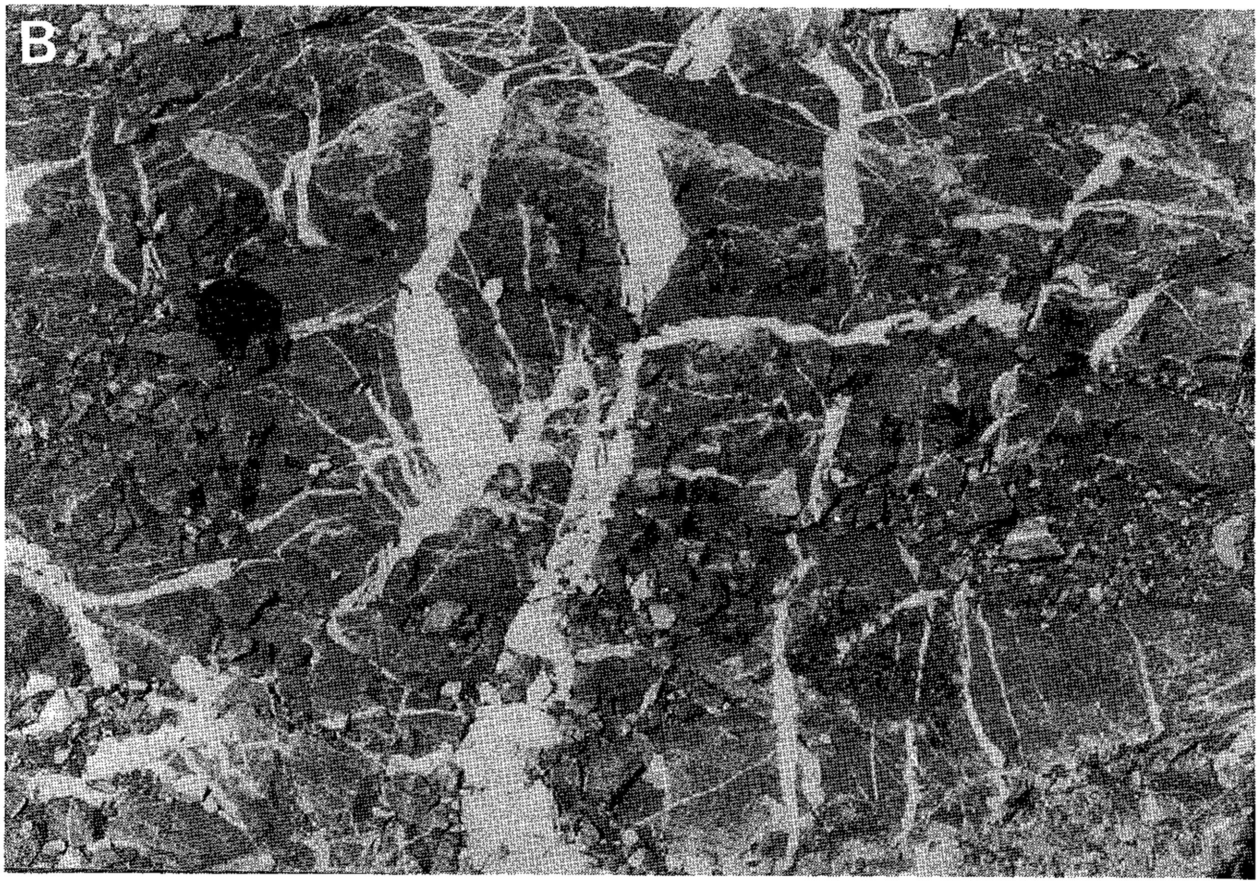
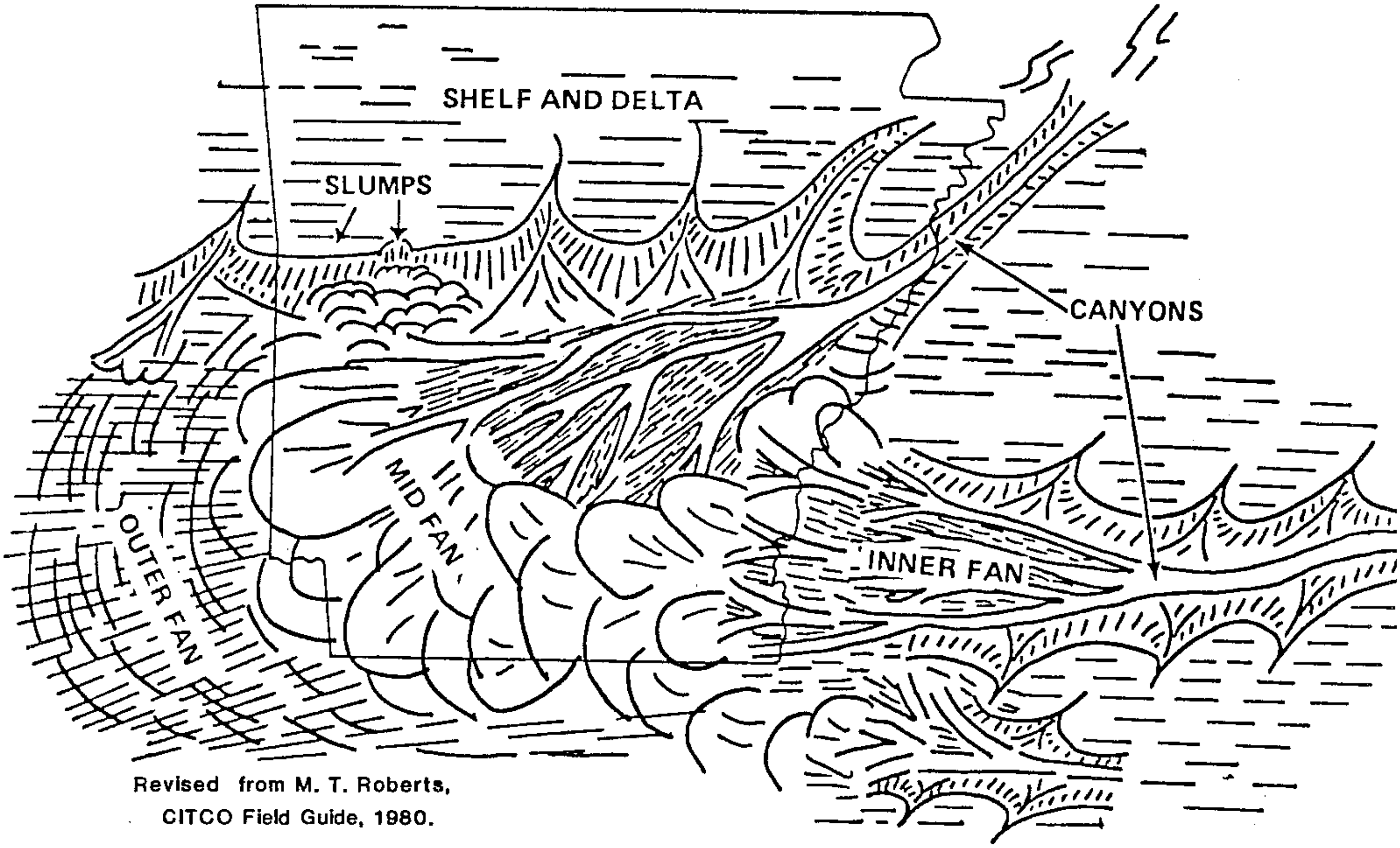


Figure 10. — Stop 14. Fracture-filling pinch and swell milky quartz veins or veinlets in a small fault zone in the lower Jackfork Sandstone at Little Bear Creek Lake spillway. Some of the veinlets are folded, suggesting changes in the direction of compression during a late stage of deformation.

During the Ouachita orogeny, the rocks were folded into east-west trending synclines and anticlines, and the anticlines along the southern part of the basin were ruptured by thrust faults. A small amount of oil has been produced from reservoirs of Ordovician, Silurian, and Pennsylvanian age in the extreme southwestern part of the basin. Approximately 4.9 trillion cu. ft. of natural gas have been produced from Ordovician to Pennsylvanian reservoirs. About 280 million short tons of coal have been produced from rocks of Atokan and Des Moinesian age.



Revised from M. T. Roberts, CITCO Field Guide, 1980.

PLATE 17. MAP DIAGRAMMATICALLY SHOWING THE DEPOSITIONAL FACIES OF THE JACKFORK SANDSTONE AND EQUIVALENT ROCKS IN ARKANSAS.

(Minor shortening has been necessitated on the Jackfork fans for this illustration)

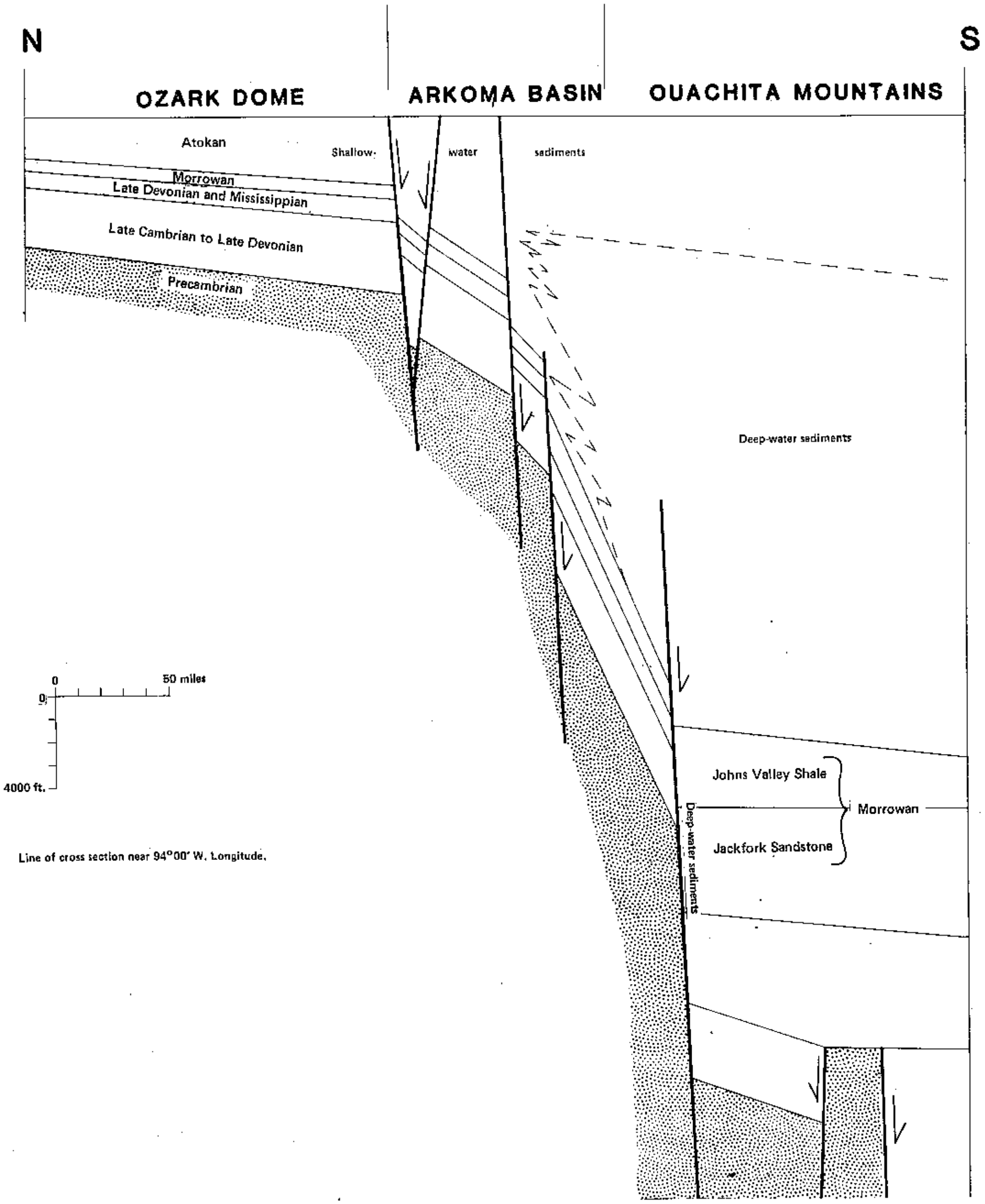


FIGURE-6 SCHEMATIC CROSS SECTION OF THE ROCKS IN THE ARKOMA BASIN AND VICINITY AT THE END OF ATOKA TIME

(From Haley, 1982)

PLATE 18

STOP 15. – GEOMEX QUARTZ CRYSTAL MINE

We wish to expresss our deepest gratitude to Mr. Paul Thompson, a geologist, and other personnel of the Geomex Company for letting us have access to their Quartz Crystal mine and also for their invaluable assistance in the examination of these classic deposits.

Mining of quartz crystals in the Ouachita Mountains of Arkansas has been going on for many years, the first miners probably being the Indian tribes that shaped them into arrowheads. Because of the clarity and perfect shape of many of the individual crystals and crystal clusters, the principal market for the quartz over the years has been as specimens in both individual and institutional mineral collections. During World War II about five tons of clear quartz crystals from Arkansas was used in the manufacture of radio oscillators to supplement the production from Brazil. Currently, the quartz crystals are being used for: manufacturing fusing quartz, which has many chemical, thermal and electrical applications; for seed crystals (lasca) for growing synthetic quartz crystals; and, of course, for mineral specimens. It should be noted that the "Hot Springs Diamonds" for sale in the local rock shops and jewelry stores are cut from Arkansas quartz crystals.

Quartz veins are numerous and are found in a wide belt extending from Little Rock, Arkansas to Broken Bow, Oklahoma, in the central core area of the Ouachita Mountains. These veins, up to sixty feet in width, commonly contain traces of adularia, chlorite, calcite and dickite. In a few places lead, zinc, copper, antimony and mercury minerals are associated with the quartz veins. At relatively few localities, however, within the quartz vein belt do individual quartz crystals and crystal clusters attain the size and clarity requisite for mining.

In the Ouachita Mountains there is a close association of quartz veins with fault zones. It is believed that the quartz veins represent, in part, dewatering processes that took place along the fault zones. The increase in pore fluids may well have contributed to overpressuring and related conditions and enhanced the overall faulting and folding process. The quartz veins with their associated minerals are presumed to be hydrothermal deposits of tectonic origin formed during the closing stages of the late Pennsylvanian-early Permian orogeny in the Ouachita Mountains.

The quartz crystal deposits at the Geomex Mine are also known as the Coleman Mine, West Chance Area, Dierks No. 4 Mine and Blocher Lead (Plate 19). The quartz crystals occur in veins in limy sandstone and conglomeratic sandstone beds of the Blakely Sandstone. Beds of conglomeratic sandstone exposed in the pit contain abundant weathered meta-arkose and granitic boulders, cobbles, and pebbles; and some clasts of limestone, chert and shale. It is likely that these sediments were deposited in submarine fan channels and were derived from a granite-rich terrane to the north-northeast. It has been postulated by Stone and Haley (1977) and a number of other workers that these exotic boulders are likely Precambrian in age. There has also been some opinion that they represent early Cambrian accumulations. The report in this guidebook by Sam Bowring on zircons from the weathered granitic and meta-arkose boulders from this pit and other sites indicates they are Middle Proterozoic in age. This area is comprised of many thrust-faulted sequences with at least two major periods of folding resulting in differing attitudes in fold hinge lines and axial planes. The mine itself is situated on the nose of a large, complexly-deformed syncline.

The quartz crystal veins are fracture fillings with the larger and more productive cavities being located at the intersection of two veins. Mining operations are relatively simple, consisting initially

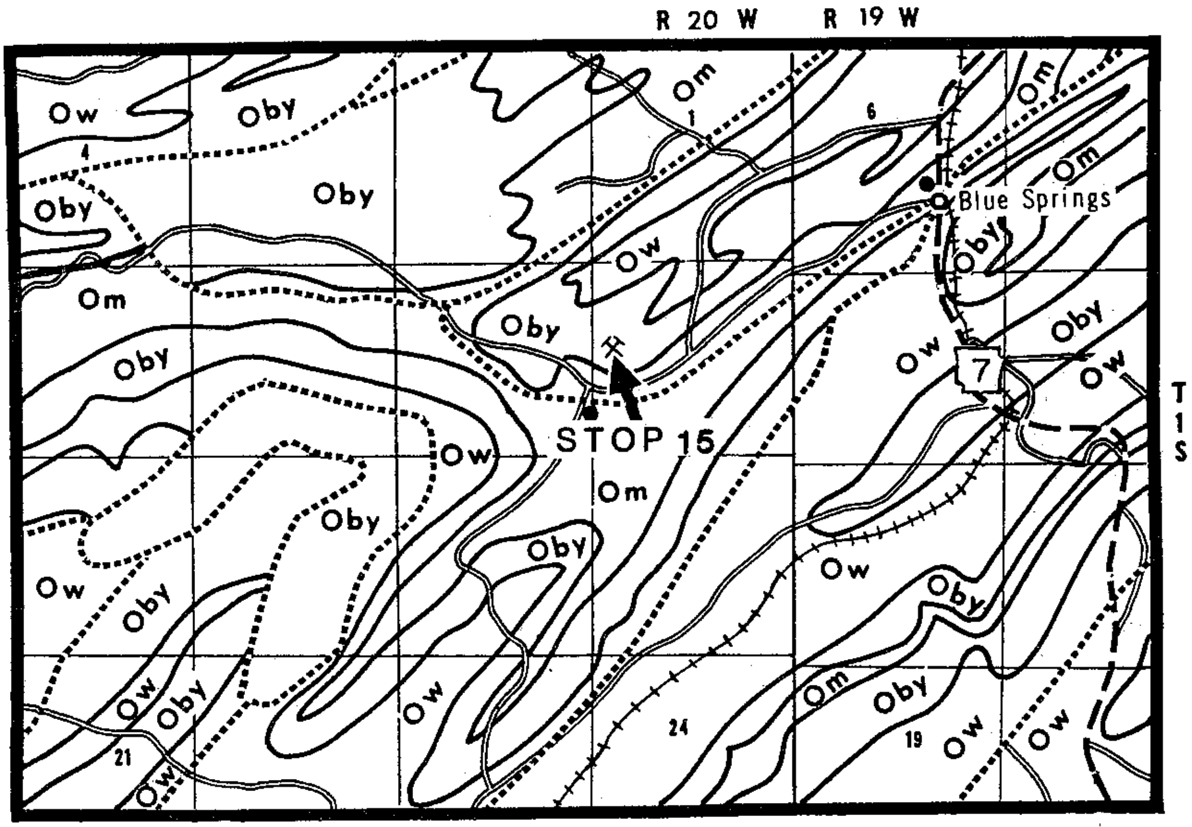


PLATE 19. GEOLOGIC MAP OF BLUE SPRINGS, ARKANSAS AND VICINITY- STOP 15

1 0 1 2 3 Miles

Geology from Haley and others (1976)

Figure 11. – Stop 15. Thick olistostromal sequences of Blakely Sandstone with various granite, meta-arkose and limy siltstone erratics in a decalcified sandstone, with some lenses of orthoquartzitic sandstone. Small faults visibly offset some of the rocks but most of the "deformation" is considered sedimentary in origin. At least two prominent directions of fracture-filling milky to clear quartz veins are present.

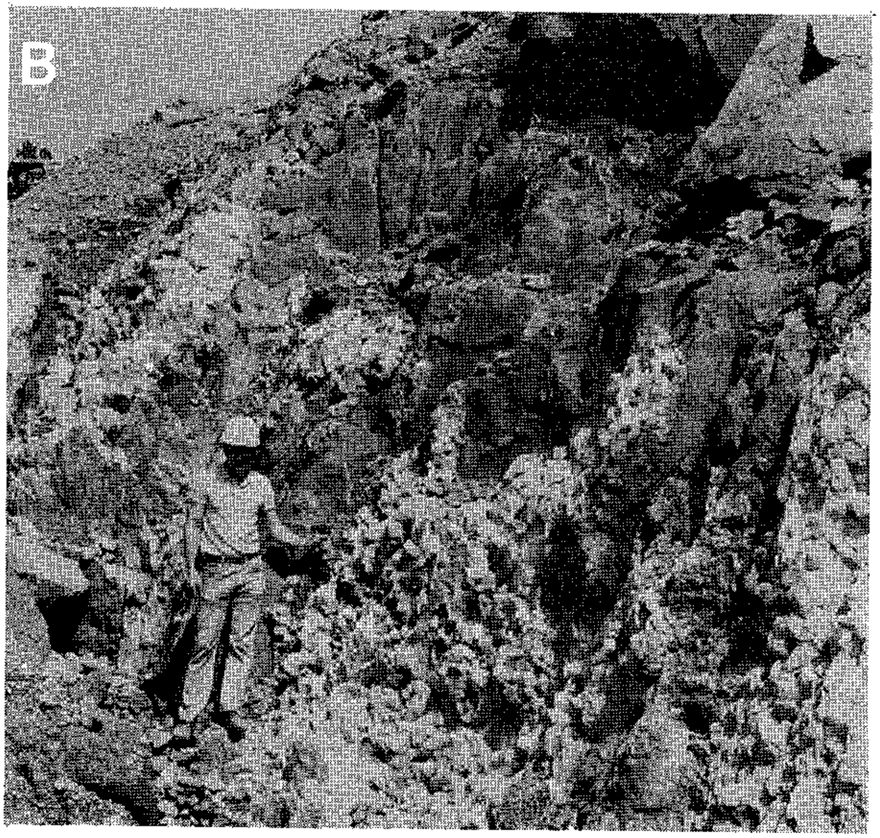


Figure 12. – Stop 15. Mr. Paul Thompson, a geologist with the Geomex Company, stands by large quartz cavities lined with clear and milky quartz crystals at the east end of the mine.

of removing overburden and loose rock with a bulldozer to expose the crystal-filled cavities, and then removing the quartz crystals with hand tools. Individual quartz crystals up to five feet in length weighing as much as 400 pounds and clusters 15 feet in length weighing over five tons have been produced from these mines.

STOP 16. — NORTHERN FACIES OF THE ARKANSAS NOVACULITE AND OTHER FORMATIONS AT WASHITA

This exposure is along Arkansas Hwy. 27 at and near the Arkansas Hwy. 88 Junction (Plate 20).

This sequence of early Ouachita trough rocks from north to south includes: greenish-black shale or slate, thin gray cherts and conglomerates in the lower Stanley Shale; greenish-tan, light brown, and gray shale, gray chert, grayish-white novaculite and minor speckled dark-gray conglomerate of the Arkansas Novaculite; greenish-gray to maroon shales of the Missouri Mountain Shale; black carbonaceous shale of the Polk Creek Shale (on the northwest side of the bridge over an upper arm of Lake Ouachita); and, gray to black chert and black shale of the Bigfork Chert (south of the bridge). A fairly intense development of low-angle cleavage occurs in various formations.

A thin conglomerate commonly occurs at the base of the Stanley throughout much of this area and is generally considered equivalent to the Hot Springs Sandstone Member of the basal Stanley Shale. The Hatton Tuff which occurs above this member in the southern and central Ouachita Mountains has not been observed in this area. Massive novaculite is rarely present in the northern Ouachita Mountains (Plate 21).

The conglomerates in the lower Stanley Shale and the Arkansas Novaculite interval may exceed 20 feet in thickness at some places in the northeastern and north-central "core area" of the Ouachita Mountains of Arkansas. These conglomerates of the Arkansas Novaculite are composed of small to quite large subrounded to angular clasts of siliceous shale, chert, novaculite, and sandstone. Many of these beds are channel-like, others are more in form of lenses. Stone and Haley (1977, p. 110) report some granitic fragments in these conglomerates. The granitic source was to the north of the depositional site possibly from an intrusive associated with submarine scarps. These coarse sediments likely were transported in the form of submarine slumps and slurries, aided by turbidity currents down the slope and through the canyon systems into the deeper early Ouachita trough. Honess (1923, p. 126–128) describes a ten inch bed containing a conglomerate composed of subangular to rounded pieces of chert, weathered feldspar, grains of granite, basalt, and volcanic ash or glass in a cherty matrix near the top of the Lower Division of the Arkansas Novaculite west of Glover, Oklahoma in the western Broken Bow uplift.

Some intervals of the lower Arkansas Novaculite and the upper Missouri Mountain Shale contain abundant "large" Radiolarians. The Missouri Mountain Shale locally contains thin conglomerates composed in part of frosted sand grains in a chert matrix.

The Blaylock Sandstone is not present in the northern Ouachita Mountains of Arkansas. Fairly abundant graptolites of late Ordovician age occur in Polk Creek Shale and Bigfork Chert at this locality. Numerous tight chevron folds, generally overturned to the south, and small faults occur in the Bigfork Chert. The Bigfork Chert is probably the most lithically consistent and recognizable unit throughout the Ouachita Mountains. In the area veinlets of hydrothermal quartz along with the aluminum phosphate minerals wavellite and variscite occur in the Bigfork Chert.

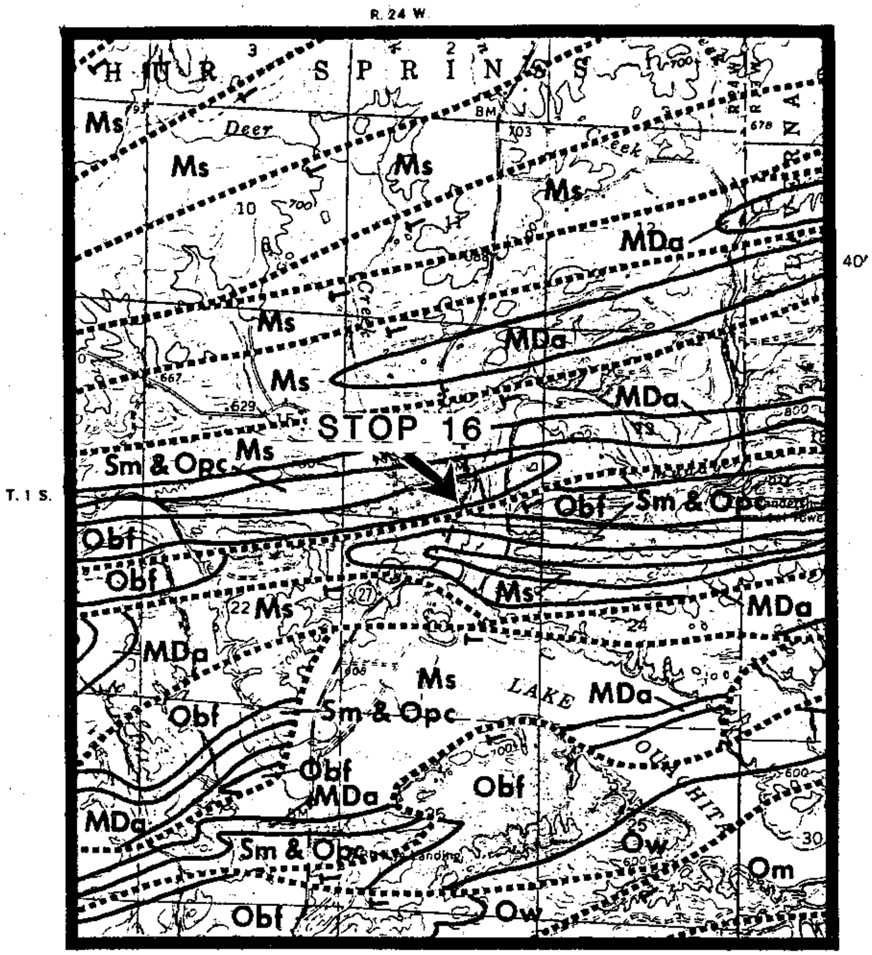


PLATE 20. GEOLOGIC MAP OF WASHITA, AND VICINITY-STOP 16.

1000 0 3000 6000 9000 FEET

Geology from Haley and others (1976)

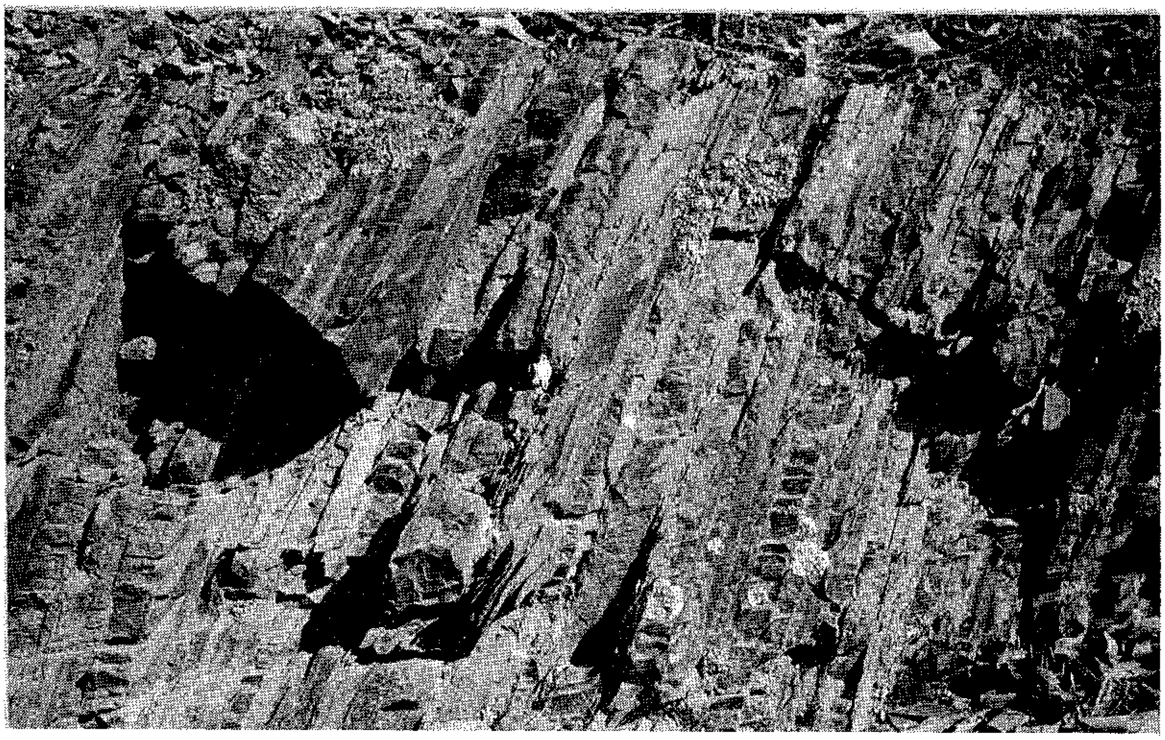


Figure 13. — Stop 16. Thin interbedded, often radiolarian-bearing, shale and chert with low northward dipping cleavage in the middle Arkansas Novaculite on Arkansas Hwy. 27. Note the cleavage refraction between the shales and cherts.

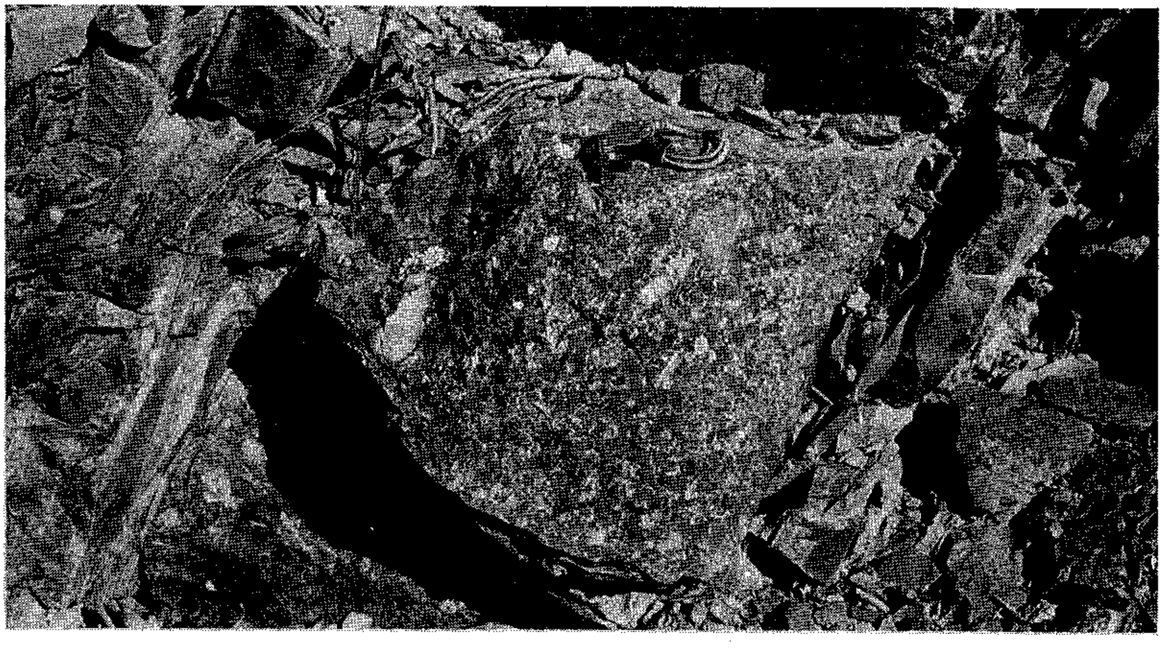


Figure 14. — Stop 16. Thin conglomerate interval containing chert, novaculite, sandstone and other clasts in the uppermost Arkansas Novaculite on Arkansas Hwy. 27.

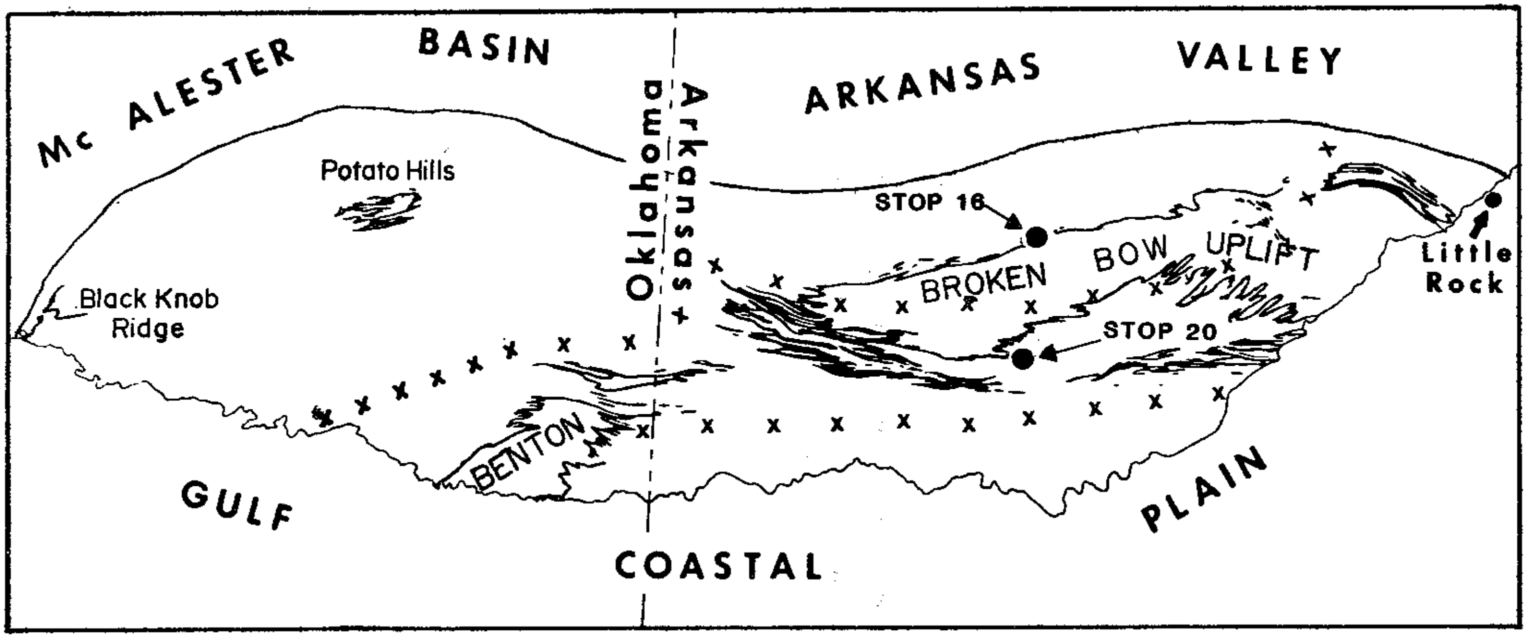


PLATE 21. MAP OF OUACHITA MOUNTAINS SHOWING OUTCROP OF THE ARKANSAS NOVACULITE (black area and lines) IN ARKANSAS AND OKLAHOMA. THICK SHALE FREE PORTIONS OF THE NOVACULITE ARE WITHIN AREA OUTLINED BY X's.– STOP 16 and STOP 20.

STOP DESCRIPTIONS — THIRD DAY

CENTRAL AND SOUTHERN OUACHITA MOUNTAINS
MT IDA—BLACK SPRINGS—NORMAN—CADDO GAP—GLENWOOD—AMITY

STOP 17. – COLLIER LIMESTONE ON LYBRAND ROAD AND IN ADJACENT STREAM

This site is located on Lybrand Road (U. S. Forest Road 215) and in an adjacent small stream to the north (Plate 2). These rocks have been examined by many geologists since Wise (1963) described some possible small algal structures in the thin, flaggy, micritic limestones of the Early Ordovician upper Collier Shale on the south side of the roadcut. The "algal" structures are now thought to be possible trace fossils. With the assistance of Hugh D. Miser and others, Wise further noted oolites, chert pebbles and frosted sand grains in a few thin to thick, conglomeratic limestones in the small stream.

Close examination of the conglomeratic limestones has revealed a few small granite and plagioclase fragments. Several of the limestones also contain pellets and oolites, which might seem to suggest shallow-water deposition. It is more likely, however, that the coarser elements are winnowed fractions that were transported into the Ouachita trough by turbidity currents and submarine slurries from a northerly flanking platform facies. The granite and plagioclase fragments are thought to represent detritus from a Precambrian mass that was present along one or more submarine scarps. The foundering that formed the Ouachita trough occurred prior to the deposition of the Early Ordovician Collier Shale.

Numerous very tight, mostly southward verging isoclinally recumbent folds, are exposed in the limestones and shales of the Collier along the stream cut. A nearly horizontal cleavage dissects the shales. Hydrothermal quartz and calcite veins fill fractures and small shear zones and may be indicative of some minor, nearly horizontal thrust faults. This site lies in the upper plate of the large Lybrand thrust fault in the western part of the Mt. Ida belt. The Collier Shale and the overlying Crystal Mountain Sandstone, which forms the ridges to the north and south, have overridden the younger Mazarn Shale and other Ordovician units. The fault trace is about 200 yards to the west near U. S. Forest Service road 92 and immediately east of the South Fork of the Ouachita River. Here it cuts across the structural "grain" of the rocks along a nearly north-south trace.

Figure 15. — Stop 17. Thin-bedded, micritic limestones in the upper Collier Shale in creek adjacent to Lybrand Road. A few of the limestones have minor silt and sand fractions and a delicately graded bedding.

Figure 16. — Stop 17. Conglomeratic limestone in the upper Collier Shale in creek adjacent to Lybrand Road. The limestone contains frosted sand grains, oolites and pellets, small fragments of granite and plagioclase and larger clasts of gray chert. A few very small potholes are visible in the limestone.

STOP 18 — MAZARN SHALE ON ROADCUT ADJOINING THE SOUTH FORK OF THE OUACHITA RIVER

This stop is on U. S. Forest Road 92 and along the adjacent South Fork of the Ouachita River (Plate 2). The Mazarn Shale exposed here is in the lower plate of the Lybrand thrust fault described at the previous stop. The abundant cedar trees growing on several intervals of the Mazarn Shale are a most useful field guide for identifying this unit. The older Collier Shale and Crystal Mountain Sandstone in the upper plate of the fault occupy the small hills immediately east of here. The Mazarn Shale at this site consists mostly of well-indurated, partially banded, gray to black and minor olive shale. There are small quantities of thin, olive-gray silty shale and some blue-gray micritic limestone. Most of the banding in the silty shale is due to the grading of minute clay (often gray) and silt (usually olive-gray) fractions. The silt likely was deposited by spasmodic, very low velocity bottom currents that interrupted the normal deep-and cold-water pelagic sedimentation. The origin of other banding is obscure but may be related to small quantities of altered volcanic ash.

Intense folding and a pervasive nearly horizontal cleavage characterize the outcrop. Flowage from the flanks of many of the folds has resulted in a crest to flank thickness ratio of three or four to one. Top and bottom criteria are difficult to find, but the fine grading within the banded intervals suggests that the isoclinally recumbent rocks have tops generally to the south and thus a southward vergence. Small fracture-filling quartz and calcite veins are present, but the calcite is often leached leaving a vuggy rhombic appearance to the milky quartz. Locally small amounts of clear quartz crystal have been mined from cavities in the quartz veins that occur in the Crystal Mountain Sandstone.

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

STOP 19. – THRUST FAULT IN ORDOVICIAN ROCKS IN THE VICINITY OF BUTTERMILK SPRINGS

Buttermilk Springs, a renowned historic site, is located about 2 miles north-northeast of Caddo Gap immediately south of Collier Creek in the southern Mt. Ida structural belt (Plate 2). The rocks in this area occur on the upper plate of the large, low-angle Buttermilk Springs thrust fault and they are: limestone, shale and other lithologies of the upper Womble Shale; black to light-gray chert and sooty, often calcareous siltstone of the Bigfork Chert; and shale and novaculite of several younger formations. The rocks immediately north of the thrust fault are: shale, siltstone and limestone of the lower Womble Shale; sandstone and shale of the Blakely Sandstone; and shale and siltstone of the Mazarn Shale. Most of the rocks are slightly cleaved and the folds are rather tight with dominant southward vergence.

Several brief sub-stops will be made in this general area to examine and discuss: (1) the locally close proximity of the Bigfork Chert to the Blakely Sandstone; (2) the cherty organic-rich limestone in a large abandoned agricultural limestone quarry in the uppermost Womble and the basal Bigfork; and (3) Buttermilk Springs, where several significant springs issue from the slightly weathered, fractured chert and limestone, mostly in the lowermost Bigfork Chert.

There has been much interest recently in the potential for base metal and other mineral deposits in the Bigfork, Womble and other formations in the Ouachita Mountains. The model often applied depicts various extensional and volcanogenic events along the periphery of the Ouachita trough, with associated submarine venting and exhalative activity. Significant amounts of zinc are reported from a few distinctive asphaltite (bitumen)-rich, black sooty shales in the upper Womble Shale. Sulphides, mostly pyrite, authigenic adularia and albite (?) and other minerals occur in a few micritic to olistostromal limestone intervals. Many of the olistostromal deposits in the Womble Shale likely had a source that included both platform and troughal facies. Alternatively we propose that some of the occurrences, notable those in the upper Womble, represent local accumulations near former sites of exhalative vents on the deep sea floor.

STOP 20. — ARKANSAS NOVACULITE AT CADDO GAP

Legend has it that in 1541 Hernando DeSoto's party was attacked here by the Tula Indians who rolled boulders down the steep slopes on them!

This classic sequence beginning at the north end of the roadcut is: olive tan to maroon shale and a thin chert sandstone conglomerate bed of the upper Missouri Mountain Shale; massive, dense, white to light gray, highly jointed, sometimes sandy in the basal portions, novaculite and chert of the Lower Division of the Arkansas Novaculite; black shale, gray chert and some gray novaculite of the Middle Division of the Arkansas Novaculite; thin bedded to massive, cream to white, and, in part, tripolitic novaculite of the Upper Division of the Arkansas Novaculite; gray chert, greenish-black shale, quartzitic sandstone and a thin chert sandstone conglomerate bed of the Hot Springs Member of the basal Stanley Shale; and greenish-black shale, and graywacke of the lower Stanley Shale. Many other good exposures of the rocks occur along the highway, railroad and Caddo River in the area. Based on the study of conodonts at this site Hass (1951) placed the Mississippian-Devonian boundary some 27 feet below the top of the Middle Division. Structurally the rocks are rather severely deformed at this site. There are numerous steeply reclined kink folds and possibly another system with flatter hinges. A tear fault is present along the southern margin of the Stop and likely affected the fold rotations. Jay Zimmerman and others have been performing detailed geological studies of Caddo Gap and at much of the surrounding region for a number of years. A report by Zimmerman in this guidebook describes more completely the geology at Caddo Gap and attached Plate illustrates the exposed section of rocks.

To most investigators novaculite is a chemically pure microcrystalline variety of chert and typically breaks with a conchoidal or subconchoidal fracture. Lowe (1977, p. 136) shows that two distinct populations of detrital quartz grains occur within the massive white novaculite. One is a fine quartz that is distributed through the novaculite and likely represents a cyclic introduction of aeolian detritus into the basin of deposition. The other is made up of well-rounded, highly spherical, medium to coarse-grained sandstone in thin beds within the lower 70 feet of the Lower Division of the Arkansas Novaculite and uppermost Missouri Mountain Shale. He postulates that this sand may indicate a shelf contribution from the north by rapid sedimentation processes such as turbidity currents. In the Middle Division of the Arkansas Novaculite, Lowe (1977, p. 138) describes thin alternating chert and shale beds with some chert beds containing coarser grains. Where they do, grading and current structures are common. He suggests that these appear to be fine turbidity current sequences and indicates the presence of C and D intervals of the Bouma sequence. Sholes (1977, p. 139) indicates that the novaculite beds are spiculitic and pelletal, whereas the chert is primarily Radiolaria-bearing.

Keller et al., (1977, p. 834) in scanning electron microscopic studies of the Arkansas Novaculite suggests that the term novaculite be restricted to the polygonal triple point texture caused by low-rank thermal metamorphism. Present SEM studies of many additional samples from various Paleozoic Formations in the Ouachita Mountains by Keller and Stone indicate the coarsest polygonal triple point texture occurs near Little Rock, Arkansas, with another area of fairly coarse texture in the Broken Bow area of Oklahoma. At Caddo Gap polygonal triple point texture is very fine to absent.

Tripoli used primarily for abrasive products has been mined from the Upper Division near

Figure 17. Stop 20. Steeply reclined kink folds with small faults in thick to thin intervals of very dense novaculites and some thin shales in the lower part of the Lower Division of the Arkansas Novaculite at the north end of the Caddo Gap section on Arkansas Hwy. 27.

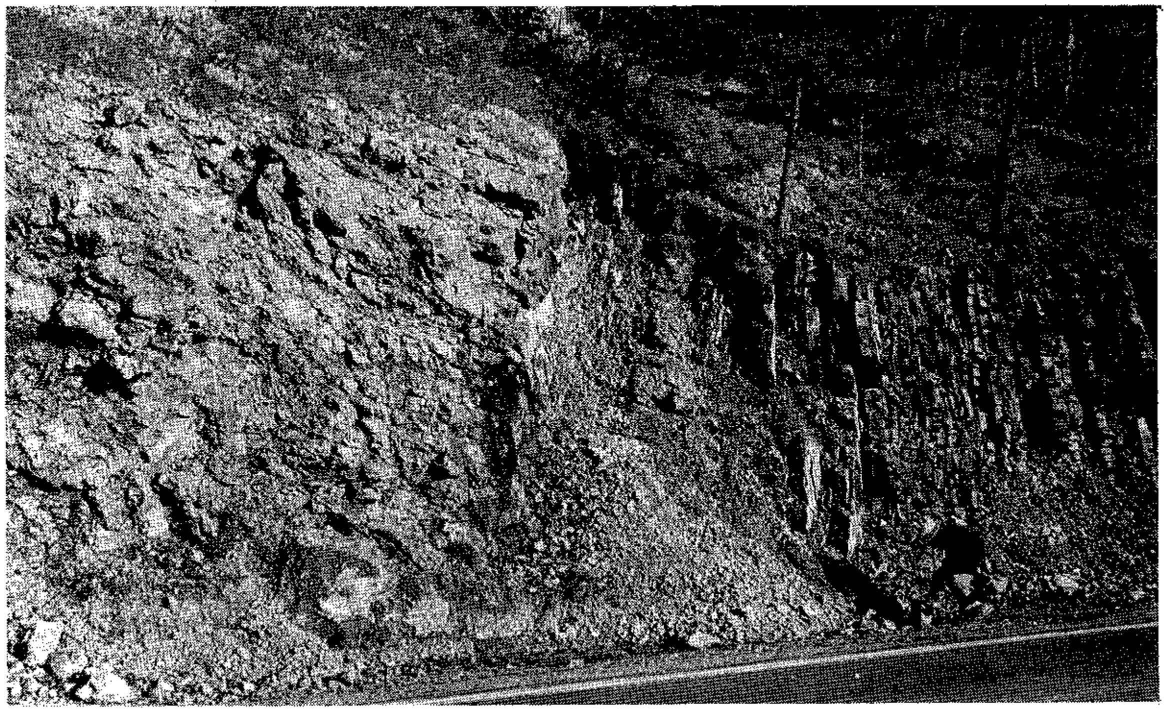


Figure 18. Stop 20. Vertical sequence of Arkansas Novaculite with altered coarse mostly novaculite breccia containing secondary manganese blebs at the top of the Lower Division (to the left), overlain by thin, often graded, chert and shale with some turquois coatings in the Middle Division near the north central part of the Caddo Gap section on Arkansas Hwy. 27.

Hot Springs, Arkansas to the east and in the Cossatot Mountains to the southwest. Novaculite is also extensively quarried, primarily near Hot Springs, for several types of the highest quality whetstone. Holbrook and Stone (1979) indicate that novaculite constitutes a tremendous resource of high-purity silica (99+%) in the central and southern Ouachita Mountains of Arkansas and Oklahoma. Manganese often occurs in the Lower Division of the Arkansas Novaculite in this area and farther to the west and likely was derived from leaching of the novaculite. Some limited mining operations for the small manganese veins and pockets have taken place in this area and westward into McCurtain County, Oklahoma. Investigations by Kidwell (1977) have disclosed a suite of rare iron phosphate minerals in some abandoned manganese mines in the Arkansas Novaculite, 10 to 35 miles west of here.

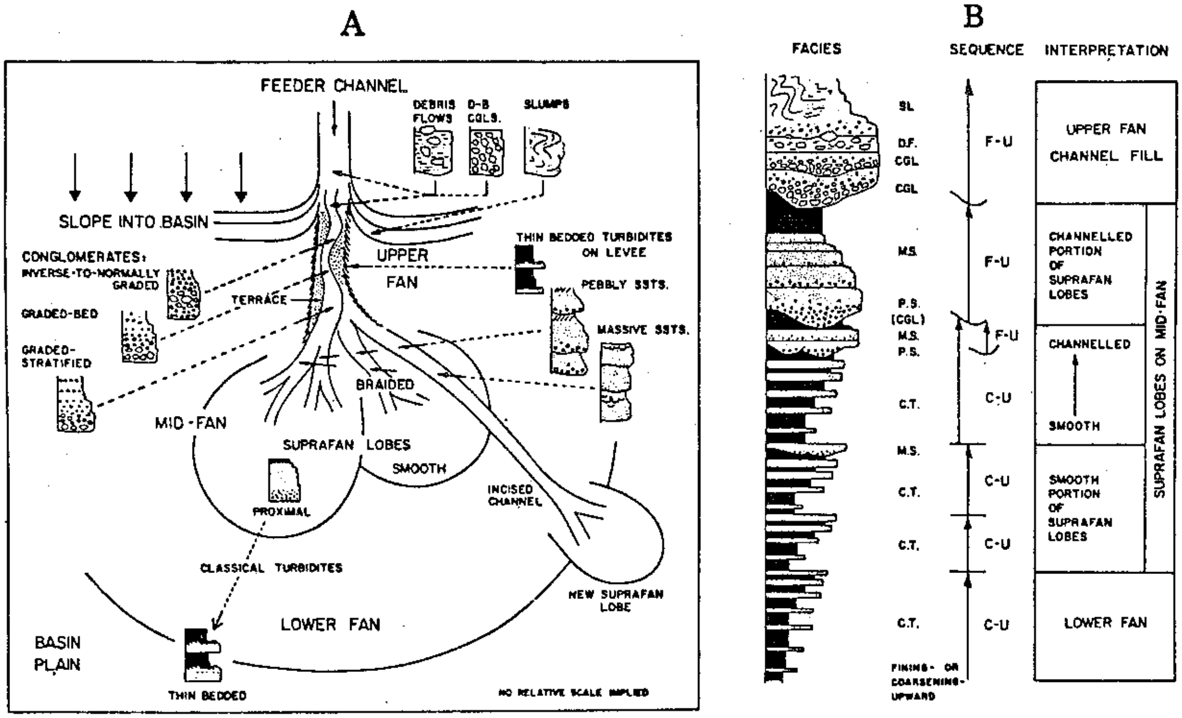


PLATE 22. A. SUBMARINE-FAN MODEL AND ASSOCIATED TURBIDITE FACIES OF WALKER (1978). B. HYPOTHETICAL STRATIGRAPHIC SEQUENCE THAT COULD BE DEVELOPED DURING FAN PROGRADATION: C-U., represents thickening-and coarsening-upward sequence; F-U., represents thinning-and fining-upward sequence; C.T., classic turbidites; M.S., massive sandstones; P.S., pebbly sandstones; CGL, conglomerate; D.F., debris flows; SL., slumps; from Walker (1978).

STOP 21. — FLAT–LYING STANLEY SHALE AT RAILROAD CUT NORTH OF AMITY

This stop is along the Missouri Pacific Railraod tracks, about 1 mile northwest of Amity, in the Amity structural belt (Plate 2). Flat-lying subgraywackes or graywackes and black shales of the lower Stanley Shale are exposed near the center of a small syncline. At this outcrop and throughout most of the Amity belt the rocks are less deformed than those in the Hopper belt immediately to the north. The strata contain no readily apparent cleavage, shearing or other obvious indications of intense deformation. However, there is a suggestion of a thrust fault at the north end of the exposure, and indeed this syncline likely has been thrust "piggyback style" an unknown distance to the north.

The sandstone beds thicken and become coarser grained upward, then this trend is reversed and they become thinner and finer grained. They apparently represent the development and gradual abandonment of a lobe on an outer submarine fan (Plate 22). A few paleocurrent features (bottom marks) indicate a probable south to north direction of sediment transport. Several of the thicker sandstone intervals are good examples of nearly complete Bouma sequences (Plate 23). A few trace fossils are present, mostly in the thin sandstones; they are a further indication of a deep-water depositional environment.

The sand probably was derived from an island arc terrane to the south of the Ouachita trough. This source area yielded extensive "dirty" deltas and other shallow-water facies, volcaniclastic materials, and large, northerly directed, submarine fans. Some of the fine clastics in the distal fans then tailed westward down the axis of the Ouachita trough. Concurrently in the Arkoma basin to the north, there was little southward transport of clastic materials, other than clay, from the Ozark dome.

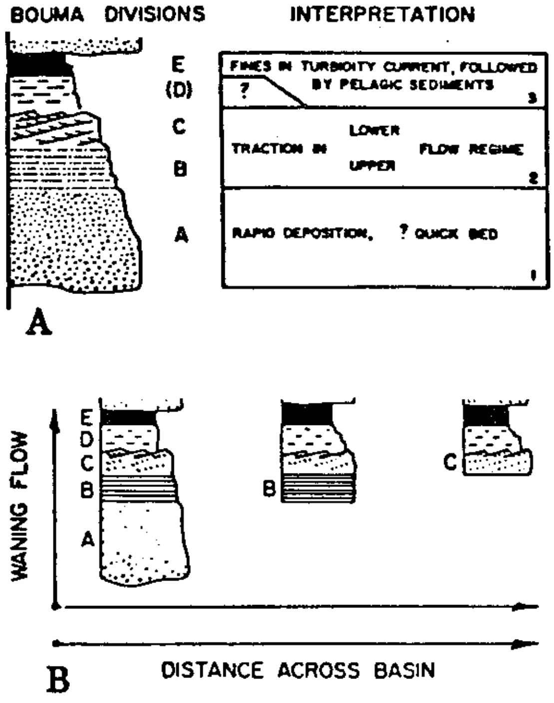


PLATE 23. A. BOUMA MODEL FOR CLASSIC TURBIDITES: division A is massive or graded, B is parallel laminated, C is rippled, D consists of faint laminations of silt and mud, and E is pelitic: after Walker (1978).

B. INTERPRETATION OF BOUMA SEQUENCE IN TERMS OF WANING FLOW: suggests that groups of turbidites beginning with divisions B and C represent deposition from progressively slower flows, presumably related to distance from source; after Walker (1978).

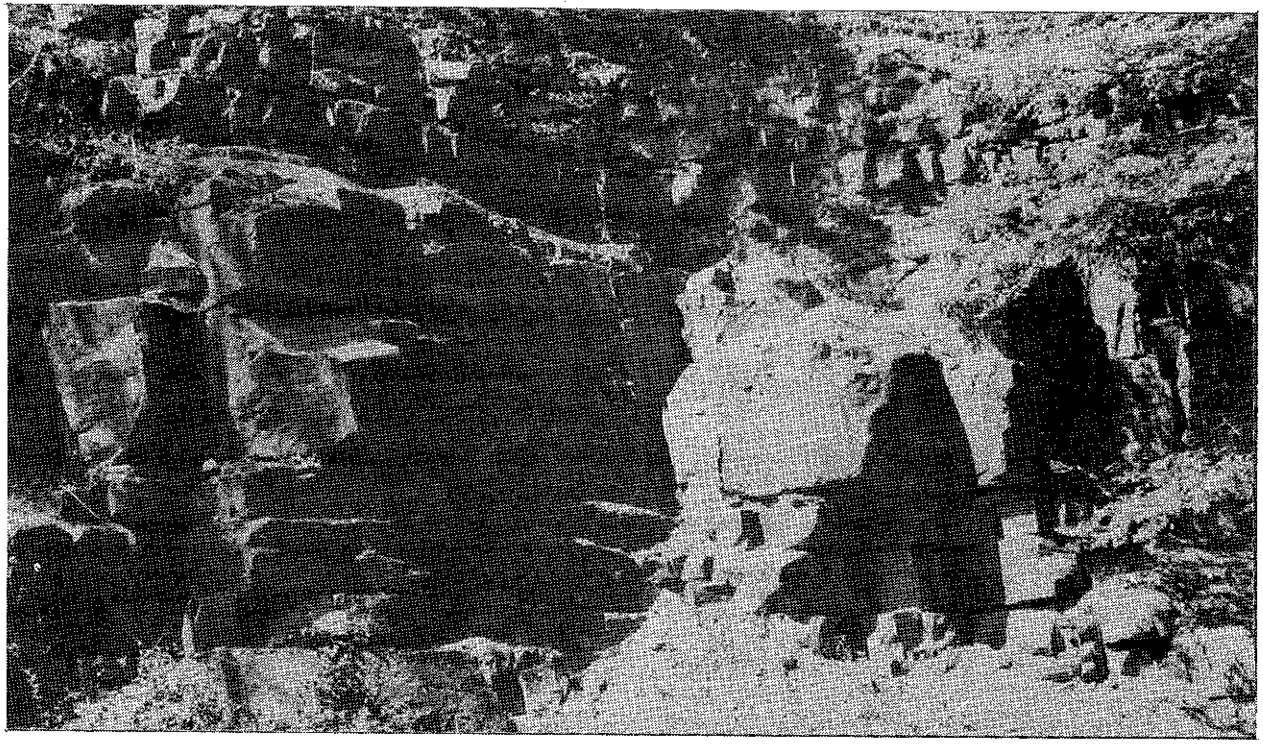


Figure 19. — Stop 21. Nearly flat-lying subgraywackes or graywackes and shales of the lower Stanley Shale along a Missouri Pacific Railroad cut northeast of Amity. The sandstone sequence thickens and coarsens upward, then reverses and thins and fines upward. It probably represents the development and gradual abandonment of a submarine lobe.

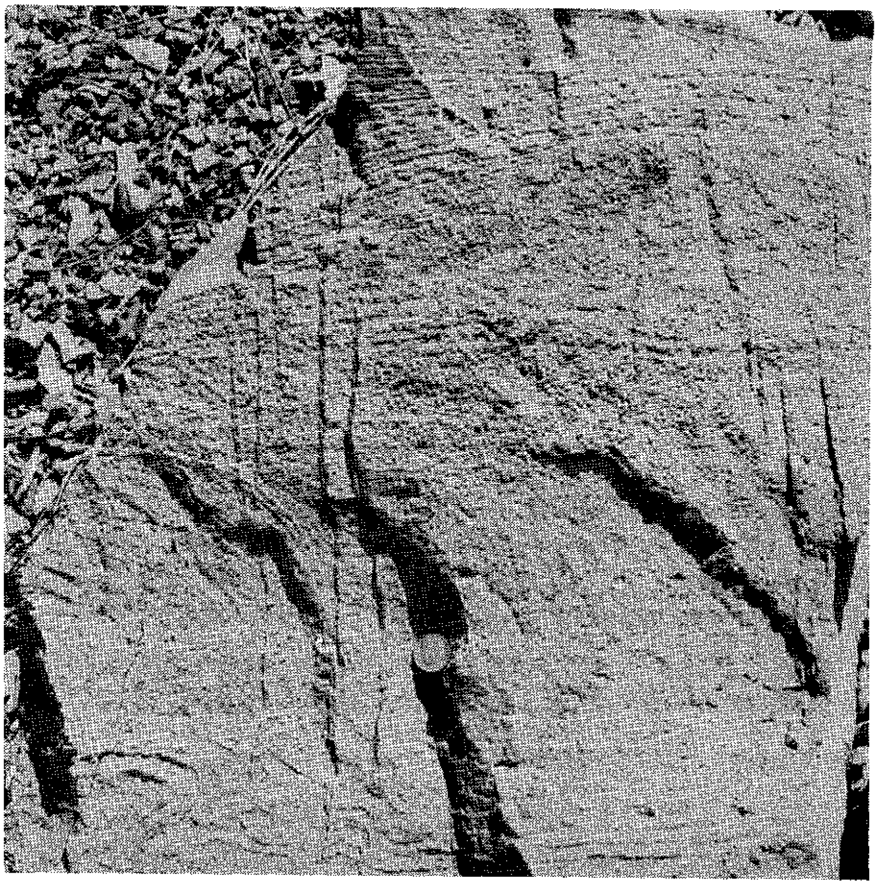


Figure 20. — Stop 21. Loose sandstone boulder viewed in inverted position, illustrating a nearly complete Bouma turbidite sequence. Convolute bedding with parabolic folds are present near the true top of the bed.

STOP 22. – FAULTED STANLEY SHALE WITH ASPHALTITE (BITUMEN) IN RAILROAD CUT NEAR ROSBORO

This intensely faulted and sheared sequence of brown graywacke and gray-black shale in the lower part of the Stanley is located along the Missouri Pacific Railroad tracks less than 1 mile west of Stop 21 and about 1½ miles southeast of Rosboro. During the late phases of tectonic deformation migrating fluid hydrocarbons probably occupied some openings in the fractured and sheared sandstones. These hydrocarbons are now preserved as small black splotches, veinlets and coatings of asphaltite (bitumen). Calcite, pyrite and other minerals may be associated with the asphaltite. A sample of a sandstone from this locality containing asphaltite, pyrite and calcite was analyzed as follows: gold – nil; silver – 0.0001%; lead – 0.002%; zinc – 0.004%; copper – 0.001%; cobalt – 0.001%; nickel – 0.003%; and vanadium – 0.007%. There has been no attempt to identify the variety of asphaltite or its basic constituents.

The rocks at this site are located on one of the lower thrust plates between the Arkansas Novaculite and the Jackfork Sandstone in the Amity structural belt (Plate 2). Although the rocks in the Amity belt are not highly deformed in most places, the convergence of several thrust faults and other less well-defined complexities in this immediate area have led to intense local deformation. There are exposures of Arkansas Novaculite about 1/5 of a mile to the east and exposures of the lower part of the Jackfork Sandstone about 1 ¼ miles to the west. This area has an obvious space problem in accommodating the thick sequence of Stanley Shale between the Novaculite and the Jackfork. There are many definitive units, including cherts, in the lower Stanley Shale, so that detailed mapping should allow the stratigraphic position of these rocks to be determined.

The presence of asphaltite at this outcrop and at many other scattered sites in the Ouachita Mountains proves that some hydrocarbons have been generated. The presence of several organic-rich Paleozoic formations further suggests that large volumes of fluid hydrocarbons may have been generated. However, little is known of their subsequent history. It is not known, for example, if large quantities escaped to the surface, or if most were subsequently destroyed by the heat generated during orogeny. It is not known if conditions exist in some parts of the Ouachitas suitable for the preservation of hydrocarbons in fluid form. What is known is that fluid hydrocarbons have not yet been found in significant quantities in the test holes that have been drilled in the Ouachita Mountains of Arkansas.

In the last few years three wells have been drilled for oil and gas in or near this area. The Sheraton Oil Corporation drilled two wildcat tests: one, the No. 1 Kyle in section 29, T. 4 S., R. 22 W., (Hot Spring County) was spudded in Stanley Shale and reached a total depth of 4545 feet; and another, the No. 1 Bean in section 15, T. 5 S., R. 23 W., (Clark County) was spudded in Stanley Shale and abandoned at 2902 feet. The Shell Oil Company drilled a well in the Trap Mountains, about 25 miles to the east, in section 21, T. 4 S., R. 20 W., (Hot Spring County) that began in the Blaylock Sandstone and bottomed at a total depth of 7868 feet. These tests were reported as dry holes and little information has been made available on them.

Stop 21. — Stop 22. Faulted and sheared interbedded subgraywackes or graywackes and shales of the lower Stanley Shale in a Missouri Pacific Railroad cut southeast of Rosboro. These rocks contain abundant veinlets and splotchy coatings of asphaltite (bitumen).

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SUMMARY OF THE GEOLOGY OF THE CENTRAL AND SOUTHERN OUACHITA MOUNTAINS, ARKANSAS

By

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Revised from Arkansas Geological Commission Information Circular 29, 1984

PHYSIOGRAPHY

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

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

GENERAL GEOLOGY

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

The uplift produced prominent east-west folds and large thrust faults in the strata. Almost without exception the present land forms are a reflection of the underlying bedrock. The softer less resistant shale, limestone and impure sandstone are more susceptible to

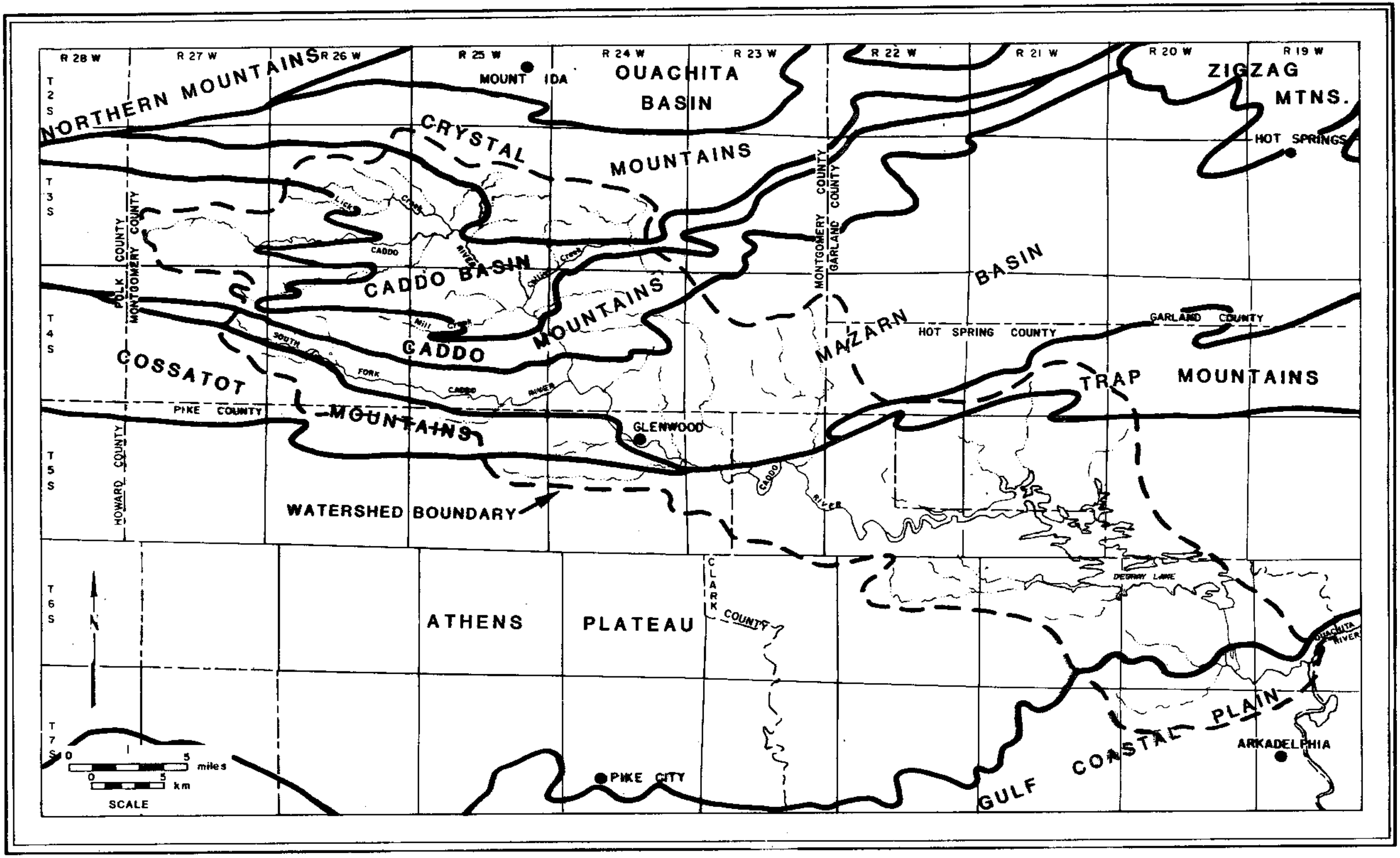

FIGURE 1. PHYSIOGRAPHIC SUBDIVISIONS OF PORTIONS OF THE SOUTHERN AND CENTRAL OUACHITA MOUNTAINS,ARKANSAS

erosion and form most of the basins, valley floors, and lower hills. The harder more resistant novaculite, chert, and relatively pure sandstone form the mountains, ridges and peaks.

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

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

FORMATION DESCRIPTIONS

Based on their lithologic character, stratigraphic position, and meager fossil content, 14 formations of the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian are defined in the area (see Plates 3, 4 and 5.

Collier Shale

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

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

Crystal Mountain Sandstone

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

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

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

Sandstone.

Mazarn Shale

The Mazarn Shale was named from Mazarn Creek northeast of Norman, Arkansas in the Crystal Mountains by Miser (1917) and later mapped by Miser and Purdue (1929). The Mazarn has a total thickness of about 3000 feet and consists mostly of black shale with some interbedded olive-green shale and silty shale, thinly laminated gray siltstone, brown quartzose sandstone, and dense blue-gray limestone. The alternating black and olive-green shale layers, often with cross-cutting cleavage, give it a banded appearance. Worm burrows and other trace fossils occur in the siltstones, and some conodonts and graptolites are found in the limestones and shales. The Mazarn typically forms fairly broad valleys with some noticeable low ridges. There have been minor quantities of commercial slate and also shale for rural road construction obtained from small pits and quarries in the Mazarn. Some of the limestone intervals could have potential for agricultural purposes.

Blakely Sandstone

The Blakely Sandstone was named from Blakely Mountain north of Hot Springs by Miser (1917) and later mapped by Purdue and Miser (1923). It ranges from 400 to 700 feet in thickness and consists of interbedded thin to fairly massive, fine to medium-grained, sometimes silty or calcareous, quartzose brownish gray sandstones and black to green shales. A gray sandy limestone occurs in places in the upper part of the Blakely and a shale sequence ranging in thickness from 100 to 200 feet is near the middle. Graptolite impressions are present in some of the shales. The Blakely forms high ridges with small, narrow intervening valleys. Small amounts of quartz crystal have been mined at a few localities near Norman from veins dissecting the sandstone. The massive or thicker packets of sandstones are suitable for rock aggregate.

Womble Shale

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

Bigfork Chert

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

Polk Creek Shale

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

Blaylock Sandstone

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

Missouri Mountain Shale

The Missouri Mountain Shale was named by Purdue (1909) for exposures in the Missouri Mountains. The Missouri Mountain Shale lies between the Arkansas Novaculite and the Blaylock Sandstone or when the Blaylock is absent the Polk Creek Shale. It is typically a red, green or buff shale or slate with minor novaculite and sandy conglomerate layers. It generally is poorly exposed and forms narrow valleys or slopes. The Missouri Mountain is about 50 feet thick in the south, reaches a maximum of 300 feet in the west-central part, and is between 175 and 200 feet along the east-central portions of the area. It has previously been quarried for ornamental red, green, olive and buff colored slates in the northwestern part of the area.

Arkansas Novaculite

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

Stanley Shale

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

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

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

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

Jackfork Sandstone

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

The Jackfork Sandstone of Early Pennsylvanian age has a total thickness of about 6000 feet along the southern part of the Athens Plateau. Approximately the lower 2500 feet of the Jackfork Sandstone is exposed in the Pigeon Roost Mountain area of the Mazarn Basin.

The Jackfork is composed of thin to massive, light-brown, fine-grained, quartzitic gray sandstone, blue-black to brown siltstone and interbedded gray-black shale. Some of the sandstones contain a few thin conglomeratic layers with pebbles that consist of rounded chert and metaquartzite. Many of the siltstones contain coalified plant fragments. A few intervebrate fossil fragments and molds occur in the sandstone and conglomerate beds. The massive sandstones are fairly resistant to weathering and typically form ridges with many rock exposures. Deposits of mercury occur in veins in the Stanley Shale and Jackfork Sandstone in the southwest portions of the area. Massive sandstone intervals in the Jackfork are worked sporadically for commercial aggregate at a number of sites.

Johns Valley Shale

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

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

This formation is about 1500 feet thick and typically consists of gray-black clay shale and rather silty thin to massive brownish-gray sandstone. Some ironstone concretions are dispersed through the shales. Rather chaotic sandstone-shale intervals are present at places in the formation. A few invertebrate fossils occur in a few lenticular siltstone masses that likely were deposited by submarine slumping from a southern source.

Atoka Formation

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

The Atoka contains about 7500 feet of thin to rather massive, fine to medium-grained subgraywacke (silty) sandstones and interbedded gray-black shales. There are chaotic intervals containing masses of sandstone, siltstone, iron carbonate concretions and possibly some erratics that suggest extensive slurries and slumps derived from submarine scarps generally to the south. A few conglomerates and calcareous sandstones contain a transported invertebrate mold fauna. The top of the Atoka is not exposed in the area and it is believed that about 15,000 to 20,000 feet were removed by subsequent erosion. Small quantities of road aggregate have been mined from the Atoka.

SEDIMENTARY HISTORY

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

The Paleozoic sedimentary rocks of the

Ouachita Mountains in Arkansas range in age from Early Ordovician to Middle Pennsylvanian and have an aggregate thickness in excess of 50,000 feet (See Plate No. 5). The stratigraphic sequence including the Early Ordovician age Collier Shale through the Early Mississippian age Hot Springs Sandstone Member at the base of the Stanley Shale is from 7500 to over 12,000 feet thick. The shales, micritic-arenitic limestones, siltstones, sandstones, cherts, novaculites and conglomerates of the sequence are considered proto-Ouachita bathyal platform or trough deposits that represent: 1) indigenous pelagic or hemipelagic deposits; 2) turbidity or bottom current-submarine fan and related deposits combined with episodes of slump and slurry detachments producing the included erratics; and 3) minor Devonian and other intrusives(?). With the exception of Silurian age Blaylock Sandstone which has a probable southeastern source, these rocks were all derived from "northerly" flanking shelf, slope and submarine ridge sources.

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

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

GENERAL STRUCTURE

The Paleozoic rocks that crop out in the area were involved in the various tectonic stages leading to the development of the Ouachita Mountains, mostly in the late Paleozoic times. The intensity of structural deformation in the Paleozoic rocks increases from south to north across the area at the surface. There are broad folds cut by numerous southward dipping thrust faults in the Pennsylvanian rocks in the southern Athens Plateau. In the central and northern Athens Plateau within the Mississippian Stanley Shale there are tight folds broken by both high-angle and near bedding plane thrust faults. Minor shearing occurs in some of the shales. The rocks in the Cossatot and Caddo Mountain ranges and the Mazarn Basin are very steep or even overturned, and locally exhibit some shearing. Thrust faults with displacements on individual plates varying from a few feet to many miles disrupt the strata. Small milky quartz veins fill fractures in some of the rocks. Strata in the Caddo Basin and the Crystal Mountains contain exceptionally complex folds (often recumbent) with several major low-angle decollements and many smaller thrust faults. These rocks are locally cut by sizeable quartz veins and a well-developed rock cleavage occurs in some shales.

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

STRUCTURAL HISTORY

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

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

In most previous investigations the deformed Paleozoic rocks of the Ouachita Mountains of Arkansas have been divided into three poorly defined structural parts; the "core area", the "frontal zone" or "frontal belt" to the north, and the "southern Ouachitas" or "southern belt" to the south. Through recent studies of the surface geology the area has been divided into seven generally east-west trending structural belts. Each belt is a unit having similar structural features and is a northward moving imbricately faulted thrust plate with a major sole fault. From north to south these belts are named Rover, Aly, Nixon, Avilla, Mt. Ida, Hopper and Amity. The Mount Ida, Nixon and Avilla belts include most of the older Paleozoic rocks and are the most intensely deformed (see Plate 2).

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

We conclude that (1) the Ouachita Mountains in Arkansas are allochthonous and formed by northward overriding imbricately faulted thrust plates with major sole faults; and (2) some thrust plates possibly involved Precambrian rocks in the subsurface; (3) the structural deformation likely narrowed the initial width of the Ouachita depositional basin by as much as 200 miles, and (4) a northward(?) dipping fossil Benioff subduction system was present to the south of the Ouachita Mountain outcrop likely south of the Sabine Uplift in northern Louisiana.

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A STRUCTURAL CROSS SECTION THROUGH THE OUACHITA MOUNTAINS OF WESTERN ARKANSAS

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INTRODUCTION

Regional cross sections across entire mountain ranges usually represent an author's attempt to depict in a general manner a synthesis of a set of geological and geophysical observations and interpretations with a geodynamic concept or model. The latter is often developed in other parts of the world and may be adapted to the new set of observational constraints. Scale restrictions of the illustrations enforce frequently severe generalizations which may lead to cartoon-like sections suffering from scale distortions, balancing problems and disregard of constraining data. Furthermore such "data" are quite often already interpretations (e. g. depth conversions of seismic data in areas of poor velocity control; or well bore picks of formation tops with indistinct lithologies and poor faunal control), the inviolate nature of which can be quite debatable. Thus, the person who undertakes the task of drawing regional crustal sections is confronted with a vast array of data, some of which are hard facts, many are soft facts of maybe only local significance or with a considerable margin of error; others may be first or second order interpretations of observations, and — not to be forgotten — myths or sacred cows often established by men of authority in the past.

Before he starts, the compiler has to establish a checklist of those facts, hard or soft, that he feels are valid enough to act as constraints that have to be honored in the construction. Such things as reliable surface maps, formation thicknesses, vertical distribution of ductile and competent units, depth to basal detachments in thrust belts, and many other geological and geophysical data sets are vital elements upon which a believable section is built. In a thrust belt like the Ouachita Mountains with its limited area of exposure, its paucity of drilling, and its uniqueness of lithology, there is still a large room left for speculation for many years to come.

OBSERVATIONAL CONSTRAINTS

The following is a tentative list of those facts and deduced facts which this author considers to have some constraining effect, both spatially and temporally, on the construction of a regional cross section. This paper cannot be the place to discuss all the strengths and weaknesses of these constraints or the real and conjectural consequences that they have on the construction. For the time being, this has to remain a list with a few hints here and there at effects and validity.

1. **Stratigraphic constraints of the pre-Carboniferous**
   (a) The abrupt appearance of the deep water Ouachita facies (not necessarily abyssal) containing radiolarian cherts and turbidite fan complexes in a sequence dominated by shale south of the Ti Valley - Y City fault has long been recognized.
   (b) The lack of an observable migeo-

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[1] The writer wishes to thank Shell Oil Company for permission to publish the figures accompanying this article.

clinal wedge of platform rock on the adjacent craton and in the frontal elements of the thrust belt is suggested by a few wells and by inference from seismic data.

(c) There is some, but not universal, lithologic and faunal correlation of units between foreland and Ouachita rocks indicating that the latter are a North American rather than an entirely foreign element.

(d) The Ouachita facies contains some organic-rich source rocks hinting at temporary stagnating conditions of depositional environment.

(e) Several olistostromal units occur in the Ouachita facies section with clasts of foreland and unknown provenances.

(f) There is no indisputable evidence for a southern basin slope in the outcrops. Coeval rocks south of the outcrops of the Broken Bow - Benton uplift have not been encountered by the drill.

2. **Stratigraphic constraints of the Carboniferous sequence**

(a) In early Mississippian time a sudden massive influx of clastic rocks occurred resulting in a flysch sequence of deep-water shales and massive turbidite fan complexes of Mississippian, Morrowan and Atokan age have a combined thickness of some twelve kilometers.

(b) Dispersal is basically parallel to the mountain range from E to W indicating a wide trough topographically confined on the N and S sides.

(c) The northernmost occurrences of Mississippian and Morrowan flysch are in an allochthonous position south of the Ti Valley - Y City fault conformably overlain by Atokan flysch. On the other hand the Atokan flysch extends northward into the Arkoma basin where it rests conformably on foreland facies and which, in turn, rest on subsided continental crust. The flysch trough thus migrated northward without any indication of an orogenic event.

(d) Basement controlled growth faults starting in Late Mississippian time and continuing through Atokan time were in part responsible for the transition of shallow water facies on the north side of the Arkoma basin to deep-water facies on the south side. Maximum thickness of the Atokan flysch at the southeastern end of the Arkoma basin reaches six kilometers.

(e) Olistostromes of almost exclusively platform facies olistoliths and numerous soft sediment and consolidated intraclasts are present in the Carboniferous flysch, particularly in the Morrow (e. g. Johns Valley Shale).

(f) Volcaniclastic tuffs occur in the southernmost exposures of the Mississippian flysch (e. g. Hatton tuff).

3. **Structural constraints**

(a) Regional angular unconformities are not recognizable in the entire Ouachita facies sequence from Early Ordovician to late Atokan (in spite of a fairly well documented metamorphic event of Devonian age in the Ordovician rocks of the Broken Bow - Benton uplift).

(b) The earliest known angular unconformity is observed in the subsurface of southern Arkansas, where shallow marine Desmoinesian successor basin sediments overlie folded and faulted Carboniferous flysch. In the Arkoma basin however, shallow marine and deltaic Desmonesian rocks rest conformably on upper Atokan rocks and are folded with their substrate.

(c) Earliest appearance of Ouachita facies detritus occurs in the Desmonesian rocks of the Ardmore (Devils Kitchen Fm.) and Fort Worth foreland basins.

(d) Thrusting and folding north and south of the Broken Bow - Benton uplift display northward and northwestward vergence, i. e. towards the craton, with a typically southward descending detachment and an orderly succession from autochthony to mild folding and to imbricated thrusting and overthrusting from north to south.

(e) A continental basement reflector descending to about 9 kilometers is observable on COCORP and proprietary seismic records and extends southward at least to the north side of the Broken Bow - Benton uplift.

(f) The vertical distribution of ductile and competent rocks in the Ouachita facies (i. e. essentially ductile from Ordovician to Mississippian, competent in the thick turbidite fan complexes of Morrowan and Atokan) has resulted in a structural style that differs greatly from the typical miogeoclinal thrust and fold belts of the Appalachians or the eastern Cordillera. Thus we see in the Ouachitas a relatively simple, orderly thrusting and flexural folding style at the top of the sequence and a highly nervous, complex, disharmonic style of short wavelength folds and narrowly spaced thrusts at the base.

(g) Distinct sutural boundaries typical of terrane accretion cannot be recognized.

(h) In addition to the general constraints listed above, the central uplifts (Broken Bow - Benton) display a separate set of characteristics unique to these uplifts:

(h_1) The uplifts cross cut the general trend of the Ouachita Mountains obliquely from southern Oklahoma to near Little Rock.

(h_2) From north to south folds pass from north vergence in the adjacent areas through an upright position to a general south vergence over the uplifts. They are accompanied by a pervasive north-dipping cleavage.

(h_3) Numerous north-dipping faults on the uplifts are upthrown on the south (i. e. they display normal fault geometries with younger beds on the hanging walls). In the transition zones on the north and south borders of the uplifts it can be observed that north-vergent thrusts pass through a vertical to an overturned "normal" fault attitude (e. g. Caddo Gap), indicating a second phase overturning of a formerly north-vergent system.

(h_4) The rocks on the uplifts display a mild greenschist facies metamorphism, a conversion of cherts into novaculite, a pervasive invasion by quartz veins, often into large open fractures, and a late Carboniferous to Permian radiometric overprinting of an earlier Devonian thermal event.

(h_5) The uplifts appear on seismic lines as giant antiforms both in the Ouachita Mountains and in their southern extension into Texas. This southward continuation is confirmed in part by the similarity of their gravity signature. In Texas, drilling of these antiforms has encountered highly contorted carbonates overlying crystalline basement and overlain by Ouachita flysch facies. On the basis of radiometric data, lithologic similarity, and subsurface proximity these carbonates were interpreted to be foreland facies Cambro-Ordovician rocks that had been overridden by Ouachita thrust sheets (Nicholas and

Rozondal, 1975).

PREVIOUS REGIONAL SECTIONS

Over the past six decades, a number of authors have published regional structural sections across all or part of the Ouachita Mountains to express their interpretation of the architecture of this mountain range. These sections display well the gradual growth of information that has put an increasing number of constraints – as well as credibility – on the interpretations.

The earliest scaled regional sections by Powers (1928) and Miser (1929, 1934) show that the general north vergence of the thrust belt was well recognized. While Powers' interpretation clearly hints at the presence (and necessity) of a common basal detachment, Miser's sections display the concept of at least a two story structural style, i. e. a relatively simple style of thrusting and folding in the post-Mississippian rocks versus a more tightly folded and thrusted style in the pre-Mississippian section. They also show Miser's perception of an unfaulted section in Arkansas with south vergence in the Benton uplift and north vergence both to the north and south of the uplift. Hendricks' et al., (1947) partial regional sections of the Oklahoma salient give a cross sectional interpretation of their map, and also portrayed their solution of the provenance of platform facies olistoliths in the Carboniferous by an early south-vergent major thrust (the "Powers fault") bringing platform rocks closer to the depositional realm of the Ouachita facies flysch. This concept did not find general acceptance and a committee under Hendricks (Tulsa Geol. Soc., 1951) published a generalized section showing the entire Ouachita region to be detached from an autochthonous crust covered by Arbuckle foreland facies. King (1959) also modified Hendricks' sections by omitting the conceptual "Powers fault".

Industry drilling and seismic exploration in the 1950's and 1960's documented the detached nature of the shallow folding in the Arkoma basin and of the frontal imbricated belt of the Ouachita Mountains. These observations were incorporated on regional structural sections by Berry (in Berry and Trumbly, 1968) and by Bucher et al., (in Hopkins, 1968). While Bucher's section shows a folded basement beneath the entire Ouachita Mountains (a concept later refuted by seismic control north of the central uplift, but confirmed beneath the uplift), he also suggests that the south vergence of the rocks exposed on the Broken Bow uplift could be a relatively thin-skinned phenomenon.

The theories of plate and gravity tectonics started to have their impact on structural interpretations in the 1960's. Viele (1966, 1973, 1979) proposed a series of evolving models of subduction and gravity spreading of a highly ductile style, while Roeder (in Wickham et al., 1976) presented a subduction model of multiple thrust sheets over a flat, uninvolved south-dipping basement. In this model the south vergence of the central uplift is shown as a late phase underthrusting ("retrocarriage") of an earlier north-vergent thrust pile. Wickham (1977) modified Roeder's interpretation by proposing an internally mild shortening of the Ouachita allochthon that overrides a somewhat imbricated foreland basement. His interpretation suggests that the Broken Bow uplift (not fully shown on his section) is the result of a duplex-like imbrication of the basement. The largest scale section across the Arkoma basin and Ouachita Mountains of western Arkansas (1:125,000) was published by Haley, Stone, and Bush (in Bush et al., 1977). Their Arkoma section deals primarily with the stratigraphic relationships and is therefore vertically exaggerated, while the Ouachita portion confines itself to a surface trace of formation boundaries, faults and bed attitudes with little interpretation at depth.

The results of a recently completed COCORP seismic reflection survey across the Ouachita Mountains in western Arkansas have been presented and interpreted by Nelson et al., (1982) and Lillie et al., (1983). Their preferred interpretation (of several alternatives presented) includes also the results of previously published gravity, magnetic and seismic refraction studies and reconfirms the existence of a south-dipping, normal-faulted foreland basement north of the Benton uplift, and suggests a north-vergent basement duplex beneath the Benton uplift and a thinner, attenuated or transitional crust south of the Benton uplift not unlike the model proposed by Nicholas and Rozendal (1975).

PRESENT INTERPRETATION

The cross section (Fig. 1) represents an attempt to combine the basic information and concepts contained in the publications of Bush et al., (1977) with that of Nelson et al., (1982) and Lillie et al., (1983) together with an interpretation of seismic data at the southern end beneath the Gulf Coastal Plain. The surface trace and outcrop data are those of Haley, Stone, and Bush et al., in Bush et al., (1977). The section depicts a subduction model of a northward progressing thrust front with a main subduction zone well to the south of the illustration. The Benton uplift is interpreted to be a late orogenic duplex structure, with one or more basement imbrications separated by blind thrusts, near the margin of the unattenuated continental crust of southern North America. The south vergence of the Paleozoics on the Benton uplift is shown to be a thin-skinned feature caused by the emplacement of the duplex structure into the very ductile strata of the pre-Morrowan. The Morrowan and Atokan turbidite fan complexes are envisioned to have formed a stiff lid (now eroded) above the ductile section, unable to move northward as easily as the underlying duplex and thus generating a south-directed simple shear of under thrusting, not unlike that of the triangle zones at the front of thrust belts. This relative southward transport over the duplex not only affected bedded strata to form south-overturned folds, but also reversed the attitude of pre-existing north-vergent recumbent and isoclinal fault geometries. Because of ductility contrasts in the overall ductile pre-Morrowan section (e.g. shales vs. cherts and sandstones) local outcrop structures unquestionably are much more complex than the schematic patterns shown on the cross section.

The postulated sequence of orogenic events leading to this cross section may be summarized as follows. The earliest, spatially and geometrically as yet undocumented event, occurred in Early Mississippian time with the southern confinement of the flysch basin and the initiation of an enormous influx of clastics from eastern and southeastern source terranes. Conformity of the flysch sequence through Atokan time indicates that a deformation front did not reach the region depicted on the cross section until late Atoka time. A north-vergent thrusting and folding period, followed (or accompanied) by uplift and erosion reached the southern Ouachita Mountains (southern Arkansas subsurface) by late Atokan, where Desmoinesian shallow marine rock truncate folded and thrusted Atokan flysch with angular unconformity, while the Atokan flysch basin had migrated northward onto the craton into the southern Arkoma basin. By early Desmoinesian time the foredeep axis had migrated northward into the Arkoma basin, flysch deposition had ceased after filling the late Atokan seaway, and Desmoinesian delta systems prograded westward along the general axis of the Arkoma basin, indicating that the thrust front had reached a position of the central Ouachita Mountains forming a mild topographic divide between the foredeep and the southern successor basin. By mid or late Desmoinesian time the deformation front reached the Arkoma basin forming approximately the present boundary of the foldbelt and shedding detritus of Ouachita facies into foreland basins (Fig. 2 A). In late Pennsylvanian and/or Permian time, the final collisional subduction created the basement duplex of the Benton - Broken Bow uplift (Fig. 2 B), accompanied by massive invasion of quartz veins and mild metamorphism. Such a late orogenic basement duplexing beneath earlier thrust complexes is suggested to have also occurred in the northern Appalachians (Nelson et al., 1982) and in the Alps (e. g. Hsu, 1979).

By Late Permian and Triassic time the hinterland of the Ouachita Mountains became involved in the rifting and attenuation events leading to the opening of the Gulf of Mexico. These stretching and subsidence phenomena unquestionably modified further the crustal configuration beneath the Mesozoic or the Gulf Coastal Plain making the resolution of the pre-Mesozoic history a very difficult, if not impossible task.

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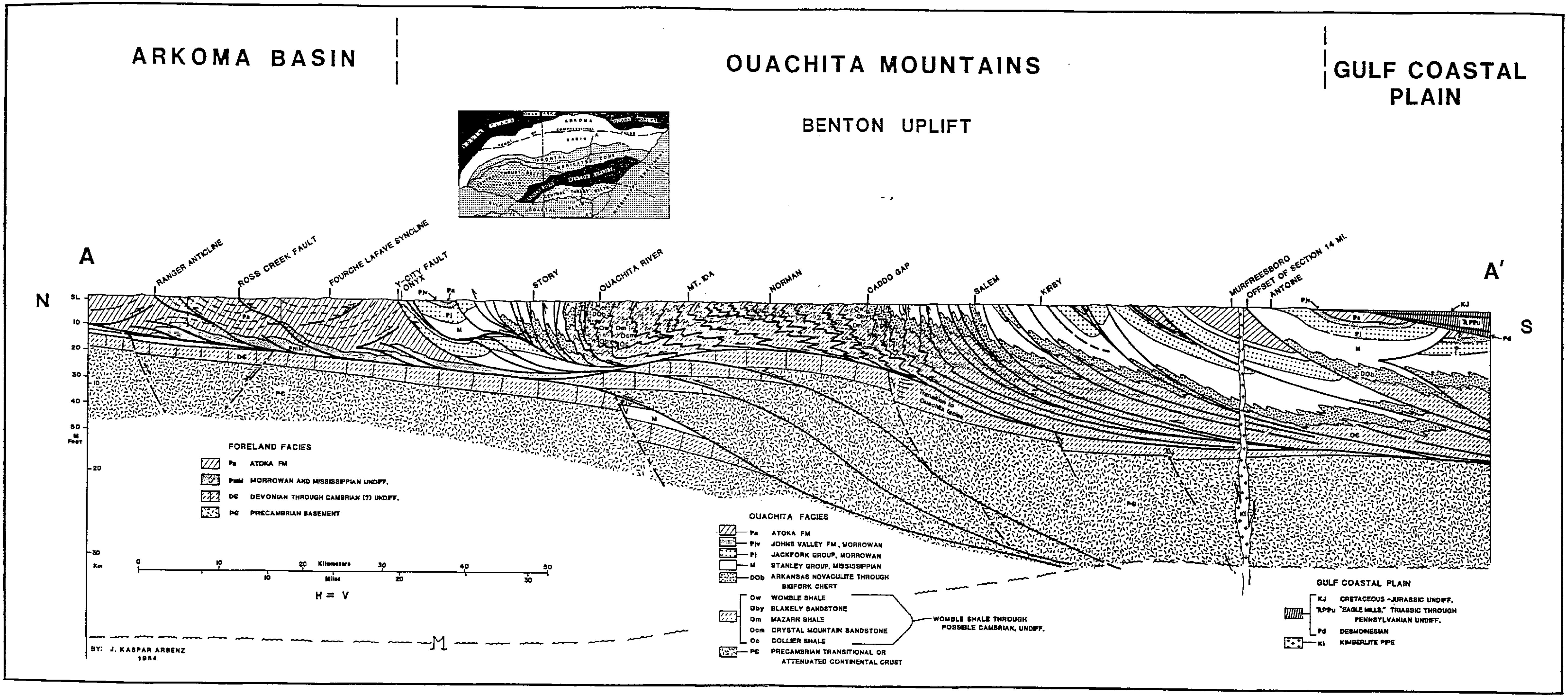

FIGURE 1. STRUCTURAL CROSS SECTION THROUGH THE OUACHITA MOUNTAINS OF WESTERN ARKANSAS

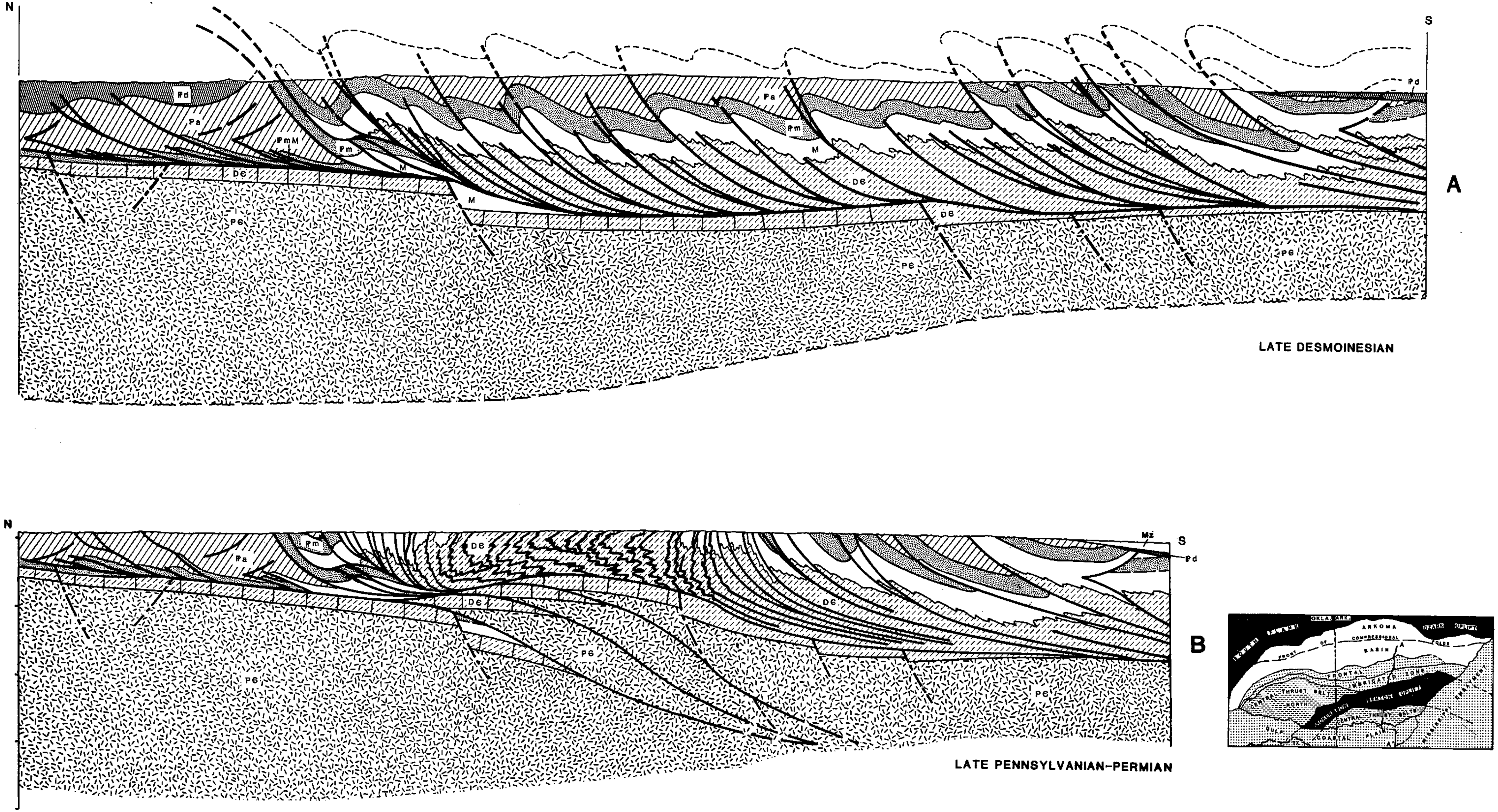

FIGURE 2. SCHEMATIC SECTION OF THE TWO MAIN DEFORMATIONAL PHASES OF THE OUACHITA MOUNTAINS

A. LATE DESMOINESIAN

B. LATE PENNSYLVANIAN–PERMIAN

*REFER TO FIGURE 1

CRENULATED AND STYLOLITIC BIGFORK CHERT WITH NEARLY HORIZONTAL CLEAVAGE
LAKE OUACHITA GEOFLOAT
PHOTOGRAPH BY JOHN D. McFARLAND, III

COCORP REFLECTION PROFILES ACROSS THE OUACHITA MOUNTAINS

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Note: The following brief report is reproduced from **Seismic Expression of Structural Styles, Amer. Assoc. Petrol. Geol., Stud. in Geol. Ser. 15, Vol. 3**, edited by A. W. Bally, page 3.1.4.83 - 3.1.4.87, 1983. Because of space limitations, the actual seismic profiles are not reproduced. The reader is referred to the original publication as well as to Lillie et al. (1983) for the actual profiles and to Kaufman (1982) for details on obtaining displays and computer tapes of the data. Figure 3 is extracted from Lillie et al. (1983) because it includes alternative interpretations of the profiles. More recent papers which contain discussions of the COCORP Ouachita profiles have been added to the reference list (Ando et al., 1984; Brewer, 1984; Lillie, 1984a,b). Permission from the American Association of Petroleum Geologists to reproduce this material is greatly appreciated.

In 1981, the Consortium for Continental Reflection Profiling (COCORP) recorded approximately 200 km (124 mi) of deep seismic reflection profiles across the Ouachita Mountains in western Arkansas. The late Paleozoic Ouachita orogenic belt forms a sinuous pattern across the south-central United States, stretching from central Mississippi to west Texas (Flawn, 1961). Paleozoic strata at the core of the belt are exposed only in the Ouachita Mountains of Arkansas and Oklahoma, and in the Marathon Mountains of West Texas (Fig. 1). Borehole and geophysical data demonstrate that the remainder of the belt is buried beneath Mesozoic and Cenozoic strata of the Gulf Coastal Plain. Many recent workers (Briggs and Roeder, 1975; Viele, 1979; Walper, 1977) interpreted the Ouachita belt as the remnants of a collisional orogeny in which an exotic terrane ("Llanoria") was sutured to the North American continent in late Paleozoic time.

The COCORP data discussed in this report are from the upper 8.5 secs of the north-south dip lines (that is, a composite of lines 1 and 3 shown on Figure 2). Detailed interpretations, emphasizing regional geological and geophysical constraints, are found in Nelson et al. (1982) and Lillie et al. (1983). A brief discussion of gross structural features interpreted from the data is presented here. The line drawing (Fig. 3a) schematically portrays prominent events observed on the unmigrated time sections for lines 1 and 3. Figure 3b is a preferred interpretation of the data in which tectonically thickened Paleozoic sediments (and metasediments) overlie crust of North American affinity. Alternative interpretations (Figs. 3c, 3d) in which crust exotic to North America extends as far north as the southern Ouachitas or the Benton Uplift, are discussed in Nelson et al. (1982) and Lillie et al. (1983). Major structural boundaries are shown in their approximate

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migrated time positions in Fig. 3b. The approximate depth scales assume that 1.0 sec of two-way traveltime represents 2.5 km (or 8,000 ft) of section. Note, however, that depth conversions given below utilize stacking velocity functions and may differ from these approximations.

The seismic lines on the north end of the survey cross the Frontal Thrust Zone, which is a foreland fold and thrust belt related to the Carboniferous Ouachita orogeny (Viele, 1979). Well data near the northern parts of the survey suggest that prominent reflections beneath the north end of line 1 represent the top of thin platform carbonates known to floor the Arkoma basin (events at 3.0 secs beneath VP 200). These lower-to-middle Paleozoic "Arbuckle facies" rocks are shown by the reflection data to continue their southward dip to at least VP 300 on line 1, where they appear to be offset by one or more normal faults. Analogous offsets beneath the Arkoma basin to the north are documented by Buchanan and Johnson (1968). Farther south, less prominent events are interpreted to represent the subsurface continuation of the carbonates to the end of line 1 and the beginning of line 3. As the carbonates were deposited on North American crust, the reflection data indicate that the mid-Paleozoic craton (or south-facing shelf) of North America extends southward in the subsurface to at least the northernmost portion of line 3.

Above the carbonates a Carboniferous flysch sequence, cut by numerous north-verging thrusts, thickens dramatically southward within the Frontal Thrust Zone (Berry and Trumbly, 1968). The wedge-shaped zone of prominent reflections in the upper few seconds of the seismic sections demonstrates that the flysch is at least 12 km (40,000 ft) thick in the southern parts of the Frontal Zone (that is, the wedge thickens to about 4.5 secs beneath VP 100 on line 3). Geometry in this zone indicates broad folds and truncated interfaces within the flysch wedge which can be closely related to surface geology. Beneath VP 340 to 370 on line 1, a series of thrust faults are mapped at the surface (Haley et al., 1976). These correlate with a series of fairly steep, south-dipping reflections which flatten out with depth. Other prominent, but more gently south-dipping events extend for several kilometers beneath the thrusts. Apparently, major north-verging thrusts within the more interior parts of the Frontal Thrust Zone are listric at depth, analogous to those in the subsurface to the north noted by Berry and Trumbly (1968).

Because no apparent reverse offsets of the lower-to-middle Paleozoic carbonate sequence are observed within the northern and central parts of the Frontal Thrust Zone, a major detachment is inferred to lie above these rocks. Above the detachment the Carboniferous flysch is deformed into a series of folds cut by north-vergent thrusts. A thrust fault apparently ramped up along the normal fault offset occurring beneath VP 300 on line 1, forming a hanging-wall anticline within the overlying flysch sequence. Because north-verging thrusts are exposed north of the survey, detachments at some level must continue beyond this structure.

South of the Frontal Thrust Zone reflection quality deteriorates, due at least in part to rugged terrain and rapid changes in near-surface velocity. The paucity of prominent reflections in the upper few seconds of the sections, however, may also be related to intense deformation of the Paleozoic sedimentary sequences in the subsurface beneath the Maumelle Chaotic Zone and the north flank of the Benton Uplift. Structures indicative of polyphase deformation have been observed at the surface in these areas (Viele, 1974). Though these features are beyond the resolution of the reflection data, structural complexity

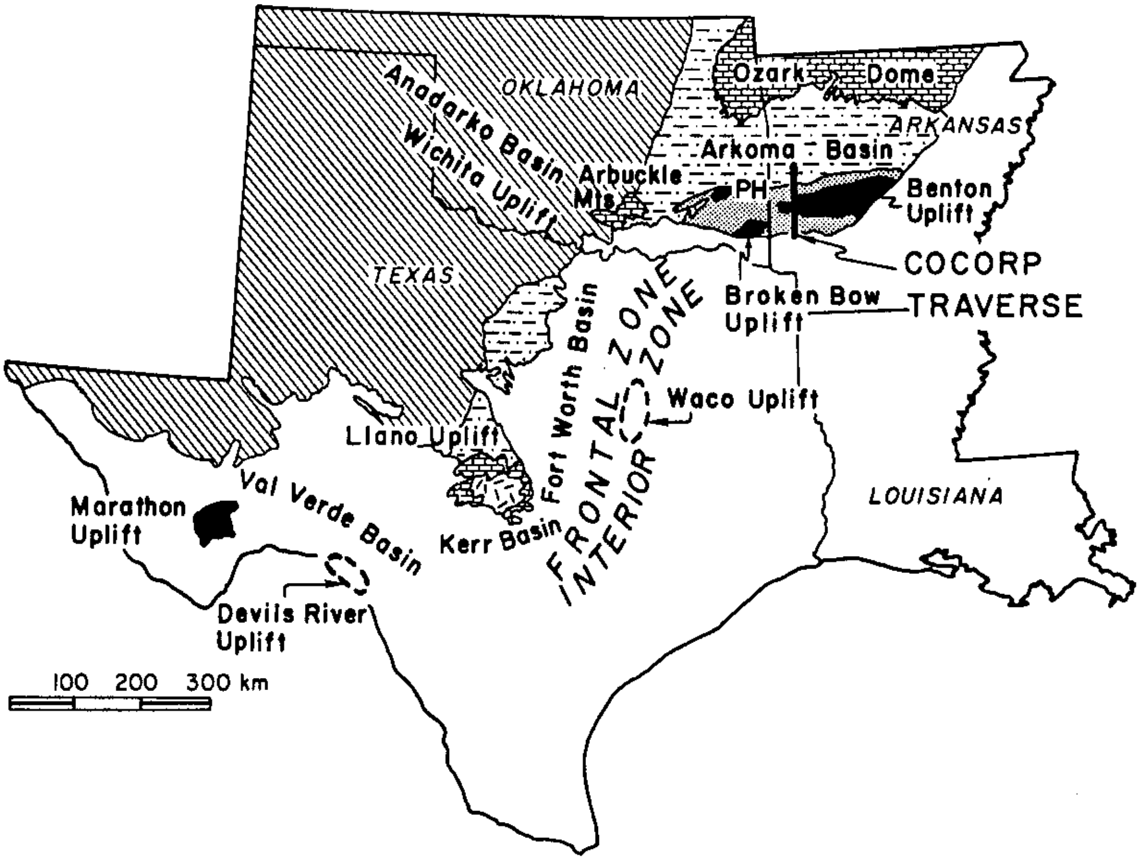

Figure 1.—Generalized geologic map of south-central United States showing the approximate location of the COCORP traverse across the Ouachita Mountains in western Arkansas. The late Paleozoic Ouachita orogenic belt extends in the subsurface around the Llano Uplift in central Texas, connecting the Marathon Uplift to the Devils River, Waco, Broken Bow, and Benton Uplifts. Parts of the belt can also be traced beneath Mesozoic and Cenozoic cover into southeastern Arkansas and central Mississippi.

within the upper few kilometers of Carboniferous flysch and lower-to-middle Paleozoic deep-marine strata exposed in these areas is schematically shown on the cross section (Nelson et al., 1982).

Below this deformed zone, a lineup of low-amplitude, north-dipping reflection segments is observed (Figure 3a). These rise from about 4.0 secs (11 km; 36,000 ft) beneath VP 380 to about 2.8 secs (7 km; 23,000 ft) beneath VP 550, where they appear to flatten out across the mapped center of the Benton Uplift. Farther to the south (2.8 secs at VP 750), events at this level gradually curve into south-dipping reflections. The Benton Uplift is therefore a surface anticlinorial feature (Figure 2) which displays a broad antiformal structure at depth on the unmigrated (and migrated) seismic section.

Without subcrop data from the Benton Uplift, it is not possible to make an unequivocal interpretation of the subsurface antiform. However, analogy with similar structures that were drilled along the Ouachita trend in Texas suggests the interpretation shown in Figure 3b. Like the Benton Uplift, the Waco and Devils River Uplifts (Figure 1) have similar deep antiformal seismic

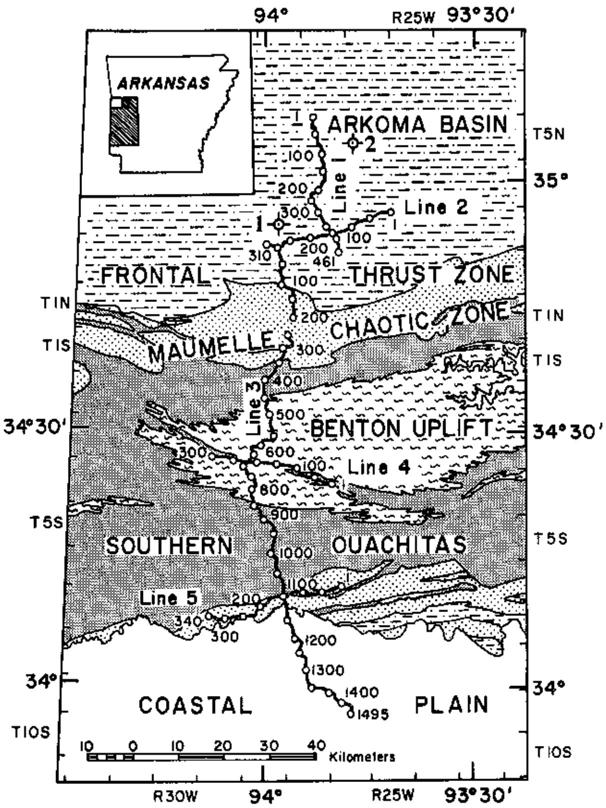

Figure 2.—Geologic map of west-central Arkansas (generalized from Haley et al., 1976) showing Vibrator Point (VP) locations along the COCORP seismic reflection lines. *Wavey Pattern:* lower-to-middle Paleozoic (Collier Shale through Arkansas Novaculite) deep marine sediments; *Fine Stipple:* Mississippian Stanley Shale; *Coarse Stipple:* Lower Pennsylvanian (Morrow) Jackfork and Johns Valley Formations; *Dash-Dot Pattern:* Lower-to-Middle Pennsylvanian (Atokan and younger) formations; *White:* Cretaceous and Cenozoic Gulf Coastal Plain onlap. *Exploratory Boreholes:* (1) El Paso No. 1 Cheesman, sec. 2, T3N, R28W; (2) Pacific No. 1 Garner, sec. 29, T5N, R26W.

expressions and lie on the same steep Bouguer gravity gradient. Nicholas and Rozendal (1975) suggested that crystalline basement rocks encountered beneath thin (metamorphosed) carbonate sequences in wells on the uplifts are of (late Precambrian) North American affinity. Most workers correlate the carbonates with strata which floor foreland basins to the northwest (for example, Lower Ordovician Ellenburger Dolomite). Hence, the mid-Paleozoic continental margin of North America is inferred to extend in the subsurface at least as far southeastward as the basement uplifts and coincident Ouachita gravity gradient.

In the interpretation shown in Figure 3b, the Benton Uplift is also cored by North American crystalline basement. The faint north-dipping events beneath the north flank of the feature are interpreted to represent the form of the lower-to-middle Paleozoic shelf carbonates (Arbuckle facies) as they continue southward in the subsurface. This interpretation requires that the lower-to-middle Paleozoic, deep-marine strata (Ouachita facies) exposed at the center of the Benton Uplift are allochthonous, since they now structurally overlie the coeval shelf strata. The decollement separating these two units is schematically shown to continue northward in the subsurface as a major detachment within the Carboniferous flysch. Arching of the basement and cover beneath the Benton Uplift is suggested to be due to movement along one or more deeper thrusts that actually cut into basement in this region. The deeper thrust zone is inferred to continue to the north as the lowest decollement surface within the Frontal Thrust Zone. Alternatively, the deep seated reverse offset may cut across earlier, higher thrusts and actually crop out within the Maumelle Zone (Figure 3c, 3d). At least one reverse fault with considerable stratigraphic throw is mapped in this region (Haley et al., 1976).

Reflections have pervasive south dips on the south side of the Benton Uplift. These project to the surface in zones of south-dipping lower-to-middle Paleozoic deep-marine strata cropping out on the Benton Uplift (Ouachita facies) and thrust imbricated

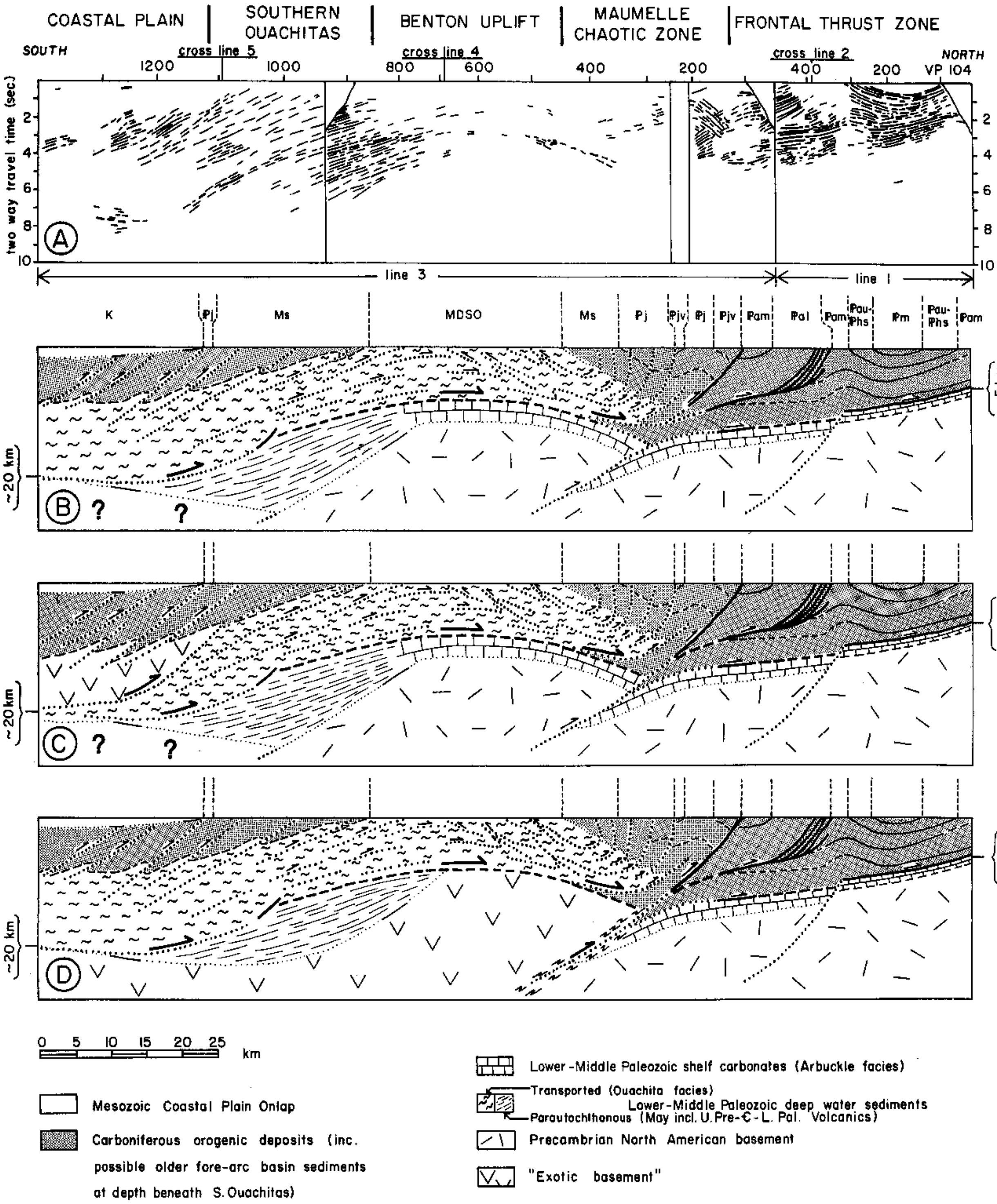

Figure 3. — A. Line drawing schematically showing major reflection events from COCORP lines 1 and 3. Section has no vertical exaggeration for seismic velocity of 5.0 km/sec (16,400 ft/sec). B. Suggested interpretation of A. Cross section uses same time scale depicted in A but incorporates geometric information from migrated time sections. Heavy lines = faults; thin lines = stratigraphic contacts. (Solid lines: interpretation consistent with surface and/or well data; dashed lines: geometry consistent with seismic reflection data; dotted lines: generalized structure consistent with regional geology). Depths represent approximate conversions using stacking velocities. Formation symbols from Haley et al. (1976).

C. Alternative interpretation showing crystalline basement, exotic to (mid-Paleozoic) North America, at shallow levels beneath the northernmost Gulf Coastal Plain.

D. Alternative in which the Benton Uplift is cored by exotic crystalline basement.

Carboniferous flysch within the southern Ouachitas (e. g., Walthall, 1967). The continuation of these events to at least 5 secs two-way traveltime on the section suggests that at least 14 km (45,000 ft) of tectonically thickened lower-to-middle Paleozoic deep-marine strata and Carboniferous flysch underlie the southern Ouachitas and northernmost Gulf Coastal Plain (Figures 3a, 3b). Possibly, gently north-dipping events occurring at about 7.6 secs beneath VP 1250-1300, represent reflections from crystalline basement at the bottom of this sequence. If so, then the total structural thickness of the Paleozoic strata (or metamorphosed equivalents) may be about 22 km (72,000 ft).

Below 3 secs beneath the south flank of the Benton Uplift, another prominent, south-dipping wedge of layered reflections is observed. The top of the wedge extends from about 3.0 secs at VP 800 to about 4.0 secs at VP 950. While interpretation of these events is not constrained by surface or well log information, their layered nature and position relative to that of the inferred lower-to-middle Paleozoic shelf sequence might suggest an off-shelf clastic sequence. Similar events, which lie near the palinspastically restored shelf edge of the (early Paleozoic) East Coast of the United States, are observed on the southern Appalachian COCORP profiles. These in turn lie on steep Bouguer and magnetic gradients, which are interpreted by Cook and Oliver (1981) to mark the buried passive margin of the (early Paleozoic) North American continent. The analogous sequences observed on the Ouachita profiles lie on similar potential field gradients (see maps of Wollard and Joesting, 1964; and Zietz, 1981) and may mark a southwestward continuation of this ancient margin in the subsurface (Lillie et al., 1983; Lillie, 1984 a, b; Ando et al., 1984).

Thus, the COCORP traverse across the Ouachitas reveals a southward-thickening wedge of Paleozoic strata interrupted by the (basement cored) Benton Uplift. Because these strata probably represent a negative density contrast within the upper crust, the observed gravity data require high densities at lower crustal levels south of the Benton Uplift (Lillie et al., 1983). These high densities are reasonably interpreted in terms of a southward shallowing of the Moho by about 10 km (30,000 ft) across the Ouachita Mountains. The resulting crustal section can be interpreted as the remnants of the early Paleozoic (Atlantic style) passive margin which was subducted beneath the thick (accretionary) wedge of Paleozoic strata in Carboniferous time (see Briggs and Roeder, 1975; Walper, 1977). The Frontal Thrust Zone represents the evolution of the accretionary wedge into a foreland thrust belt as the margin entered the (south-dipping) subduction zone. The Benton Uplift is interpreted as a late-stage uplift along the margin as reverse faults cut deeply into the underlying crystalline basement (Nelson et al., 1982; Brewer, 1984).

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CONODONTS FROM ORDOVICIAN ROCKS, OUACHITA MOUNTAINS, ARKANSAS

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INTRODUCTION

The lower Paleozoic rocks of the core of the Ouachita Mountains are sparsely fossiliferous, but graptolites were obtained in sufficient numbers to permit age assignments at the time the sequence was subdivided into formations (Purdue, 1909). Graptolites continued to be the sole basis for the correlation of the rocks of the Ouachita facies for nearly 70 years, although no detailed collections have been reported since the mid 1930s. A restudy of the graptolite faunas is presently being conducted by Dr. Stanley Finney of Oklahoma State University, and this effort will contribute documentation of occurrences that largely is lacking in earlier reports.

Occasional citations of the discovery of conodonts in Ouachita rocks have appeared episodically (e.g. Miser, 1917; Hendricks, Knechtel, and Bridge, 1937; Harlton, 1953), but they were based on limited collections from isolated localities and were treated as curiosities. Repetski and Ethington (1977) demonstrated that conodonts can be obtained in at least modest numbers and in relatively good preservation from the thin beds and lenses of limestone that occur within the well-indurated shales of the Ouachita facies. Their report was based on reconnaissance collections from the Ordovician units and did not provide a comprehensive biostratigraphy for those formations. Nevertheless their preliminary data demonstrated that conodonts can complement graptolites in efforts to develop a more sophisticated biostratigraphy for the region.

Subsequent to the work of Repetski and Ethington, many more samples have been collected in the core of the Ouachita Mountains and processed for conodonts. Many of the collecting localities were identified by graduate students of the University of Missouri-Columbia who were conducting mapping projects in the area surrounding the eastern half of Lake Ouachita in Garland County, Arkansas. I am indebted particularly to Professor George W. Viele, T. J. Focht, S. H. Brown, and J. M. Stewart for suggestions and for guidance in the field. The collections made with their assistance have enlarged the data base for conodonts of west-central Arkansas and have allowed refinement of the age determinations made earlier on the basis of graptolites and conodonts.

Interpretation of the Ouachita rocks is made difficult by the complex geologic structure of the area and by the lack of continuous exposures in what is largely a heavily forested area. For this reason, most of the conodonts studied to date have been found in samples of limestones exposed in stream beds and banks or in road cuts. Generally a stratigraphic sequence of more than a few tens of meters is all that is available at these localities, and the stratigraphic relations of adjacent outcrops often are uncertain. Fortunately the ranges of conodonts have been established in thick and continuous sections in the southern Appalachians (Bergström, 1971) and in the platform carbonates of northern Arkansas and Missouri (Ethington and Clark, 1971; Sweet, Ethington, and Barnes, 1971). Geographically isolated collections from the Ouachita facies can be positioned biostratigraphically relative to each other by comparison with these external standards, and as a result the general relations that exist between outcrops of many of the Ouachita formations can be determined if conodonts are present.

The paragraphs that follow will summarize the information that has been assembled to date. Further refinement is likely as additional samples are examined from parts of the section where data still are sparse and as the investigation is expanded into areas that have not been sampled.

PRESERVATION AND COLOR ALTERATION

Preservation varies markedly among the conodonts recovered from the Ordovician rocks of the Ouachita region. In general, those from the Womble Shale display better preservation than those from the older units, but the least well-preserved conodonts in the Womble rival those of the Collier and Mazarn. Such specimens display many transverse fractures, particularly of their cusps and denticles, and commonly are eroded and bleached in the damaged areas. Probably the fractures were developed during the deformation of the enclosing rocks and subsequently were loci of accelerated chemical attack. Commonly only very general identifications can be made for severely damaged forms. A few samples yielded specimens with so much quartz silt adhering to their surfaces that identification is limited to generic level if it is possible at all.

Most collections from the Ouachita rocks show a high proportion of nearly complete specimens with little surface etching or other *post mortem* modification. The conodont elements are opaque, dark gray to jet black, and show almost no traces of light-colored substance within them. Similar specimens from other localities, including many in the central craton, are straw-colored and translucent; most of them display regions in their interiors that are composed of an opaque, ivory-colored substance that has been identified as albid or white matter. This general appearance is believed to be characteristic of unaltered conodonts, and hence the specimens from the Ouachita region have been exposed to situations that produced the dark character that they display uniformly.

Epstein, Epstein, and Harris (1977) showed that conodonts experience a regular and progressive change in color with exposure to increasing temperatures. They subdivided the spectrum of conodont colors that they observed empirically among natural occurrences of conodonts and that they developed experimentally by heating specimens in the laboratory into numbered categories (color-alteration indices; CAI) representing finite ranges of temperature to which conodonts had been exposed. The conodonts thus far studied from the core of the Ouachita Mountains display CAI values of 4.5 to 5, indicating paleotemperatures on the order of 250-300 C. for the region.

BIOSTRATIGRAPHY

Collier Shale. — Conodonts recovered from the Collier Shale are limited thus far to those reported by Repetski and Ethington (1977). Those collections were obtained from limestones in the upper part of the formation at six localities in Montgomery and Garland Counties, Arkansas, and at one locality in the Broken Bow anticline of southern Oklahoma. Conodonts recovered from the Collier are very small and occur sparsely with less than 10 specimens in a kilogram of rock. About half of the samples that were processed did not produce conodonts.

Although represented by only a small number of specimens in the collections at hand, the conodonts from the upper Collier are easily recognized and are markedly different, both individually and collectively, from those in the overlying formations. In particular, *Acanthodus lineatus, Acodus oneotensis, Cordylodus angulatus, Loxodus bransoni, "Oistodus" triangularis, Paltodus bassleri,* and *Rossodus manitouensis* are diagnostic components of the population that characterizes Fauna C of Ethington and Clark (1971) which is known to occur widely in Lower Ordovician strata in North America. It is present in the upper McKenzie Hill Formation in Oklahoma (Mound, 1968) and also occurs in the Gasconade Formation of the northern Ozark region (Kurtz, 1980) which are thereby correlatives of the upper Collier.

Mazarn Shale. — The limestones of the Mazarn Shale, like those of the older Collier, have produced only small numbers of conodonts with the most productive samples yielding no more than 10 specimens per kilogram of processed rock. These conodonts include representatives of the North Atlantic Faunal Province, an association of species that is believed to have lived in deep- and/or cold-water environments in the Ordovician seas, as well as forms of the North American Midcontinent Province that occur typically in platform-carbonate rocks of shallow-water origin. Presumably the former actually lived in the deep basinal environments in which Ouachita sediments were deposited, whereas the latter conodonts, which usually are subordinate in abundance, may have been introduced with sediment derived from shallower regions flanking the Ouachita depositional area. The mutual occurrence of these provincial faunas, which normally are not found in the same rocks, offers an opportunity to relate the zonal schemes that have been established for the two provinces, and allows the correlation of the Mazarn with stratigraphic units that accumulated under a variety of depositional settings.

The conodonts of the Mazarn that are characteristic of the Midcontinent Province are dominated numerically by *Glyptoconus quadraplicatus* and *Eucharodus parallelus* but include specimens of *Oneotodus costatus, Tropodus comptus,* and species of *Ulrichodina.* These are long-ranging species in the Ibexian (Lower Ordovician; = Canadian of authors) and hence provide only a general age assignment for the Mazarn. This association of species occurs in the Cotter-Powell-Smithville sequence of northern Arkansas and in the Cool Creek, Kindblade, and West Spring Creek Formations (middle and upper Arbuckle Group) of southern Oklahoma. *Oepikodus communis,* another typical Midcontinent conodont, has been found in several samples collected in the Mazarn near Jessieville, northern Garland County, Arkansas. This species is present at the top of the Jefferson City Formation in central Missouri and in the uppermost Kindblade through most of the overlying West Spring Creek in the Arbuckle Mountains of Oklahoma. Where present, it serves to limit the age of the rocks in which it occurs to very late Ibexian (equivalent to upper Arbuckle Group).

The most significant conodont from the North Atlantic Province in the Mazarn is *Oepikodus evae* which also has been found in the vicinity of Jessieville, Arkansas. Although occurrences of North Atlantic conodonts are not as completely documented for North America as are those of the Midcontinent faunas, their presence in the Mazarn allows some tentative correlations. *Oepikodus evae* is known to occur in the upper Marathon Limestone of west Texas (Bergström and Cooper, 1973), in the Ninemile Formation of central Nevada (Ethington, 1972), and in the Deepkill Shale of the Taconic sequence in New York (Landing, 1976). The conodonts with *O. evae* are the stratigraphically highest collections obtained from the Mazarn; they indicate that the formation ranges at least as high as the youngest Early Ordovician. The samples with *O. evae* are from isolated ledges that are located an unknown distance below the top of the Mazarn. The possibility therefore exists that uppermost Mazarn includes low Middle Ordovician (basal Whiterockian) beds, a possibility that is reinforced by the graptolites that Ulrich (1911) collected near Little Rock from strata that he considered to be part of the Mazarn. These graptolites suggest that the rocks at that locality may be of early Whiterockian age (S. C. Finney, pers. commun., 1983). Samples of limestones should be sought from sections that include uppermost Mazarn and basal Blakely in order to evaluate this possibility.

In the same way, the stratigraphic position of the basal Mazarn has not been documented by diagnostic conodonts and additional effort is being directed toward seeking such conodonts from this part of the formation. The available evidence indicates that the Mazarn represents all but the oldest Early Ordovician.

Blakely Sandstone. — Conodonts have been found in limestone clasts in debris flows in the Blakely near Three Sisters Landing in Lake Ouachita State Park and in limestones interbedded with black shales and sandstones of the upper Blakely at a locality three miles west of Crystal Springs, western Garland County, Arkansas. The latter occurrence is of importance because the Blakely is in stratigraphic continuity with the Womble Shale at that locality. The conodonts in the clasts are the same species as those from the *in situ* limestones, and both occurrences are believed to provide valid evidence for the stratigraphic position of the rocks in which the conodonts occur. The most common species, *"Cordylodus" horridus, Paraprioniodus costatus,* and *Histiodella holodentata,* have been demonstrated to be characteristic of middle and upper Whiterockian (lower Middle Ordovician) rocks in central Nevada (Harris et al., 1979). Their presence near the top of the Blakely at the locality near Crystal Springs offers evidence that the formation probably does not include Chazyan strata. The conodonts suggest that the Blakely is approximately equivalent to the Everton and probably the lower St. Peter Sandstone of northern Arkansas and to the Joins and Oil Creek Formations (lower Simpson Group) of Southern Oklahoma.

Womble Shale. — The limestones of the Womble Shale have been more productive of conodonts than those of the underlying units, both in abundance and diversity of specimens and in having relatively fewer barren samples. In addition, continuous sections of Womble have been examined at several places (along Highway 270 about three miles west of Crystal Springs; limestone quarry near Mountain Pine), so that conodont occurrences over more than a few meters of local exposures have been studied. Most of the conodonts found in the Womble represent the deep-/cool-water faunas of the North Atlantic Province, but occasional specimens have been encountered that are characteristic of the shallow-/warm-water faunas of the Midcontinent Province. As was the case with the conodonts of the Mazarn, the latter group of species may have been introduced into the Womble with sediment that was transported into basinal settings from shallow marginal platforms of the craton.

The oldest conodonts recovered from the Womble are characteristic of the *Pygodus serra* Zone of Bergström (1971). The fauna, which is quite diverse, includes *Phragmodus flexuosus, Belodina monitorensis, Belodella nevadensis, Periodon aculeatus,* and species of *Panderodus* and *Protopanderodus.* Elements of species of *Eoplacognathus* are rare in the collections from this part of the Womble, and all recovered to date are too fragmented or nondiagnostic to allow assignment of these rocks to one of Bergström's subzones. Occurrence of *Cahabagnathus friendsvillensis* with *P. serra* in rocks along North Mill Creek near Jessieville in the Hamilton quadrangle limits the rocks at that place to one of the upper three of these subzones.

The conodonts of the *P. serra* Zone are present in lower Womble in stratigraphic continuity with the underlying Blakely Sandstone at the locality west of Crystal Springs. Because the *P. serra* Zone is known to be present in lower Chazyan rocks of eastern United States, its presence in Womble at many places in the Ouachitas coupled with the several known occurrences of Whiterockian conodonts high in the Blakely indicates that the base of the Womble is near the top of the Whiterockian Stage as that unit was conceived (Cooper, 1956; middle Whiterockian according to the redefinition of Ross et al., 1982).

Conodonts of the *Pygodus anserinus* Zone were reported by Repetski and Ethington from massive limestones that are exposed in the quarry a few miles northeast of Mountain Pine, northern Garland County, Arkansas. Many of the common conodont species of the lower Womble are present here also, but they are joined by *Cahabagnathus sweeti,* a species of *Appalachignathus,* and *P. anserinus.* This association of conodonts is characteristic of upper Chazyan strata in the Appalachian region, indicating that the rocks in the quarry are younger than those containing the conodonts of the *Pygodus serra* Zone.

Still younger conodonts of probable Blackriveran age have been found in the Womble near the Caddo River, about five miles west of Norman, southern Montgomery County, Arkansas. The same fauna has been identified tentatively in a sample collected in limestone rubble in the Womble in the vicinity of Manfred, near Caddo Gap, southern Montgomery County, Arkansas. These collections are dominated numerically by elements of *Peridon aculeatus* and *Protopanderodus varicostatus* as is the case with almost all samples from the Womble. Also present are *Prioniodus gerdae* and *Eoplacognathus elongatus,* both diagnostic species of the *P. gerdae* Subzone (*Amorphognathus tvaerensis* Zone) of the Ordovician of the North Atlantic Province (Bergström, 1971).

Although assembled from widely scattered localities, many of which expose only a few meters of rock, the conodont collections at hand delimit the stratigraphic range of the Womble Shale. Its base is near the base of the Chazyan and it ranges upward into at least the Blackriveran. Conodonts have not been recovered from strata that are known to be near the contact between the Womble Shale and the overlying Bigfork Chert, so that discovery of still younger conodonts is possible. However, graptolites from low in the Bigfork in Oklahoma suggest Blackriveran age (S. C. Finney, pers. commun., 1983) and thus it is unlikely that such conodonts, if found, will extend the upper limit of the Womble significantly.

Bigfork Chert. -- Hendricks et al. (1937) and Harlton (1953) reported the presence of conodonts in the Bigfork Chert on Black Knob Ridge near Ada, Oklahoma. Neither of these studies indicated which conodonts are present, and they offer no basis for interpretation or correlation. Limestones and shales are known to be present in the Bigfork in Oklahoma, and it may be possible to obtain significant collections of conodonts from them. The several outcrops of Bigfork that I have examined in Arkansas do not contain limestones so that no possibility existed for recovery of conodonts by conventional techniques.

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PALEOMAGNETIC MEASUREMENTS IN THE EASTERN OUACHITA MOUNTAINS, ARKANSAS

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ABSTRACT

One hundred and eight of 163 oriented core samples collected from 23 drill sites (five lower Paleozoic formations and two upper Paleozoic formations) within the eastern Ouachita Mountains, Arkansas, were analyzed with a cryogenic magnetometer to determine paleomagnetic behavior and subsequent tectonic implications. A stepwise thermal demagnetization sequence permitted the construction of Zijderveld diagrams which revealed from one to three magnetic components. The analyses yielded pole positions for: (1) The Collier Shale component A corresponding to the North American Ordovician pole and Collier Shale component B corresponding to the earth's present field; (2) the Mazarn Shale similar to the North American Ordovician pole; (3) the Womble component B which is probably Ordovician in age and the Womble component C which is similar to the earth's present field; and, (4) the Stanley Shale and Jackfork Sandstone which are thought to be Carboniferous in age. Differences in calculated pole positions from established pole positions for North America are attributed to rotation and thrusting of the Ouachita rock units during tectonic deformation.

INTRODUCTION

General

With the development of the concept of plate tectonics, scientists have strived to evaluate possible configurations of landmasses and major tectonic features associated with present-day continents. Reconstructions of plate margins and proposals of tectonic histories have been based on geological, structural, paleontological, and geophysical evidence. Recent technological advances in instrumentation and techniques have established paleomagnetism as one of the major tools in the study of polar wandering and tectonics. Information on many different regions has been obtained with paleomagnetic data, and that information in turn has been essential in the reconstruction of the histories of those areas.

Ouachita Mountains

Structural and stratigraphic evidence of large-scale deposition and deformation within the Ouachita Mountains shows a complex tectonic history. The Ouachitas are characterized by major recumbent folds and thrust faults in Paleozoic sedimentary rocks ranging from Early Ordovician to Late Pennsylvanian in age. Many comprehensive and detailed descriptions of the geology of the region are cited elsewhere in this guidebook. Rocks of the lower Paleozoic consist of micritic and some oolitic limestones, clean sandstones, laminated shales and a thick novaculite (Viele, 1966). Huge thicknesses of Carboniferous flysch are conformably deposited over the novaculite, and represent a significant change in sediment source area and tectonic environment.

Viele (1973) described the Ouachita Mountains as consisting of four different tectonic provinces (Fig. 1): Arkoma basin, Maumelle chaotic zone, Benton-Broken Bow uplift, and the Athens Plateau. The complexity of superimposed fold systems and a nappe structure for the lower Paleozoic rocks has fostered many theories on the formation of the Ouachitas and their link to the tectonic history of the Gulf of Mexico. Wickham et al. (1976), Dewey and Bird (1970), and Keller and Cebull (1973), among others, suggested models involving some form of Precambrian rifting of continental crust to form a south-facing margin near the present site of the fold belt. Subsequent subduction and convergence with the Afro-South American landmass apparently provided the stress necessary for deformation and perhaps served as the source regions of the flysch deposits.

The diversity of tectonic models for the Ouachita belt and the general lack of unanimity in acceptance for any one version reveals the need for additional information. This report describes and initial attempt to determine the magnetic behavior of the Paleozoic rocks of the Arkansas Ouachita Mountains.

Paleozoic Paleomagnetic Work

To date, no paleomagnetic research has been reported for the Paleozoic rocks of the Ouachita Mountains. Paleomagnetic studies of Paleozoic rocks in other regions are well-documented (e.g. Kent and Opdyke, 1978; Irving and Opdyke, 1964) and paleopole positions for the Ordovician and Carboniferous Periods have been calculated at many localities in both North and South America (table 1).

The derivation of Paleozoic magnetic pole positions for the Ouachita is important for an evaluation of the tectonic history of the Ouachita Mounains and their relationship to the Appalachian and Marathon orogenic belts. Pole positions derived from the leptogeosynclinal and flysch deposits of the Ouachita Mountains provide a significant contribution to our knowledge and understanding of possible plate movements during the evolution of the southern margin of North America.

PROCEDURES

Field Samples

A total of 163 oriented core samples were collected at 23 drill sites in the eastern Ouachita Mountains (Fig. 2; table 2). Cores were taken from the Jackfork Formation in both the Maumelle chaotic zone and the Athens Plateau; the Stanley Shale in the Athens Plateau; and the Womble Shale, Blakely Sandstone, Mazarn Shale, Crystal Mountain Sandstone, and Collier Shale in the Benton uplift region. The choice of sites reflects the accessibility of outcrops in those areas. Sample site selection was influenced by the degree of weathering present and by the potential for correctly orienting the cores in highly contorted exposures.

The selected outcrops were drilled with a small, portable, water-cooled gasoline rotary drill. Cores approximately 10 cm deep and 2.25 cm in diameter were obtained. A sample length of 2.5 cm was later machined from the core, thus avoiding highly weathered surfaces. Orientations of the cores were determined before they were extracted. The orienting device consisted of a simple hollow aluminum tube, machined for the purpose, with an adjustable leveling table for a compass on one end.

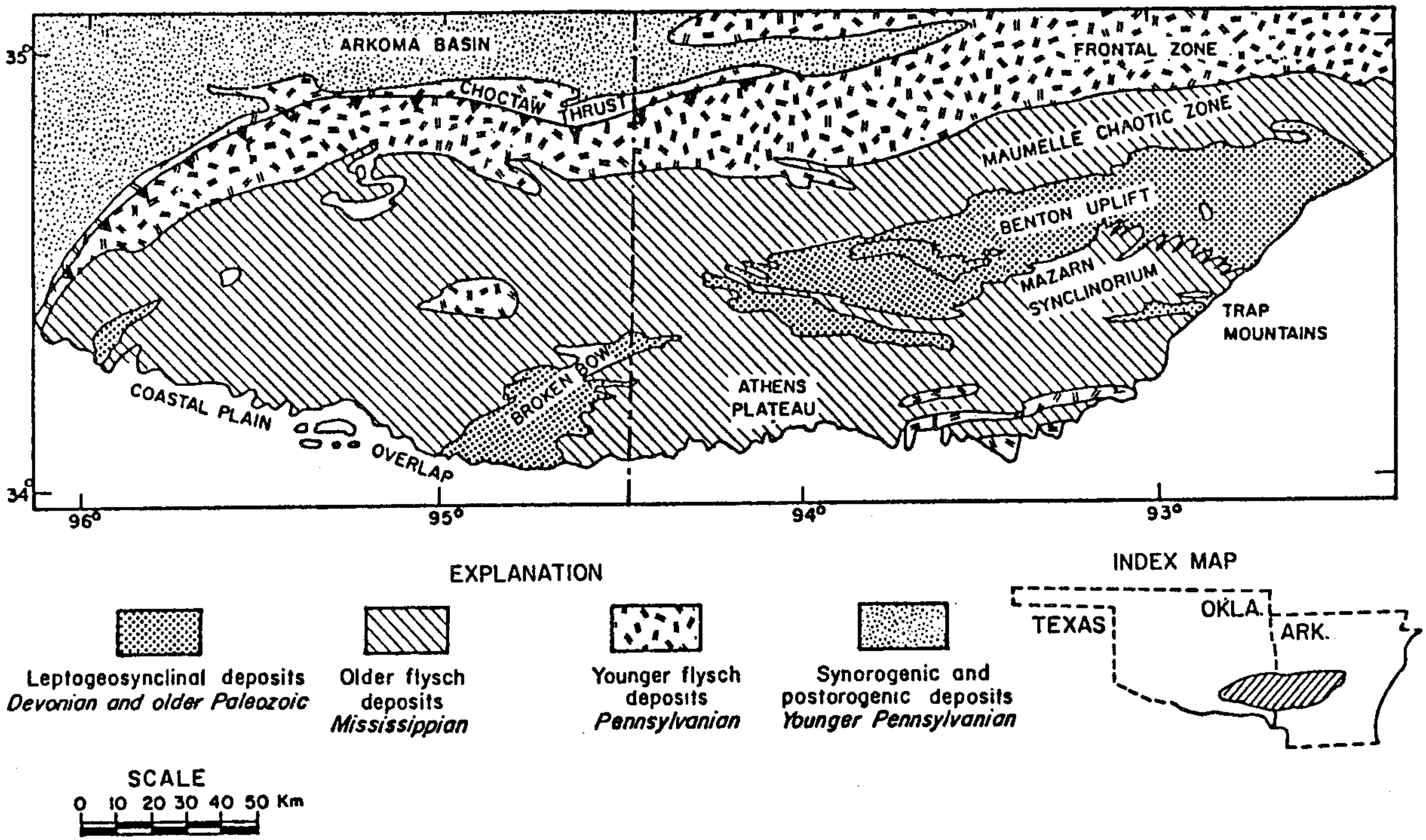

Figure 1. — Ouachita Mountains showing tectonic provinces and other features. Modified from Viele, 1973.

Table 1. — Published V.G.P. positions, North and South America, for the Ordovician and Carboniferous (as compiled by Jenkins, 1983).

Rock Unit and Location	Site Latitude	Site Longitude	Mean Declination	Mean Inclination	Pole Latitude	Pole Longitude
North America						
Ordovician:						
Juniata Formation, Pennsylvania	40.0°	-75.0°	131.0°	26.0°	20.0°	153.0°
Trenton Group, New York	43.5°	-75.0°	179.0°	82.0°	27.0°	-75.0°
Trenton Group Conglomerate, New York	42.5°	-75.0°	177.0°	71.0°	9.0°	-74.0°
Beemerville Complex, New Jersey	41.2°	-74.7°	163.0°	22.0°	35.0°	126.0°
Coo-ROD, Colorado	39.0°	-106.0°	0.0°	0.0°	41.0°	111.7°
Moccasin Bays Formation, Tennessee	---	---	---	---	33.0°N	147.0°E
Chapman River, Tennessee	---	---	---	---	37.0°N	112.0°E
Carboniferous:						
Mauch Chunk Formation, Pennsylvania	40.0°	-77.0°	162.0°	8.0°	43.0°	127.0°
Barnett Formation, Texas: Normal	31.0°	-99.0°	319.0°	8.0°	41.0°	144.0°
Barnett Formation, Texas: Reverse	31.0°	-99.0°	149.0°	19.0°	39.0°	123.0°
Alleghenian Coal, Ohio	---	---	---	---	35.0°N	129.0°E
South America						
Ordovician:						
RFD Sediments, Bolivia	-17.5°	-55.5°	42.0°	84.0°	4.0°	-58.0°
Jujuy Sediments, Argentina	-23.5°	-65.5°	63.0°	-7.0°	11.0°	-27.0°
Ordovician sandstone, Salta, Argentina	-24.5°	-65.5°	53.0°	0.0°	31.0°	13.0°
Carboniferous:						
Tubarao Series, Brazil	-25.0°	-50.0°	29.0°	-24.0°	-59.9°	159.1°
Piaui Formation, Brazil	-5.7°	-42.8°	160.0°	52.0°	-50.0°	-15.0°
Taiguati, Bolivia	-17.6°	-65.4°	319.0°	-62.0°	-45.0°	-20.0°
Ambo Group Tuffs, Peru	-12.0°	-75.0°	315.0°	75.0°	8.0°	-85.0°
Middle Paganzo Redbeds, Argentina	-30.0°	-68.0°	164.0°	67.0°	-65.0°	-44.0°
La Colina Redbeds	-29.9°	-67.3°	171.0°	53.0°	-82.0°	-11.0°
Lagares Redbeds	-30.0°	-67.2°	177.0°	52.0°	-85.0°	-25.0°

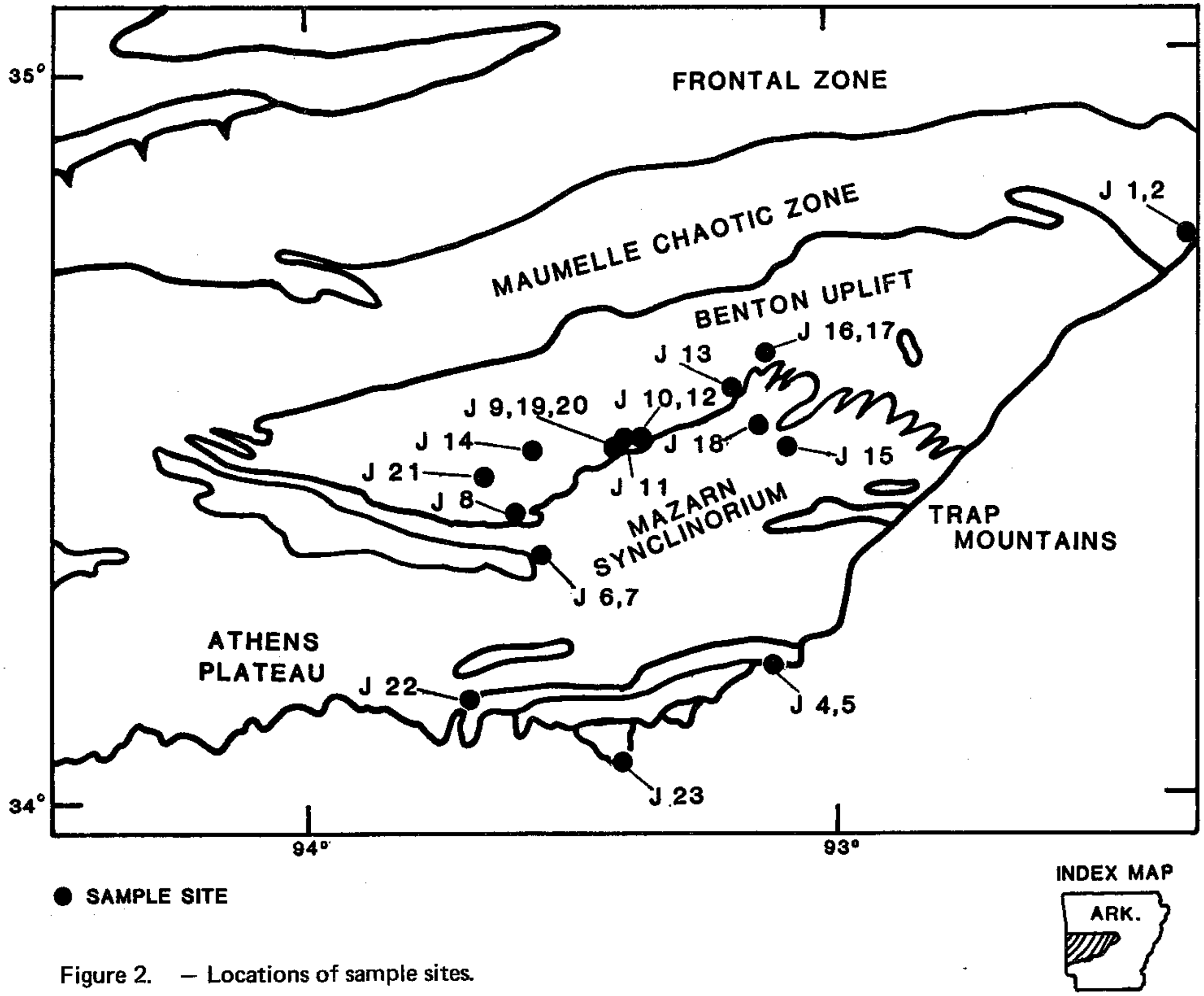

Figure 2. — Locations of sample sites.

Table 2. — Sample site information.

Age	Formation	Site Names	Sample Names	Site Latitude	Site Longitude	Province
Carboniferous	Jackfork	J1	A-F	34.7°N	92.3°W	Maumelle Chaotic Zone
	"	J2	A,B,D-G	34.7°N	92.3°W	" " "
	"	J3	A-F	34.7°N	92.3°W	" " "
	"	J4	A,B,D-G	34.2°N	93.1°W	" " "
	"	J5	A-G	34.2°N	93.1°W	" " "
	"	J22	A-J	34.2°N	93.8°W	Athens Plateau
	"	J23	A-H,J,K	34.1°N	93.5°W	" "
	Stanley	J6	A-H	34.4°N	93.6°W	Athens Plateau Zone
	"	J7	A-G	34.4°N	93.6°W	" " "
	"	J15	A-K	34.5°N	93.1°W	" " "
	"	J18	A-C,E-H	34.5°N	93.1°W	" " "
Ordovician	Womble	J8	A-H	34.4°N	93.6°W	Benton Uplift
	"	J16	A-E	34.6°N	93.1°W	" "
	"	J17	A-J	34.6°N	93.1°W	" "
	Blakely	J12	A-H	34.5°N	93.3°W	" "
	"	J13	A-J	34.6°N	93.2°W	" "
	"	J14	A-C	34.5°N	93.5°W	" "
	Mazarn	J21	A-F	34.5°N	93.7°W	" "
	Crystal Mountain	J9	A-J	34.5°N	93.4°W	" "
	Collier	J10	A-D,F,G	34.5°N	93.3°W	" "
	"	J11	A-G	34.5°N	93.3°W	" "
	"	J19	A-E	34.5°N	93.3°W	" "
	"	J20	A-D	34.5°N	93.3°W	" "

Laboratory Analyses

Remanent magnetization of the core samples was measured using a Technology A100 series superconducting rock magnetometer which is cooled with liquid helium. The magnetometer is housed inside a ferromagnetic, mu-metal shield to create a field free environment. On-line computer analyses of the magnetic measurements in a variety of sample orientations permitted calculation of magnetic intensity, inclination, declination, and paleolatitude values, as well as statistical parameters.

Prior to and during magnetic measurements, demagnetization steps were taken to remove secondary magnetization acquired since deposition and to isolate various other magnetic components of each formation. Both thermal and alternating field demagnetization was achieved, but the thermal process yielded the best results. Samples were heated in 50°C intervals to approximately 600°C. A complete description of the preparation and measurement procedures is given by Jenkins (1983).

RESULTS

Computations

Of the 163 samples collected, 108 were analyzed in detail. Intensities, which can be attributed to a probable combination of detrital remanent magnetization and chemical remanent magnetization within the samples, ranged from 10^{-3} to 10^{-6} A/M. Calculated inclination and declination values for each sample were corrected for the observed bedding tilts of the units from which the samples were collected. Although the corrected determinations are credible, they do not include any large-scale translation or rotation which the Ouachita region may have experienced during deformation. Tables 3 and 4 show the computed inclination, declination, paleolatitude, and virtual geomagnetic pole (V.G.P.) positions for each of the measured samples.

Figure 3 shows the corrected V.G.P. positions with circles of confidence and the Cambrian to Triassic (C – Tr) polar wander path for North America. The V.G.P. positions fall into three groups: (1) those similar to published pole positions for North American rocks of the same age, (2) those similar to pole positions for North American rocks of different age, and (3) those possessing no similarity to North American (nor South American) rocks.

Discussion

Zijderveld diagrams were constructed for all samples measured and were used to determine the nature of the magnetic components for each sample. Thus, common components for sites and/or formations could be identified. The complete review of the background and results of that process are in Jenkins (1983). A brief review of the findings and the V.G.P. positions are given here.

Zijderveld diagrams constructed on the Collier and Mazarn samples indicated good two-component systems for each formation. The V.G.P. positions calculated for Collier component A after correcting for tilt were at latitudes similar to published latitudes of other North American Ordovician poles, but varied in their longitude values. The difference in longitude values is probably due to rotational deformation of the Collier beds.

Component A consisted of two sets of similarly directed components, which were combined to get two mean declinations, inclinations, and pole positions. The positioning of these poles implies differential rotation of these two sets of sites whose paleopole directions are undoubtedly pre-tectonic and probably Ordovician. The paleolatitude

Table 3. — Mean inclination, declination, and paleolatitude value for magnetic components before and after bedding correction.

Component Name	Strike and Dip	Uncorrected Mean			Corrected Mean		
		Inclination	Declination	Paleolatitude	Inclination	Declination	Paleolatitude
Collier J10 Com-A	78°, 46°S	3.53°	263.3°	1°	25.70°	212.10°	13°
Collier J11 Com-A	89°, 47°S	13.20°	265.6°	7°	40.80°	198.80°	26°
Collier J10/11 Com-A	---	---	---	---	33.26°	206.17°	17°
Collier J19 Com-A	47°, 37°S	25.90°	127.5°	13°	-8.95°	125.20°	5°
Collier J20 Com-A	63°, 88°S	38.00°	120.5°	23°	-38.10°	109.60°	23°
Collier J19/20 Com-A	---	---	---	---	-20.83°	119.17°	11°
Collier J10 Com-B	78°, 46°S	-52.70°	215.3°	34°	-11.10°	280.00°	6°
Collier J11 Com-B	89°, 47°S	-47.7°	204.8°	29°	-3.70°	281.80°	1°
Collier J19 Com-B	47°, 37°S	51.50°	358.5°	33°	57.90°	118.50°	40°
Collier J20 Com-B	63°, 88°S	41.90°	351.7°	26°	28.50°	150.40°	15°
Mazarn J20 Com-A	102°, 40°S	46.40°	135.3°	27°	4.90°	147.50°	3°
Blakely J14 Com-A	143°, 62°S	19.30°	82.2°	10°	-12.70°	89.10°	7°
Womble J16 Com-B	218°, 39°N	54.50°	127.8°	36°	71.90°	144.90°	57°
Womble J17 Com-B	200°, 27°N	25.70°	127.5°	14°	50.40°	136.20°	31°
Womble J16 Com-C	218°, 39°N	54.20°	330.1°	36°	20.00°	317.90°	11°
Womble J17 Com-C	200°, 27°N	49.70°	338.7°	29°	37.20°	320.90°	23°
Stanley J15 Com-A	91.5°, 20°S	29.20°	296.5°	16°	61.60°	254.7°	44°
Jackfork J2 Com-A1	125.0°, 34°S	22.80°	322.6°	12°	-31.50°	313.8°	16°
Jackfork J23 Com-A3	125.0°, 34°S	24.20°	147.1°	13°	24.70°	14.5°	13°
Jackfork J2-A1/J23-A3	---	---	---	---	-28.30°	319.4°	14°

Table 4. — Virtual geomagnetic pole positions, before and after bedding correction.

Component Name	Strike and Dip	Uncorrected V.G.P.		Corrected V.G.P.	
		Latitude	Longitude	Latitude	Longitude
Collier J10 Com-A	78°, 46°S	4.54°	178.0°	33.10°	48.40°
Collier J11 Com-A	89°, 47°S	1.77°	183.5°	29.50°	66.80°
Collier J10/11 Com-A	---	---	---	21.80°	57.18°
Collier J19 Com-A	47°, 37°S	20.70°	142.2°	31.20°	158.60°
Collier J20 Com-A	63°, 88°S	10.60°	141.4°	27.60°	184.70°
Collier J19/20 Com-A	---	---	---	30.50°	168.54°
Collier J10 Com-B	78°, 46°S	60,80°	34.9°	4.21°	164.60°
Collier J11 Com-A	89°, 47°S	68.22°	355.1°	8.62°	168.40°
Collier J19 Com-B	47°, 37°S	87.40°	115.9°	6.31°	127.40°
Collier J20 Com-B	63°, 88°S	77.40°	123.6°	32.90°	121.00°
Mazarn J21 Com-A	102°, 40°S	14.80°	126.5°	42.10°	132.70°
Blakely J14 Com-A	143°, 62°S	10.43°	228.8°	2.90°	182.40°
Womble J16 Com-B	218°, 39°N	5.10°	127.4°	6.10°	111.30°
Womble J17 Com-B	200°, 27°N	20.80°	142.4°	12.40°	124.20°
Womble J16 Com-C	218°, 39°N	65.50°	185.9°	44.70°	154.70°
Womble J17 Com-C	200°, 27°N	71.70°	169.9°	53.10°	165.30°
Stanley J15 Com-A	91.5°, 20°S	30.50°	266.9°	2.86°	182.40°
Jackfork J23 Com-A1	125.0°, 34°S	33.80°	126.2°	32.30°	128.10°
Jackfork J23 Com A3	125.0°, 34°S	136.30°	136.8°	8.80°	115.80°
Jackfork J2-A1/J23-A3	---	---	---	27.60°	131.12°

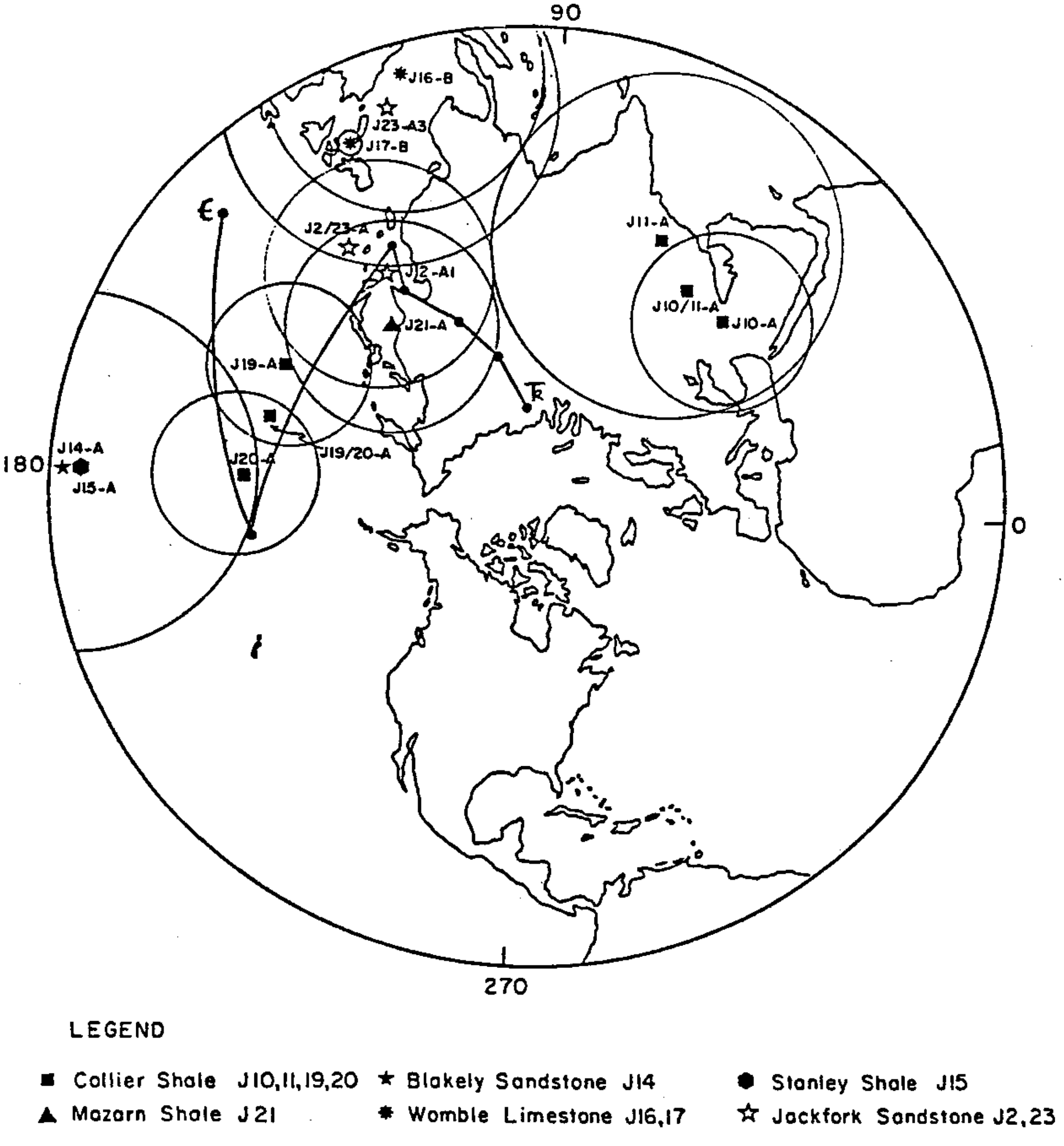

Figure 3. — Plot of corrected positions of virtual geomagnetic poles (V.G.P.) calculated for rocks in the eastern Ouachita Mountains. Polar wander path (Cambrian to Triassic) also shown.

calculations for the Collier Shale components were 17° and 11° north. These are not significantly different from the paleolatitudes expected from a comparison with the Juniata Formation of Pennsylvania which is also Ordovician in age and yielded a paleolatitude of 13° north. The V.G.P. positions calculated for Collier component B are thought to represent the earth's present field.

The uncorrected V.G.P. position calculated from the higher temperature Mazarn component has a longitude consistent with published North American Ordovician rocks, but has a lower latitude (14.8°). The corrected pole position for this component fell close to the published pole positions for North America, and may well have been acquired during the Ordovician. The paleolatitude as calculated for the Mazarn is 3° which is lower than expected for the Ouachita system.

Samples from the Blakely Sandstone were generally too weathered to yield useful information. Both the uncorrected and corrected V.G.P. positions varied from the published pole positions for North and South America. Differences in V.G.P. positions may be attributed to deformation of these rock units after acquisition of the magnetization. This would place the component as pre-Pennsylvanian/Permian.

Some samples of the Ordovician Womble limestone displayed evidence of a two component system. Womble component B yielded corrected and uncorrected V.G.P. longitudes which were similar to those published for North America, but had lower latitudes. The difference in latitudes can be attributed to deformation of these beds. The corrected inclination gave paleolatitudes of 57° and 31° which are higher than the Ouachita sediments are believed to have been positioned.

Womble component C had uncorrected V.G.P. positions which compared to the published Cretaceous pole positions for North America. These pole positions are thought to represent the earth's present field and not the Cretaceous due to the lack of any tectonic activity in the Ouachitas during this time.

The V.G.P. position calculated from a single component in the Mississippian Stanley Shale varied from any published pole positions for either North or South America or Africa. The Stanley formation is an extremely deformed and weathered unit. The position of this pole is thought to be due to this high amount of weathering and from the small number of samples (3). This position should be regarded with caution until more studies are done on the paleomagnetic nature of these rock units.

Zijderveld diagrams constructed for the Pennsylvanian Jackfork Sandstone formation produced a three component system from which two V.G.P. positions were calculated. Jackfork component A, after tilt correction, yielded a V.G.P. position comparable to other published pole positions for North America during the Carboniferous Period. This component is considered to be that age and could have been acquired as a detrital or a chemical remanent magnetization, or it could be related to the tectonic activity occurring within the Ouachita Mountains during this time.

Jackfork component B produced a V.G.P. position which had a slightly lower latitude value than the paleopole from component A. The circles of confidence, however, indicate that the directions from the two sites are not significantly different.

CONCLUSIONS

The samples collected from the six formations — the Collier, Mazarn, Blakely, Womble, Stanley, and Jackfork formations — are suitable for paleomagnetic study. These samples showed generally similar magnetic components and magnetic behavior.

Although problems with weathering and structural complexity were formidable, the measurements demonstrated that paleopole positions for the major formations comprising the eastern Ouachitas can be compared to those previously established for North America. The differences in V.G.P. positions are not unexpected and can easily be reconciled with the intense deformation experienced by the formations. The paleomagnetic studies provide no evidence to dispute the assigned ages of the units sampled, nor do they demonstrate tectonic transport, relative to the North American craton, of greater magnitude than the uncertainties caused by the physical condition of the rocks sampled.

The values obtained do not preclude a southerly source for the Carboniferous flysch sediments. They do, however, imply that some rotation and limited translation of the Ouachita foldbelt may have occurred as a result of the deforming stresses. Finally, the successes of this initial study prove the applicability of paleomagnetic research to the deformed sedimentary rocks of the Ouachita Mountains.

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GEOMETRY AND ORIGIN OF FOLDS AND FAULTS IN THE ARKANSAS NOVACULITE AT CADDO GAP

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INTRODUCTION

Exposures of Arkansas Novaculite (Devonian-Mississippian) at Caddo Gap clearly illustrate elements of fold and thrust fault geometry that characterize relatively late stages of deformation in the Ouachita thrust belt.

Caddo Gap, located 9.4 km (5.85 miles) northwest of Glenwood, Arkansas, was formed by downcutting of the Caddo River through a macroscopically folded and thrust-faulted, east-west trending novaculite ridge (Stone and others, 1973, p. 85). A sequence of exposures (610 m (2000 feet) long occurs in a roadcut on the east side of State Highway 27. There are limited but instructive outcrops along the Missouri Pacific Railway tracks west of and parallel to the road.

The Arkansas Novaculite at Caddo Gap is about 274 m (900 feet) thick. Sholes (1977) divided the formation into five members: Lower Chert and Shale, Lower Novaculite, Middle Chert and Shale, Upper Novaculite, and Upper Chert and Shale. All members except the Lower Chert and Shale are easily identified in these outcrops. For this discussion, the lowermost two members will be referred to the Lower Novaculite Division of Miser and Purdue (1929).

Throughout most of the outcrop sequence, beds strike approximately east-west, dip steeply to vertically, and top to the south. Horizontal or north-dipping, upright beds occur on short, front limbs of rotated kink folds or adjacent to thrust faults.

FOLD GEOMETRY

Folds range in scale from large to small mesoscopic structures.

Large Mesoscopic Folds

Large, open, inclined, monoclinic, eastward-plunging kinks with north-dipping axial surfaces are exposed in the Lower Novaculite Division and the Middle Chert and Shale Member. Average height to width ratio is 0.26; maximum short-limb height is about 9 m (30 feet); mean interlimb angle is 97 degrees; and the average plunge is 50 degrees toward 106 degrees (ESE). Most folded novaculite beds fall into Ramsay (1967) classes 1B and 1C, and interlayered shales typically have class 3 geometry. Wavelengths of several larger folds exceed the height of the outcrop, and these structures are represented by a single hinge. The unfolded, steeply dipping beds typical of most of the outcrop are probably long back limbs of widely spaced kinks.

Small Mesoscopic Folds

There are two types of small-scale folds at Caddo Gap. One is geometrically similar to the large mesoscopic kinks and occurs in thinly-bedded units such as the Middle Chert and Shale Member.

The second type is much more common and results from flow of shale into the hinge areas of folded, less ductile novaculite or chert. Where shale layers were sufficiently thick, relatively tight folds (interlimb angles = 60 to 80 degrees) with class 3 geometry have been produced. In some instances, particularly in the lower part of the Lower Novaculite Division, isolated chert beds on the order of 1 cm thick were disharmonically folded and/or dismembered during flow of the enclosing shale. Some small-scale folds have been flattened by continued flexure of more competent, thicker bedded novaculite. It is probable that flattening of these disharmonic forced folds has, at times, been misinterpreted as indicative of separate, earlier phases of deformation.

Kink Orientation

Most kinks are characterized by counterclockwise (looking east) rotation (northward vergence) suggesting that they were produced during the north-directed thrust transport typical of the Ouachita Mountain belt. Their present spatial orientations (subhorizontal front limbs, subvertical back limbs, and northward dipping axial surfaces) indicate that the entire section was rotated in the opposite (clockwise) sense after the major period of thrust-related, monoclinic folding. This relatively late rotation is also suggested by the attitudes and shear senses of back-limb thrust faults (see below).

FAULTS

Thrust faults with displacements of less than 1 m to at least 10 m occur throughout the entire length of the roadcut. These typically dip to the south and are parallel or subparallel to bedding on the back limbs of kink folds. Other small thrusts cut across the hinge areas and front limbs of large mesoscopic kinks and tend to complicate the determination of fold geometry. The bedding-parallel faults may have formed synchronously with monoclinic folding, but the cross-cutting variety is clearly younger than fold formation and may be related to the later clockwise rotation of the sequence. Individual small kinks may have been produced by drag along the thrust faults.

The trace of a major thrust fault (Stone and others, 1973, p. 85) is marked by a wide gap in the outcrop opposite the road to the former low-water bridge across the Caddo River (Fig. 1). The amount of displacement on this fault has not been determined but is probably at least several hundred meters. The thrust divides the roadcut into a northern, footwall block that includes a nearly complete section of Arkansas Novaculite and a southern, hanging wall block in which internal faulting has juxtaposed various members of the formation (Fig. 1).

NORTH TO SOUTH TRAVERSE THROUGH CADDO GAP

A traverse beginning at the northernmost outcrop and proceeding southward along the highway leads up-section both stratigraphically and structurally. Distances cited below were measured along the east edge of the roadcut from the northernmost exposure of Arkansas Novaculite near the top of the outcrop.

The first 326 m (1070 feet) of roadcut comprise the footwall block of the major thrust. The first exposures are in shales of the uppermost part of the Missouri Mountain Shale (Silurian) that grade into thin cherts and shales of the Lower Novaculite Division. Rocks of the Lower Novaculite have been folded into the large, eastward-plunging, open, monoclinic kinks cited above. Overall parallel fold geometry and slickensides subperpendicular to the hinges of several folds suggest that the novaculite deformed by flexural slip. Thickening of some hinges and limbs indicates local viscosity variation during folding. The effects of flow of interlayered shale during folding of the novaculite are clearly illustrated in the lower part of the Lower Novaculite Division. Numerous small thrust faults have modified fold hinges and produce apparent bedding discontinuities in this sequence. About 40 m (130 feet) up-section from the base of the formation, the novaculite becomes very thickly bedded. Mesoscopic structural elements other than fractures are rare in this interval. Varve-like lamina (Lowe, 1976) parallel to vertical

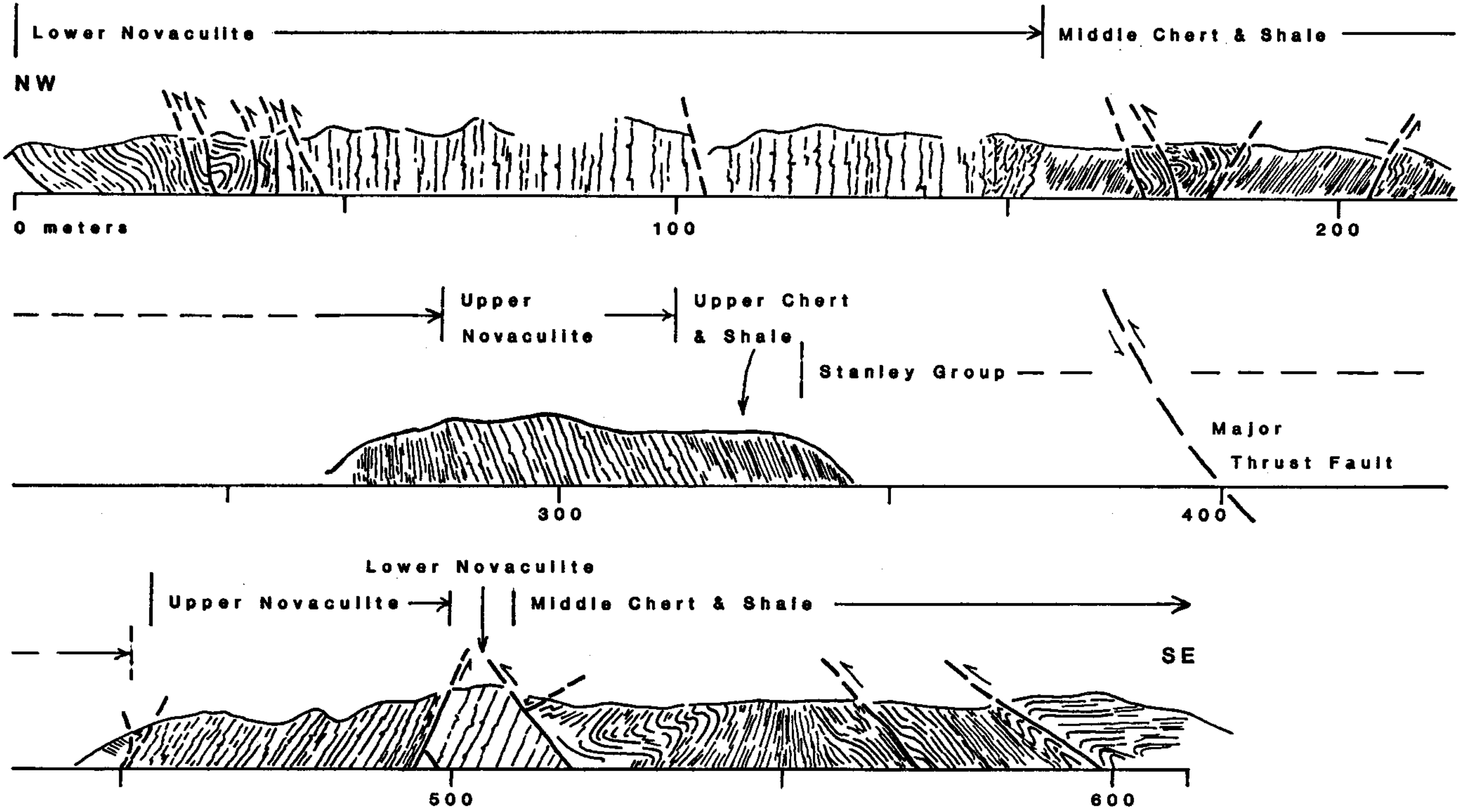

Figure 1.

Figure 1. — Simplified cross section along Caddo Gap roadcut. Distances (in meters) are approximate owing to distortion in the photographic traverse from which this cross section was composed, and should be considered as only general guidelines.

bedding occur locally. Kink folding, if present, is obviously of too great a wavelength to be visible in the outcrop. The contact between the Lower Novaculite Division and the Middle Chert and Shale Member is located about 158 m (520 feet) from the beginning of the traverse. It is marked by an abrupt change from heavily brecciated, thickly bedded novaculite to thinly bedded, dark chert and shale. This member contains open kinks of somewhat smaller dimensions than those lower in the sequence. Several folds have been modified by high-angle faults that cut across hinge areas.

A gap in the outcrop that may mark the location of a fault occurs between 221 and 244 m (726 and 800 feet). In the first exposure north of the gap, Middle Chert and Shale is overlain by thickly bedded Upper Novaculite, fresh surfaces of which typically have a rough, "tripolitic" texture. The Upper Novaculite is succeeded by thin, greenish beds of the Upper Chert and Shale Member. Layering in both units dips steeply to the south and is unfolded on the scale of the outcrop. The Upper Chert and Shale grades into greenish-brown Stanley Group shales at the top of the footwall block, opposite the side road to the low-water bridge and the parking area.

At this point, the traverse crosses the east-west oriented trace of the major thrust fault (Fig. 1) and continues into the base of the hanging wall block. In the first exposures, Stanley Group shales are faulted against a thin thrust slice of Middle Chert and Shale that is, in turn, faulted against north-dipping beds of Upper Novaculite. Farther up-section, these rocks are in fault contact with a large block of the upper part of the Lower Novaculite Division. In its present orientation, this fault shows normal, down-to-the-north relative motion but may be a rotated thrust. The Lower Novaculite block is overlain by kinked, thinly bedded Middle Chert and Shale across a south-dipping, bedding plane fault. From this point southward, the remaining part of the traverse is in the Middle Chert and Shale Member. This unit contains a relatively large number of folds. The northernmost structures include both large and small mesoscopic inclined kinks that closely resemble those found in the footwall block in geometry and attitude. Farther to the south (past 548 m) plunge of the folds increases markedly, and the kinks become reclined. This change is one of spatial orientation rather than style or geometry of folding. The reclined folds are closely associated with bedding-parallel thrust faults. It is probable that the former developed at the same time as other kinks in the footwall and hanging wall blocks and were subsequently rotated into a very steep eastward plunge by late-stage scissoring motion along the fault planes. Fold rotation of this type may mark the youngest structural event that has directly modified the rock sequence at Caddo Gap.

The roadcut ends in the Middle Chert and Shale Member, approximately 610 m (2000 feet) south of the contact between the Missouri Mountain Shale and the Arkansas Novaculite. Rubble containing fragments of rock from the Upper Novaculite Member and the Stanley Group can be found in road gutters farther to the south.

SUMMARY AND CONCLUSIONS

Fold geometry of novaculite and chert beds and the presence of slickensides in zones normal to the hinges of several structures suggest that flexural slip was the mechanism operative during development of kinks in the Arkansas Novaculite. Class 3 folding of shale reflects viscosity contrast between synchronously deformed rocks in the interbedded sequence, and complex folding of thin, isolated chert layers contained in shale beds can be explained by flattening during flexural slip of the more competent units. The folds discussed in this paper were probably formed during a single deformative event that accompanied northward thrust transport of major parts of the Ouachita orogen. Evidence for an earlier structural event at Caddo Gap (Zimmerman and Evansin, 1982) will be examined in a paper currently in preparation.

Some small-scale thrust faults may have formed at the same time as the kinks, but others cut across fold elements and are clearly of later origin. Much of the minor thrusting can probably be attributed to the clockwise rotation that resulted in the present spatial orientation of principal structural elements. This rotation affected a considerable volume of rock, and its origin is still a matter for speculation. It may have occurred as a result of ramping of several major thrust sheets during the main phase of thrust faulting. Evidence from fold and thrust geometry and mechanisms, together with the lack of significant regional metamorphism, indicates that the deformation recorded at Caddo Gap occurred at a relatively high level in the crust. The absence of younger, superimposed structures further indicates that it occurred during a late stage in the development of the Ouachita orogenic belt.

ACKNOWLEDGMENTS

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SOUTHERN SOURCE FOR UPPER JACKFORK SANDSTONE OUACHITA MOUNTAINS, ARKANSAS

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ABSTRACT

The upper Jackfork Sandstone of the southern Ouachita Mountains of Arkansas was derived from the same source terrain as the coeval Parkwood Formation of the Black Warrior basin. The source of both formations lay to the south and was composed of uplifted continental margin metasedimentary rocks.

The upper Jackfork Sandstone exposed at DeGray Dam, southeastern Ouachita Mountains, is a quartz arenite with only minor amounts of matrix, feldspar, and lithics. Coeval sandstones from adjacent basins which might be genetically related to the Jackfork are also highly quartzose. In this study (Owen, 1984) I have developed two techniques which make it feasible to compare quartz arenites and to test the probability that they have been derived from a common source area.

The upper Jackfork was compared with the Parkwood and the Pottsville Formations of the Black Warrior basin of Alabama and with collections of Chesterian-age sandstones from the Illinois basin, and the Caseyville Formation of the Illinois basin. Standard thin section petrography revealed excessively overlapping fields on a Qm-F-Lt ternary diagram (Fig. 1), thereby yielding no information about possible genetic affinities. In order to facilitate comparison of the five sandstones of this study, I employed cathodoluminescence of quartz and hafnium composition of zircons. Cathodoluminescence (CL) of quartz in any sandstone reveals two distinct color populations, brown and blue CL. The percentage of brown CL quartz in a sandstone is a reflection of the contribution of low-grade metamorphic source rocks to the sandstone; sandstones with statistically similar distributions of percent brown CL are potentially related to each other (assuming that paleogeographic constraints permit). Statistical analysis (oneway ANOVA, followed by Duncan's Multiple Range Test) of percent brown CL quartz distributions (Fig. 2) from 112 thin sections indicated that only the Parkwood shared a common source area with the Jackfork.

Detrital zircons in sandstone carry a compositional signature of the source terrain from which they were derived. The principal variable in zircon composition is the abundance of hafnium which substitutes for zirconium in solid solution. Hafnium composition was determined by electron microprobe for 1,595 zircons from the five sandstones of this study (Fig. 3). Statistical similarity of hafnium composition distributions indicates that only Jackfork and Parkwood zircons were derived from the same source rocks.

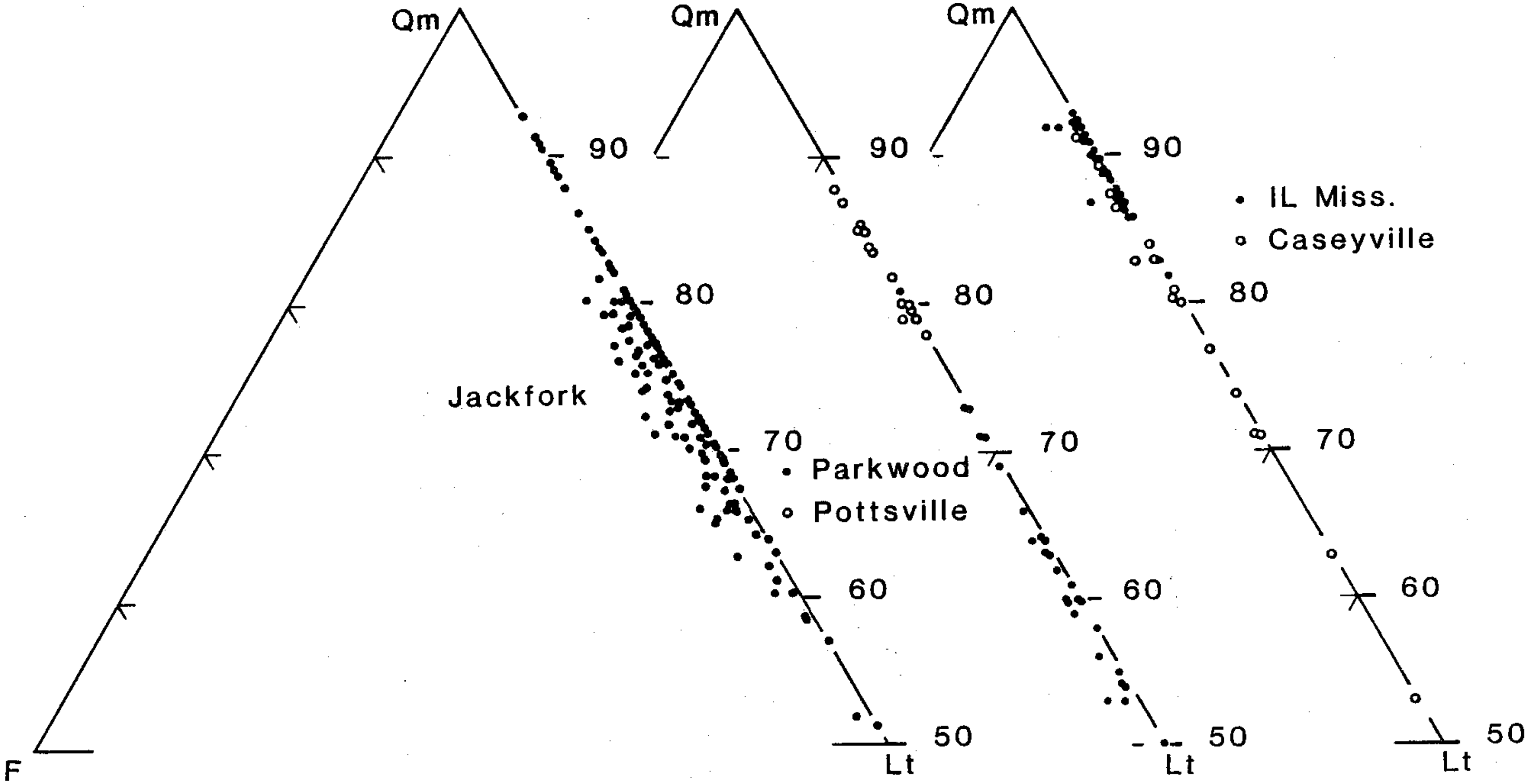

Figure 1. — Composition of 266 samples of sandstone from the Jackfork Sandstone and coeval units from adjacent basins. Values determined by point counts of 200—250 framework grains per thin section. Qm=monocrystalline quartz, F=total feldspar, Lt=total lithic fragments.

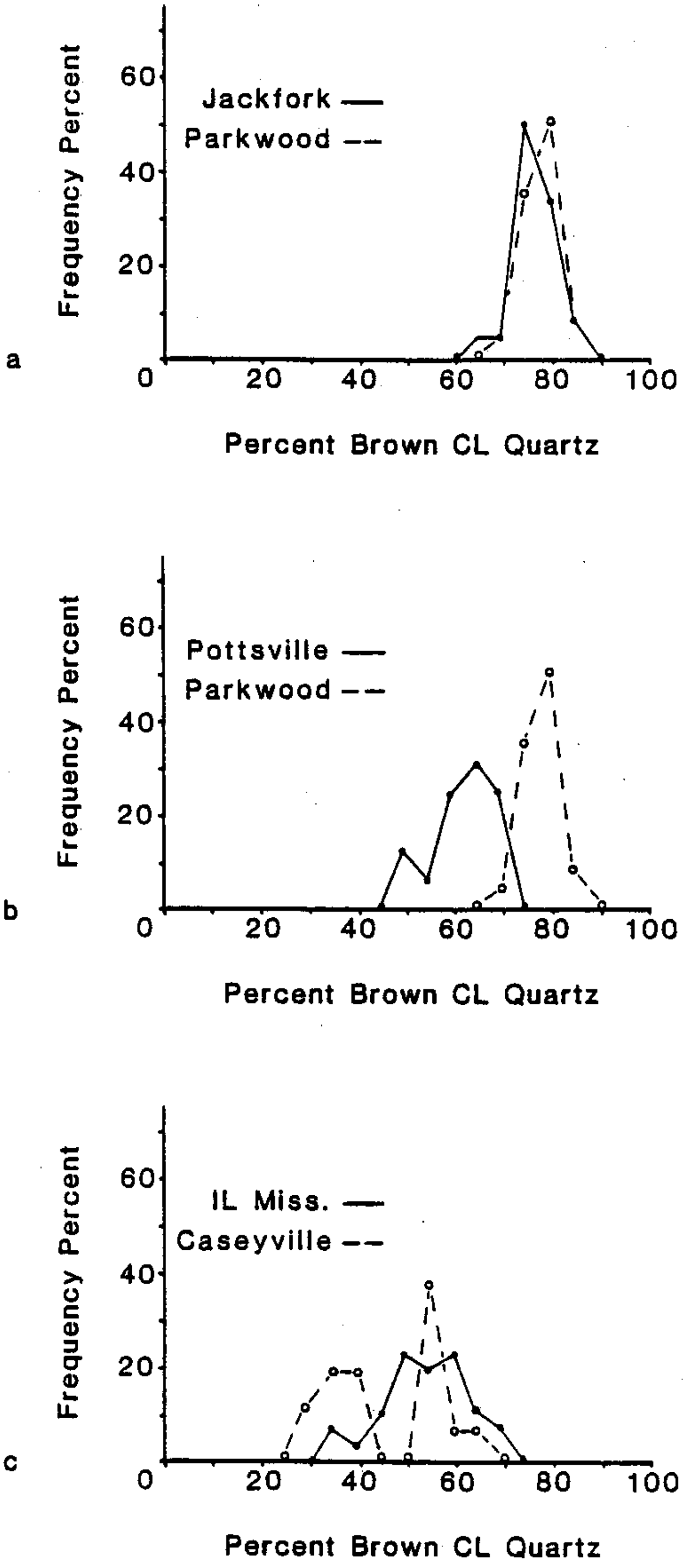

Figure 2. — Pairwise comparison of CL point count distributions.

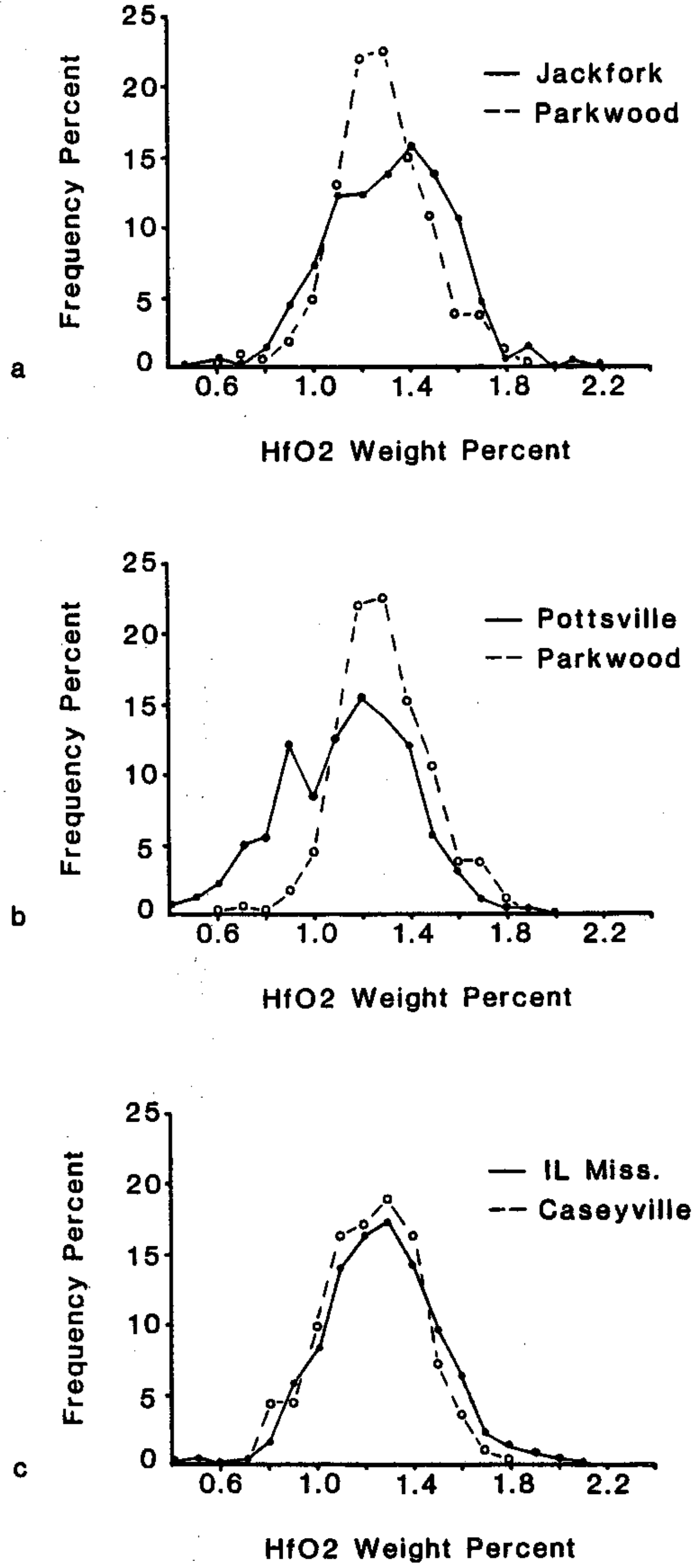

Figure 3. — Pairwise comparison hafnium content of zircons.

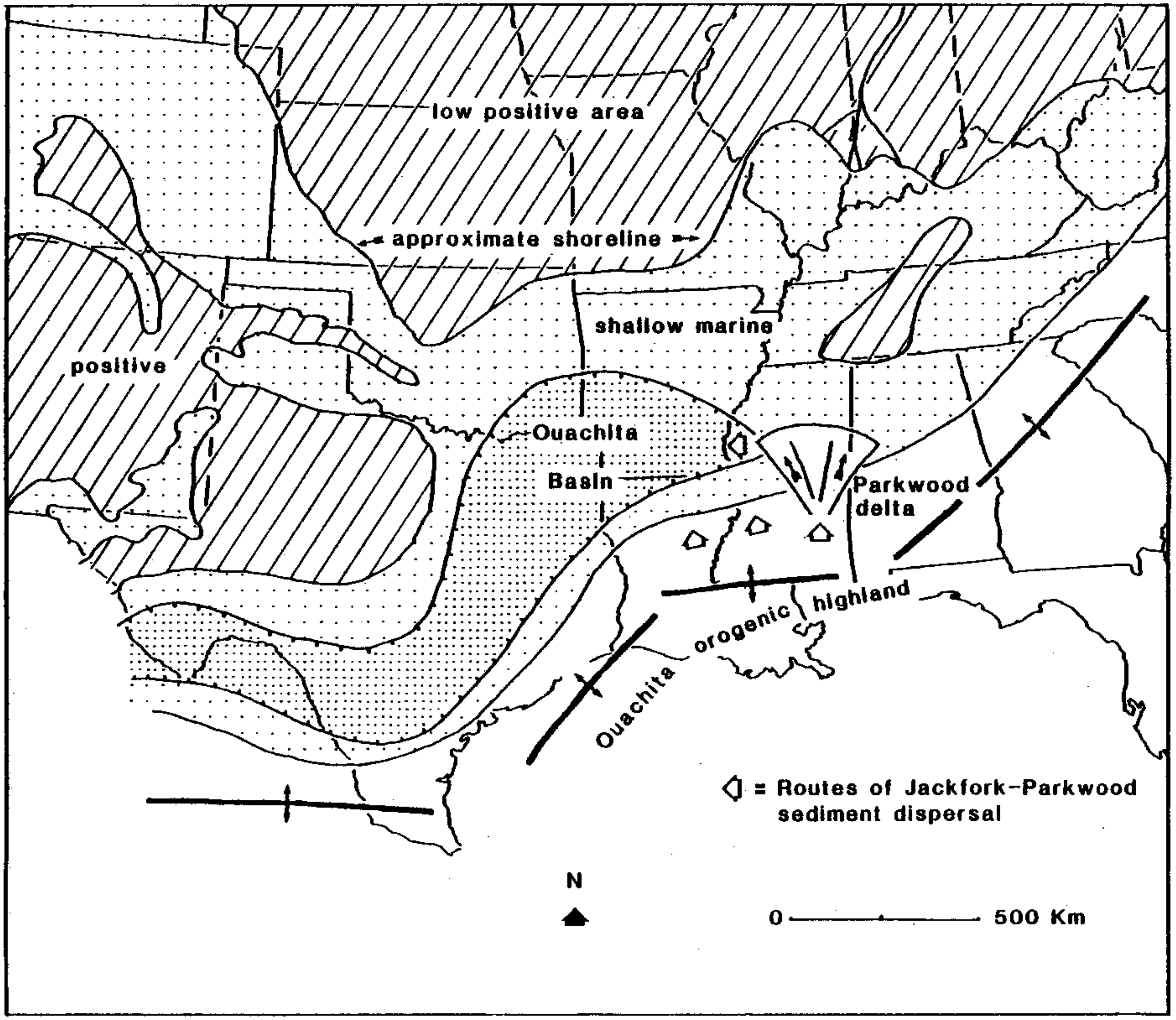

Figure 4. — Paleogeographic reconstruction of the Ouachita basin and surrounding area during late Chesterian and early Morrowan time.

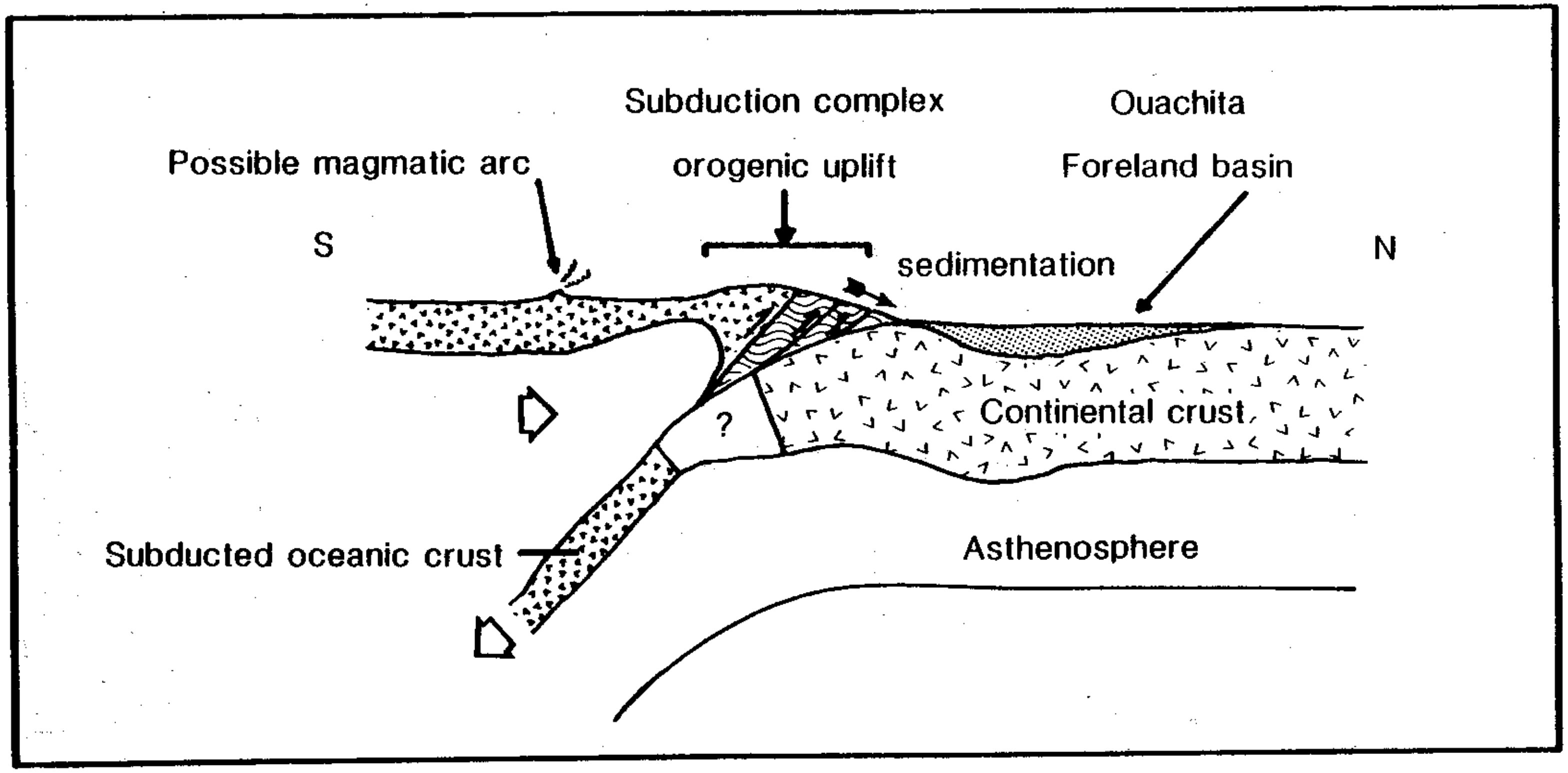

Figure 5. — Schematic geologic section across the Ouachita basin and adjacent orogenic uplift during deposition of the upper Jackfork Sandstone.

Thomas and Mack (1982) demonstrated that Parkwood sediments were derived from a source to the southwest of the present Black Warrior basin. A southern source area for the Jackfork was originally proposed by Miser (1921). Results of the present study demonstrate that both the Jackfork and the Parkwood were derived from the same source area. By accepting the work of Thomas and Mack for the Parkwood, my study supports Miser's proposal and suggests that both units had the same southern source area (Fig. 4).

The high percentage of brown CL quartz in the two formations, in conjunction with a predominance of micaceous rock fragments in the lithic suite in the two formations, and a near absence of feldspar suggest that the Jackfork-Parkwood source area was dominantly a low-grade metamorphic terrane and not an island arc. Therefore the Ouachita basin should be considered as a peripheral foreland basin whose sediment supply came from uplifted metasediments of the North American continental margin (Fig. 5). By this interpretation the Ouachita basin was floored by continental crust and its orogenic source area must lie to the south, beneath a thick cover of Coastal Plain sediments.

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U-Pb ZIRCON AGES OF GRANITIC BOULDERS IN THE ORDOVICIAN BLAKELY SANDSTONE, ARKANSAS AND IMPLICATIONS FOR THEIR PROVENANCE

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The occurrence and origin of beds of granitic cobbles and boulders in the Ordovician Blakely Sandstone in Saline and Garland Counties, Arkansas, has been the subject of much discussion. Of particular importance in determining the provenance of the granite boulders and cobbles is their age. Paleozoic Rb-Sr whole-rock ages from these boulders are not interpreted as crystallization ages (Denison and others, 1977), and thus three samples of granitic boulders and one sample of arkosic sandstone were collected from three localities for U-Pb zircon age determinations.

At the Uebergang uranium prospect in northern Saline County, Arkansas, numerous boulders and cobbles of granite and quartzite occur within the Blakely Sandstone in addition to a few cobbles of gabbro and porphyritic andesite. One granite boulder yielded abundant, euhedral, slightly discordant, zircons that have an age of 1284±12 Ma.

Two granite boulders were collected from the Blakely Sandstone at Coleman's (now Geomex) quartz mine west of Blue Springs, Garland County, Arkansas. One boulder, about 1 meter in diameter, is a coarse-grained granite which yielded abundant euhedral zircons that range from colorless to dark brown. Four fractions of both clear and brown varieties are moderately discordant and lie on a chord which yields an age of 1350±30 Ma. A boulder of medium-grained granite from the same outcrop yielded discordant zircons with an age of 1407±13 Ma.

Detrital zircons separated from a sample or arkosic Blakely Sandstone from northern Saline County yielded several distinct populations of zircons that range from round to euhedral. Preliminary analysis of both rounded and euhedral fractions indicates a source age for the zircons between 1300-1350 Ma.

Analysis of zircons from the Blakely Sandstone yields ages that range from 1286-1407 Ma, possibly corresponding to a 1350-1400 Ma terrane of epizonal granites and rhyolites that extends from the Texas panhandle through eastern Oklahoma (Thomas et al., 1984). Although there are no known exposures of Precambrian rocks in Arkansas, the 1350 to 1400 Ma old terrane has been extended into the subsurface of Arkansas based on aeromagnetic signatures (Thomas et al., 1984). The simplest interpretation of the age data derived from the Blakely Sandstone is that the granite boulders and arkose were derived from Precambrian basement to the north, perhaps along submarine fault scarps, as suggested by Stone and Haley (1977).

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BARITE IN THE WESTERN OUACHITA MOUNTAINS, ARKANSAS

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Barite or $BaSO_4$, a heavy nonmetallic mineral used primarily as a weighting agent in drilling for petroleum, has been identified at several localities on the south flank of the Ouachita Mountains (Fig. 1). The largest, Chamberlain Creek, is located near Magnet Cove on the east end of the Mazarn basin (Fig. 2). This property for a number of years was the largest producing barite mine in the world. On the west end of the Mazarn basin several barite occurrences have been identified west and north of Hopper, Arkansas in the Fancy Hill district. They are known as the Fancy Hill (Henderson), McKnight, Dempsey Cogburn, and Gap Mountain deposits. Barite also occurs near Pigeon Roost Mountain northeast of Glenwood and near Hatfield and Dierks, Arkansas.

The properties near Hatfield occur in the Middle Division of the Arkansas Novaculite as small stratabound lenses of coarsely crystalline black to gray-green barite. There are similar occurrences at Boone Springs and Polk Creek Mountain northwest of Fancy Hill. The occurrences at Dierks are Cretaceous gravels and sands cemented by barite. All of these latter barite occurrences seem to have limited economic potential so discussion in this paper will concentrate on the bedded barites at Fancy Hill, McKnight, Dempsey Cogburn, and Gap Mountain.

Regional Stratigraphic Relationships

The commercial bedded barite deposits of the western Ouachita Mountains are restricted to the lower 100 feet of the Stanley Shale immediately overlying the Arkansas Novaculite (Fig. 3). The novaculite is on the order of 900 feet thick in this area and consists of three units. The Lower Division is between 250 and 400 feet thick. The Middle Division is 210 feet thick at Fancy Hill, 390 feet thick at Gap Mountain, and 364 feet thick at Caddo Gap. The Upper Division is 70 feet thick at Fancy Hill, 120 feet thick at Gap Mountain, and 118 feet thick at Caddo Gap. The upper surface of the Novaculite in this area is an 18 inch thick rubbly broken zone, in places cemented by pyrite (Fig. 4). This zone is very well displayed at the Dempsey Cogburn mine on the exposed Novaculite wall and also at Chamberlain Creek. On a regional scale this stratigraphic horizon is represented by a chert pebble conglomerate of greatly varying thickness. At Hot Springs the zone is the Hot Springs Sandstone Member, which is mapped in the basal Stanley Shale. In the western Ouachitas the zone is from zero to 25 feet thick and consists of chert or novaculite clasts, usually one inch or less in size, in a siliceous matrix.

Above the Novaculite is the Stanley Shale, an approximately 6000-foot-thick (Scull, 1958) turbidite sequence of shale and sandstone. It represents a radical change in depositional character from the Novaculite. Deposition changed from the very slow accumulation of mud to a rapid accumulation of turbidites with perhaps a ten-fold increase in the rate of accumulation. The lower 100 feet of the Stanley, where the barite occurs, is primarily shale, but some lenses of dense gray sandstone are present, and they increase

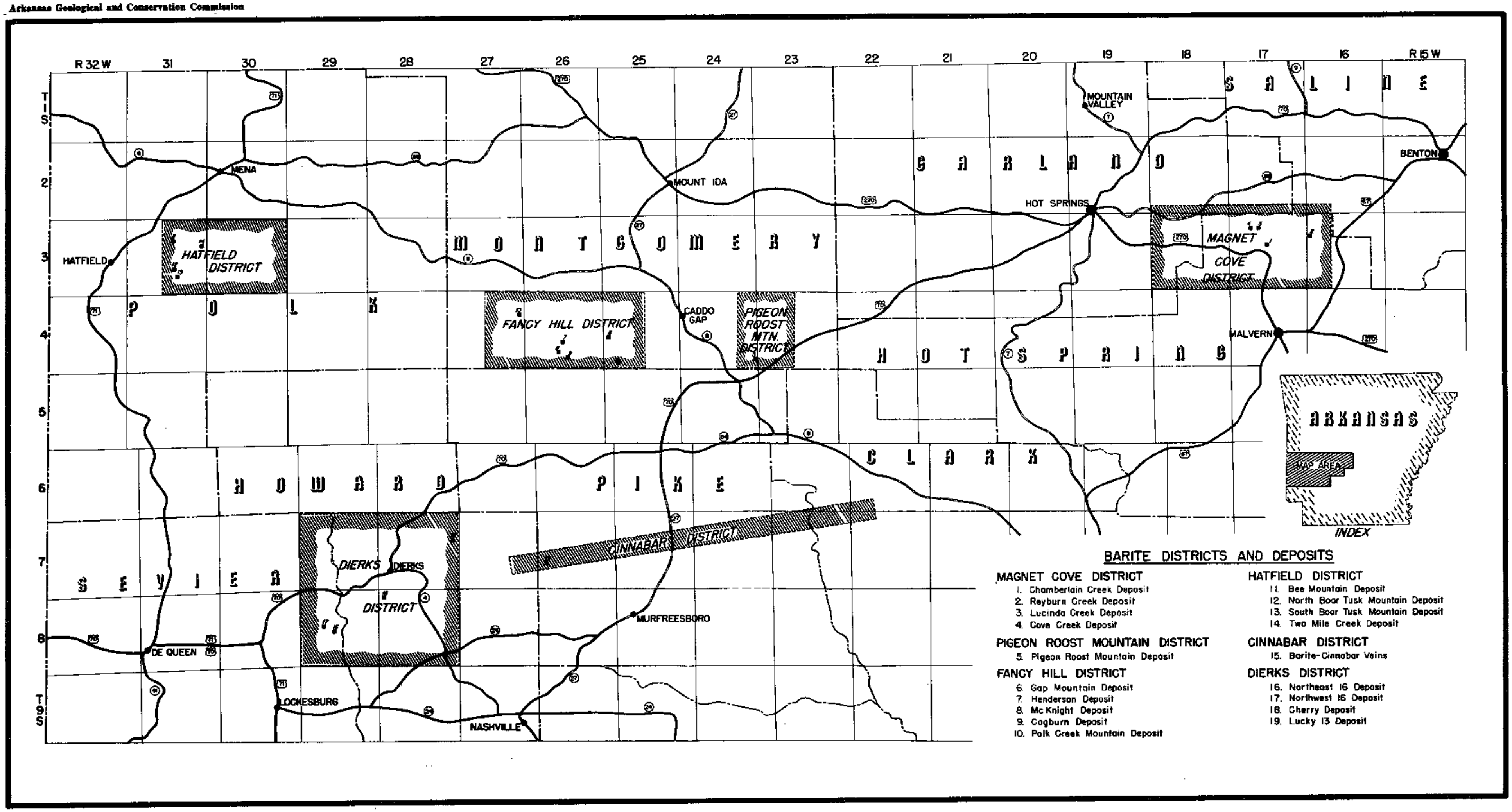

Figure 1. — Location map showing barite districts and larger known deposits in the Ouachita Mountains, Arkansas (from Scull, 1958).

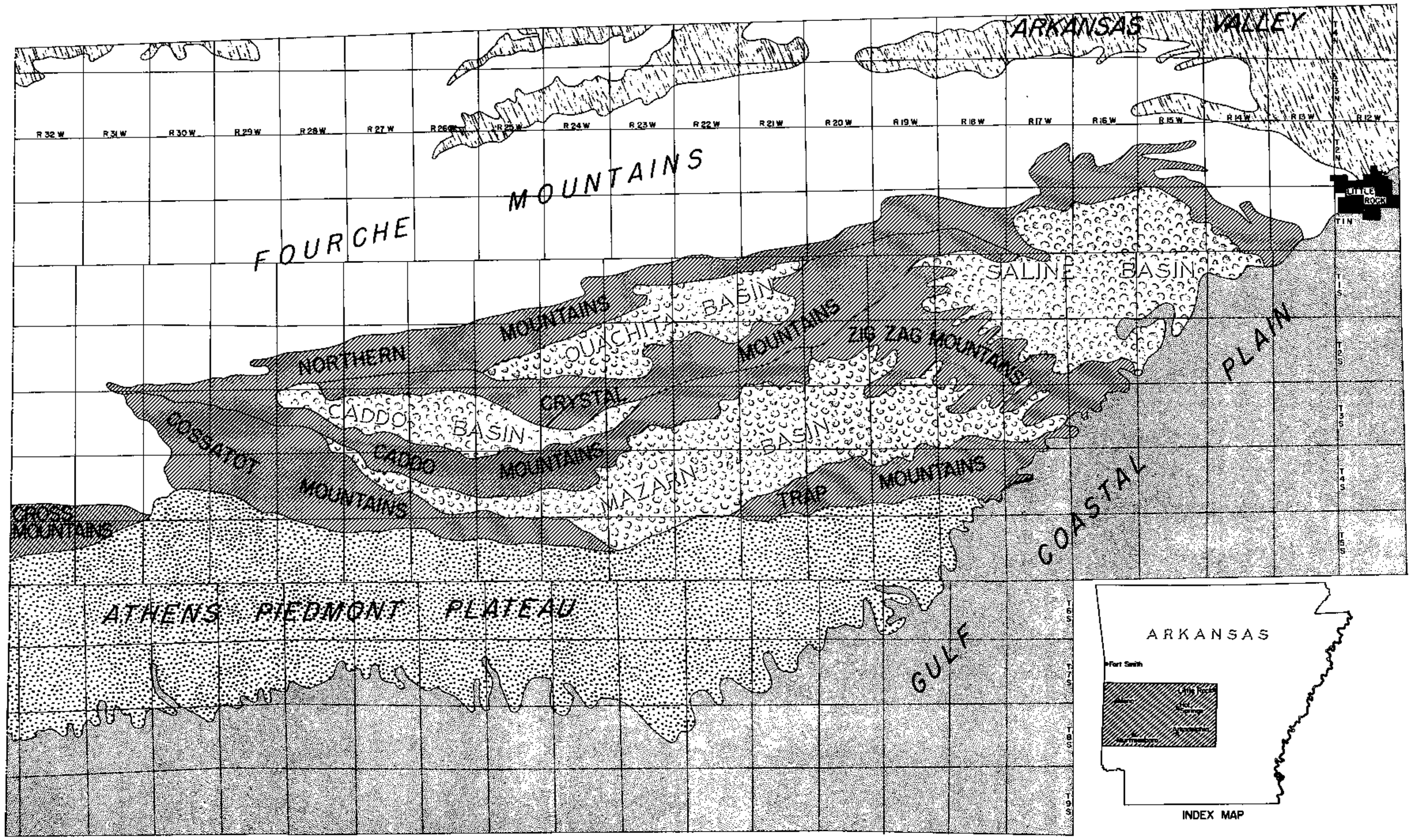

Figure 2. — Map showing physiographic provinces in the Ouachita Mountains, Arkansas (from Scull, 1958).

- Mesozoic
  - Upper Cretaceous
    - Woodbine formation—tuffaceous sands and clays
  - Lower Cretaceous
    - Trinity formation—Pike gravel member at base, overlain by loosely consolidated sandstones with Dierks and DeQueen limestone lentils, some gypsum and celestite beds, maximum thickness 600 feet.
- Paleozoic
  - Pennsylvanian
    - Jackfork sandstone—thick massive sandstone units separated by thinner and less extensive shale units, maximum thickness 6000 feet.
  - Mississippian
    - Stanley formation—gray-green weathering dark gray shale with thick siltstone and sandstone members, locally tuff beds near base, maximum thickness 6,000 feet.
  - Devonian-Mississippian
    - Arkansas novaculite
      - Upper Division—tan to gray massive calcareous novaculite, locally quartzitic, maximum thickness 120 feet.
      - Middle Division—thin-bedded dark colored novaculite and shale, maximum thickness 450 feet.
      - Lower Division—white to gray, dense, thick-bedded novaculite, maximum thickness 450 feet.
  - Devonian
    - Missouri Mountain shale—black, green and red fissile shale, maximum thickness 300 feet.
  - Silurian
    - Blaylock sandstone—tan to gray, fine to medium-grained, thin to medium-bedded quartzitic sandstone, intercalated gray to black graptolitic shale, maximum thickness 1500 feet.
  - Ordovician
    - Polk Creek shale—contorted and crumpled black graptolitic shale, maximum thickness 300 feet.
    - Bigfork chert—gray to black medium-bedded chert, thin black graptolitic shale partings, strongly crumpled, maximum thickness 800 feet.

Figure 3. – Stratigraphic column for the Ouachita Mountains, Arkansas (from Scull, 1958).

Figure 4. — Novaculite breccia at the top of the Upper Division of the Arkansas Novaculite at the Dempsey Cogburn mine. The face on the right is a cross fault showing novaculite below the breccia zone.

upward from the barite.

One interesting stratigraphic relationship in this area which should be mentioned is the rapid thinning of the Blaylock Sandstone. Just south of the Dempsey Cogburn mine the Blaylock is about 600 feet thick and only three miles north it is absent.

Structure

The rocks are folded into a series of tight isoclinal folds which trend east-west. South of Fancy Hill the folds have broken along axial planes into a series of stacked thrust sheets which repeat the section several times. The sheet containing barite south of Fancy Hill appears to have torn into several pieces. Seismic work has shown that the barite on Fancy Hill forms a synclinal trough in the Back Valley to the south (Fig. 5).

The rapid thinning of the Blaylock from 600 feet to zero in three miles indicates that a growth fault was present through this area during Silurian time. Another indication of a possible deep structure is the presence of hot springs at Caddo Gap, also two miles southwest of Caddo Gap, and 3½ miles west of Fancy Hill. There are also two igneous dikes in the area, one at Pigeon Roost Mountain and in Long Creek near the last hot spring mentioned.

The presence of the barite, hot springs, dikes, and the thinning Blaylock all seem to point strongly toward a growth fault, which was active during Silurian time and reactivated at the end of Novaculite time. This reactivation caused the brecciation of the upper surface of the Novaculite and provided the conduit for hydrothermal fluids which precipitated sulfides in the form

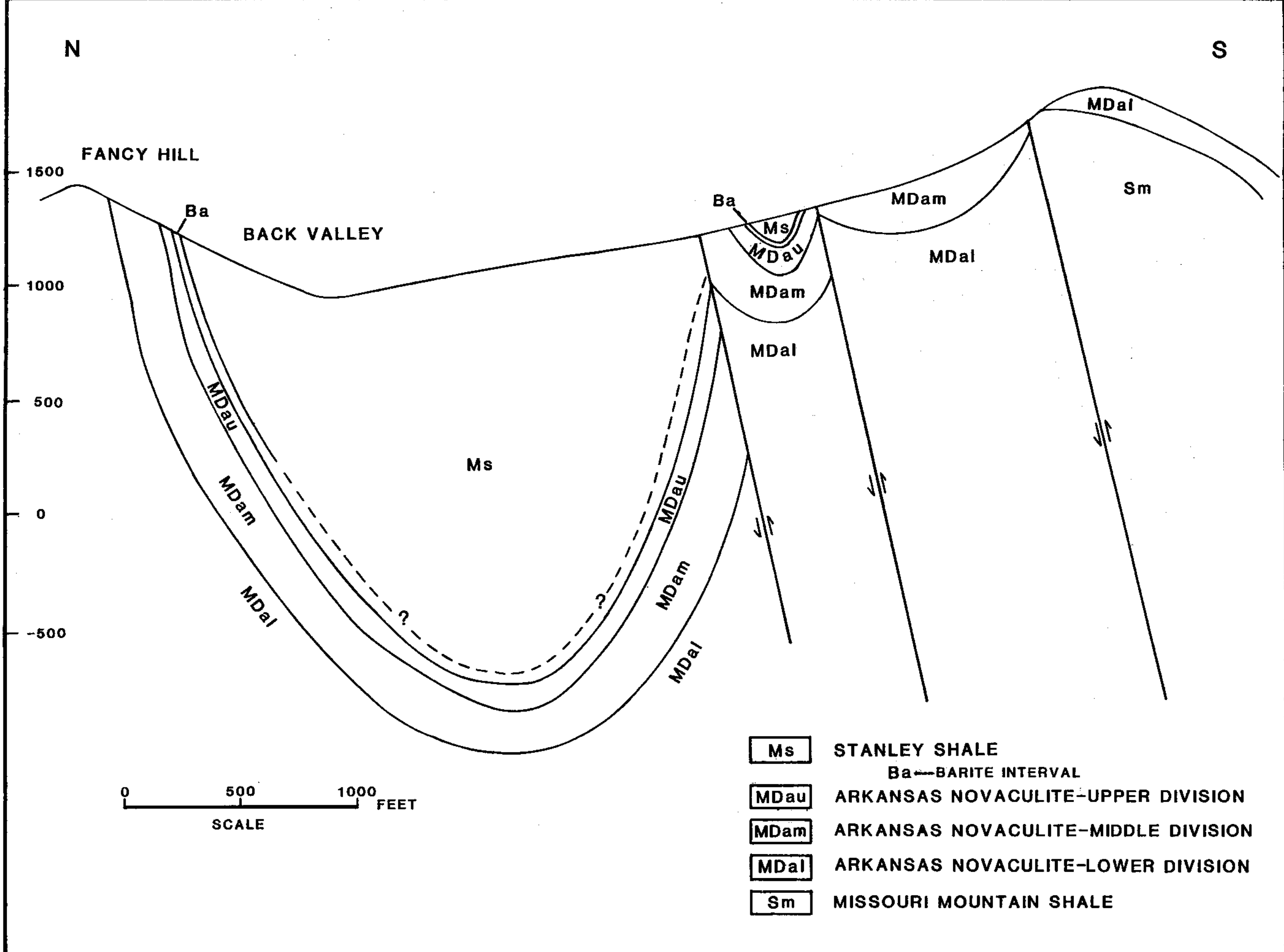

FIGURE 5: Section across Back Valley showing the generalized geology of the area (modified from E. F. Lawrence).

of pyrite, and later, barite. The growth fault also provided the relief necessary to form the chert pebble conglomerates and the Hot Springs Sandstone which probably accumulated as lobes at the base of canyons cutting across the escarpment (Fig. 6). Since this growth fault was a zone of weakness, it probably broke as a thrust fault during compression, and therefore cannot now be identified.

Orebodies

The barite deposit at Fancy Hill follows a nearly straight line along the south side of Fancy Hill for over 9000 feet and dips to the south at 80 degrees. A series of northeast trending cross faults of generally small displacement have offset the beds from one to ten feet, but in a few places much larger displacements can be seen.

The footwall of the deposit is primarily shale, 2 to 50 feet thick. On the east end barite rests on sandstone. The shales in places are highly carbonaceous and pyritic. Above the barite 10 to 40 feet of shale are overlain by gray sandstones.

The barite zone averages 15 or 20 feet in thickness, but varies from 0 to 40 feet. Three types of barite are common in the ore: (1) massive, finely crystalline gray to black ore of generally high grade (60–80% $BaSO_4$), (2) masses of coalesced nodules which form a solid layer of barite (40–50% $BaSO_4$), and (3) scattered nodules in shale (0–40%

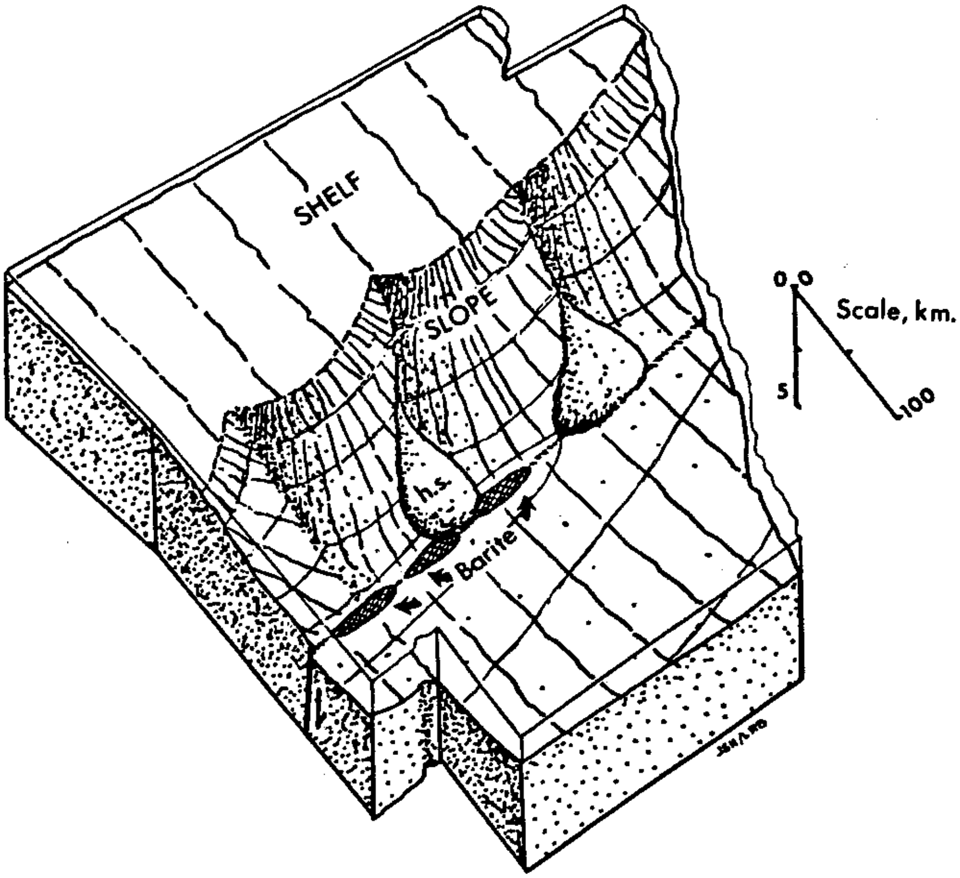

Figure 6. — Conceptual model showing the Hot Springs Sandstone Member (h.s.) and the growth fault along which hydrothermal fluids migrated to form pyrite and barite (modified from Hanor and Baria, 1977).

$BaSO_4$). Some fractures across the barite also contain crystals of barite up to two inches across.

Along strike the barite pinches and swells to form several distinct lenses of ore. Between the lenses, weak nodular zones can be seen in the shales. Down dip the continuity of the ore has been proven to depth of at least 600 feet. Toward the west two ore layers occur separated by interbedded shale and sandstone.

Origin

Based on the structural and stratigraphic features of the barite deposits, it appears that they are very much like the barite deposits of the Selwyn Basin in the Yukon Territory of Canada. In both areas the barite occurs in a sequence of rocks which represent initially a very quiescent depositional environment followed by growth faulting and deposition of sulfides and barite. In the Ouachita Mountains the growth faulting caused the brecciated upper surface of the Novaculite and provided the relief to form the chert pebble conglomerate and the Hot Springs Sandstone. It also provided a conduit for the hydrothermal fluids from which the barite precipitated. The barite probably formed in small local depressions in the seafloor which occasionally received influxes of mud and sand. The quality of the ore depended on the balance between barite and sediment influx; high-grade massive barite formed when sediment influx was near zero; as the rate of deposition increased, the quality would decrease and a more nodular ore would result; when shale completely overpowered the barite deposition, or barite influx decreased, then more sparsely nodular material was formed.

Since the Canadian occurrences are also associated with lead-zinc-silver deposits, there has been some interest in examining this area for metals. Since the structural and stratigraphic settings are so similar, this basin appears to be a good target for further metal exploration based on the sedimentary exhalative model.

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