GB 94-1

STATE OF ARKANSAS
ARKANSAS GEOLOGICAL COMMISSION

Norman F. Williams, State Geologist

GUIDEBOOK TO
PALEOZOIC ROCKS IN THE EASTERN OUACHITA MOUNTAINS
ARKANSAS

By

CHARLES G. STONE, BOYD R. HALEY, AND MILFORD H. DAVIS

With Contributions

By

JOHN E. REPETSKI, R.L. ETHINGTON, JAMES STITT,
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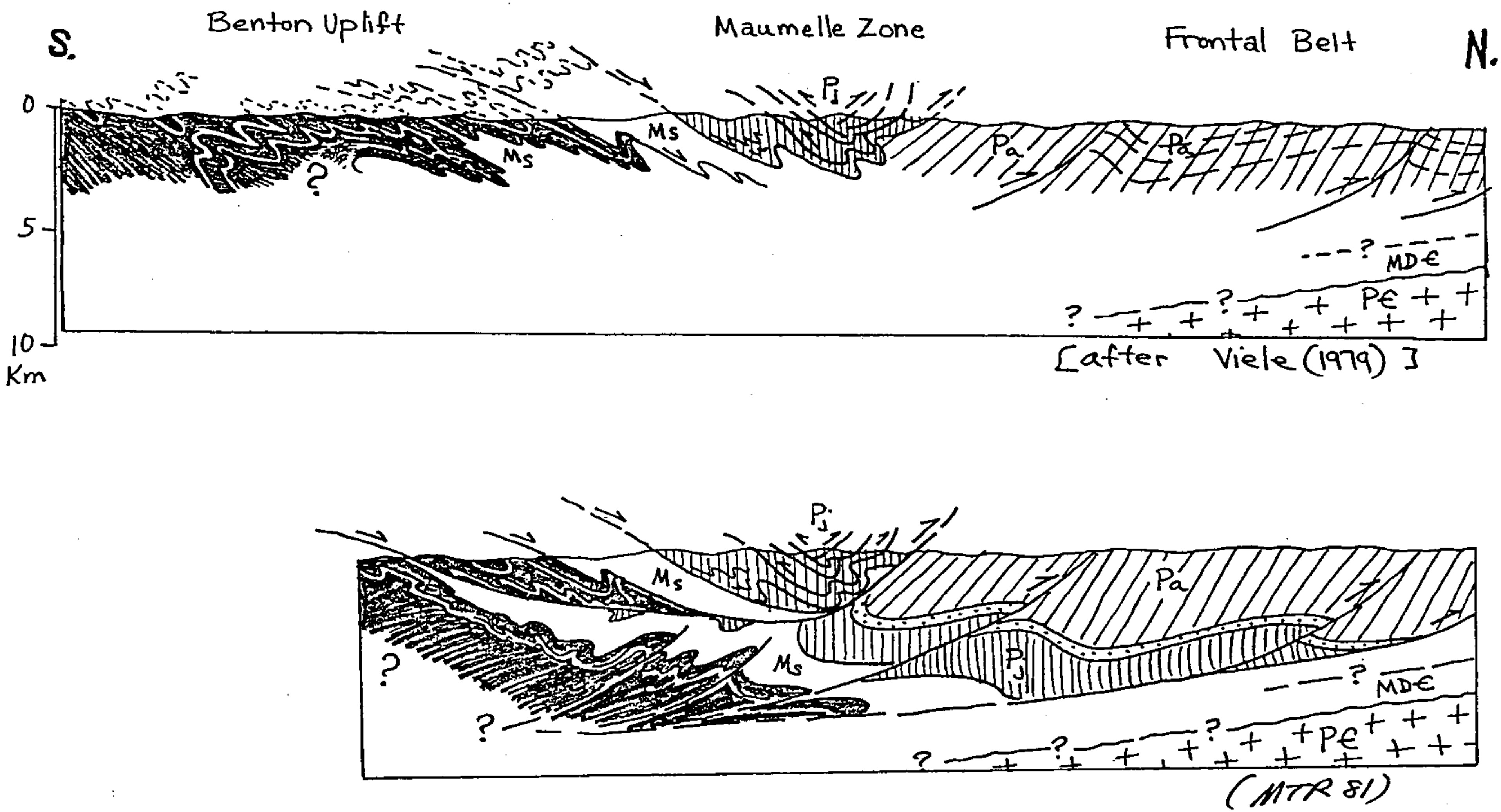
CORRELATION OF PALEOZOIC ROCKS IN THE OZARK, ARKANSAS VALLEY, AND OUACHITA MOUNTAIN REGIONS, ARK.

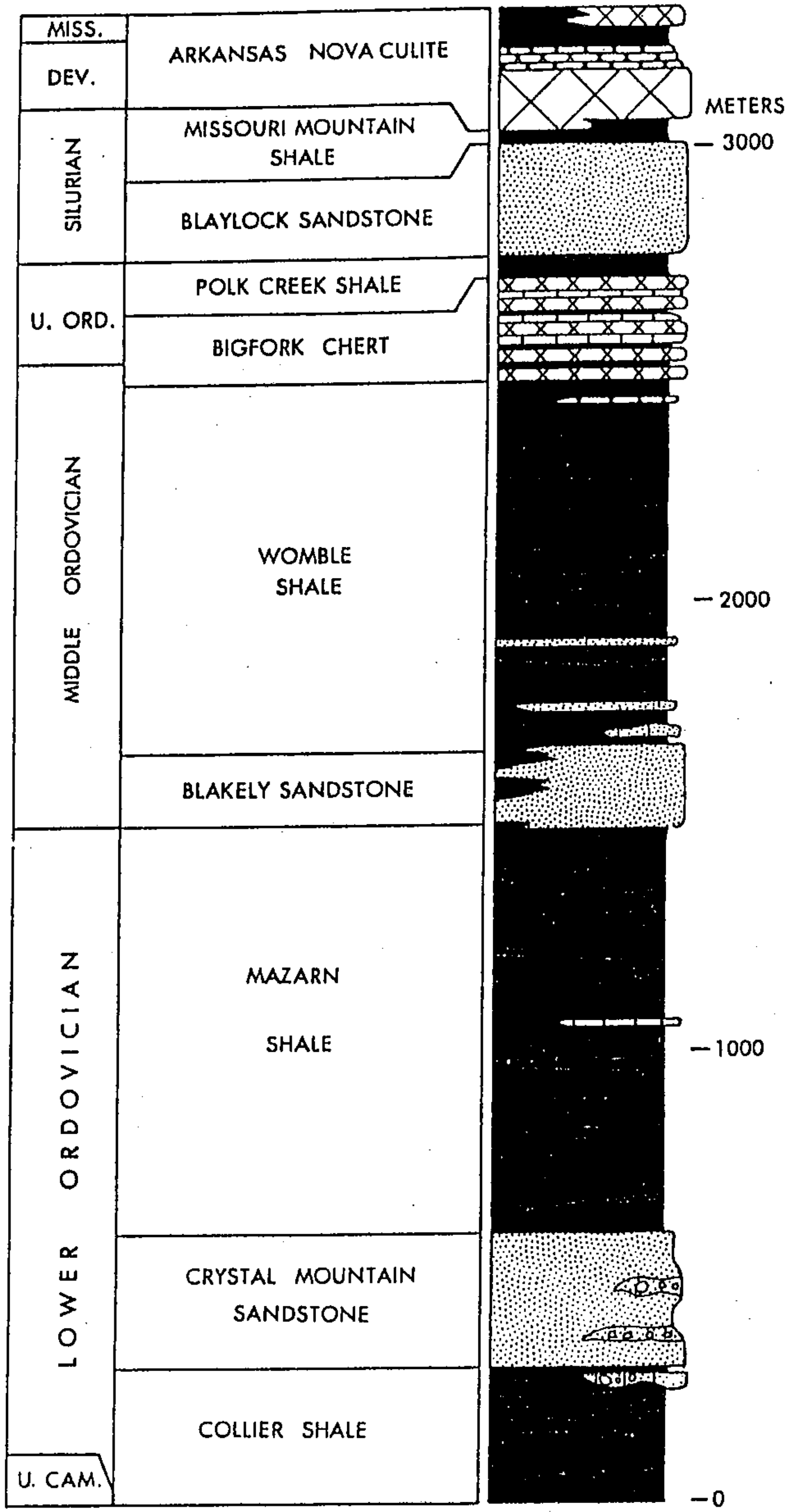
AGE			OZARK – ARKANSAS VALLEY SECTION		MAP SYM.		OUACHITA MTN. SECTION		MAP SYM.
CARBONIFEROUS SYSTEM	PENNSYLVANIAN	DES MOINES	Boggy Fm.		IPby		Missing		
			Savanna Fm.		IPsv				
			McAlester Fm.		IPma				
			Hartshorne Sandstone		IPhs				
		ATOKA	Atoka Fm.		IPa		Atoka Fm.		IPa
		MORROW	Bloyd Shale,	Kessler Ls. Mbr.	IPbh	IPbk	Johns Valley Shale		IPjv
				Woolsey Mbr.		IPbw			
				Brentwood Ls. Mbr.		IPbb	Jackfork Fm.		IPj
			Hale Fm.	Prairie Grove Mbr.		IPhp			
				Cane Hill Mbr.	IPhc				
	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			Hatton Tuff	
			Moorefield Fm.		Mm			Hot Springs SS Mbr.	
		LOWER	Boone Fm.	Short Creek Oolite Mbr.	Mb		Arkansas Novaculite	Upper Div.	MDa
				St. Joe Ls. Mbr.					
			Chattanooga Shale		MDcp			Middle Div.	
DEVONIAN		UPPER		Sylamore SS					
		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				Polk Creek Shale		Opc
			Fernvale Limestone		Of		Bigfork Chert		Obf
		MIDDLE	Kimmswick Limestone		Ocj				
			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		Collier Shale		O€m
			Gasconade-Van Buren Fm	Gunter Mbr.					
CAMBRIAN		UPPER	Eminence Dolomite						
			Potosi Dolomite						
			Derby-Doerun-Davis Fm.				Basal Collier and Older rocks not exposed		
			Bonneterre Dolomite						
			Lamotte Sandstone						
PRE-C			Igneous Rocks						

STRATAGRAPHIC 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'
TERTIARY SYSTEM	
Wilcox Group - clay, sand, lignite, bauxite	120'
Midway Group - marl, limestone, shale	75'
CRETACEOUS SYSTEM	
Tokio Formation - gravel, sand, clay	300'
Brownstown Marl - gravel, sand, marl, and clay	250'
Igneous rocks - nepheline syenite, phonolite, ijolite, peridotite, kimberlite	--
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, some chert and minor tuff	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	900'
Blakely Sandstone - shale, sandstone, and erratic boulders	450'
Mazarn Shale - shale with some sandstone and limestone	3,000'
Crystal Mountain Sandstone - sandstone, shale and erratic boulders	850'
CAMBRIAN AND ORDOVICIAN SYSTEMS	
Collier Shale - shale and limestone	1,000'



CROSS SECTION OF G. W. VIELE AND ALTERNATE INTERPRETATION OF M. T. ROBERTS IN EASTERN OUACHITA MOUNTAINS.



MISS.
DEV.
ARKANSAS NOVA CULITE
SILURIAN
MISSOURI MOUNTAIN SHALE
BLAYLOCK SANDSTONE
U. ORD.
POLK CREEK SHALE
BIGFORK CHERT
MIDDLE ORDOVICIAN
WOMBLE SHALE
BLAKELY SANDSTONE
LOWER ORDOVICIAN
MAZARN SHALE
CRYSTAL MOUNTAIN SANDSTONE
COLLIER SHALE
U. CAM.
METERS
3000
2000
1000
0

CONTENTS

FOREWARD

This guidebook provides information on selected outcrops of mostly early Paleozoic rocks in the Benton uplift and "Maumelle chaotic zone" in the eastern Ouachita Mountains of Arkansas. The purpose of the trip is to demonstrate the intensity and styles of deformation in various structural belts, show the distinctive lithologies, discuss the depositional environments, and to define the biostratigraphic framework. Some emphasis is placed on the formation of late Paleozoic hydrothermal quartz veins, and Late Cretaceous igneous intrusives. Some examples of pre-Tertiary and Tertiary weathering and overlap are visited.

The traverse begins in the frontal Ouachita Mountains and "Maumelle chaotic zone" at Little Rock, proceeds west-southwest through the Benton uplift to Jessieville, Garland County, and then returns east via another route to Little Rock. We will visit exposures of Lower Pennsylvanian through Upper Cambrian mostly pre-orogenic strata at some 13 scheduled stops. The classic exotic-bearing, proximal fan-channel deposits in the Crystal Mountain Sandstone at the Ron Coleman quartz crystal mine should be a highlight!

Our deepest gratitude is expressed to the many investigators who have contributed to the better understanding of the rocks in this area. We wish to make a special acknowledgement of Hugh D. Miser (deceased), U.S. Geological Survey, G.W. Viele, University of Missouri, Columbia, MO, and J.K. Arbenz, Boulder, CO. We are indebted to George W. Colton, who assisted with many of the editorial chores and to Norman F. Williams and William V. Bush who made it all possible. We thank Adrian Hunter, Lynn Kover, Susan Young, and Walter Mayfield of the Arkansas Geological Commission for their diligent efforts in the compilation of this volume.

Sincere thanks are expressed to all the individuals who have granted us permission to be on their property or who have been of assistance in other ways! Some of these people include: Jeanie Leonard, Baseline Transport, Inc.; Farrell Beck, Nance, AR; Gayle Oglesby, Joanna Williams, and Ernie Deaton, Hot Springs Village; Clyde Dickson, Valley Gravel Company; Ron Coleman, Ron Coleman Quartz Company; Jim Coleman, Jim Coleman Quartz Company; and many others.

Charles G. Stone
Boyd R. Haley
March 20, 1994

MAUMELLE CHAOTIC ZONE

by

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The Maumelle chaotic zone is a narrow band of highly complex structures and stratal disruption that lies between the frontal thrust belt and the Benton uplift of the Ouachita Mountains. The zone contains several, well exposed terranes gradational with one another both across and along strike and can be traced from Little Rock, Arkansas westward into southeastern Oklahoma. The terranes include: belts of structurally coherent strata; belts of pervasively disrupted strata; and belts of penetrative folding and cleavage. Several workers (Viele, 1979; Viele and Thomas, 1989; Nielsen and others, 1989) have attributed many of the structural features in the Maumelle zone to stratal disruption by tectonic melange at the toe of an accretionary wedge.

Figure 1 shows two regional tectonic components in the area, each with its own distinct structural style. In some terranes the sedimentary strata show only slight deformation in that the structural style is one of broad open folds, gently dipping strata, and locally fractured rocks. In adjacent more chaotic terranes, the strata are pervasively disrupted and sheared. Isolated folds of sandstone are scattered in a scaly shale matrix and show no apparent genetic relationship to adjacent, undeformed beds. The extent of the individual zones of stratal disruption is difficult to map due to limited exposures. Fortunately, the coherent terranes provide better control and have areal extents ranging from a few meters to several square kilometers.

STRUCTURAL FABRICS

Planar Surfaces

The dominant planar surface within the less deformed sequences of the Maumelle zone is the original bedding (S_0). In thin section, S_0 is defined by sandstone or siltstone laminae containing detrital grains of quartz with minor amounts of detrital phyllosilicates. In the shales, the foliation is a weak compaction parting of aligned clay minerals. Most of the grains do not show any deformation features except for diagenetic compaction and local dissolution.

Within the chaotic belts, the S_0 layering is transposed into parallelism or near parallelism with the fold axial planes and the original stratification is lost. The most pronounced planar fabrics in these belts are S_1 and S_2. These are defined in a similar fashion as Byrne's (1984) classification of structural elements within the Ghost Rocks Formation of Kodiak Island, Alaska.

The transposed layering (S_1) is defined by compositional layering and an alignment of rock inclusions or blocks. Thin laminae forming a tracery of siltstone indicate transposed stratification, original bedding that has been folded and thinned. The laminae commonly increase in grain size and thickness along their trend, forming pinch and swell structures. At the microscopic scale, the S_1 foliation appears as a thin, fine-to very fine-grained siltstone or sandstone lamination interlayered with mud or shale. Aligned boudins commonly lie within planes that define the S_1 foliation, which, in turn is subparallel to a weak, scaly parting in the

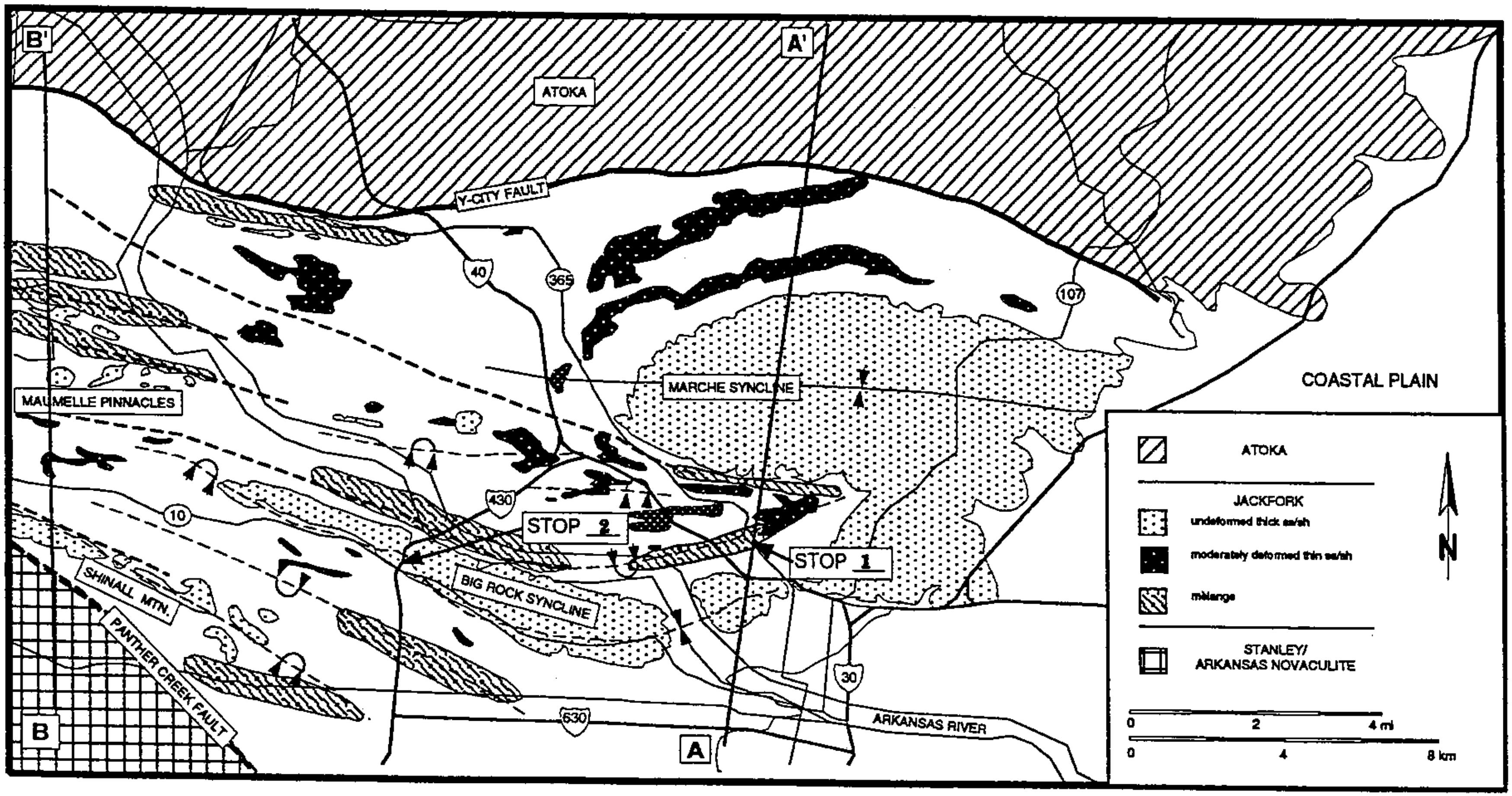


Figure 1. Geologic structure map of the Maumelle Zone, Eastern Ouachita Mountains, showing locations of Stop 1 and Stop 2. The locations of cross sections A-A' and B-B' are also indicated.

host matrix. Typically, the boudins form pull-apart trains of the original bedding. Pre-existing sedimentary structures are generally truncated against the margins of boudins, indicating that the sediments were partially lithified prior to extension.

Th S_2 foliation is a north-dipping, pressure-solution cleavage. On a regional scale, the cleavage is best developed in the shales and siltstones, but it can be found locally within thin sandstone beds. In some outcrops, S_2 parallels bedding and is difficult to separate from it. In the highly disrupted zones, the S_2 foliation forms an anastomosing network of surfaces that imparts a "phacoidal cleavage" to the matrix. Contained within this fabric are aligned lens-shaped clasts of shale and mudstone, which commonly show striated and polished surfaces and have dimensions in millimeters and centimeters.

In thin section, the S_2 foliation is characterized by an anastomosing solution cleavage. The foliation is limited mostly to zones of stratal disruption, but some of the shale intervals along the margins of the coherent units show development of a cleavage foliation. The foliation is defined by seams of dark organic material that develop along the margins of quartz grains and siltstone phacoids. The seams vary in width and spacing and appear best developed in fine siltstone or shale laminae.

Web Structure

Some of the sandstone blocks show an anastomosing array of fractures that may or may not be penetrative at the mesoscopic scale. In some extended beds, the fractures appear as dark veins that dissect the rock but more coherent sandstones show light-colored veins reflecting a lesser amount of clay material along the fractures. These fractures give a web-like structure (Cowan, 1982) to the rock that has been interpreted to reflect tectonic dewatering of the sediments along preferred cataclasite zones. Similar fractures have been described in the Maumelle zone of eastern Oklahoma.

Tectonic Origin of the Maumelle Zone

Two schematic cross sections of the eastern Maumelle zone show the regional structure (Fig. 2). Cross-section A-A' runs N-S through the eastern half of the field area and shows the structural style of the macroscopic fold systems. Cross section B-B' shows a N-S profile through the western half of the area and shows the deeper portions of the regional structure.

The belts of stratal disruption are restricted to the macroscopic anticlinal regions of the field area, particularly along the limbs of the folds. This suggests that the stratal disruption may be genetically related to the regional folding. Generally, the limbs of the anticlines are characterized by thick shaly intervals where original stratification is completely masked by the S_1 and S_2 foliations, resulting in sandstone blocks isolated in a scaly shale host.

In a summary of the tectonic history of the Ouachita Mountains, Viele and Thomas (1989) have argued that the abyssal sediments composing the Benton and Broken Bow uplifts were stacked in an accretionary prism above oceanic crust as the North American plate was being subducted southward. The basin developed into a narrow trough, in which flysch deposition was restricted to two regions; behind the accretionary prism in the fore-arc basin, and along the trench in front of the prism. The accretionary prism finally was thrust onto the North American plate during the Ouachita orogeny. DSDP studies of modern accretionary prisms indicate that the greatest deformational strains occur at or adjacent to the toe of the accretionary prism (Moore and others, 1982; Moore and others, 1986). If the Benton and Broken

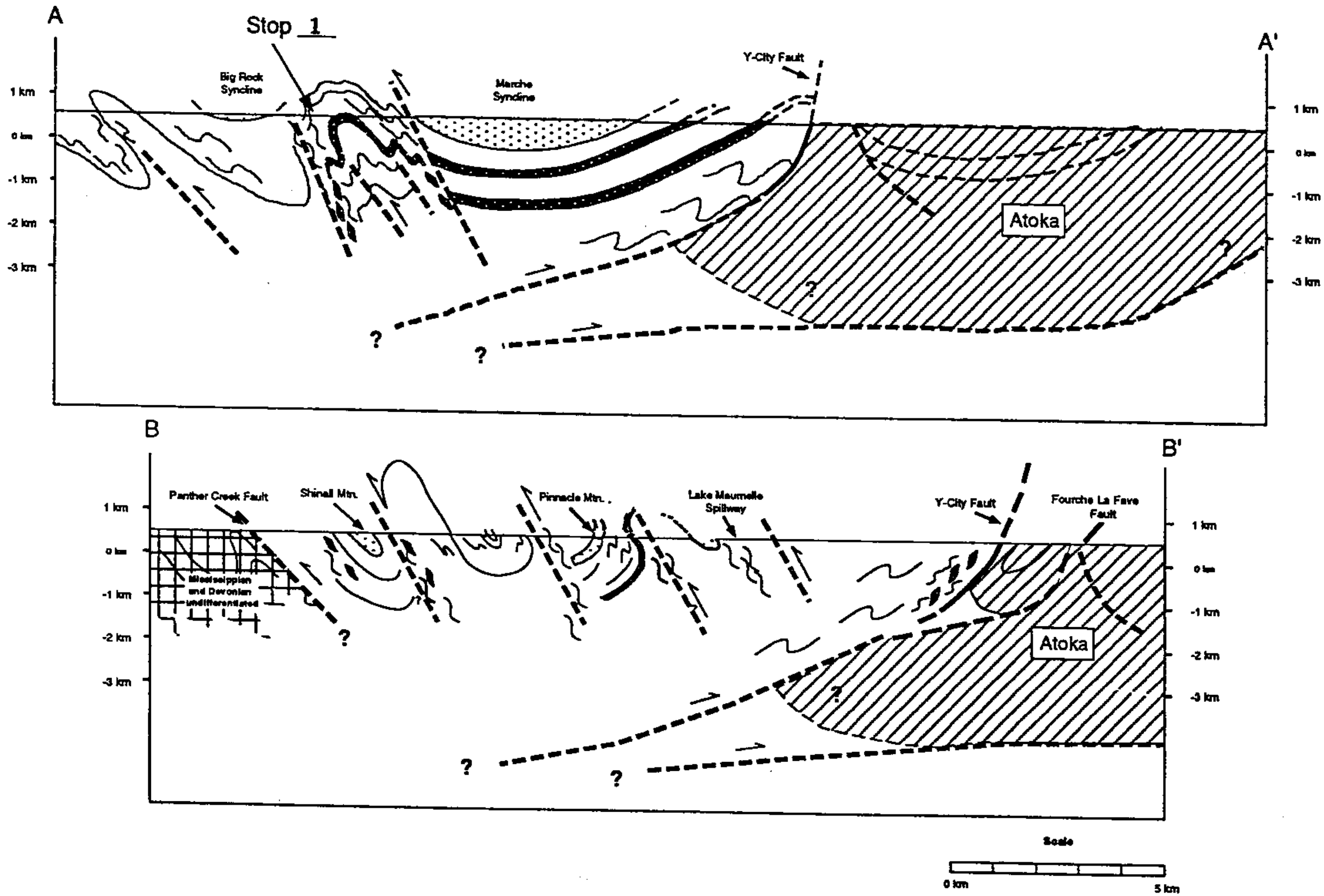


Figure 2. Schematic cross sections through the eastern Maumelle zone. Refer to Fig. 1 for location of section lines.

Bow uplifts are made up of abyssal sediments stacked in an accretionary prism, the Maumelle chaotic zone conceivably is positioned where the highest strains were concentrated. This would suggest that the zones of stratal disruption are tectonic in origin, analogous to the tectonic melanges that have been recognized in modern and ancient accretionary complexes. Similar fabrics as those found in the Maumelle zone have also been described in tectonic melanges on Kodiak Island, Alaska, the Barbados Ridge, the Franciscan of California, and the Taconic melanges of New York (Behrmann and others, 1988; Byrne, 1982a; Byrne, 1984; Moore, J.C., Mascle, A., et al., 1988; Bosworth and Vollmer, 1981; and Lash, 1985, 1987).

The structural vergence in the Maumelle zone mimics landward vergence in the collision model of Needham and Knipe (1986). This model relates to thrusting of an accretionary wedge onto continental crust. Continental basement acts as a barrier and inhibits slip between the two plates. Displacement is accommodated by backthrusting and a reverse in structural geometry, creating a regional "pop-up" structure (Fig. 3). These later collision-related structures are superimposed onto the earlier structures. South-verging structures in the Benton uplift developed during the collision of the Ouachita prism with North American continental crust. This deformation phase caused backfolding of earlier duplex structures formed during initial subduction (Viele and others, 1985). This implies that the melanges in the Maumelle zone may have formed prior to the collision as north-verging structures and were later backfolded in a similar manner as the sediments were thrust onto North American continental crust.

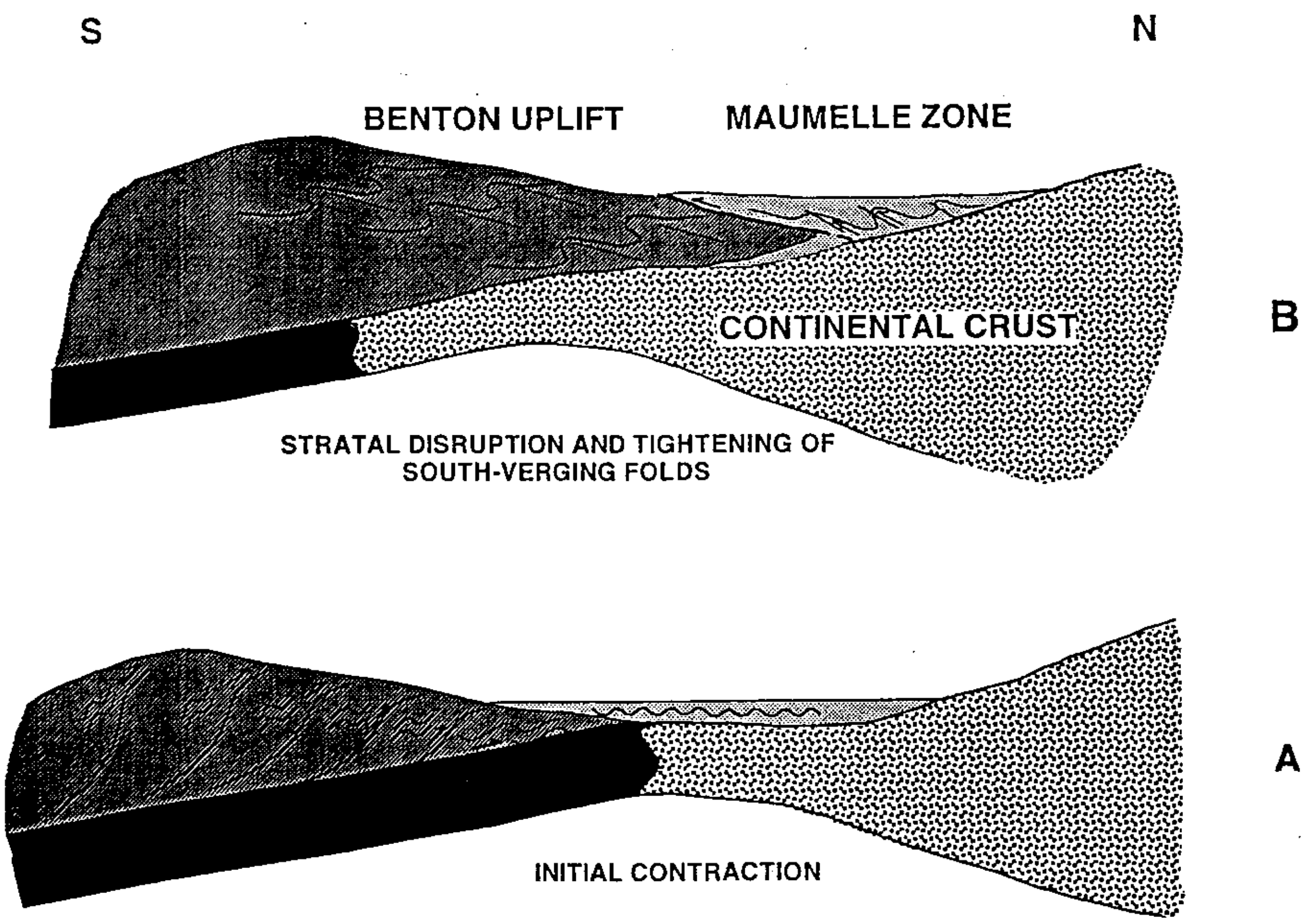


Figure 3. Collision model for the Maumelle zone. The model is based on the Needham and Knipe (1986) model for accretion- and collision-related deformation of an accretionary wedge. Trench sediments are accreted during subduction (A) then backfolded during continental collision (B).

STOP 1 - ZONE OF STRATAL DISRUPTION WITHIN JACKFORK SHALE

An excellent exposure of chaotic shale is present where Arkansas Highway 365 has cut approximately 250 m through the core of a belt of intense stratal disruption near the hinge zone of a macroscopic antiformal structure (Fig. 4). The vertical scale has been exaggerated slightly to show the geometry of the structural style of the exposure.

Because of the intense stratal disruption at this exposure, original bedding (S_0) is difficult to distinguish. However, a compositional banding or layering (S_1) may reflect transposed bedding. A strong, north-dipping phacoidal cleavage (S_2) persists throughout the shale sequence. The S_2 foliation, averaged for the whole outcrop, dips northward at a slightly steeper angle than bedding (S_1). However, S_1 in many places is sub-parallel to, or steeper that S_2 and even reverses dip. The shale is intensely sheared as is evidenced by the polished and striated surfaces along the margins of phacoids. In the siltier intervals, a local solution slaty cleavage is present, oriented nearly parallel to the phacoidal cleavage; flattening as well as shear is indicated.

Blocks of sheared sandstone are scattered throughout the shale with no apparent correlation to one another. Along zones of extension, the bedding has extended into pull-apart trains and aligned blocks or inclusions. Most have the same general shape: elongate boudins or clasts with tapered ends. Some of the thicker sandstone blocks have been folded but show elongation features such as extension veins, pinch and swell structures, and boudinage. Many of the long axes of the clasts lie in a plane parallel to the S_2 foliation. Some appear as isolated hinges with z-shape symmetry (viewed down-plunge). These hinges have been transposed through the disrupted shale, away from their "disconnected" limbs, indicating contraction of an earlier bedding or S_1 surface followed by extension or shear. The extended limbs of the early S_1 folds have been tightened owing to progressive rotation of the regional anticline toward the flattening plane of the finite stain ellipse. The scaly nature of S_2, the ubiquitous shear surfaces that truncate earlier bedding, and a consistent hinge orientation of isolated folds that parallels the macroscopic fold hinge suggests that there is a strong tectonic component taking part in the stratal disruption.

STOP 1

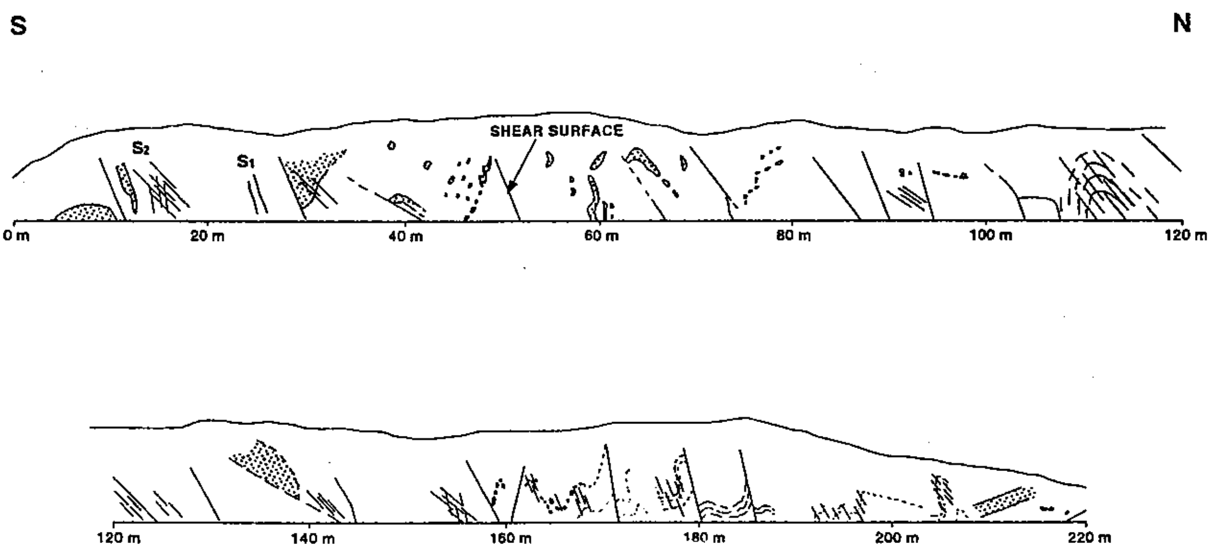


Figure 4. Field drawing of a chaotic shale interval exposed along Arkansas Highway 365. The cut is characterized by sandstone blocks and inclusions dispersed in a scaly shale. Bedding and cleavage relationships indicate that the section is overturned.

STOP 2 - SOUTH LIMB OF THE BIG ROCK SYNCLINE, INTERSTATE 430 ROAD CUT

Another exposure showing stratal disruption occurs along Interstate 430 on the southern limb of a south-verging syncline just south of the Arkansas River. Here, a zone of chaotic shale grades up into a less deformed, medium- to thick-bedded turbidite sandstone sequence (Fig. 5). An average bedding orientation for the south limb of the syncline is 115 degrees with a north dip of 65 degrees.

The dominant structural feature associated with the shale interval at the southern end is a pervasive north-dipping phacoidal cleavage (S_2) which appears to be axial planer to local chevron folds and isolated folded boudins. The cleavage obscures the original bedding, which is marked only by thin laminae of siltstone and trains of sandstone blocks. Many of the S_2 surfaces are polished and grade into shear surfaces that truncate the margins of the blocks. The cleavage has an average strike of 126 degrees with a dip of 40 degrees to the northeast. Folds typically occur as isolated, tight to isoclinal folds with an overall chevron shape. Most are outlined by pull-apart trains of sandstone boudins. The folds are cut by the phacoidal cleavage, which shows a greater amount of shear along the limbs as evidenced by polished surfaces.

The coherent section toward the north is characterized by alternating beds of sandstone and shale. Graded beds and sole marks indicate that the beds are upright. Sandstone makes up about 75 percent of the outcrop with bed thickness ranging from 5 cm to almost 5 m. The structural features of the coherent interval reflect layer-parallel extension of original stratification. The sandstone beds are cut by numerous shears that truncate bedding surfaces at a steep angle. Some of these shears extend across more than one bedding surface. During extension, the shales deformed in a more ductile fashion whereas the competent sandstone beds failed by brittle fracture. Extension of sandstone beds by structural slicing along shear fractures formed rhombic blocks of sandstone. With continued extension and rotation, the fractures become surfaces of slip. This leads to rhombic-shaped blocks that become isolated floaters in the shale matrix. The average orientation of the shear fracture is about 290 degrees with a 66 degree dip to the south. A second, minor shear fracture has an orientation of 224 degrees with a 35 degrees dip to the south.

Bedding at this exposure dips steeper than cleavage, suggesting an overturned limb of a fold. However, sedimentary structures in the coherent sandstones indicate that the beds are upright. This implies a transecting cleavage across the regional fold.

We (CGS and BRH) are pleased to include this fine description of the structure and interpretation of the "Maumelle chaotic zone" by Mr. Milford H. Davis. But we also wish to indicate that alternative models have been suggested for this zone by other investigators.

Voicing another opinion, Morris (1985, p. 29) noted that from all appearances the rubble bedding in this area is indistinguishable from that in the Jackfork in other parts of the frontal Ouachita Mountains. He further offered the following in rebuttal:

"1) The rocks of the "Maumelle Zone" are an integral part of the Jackfork Group. 2) The Jackfork had a clear connection with the shelf/slope area of North America, having received from there the limestone, chert, and non-feldspathic sandstone clasts in rubbly flows and the rounded, mature mineral suite for the sands forming the slope fans. 3) Point 2 may be repeated for the underlying Stanley as well as the overlying Johns Valley. And 4) The rubbly zones, many in number, can be mapped, although little of this has been done".

Certainly, at least, two of us (CGS and BRH) are presently much in favor of the opinion stated by Morris!

STOP 2

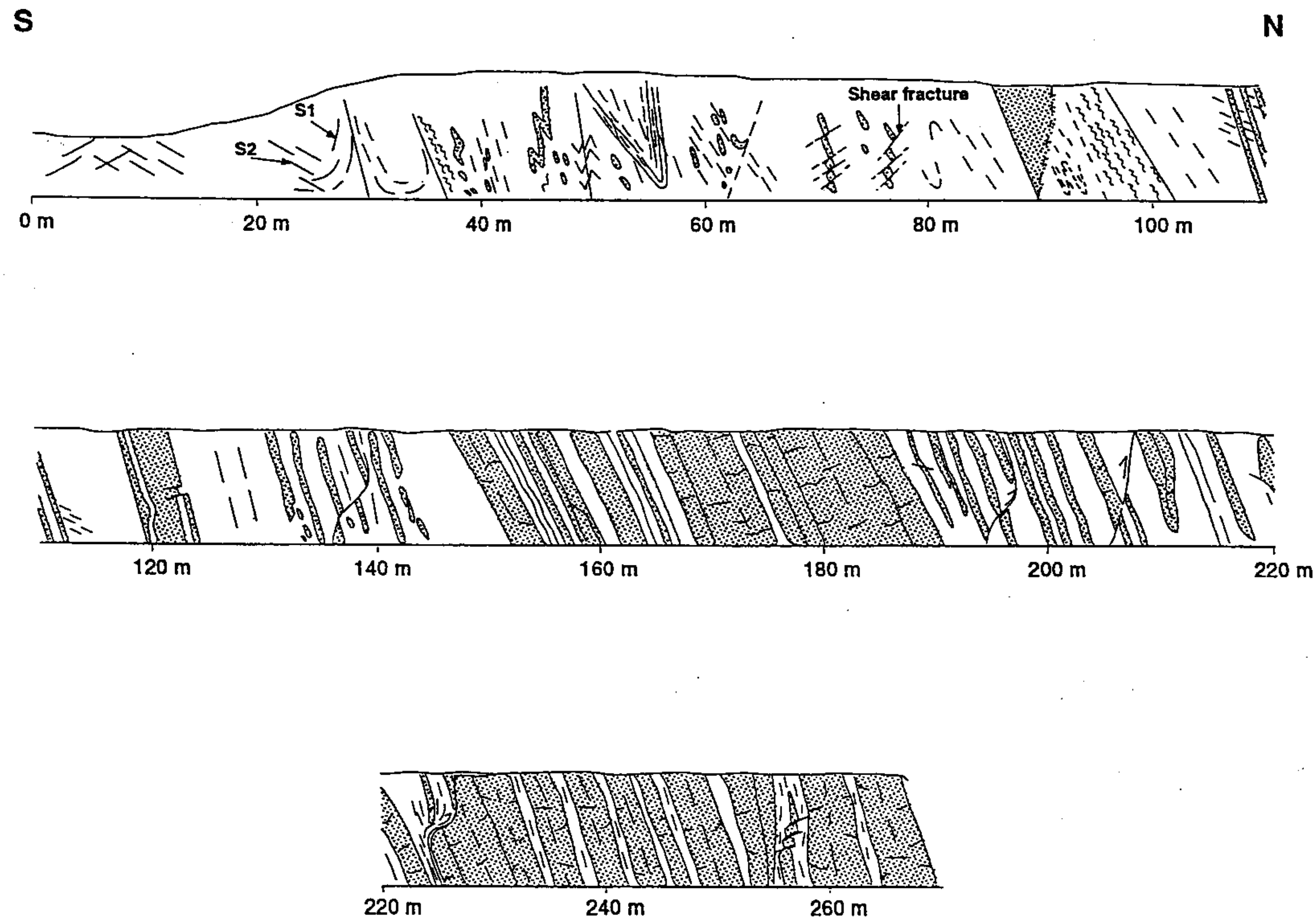


Figure 5. Field drawing of the Interstate 430 highway cut along River Mountain Road through the south limb of the Big Rock syncline. The Jackfork here is characterized by a chaotic shale interval that grades upward into a less deformed sandstone turbidite sequence.

STOP 3 -- BIGFORK CHERT TO ARKANSAS NOVACULITE IN SOUTHWEST LITTLE ROCK

A long sequence of intensely sheared and tightly folded Ordovician to Devonian-Mississippian rocks is exposed on both sides of Interstate 430 about 0.4 miles north of Arkansas Highway 5 (Figure 6). From north to south the sequence consists of: 1) chert and siliceous shale of the Ordovician Bigfork Chert, 2) black shale and dark gray chert of the Polk Creek Shale (also Ordovician), 3) gray and tan shale with thin chert and novaculite beds of the Silurian Missouri Mountain Shale, 4) massive-bedded very light gray novaculite (tripolitic at the base) of the Lower Division of the Devonian Arkansas Novaculite, and 5) black siliceous shale and chert of the Middle Division of the Devonian-Mississippian Arkansas Novaculite. The sediments from which these rocks formed indicate very slow rates of deposition.

The rocks (Figures 7 and 8) dip to the north and are overturned to the south. The style of folding varies with lithology. Pervasive north-dipping cleavage is evident in the Bigfork. Some northward-dipping thrust faults with quartz veins and minor gouge are also present. Their direction of displacement is as yet unclear. The intense shearing has obliterated many of the lithic characteristics and apparently most microfossils. However some conodonts, sponge spicules, and radiolaria are present in a few beds in the Middle Division of the Arkansas Novaculite.

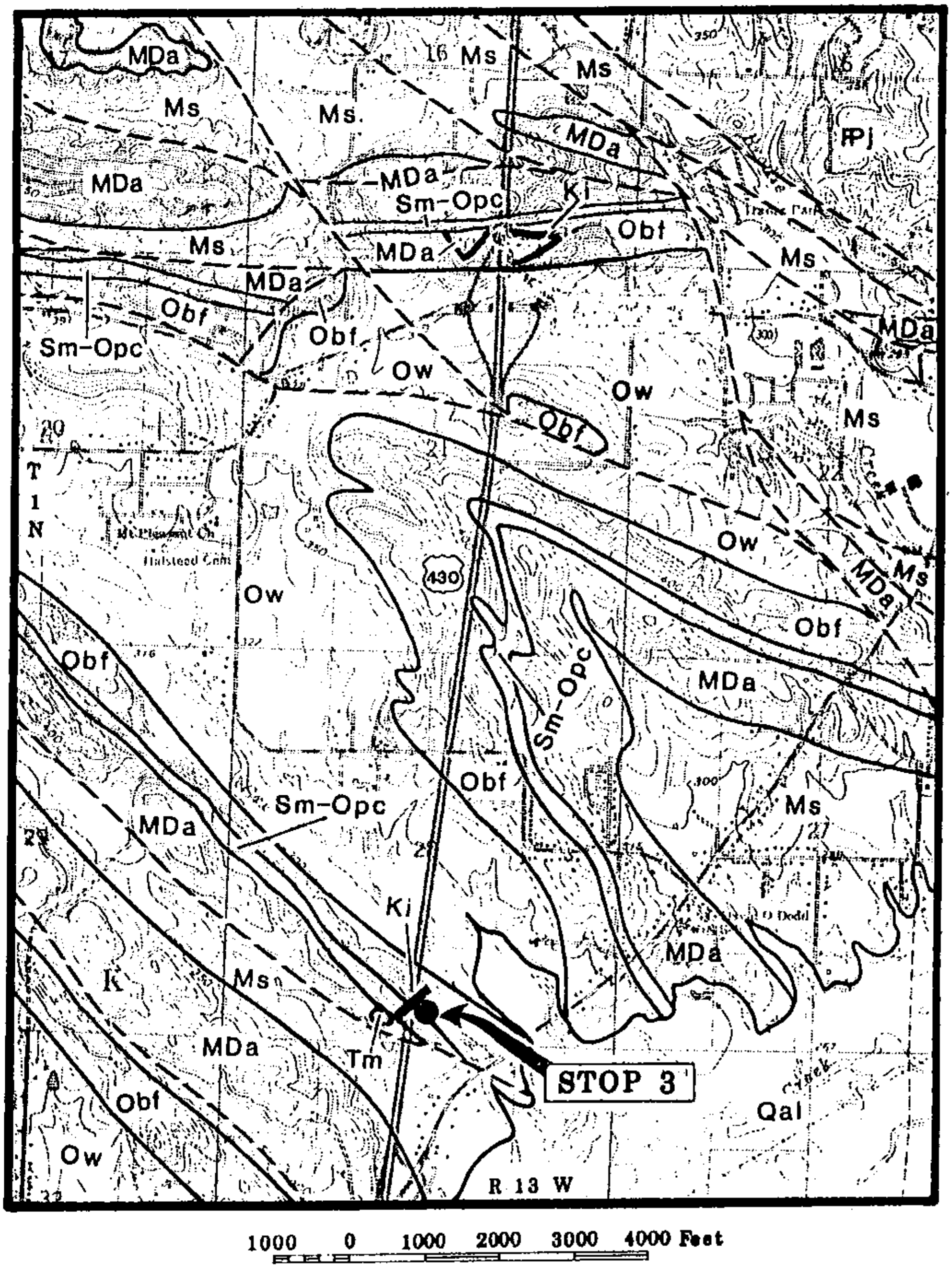
An alkalic igneous dike which has been altered to clay dissects the Middle Division of the Arkansas Novaculite on the west side of the road. It is assumed to be of the same age, i.e., early Late Cretaceous, as the nepheline syenite stock at Granite Mountain a few miles to the east and other intrusive bodies in central Arkansas. Both the novaculite and the dike are overlain unconformably by a thin cover of clay, sand, and some gravel that may represent a remnant of the Midway Group of Paleocene age.

Keller et al. (1985) have shown that the size of the polygonal triple-point grains developed during recrystallization of chert or novaculite at this stop is probably related to low-rank regional (thermal) metamorphism, perhaps enhanced by the emplacement of a pluton nearby. The triple-point grains average about 40 microns in diameter and are among the coarsest yet measured from the Ouachita Mountains. Most of the triple-point texture was formed during late Paleozoic deformation.

In nearby localities, graptolites of Middle Ordovician age have been collected from shale in the upper part of the Womble and graptolites of Late Ordovician age from shale in the Polk Creek.

According to Viele (1973), two major fold trends have been developed in the lower and middle Paleozoic rocks in this general area.

Several opinions have been suggested to explain the complex structure of these rocks. Viele (1973) proposed gravitational sliding and cascading of rock units northward from a series of nappes. Stone and McFarland (1981) suggested a series of northward-moving thrust plates with an overall southward increase in the structural complexity of the rocks in each thrust plate. They attributed the southward-overturning of the rocks and fault planes south of Stop 2 to backfolding of the toe of each thrust plate and also to subsequent thrust faulting. Arbenz (1984) and Stone and Haley (1984, 1986) generally concurred with the premise of this latter model, but further suggested that much of the deformation in this belt was the result of compounding by later structural movements via mega-flowage and crowding in a large triangle-teepee zone. There are several other models related to the structural deformation in this area. The most notable, of course, are Viele (1989), Davis (1990), and Davis in this guidebook.



Qal	Alluvium	MDa	Arkansas Novaculite
Tm	Midway Group	Sm-Opc	Missouri Mountain Shale-Polk Creek Shale
Ki	Igneous dikes	Obf	Bigfork Chert
ℙj	Jackfork Sandstone	Ow	Womble Shale
Ms	Stanley Shale		Contact ——— Thrust fault - - -

Figure 6. Geologic map in vicinity of western Little Rock showing location of Stop 3.

Figure 7. Stop 3. Bigfork Chert and Polk Creek Shale exposed on west side of Interstate 430. Shale and chert of the Bigfork (to the right, i.e. north) in fault contact with black shale and some chert of the Polk Creek (to the left, i.e. south).

Figure 8. Stop 3. Massive-bedded novaculite of the Lower Division of the Arkansas Novaculite on the right (north) and thin beds of chert and siliceous shale of the Middle Division of the Arkansas Novaculite on the left (south). The rocks are capped by a thin sandy rubble that may be a remnant of the Paleocene Midway Group. The exposure is on west side of Interstate Hwy. 430.

STOP 4. BIGFORK CHERT AND WOMBLE SHALE AT BASELINE TRANSPORT, INC. QUARRY

This exposure is near the northeastern margin of the Benton uplift in a small quarry operated for rock aggregate by the Baseline Transport, Inc. Ms. Jeanie Leonard, President and General Manager of the company, has very kindly given permission for us to visit the site.

Most of the outcrop is composed of northward dipping, light gray siliceous shale and gray chert that is typical of the Bigfork Chert in this region. In places at the base are several weathered, brown to buff-cream decalcified siltstone, cherty shale, and maroon to gray shale intervals of the upper Womble Shale (Figure 9 and 10). There are extremely tight, flattened, chevron folds inclined to the south, small sets of crenulations, and highly pervasive northward-dipping cleavage(s). Numerous slickenside and mullion surfaces occur throughout most of the interval. A minor decollement with small splays occurs near the Bigfork-Womble contact. A southward transport direction apparently is indicated by small "drag folds" and stratigraphic pinchouts.

Milky quartz veins fill some early formed fractures in the rocks. These veins are a late Paleozoic thermal event. Considerable thinning of the strata has occurred by thinning on the limbs and by thickening and crowding in the fold hinges. The thickness ratio from flank to hinge varies from 4:1 to 6:1, depending mostly upon the lithology.

In recent years, sedimentary exhalative (SEDEX) occurrences containing zinc and minor lead anomalies have been prospected by several mining companies, particularly in the upper Womble-lower Bigfork interval, mostly in the western Benton uplift of Arkansas. While some copper-lead-zinc-silver mineralization has been noted in this region, there have been few detailed field evaluations. These strata-bound ("ponded") occurrences are considered by several investigators to have formed by mineralized hot fluids and gases escaping from vents ("smokers") along submarine scarps and extensional faults in an attenuated continental crust of the early Ouachita back-arc basin.

Also occurring at or near the Womble-Bigfork contact, notably along this structural trend, are: (1) masses of deformed greenschist-facies metagabbro; and (2) bodies of soapstone-serpentinite, about 2 and 12 miles, respectively, to the west. Investigations by Morris and Stone (1986) and Cox (1986) suggests that these alkalic ultramafics were tectonically-diapirically emplaced. Two of us (CGS and BRH) propose that these masses were, at least in part, deposited as submarine slumps. The metagabbro has been dated at 1025 ± 48 Ma by whole-rock K/Ar. The metagabbro is related either to transform motion or rifting in the early Ouachita trough or it represents transform-related (EMORB--enriched mid-ocean-ridge basalt) fragments of oceanic crust. The serpentinite in the Warner and other nearby pits was originally derived, at depth, from peridotite.

Regardless of the model, the ultramafic bodies were emplaced into the pre-orogenic Ouachita trough and later they were uplifted, folded, and faulted into their present form and location by the Ouachita orogenic events. We further propose that these (SEDEX) and (ultramafic) occurrences are genetically related.

Figure 9. Stop 4. Panorama of Baseline Transport Inc. quarry in southward-verging Bigfork Chert and Womble Shale.

Figure 10. Stop 4. Small buckles and crenulations in weathered siltstones and shales in the Womble Shale.

STOP 5. MAZARN AND WOMBLE SHALE AND IGNEOUS ROCK AT NANCE

This exposure near the southern boundary of the Saline basin is in a shale pit and along a county road on the south bank of the South Fork of the Saline River at Nance, Arkansas. The pit is owned by Mr. Farrell Beck and he has graciously given us permission to visit the site, but requests that we be careful, especially along the highwalls.

We begin the Stop at the roadcut about 150 yards southwest of the pit in order to see the sequence Womble Shale> thrust fault> igneous dike> Mazarn Shale. The Lower Ordovician Mazarn Shale exposed here is probably in the upper part of the formation, but a significant thrust fault (decollement?) that occurs immediately to the south makes this determination difficult. Many milky quartz veins occur in this disrupted interval. South of the fault, gray to black shales, silty brown siltstones, and some pyritic carbonaceous black nodular siltstones are identified as the Middle Ordovician Womble Shale.

A 10-inch wide, east-west trending greenish-gray lamprophyric igneous dike is unique because of the 1/2-to 3/4-inch round "pisolites" that occur in its middle (Figure 11). Do these "pisolites" represent a weathering feature; are they "ball-bearings" formed by further movement of a "mushy" magma during intrusion; or, are they formed by some other process? J. Michael Howard of our staff is currently trying to determine their origin. In this region there are numerous other weathered, lamprophyric-phonolitic dike swarms (Late Cretaceous) that are genetically related to the Magnet Cove and Wilson Springs intrusives a few miles to the south.

The Mazarn Shale at this site consists mostly of well-indurated, partially banded, gray to black and minor olive shale. There are a few thin layers of olive-gray silty shale and some laminae of buff gray siltstone. 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 apparently was deposited by spasmodic, very low-velocity bottom and turbidity 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. Some spectacular specimens of pyrite occurs in nodules in the carbonaceous silty shale.

Intense folding, small northwest-dipping thrust faults, and a pervasive cleavage characterize the outcrop. The cleavage is rather crenelated and the surfaces are coated with a thin whitish-gray clay (illite?) mineral. Structural boundinage is evident in a few of the thicker siltstone layers. 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 southeast 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.

The Mazarn represents relatively quiet basin-plain deposition with minor fine clastics derived from sources to the north or northeast. However, we must point out that bottom markings in a series of Mazarn exposures in a creek about three miles to the east of this site indicate paleocurrent flow from the south-southwest, if a single fold rotation is performed.

Viele (1973) notes that in the southern part of the Saline basin, the folds are recumbent. The axial planes form a broad low arch for they dip toward the north or northwest in the western part but toward the south in the south-central portion. The arch thus formed has a northeast-southwest (Hot Springs?) trend. Hinge lines in the southwest generally are horizontal; those in the south central part are raking or reclined. The direction of overturning is dominantly toward the southeast.

Figure 11. Stop 5. Small "pisolitic" lamprophyre dike cutting Mazarn Shale.

STOP 6. DEFORMED BASINAL-PLAIN DEPOSITS IN MAZARN SHALE NEAR CROWS

Along a rural road and the adjoining Middle Fork of the Saline River south of Crows, Arkansas, there is about a 1/4-mile-long exposure of northward-dipping, mostly overturned, Lower Ordovician Mazarn Shale (Figure 12 and 13). This sequence is composed of very thin layers of brownish-gray calcareous to clean quartzose siltstone and gray shale that, in places, is intensely crinkled and buckled. These strata are typically dissected by pervasive cleavage that is inclined to the north. Small thrust faults and milky quartz veins occur at several localities. Recent conodont determinations by Ray L. Ethington and John E. Repetski from a few thin blue-gray micritic limestones in nearby exposures further confirm that this sequence is the Mazarn Shale.

A real structural dilemma concerns whether or not most of the strata in the southern portions of the Benton uplift have a direct association with the younger Paleozoic Formations forming the southwest plunging and southeast-verging sequences in the Zigzag Mountains immediately to the west? In many respects these rocks appear to be separated from the Zigzag Mountains by a large folded decollement. If this is indeed the case, these units in the southern Benton uplift represent a distinctly separate lower nappe-window complex(s)!

We believe that the fine clastic components of these deposits represent waning cycles of turbidity currents and that the coarser clastics were mostly restricted to the adjacent foreland due to a high stand of sea level. These strata are characterized by Bouma facies D and E (Figure 14), which are thought to represent basin plain deposits. Cross laminations and bottom markings are present, but mostly due to structural complexities, a paleocurrent flow direction from the east-northeast is proposed -- but only tentatively.

Examine this interval and see if you can tell tops and bottoms, current directions(s), structural repetition, thrust faulting, etc. Also there are some hints of deep-marine trace fossils--that is, if they are not structural boudins, mullions, and other phenomena.

What cycles of deposition formed these rather "varve-like" thinly banded, laminated to minutely cross-laminated deep-water shales and siltstones? Do these deposits afford a true parameter for the many thousands of episodes of their accumulation in this early Ouachita basin? Another related possibility: does each apparent lithic "pair" represent a yearly climatic cycle (winter-summer/hot-cold/wet-dry) with waxing and waning input of fine clastic nutrient? The coarse fractions deposited (wet cycle) distally by weak turbidity or bottom currents and the finer clays (dry cycle) being suspended clouds -- hemipelagic materials? You are most welcome to present other hypotheses!

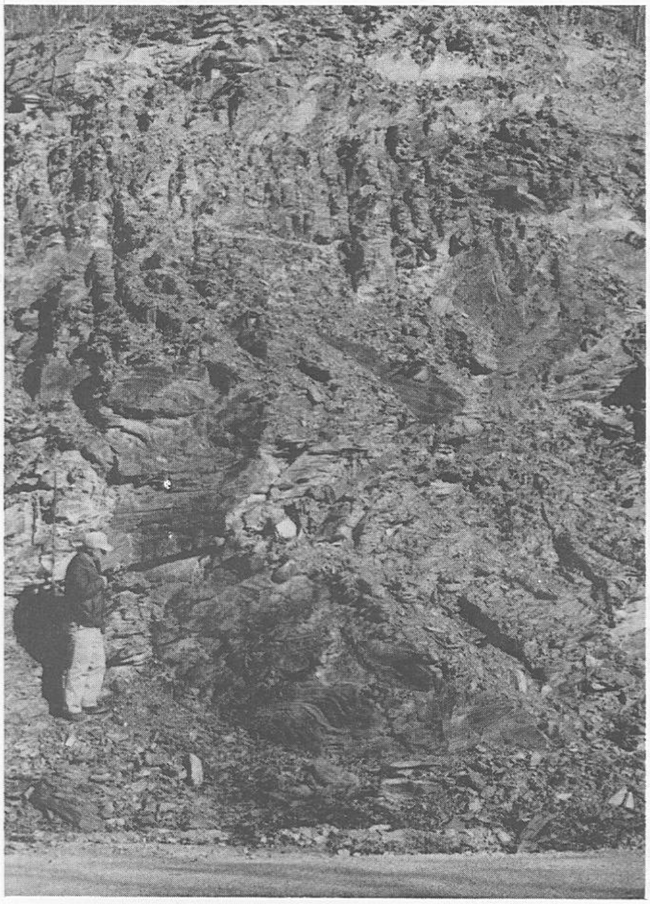


Figure 12. Stop 6. Series of tight folds and pervasive cleavage in Mazarn Shale.

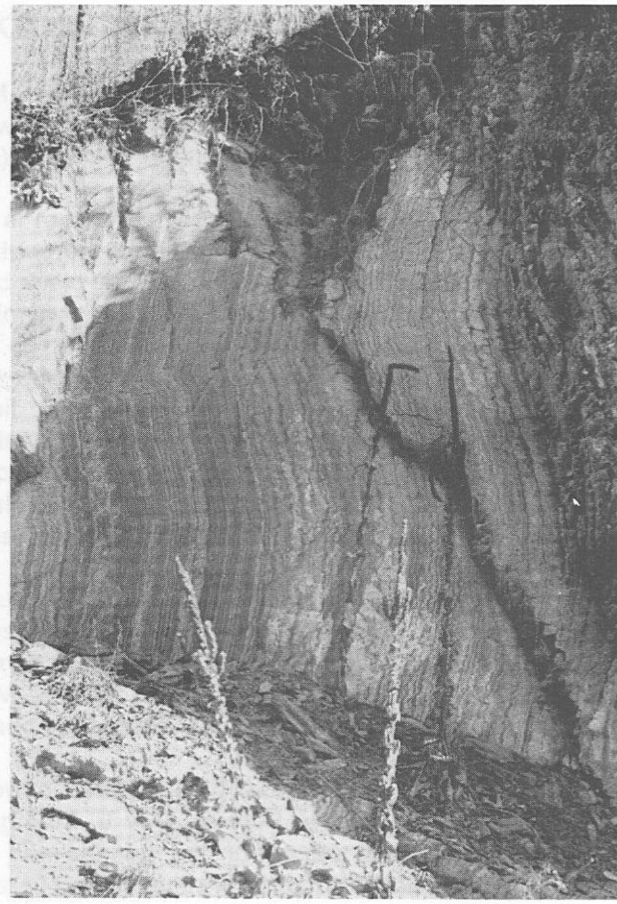
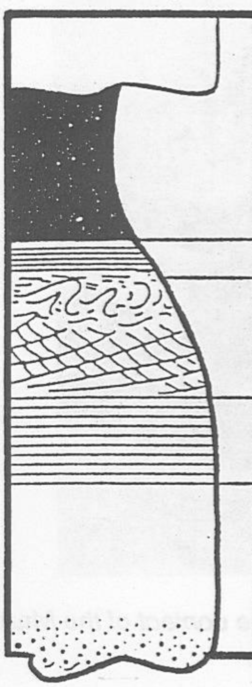


Figure 13. Stop 6. Alternating siltstones (light) and shales (dark) in Mazarn Shale.



GRAIN SIZE	BOUMA (1962) DIVISIONS	INTERPRETATION
Mud	E Laminated to homogeneous mud	Deposition from low-density tail of turbidity current ± settling of pelagic or hemipelagic particles
Silt	D Upper mud/silt laminae	Shear sorting of grains & flocs
Sand	C Ripples, climbing ripples, wavy or convolute laminae	Lower part of lower flow regime of Simons *et al* (1965)
	B Plane laminae	Upper flow regime plane bed
Coarse Sand	A Structureless or graded sand to granule	Rapid deposition with no traction transport, possible quick (liquefied) bed

Figure 14. Bouma sequence for turbidites (after Pickering and others, 1989).

STOP 7. MAZARN SHALE AND BLAKELY SANDSTONE AT LAKE PINEDA SPILLWAY

The Lower Ordovician upper Mazarn Shale and Middle Ordovician lower Blakely Sandstone are exposed along the spillway on Lake Pineda and Cedar Creek in the southern portion of Hot Springs Village, Arkansas (a large Cooper Enterprise development).

The upper part of the Mazarn is nicely exposed beginning at the base of the spillway and extending upward to about the center of the exposure (Figure 15, 16, and 17). It consists mostly of greenish-black to gray-black banded shale and some thin gray siltstone, light gray fine-grained sandstone, and dark gray micritic limestone. Nereites are rather abundant in a few thin clastic beds and are considered to be indicative of bathyal to abyssal water depths. The basal Blakely occurs at the south abutment of the spillway. It consists of thin-bedded gray shale and thin-bedded (for the most part), fine to rather coarse-grained, brownish-gray quartzitic sandstone. Bottom marks, cross laminations, graded bedding, and the position of the Blakely all indicate that the top of the rather complexly folded sequence or section is to the south. Discontinuous sandstone masses, sedimentary pull-aparts, structural boundinage, and well-developed northward-dipping cleavage are present.

A prograding outer to middle submarine-fan setting is suggested for these Mazarn to Blakely deposits, which are characterized mostly by C, D, and E facies of Bouma. Some paleocurrent indicators suggest a dominantly south-southeast to southwest directed flow regime for these deep-marine clastics. Most of the small folds are overturned toward the south-southeast and hinge lines rake gently north-northeast.

Considerable biostratigraphic work, primarily using conodonts, by John E. Repetski (U.S. Geological Survey), Ray L. Ethington (University of Missouri) and their co-workers has taken place mostly on the micritic and other limestones in the early Paleozoic strata in the Ouachita Mountains of Arkansas and Oklahoma. The following two Figures (18 and 19) illustrate some of the conodont fauna recorded in the early Paleozoic (mostly Ordovician) formations in this region.

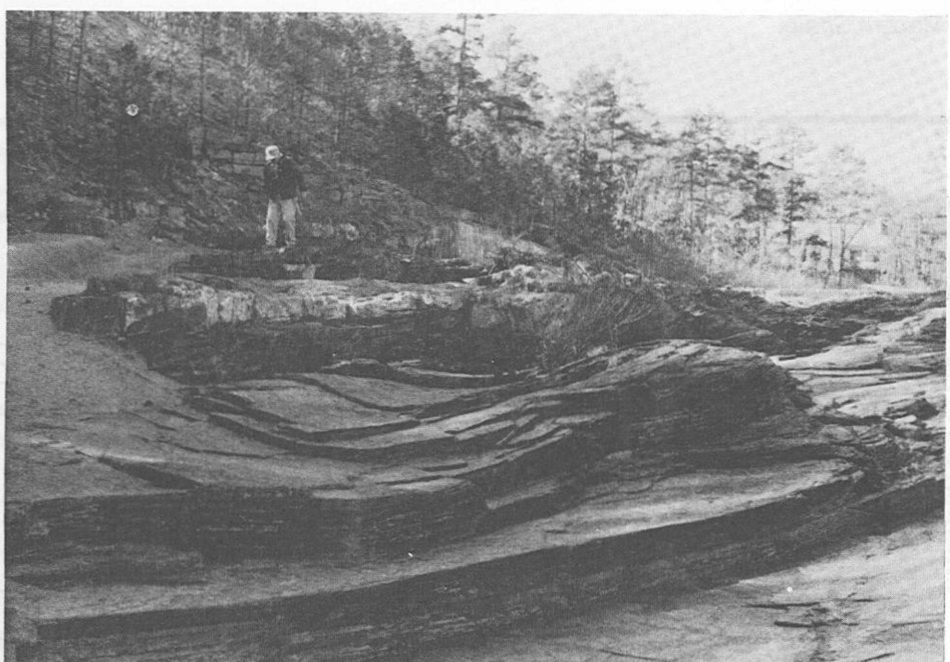


Figure 15. Stop 7. Buckles in shale (dark) and sandstone (light) at the contact of the Mazarn Shale (below) and Blakely Sandstone (above) at Lake Pineda Spillway.

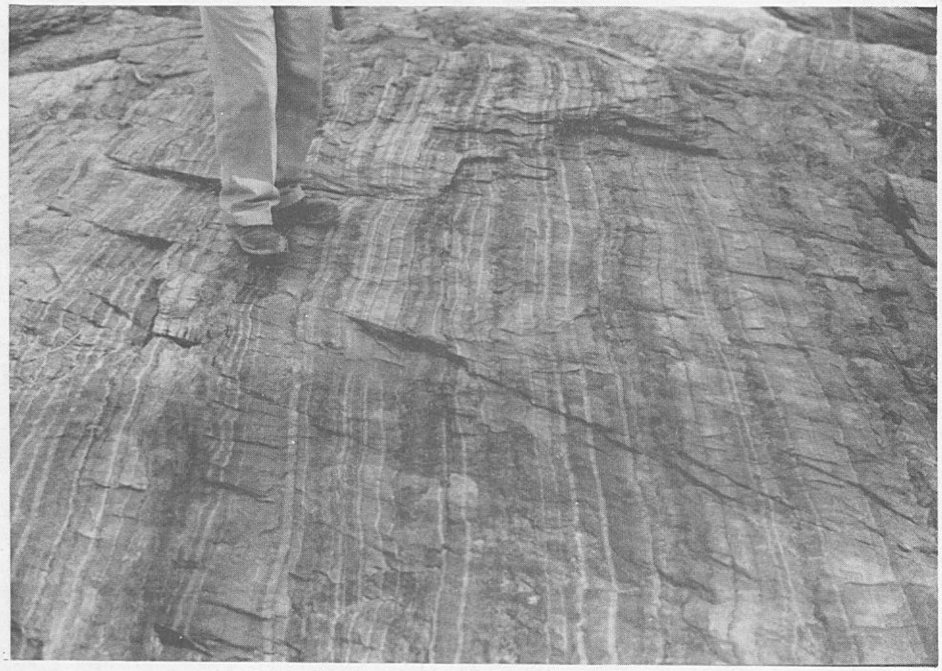


Figure 16. Stop 7. Cleaved, "varve-like", shale (dark) and siltstone (light) in the Mazarn Shale at Lake Pineda Spillway.

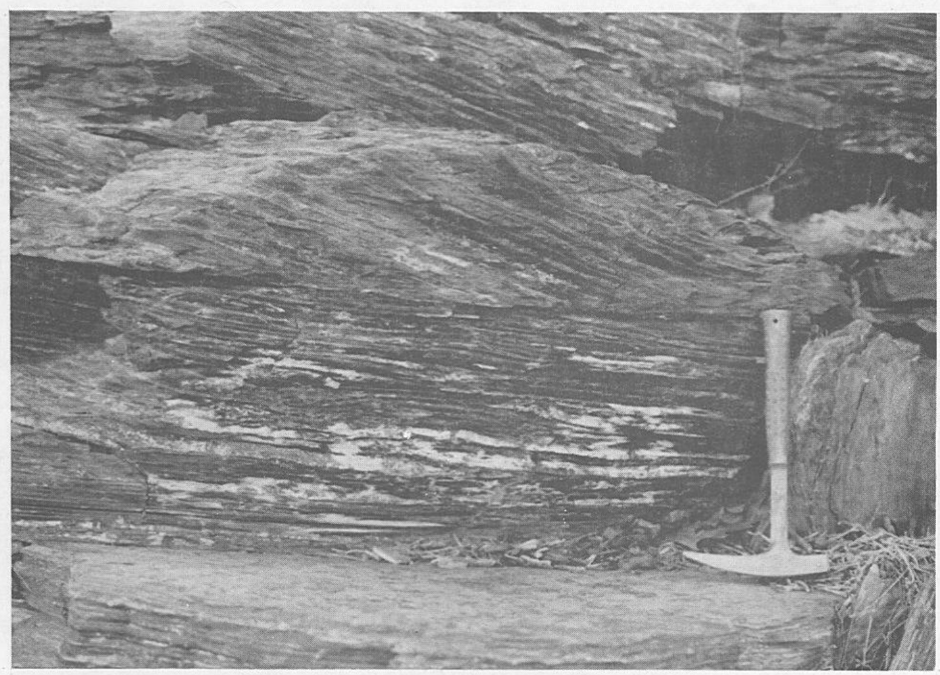


Figure 17. Stop 7. Nearly horizontal shear cutting fold hinge in banded upper Mazarn Shale at Lake Pineda spillway.

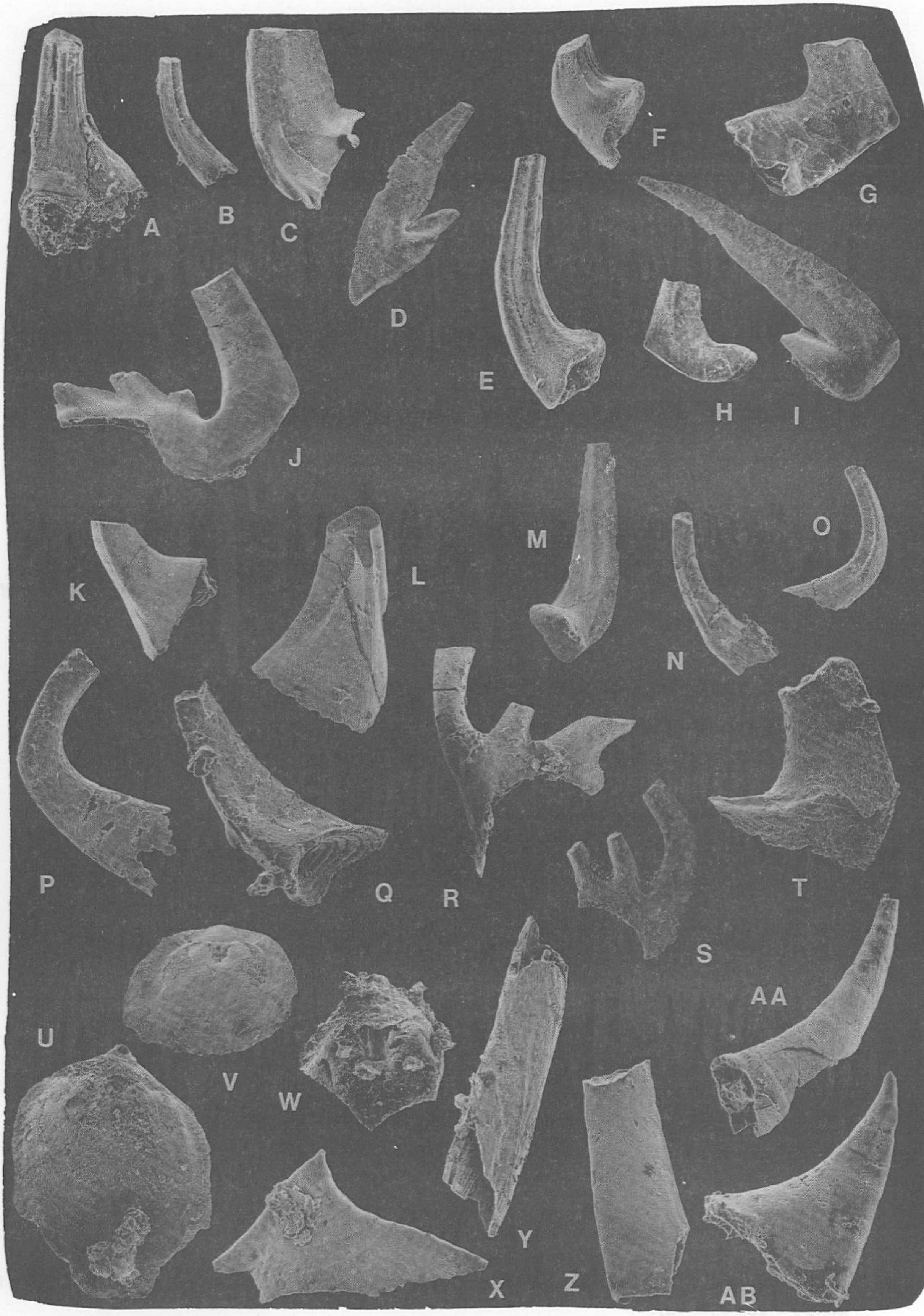


Figure 18. Conodonts from the Collier Shale, Crystal Mountain Sandstone, and Mazarn Shale.

Figure 18

A-I: Conodonts from the Mazarn Shale; sample CGS-16-93; USGS fossil locality 11013-CO; NW 1/4, NE 1/4, SW 1/4, Sec. 1, T.2S., R.21W., Mountain Pine 7-1/2 minute quadrangle, Garland Co., Arkansas.

[All illustrations on Plates 1 & 2 are SEM photomicrographs; illustrated specimens reposited in type collections of Paleobiology Department, U.S. National Museum of Natural History, Washington, D.C., under the USNM catalogue numbers given below.]

A. *Parapanderodus* sp.; asymmetrical element, posterior view, x 54, USNM 482893.

B. *Parapanderodus striatus* (Graves & Ellison); posterolateral view, x 73, USNM 482894.

C. *Paltodus? sweeti* Serpagli, s.f. (=*sensu formo*); lateral view, x 52, USNM 482895.

D. *Diaphorodus*? sp.; oistodontiform (M) element, inner lateral view, x 52, USNM 482896.

E. *Glyptoconus quadraplicatus* (Branson & Mehl); lateral view, x 73, USNM 482897.

F. *Oneotodus costatus* Ethington & Brand; lateral view, x 54, USNM 482898.

G. *Drepanodus arcuatus* Pander; drepanodontiform-sculponeaform element, inner lateral view, x 44, USNM 482899.

H, I. *Paroistodus parallelus* (Pander); drepanodontiform (H) and oistodontiform (I) elements, inner lateral views, x 44, USNM 482900 and 482901.

J: Conodont from limestone in the Crystal Mountain Sandstone; sample CGS-24-93; USGS loc. 11014-CO; near center, SW 1/4, SE 1/4, Sec. 2, T.1S., R.21W., Hamilton 7-1/2 minute quad., Garland Co., AR.

J. *Cordylodus angulatus* Pander; inner lateral view of P(?) element, x 60, USNM 482902.

K-AB: Conodonts and phosphatic brachiopods from limestones in the Collier Shale. K-T from Ordovician samples JR5-24-90A and B, in creek bed and cuts below Lake Cortez spillway, Hot Springs Village; USGS locs. 11015-CO and 11016-CO; SW 1/4, SW 1/4, Sec. 31, T.1N., R.18W., Goosepond Mountain 7-1/2 minute quad., Saline Co., AR.;
U-AB from presumed Cambrian samples CGS-19-93 [USGS locs. 11017-CO; near center of Sec. 22, T.2 S., R.26W., Oden 7-1/2 minute quad., Montgomery Co. AR.] and CGS-29-93 [USGS loc. 11018-CO; near center Sec. 22, T.1S., R.22W., Avant 7-1/2 minute quad., Garland Co., AR.].

K, M. *Rossodus*? n. sp.; asymmetrical coniform and scandodontiform elements, inner lateral views, x 68, USNM 482903 and 482904; both from sample 11016-CO.

L. *Scolopodus? sulcatus* Furnish; upper posterolateral view of "oneotensis" element, x 120, USNM 482905, sample 11016-CO.

N, O. *Variabiloconus bassleri* (Furnish); inner lateral views, x 97, USNM 482906 and 482907, both from sample 11015-CO.

P. *"Oistodus" triangularis* Furnish; inner lateral view, x 126, USNM 482908, sample 11015-CO.

Q, T. *Rossodus tenuis* (Miller); inner lateral views of asymmetrical coniform (Q), x 180, and scandodontiform (T), x 170, elements, respectively; USNM 482909 and 482910; both from sample 11015-CO.

R, S. *Cordylodus* spp.; lateral views of S(?) elements, x 85 and x 80, respectively; USNM 482911 and 482912; both from sample 11016-CO.

U-W. Phosphatic brachiopod valves, x 45 (U) and x 35 (V, W), USNM 482913-482915; sample CGS-29-93.

X. *Proacodus* sp. [paraconodont]; inner lateral view, x 70, USNM 482916, sample CGS-29-93.

Y. *Phakelodus tenuis* (Müller) [protoconodont]; posterolateral view, x 45, USNM 482917, sample CGS-19-93.

Z. *Phakelodus elongatus* (An) [protoconodont]; lateral view, x 130, USNM 482918, sample CGS-19-93.

AA. *Prooneotodus rotundatus* (Druce & Jones) [paraconodont]; lateral view, x 155, USNM 482919, sample CGS-19-93.

AB. *Prooneotodus gallatini* (Müller) [paraconodont]; inner lateral view, x 180, USNM 482920, sample CGS-19-93.

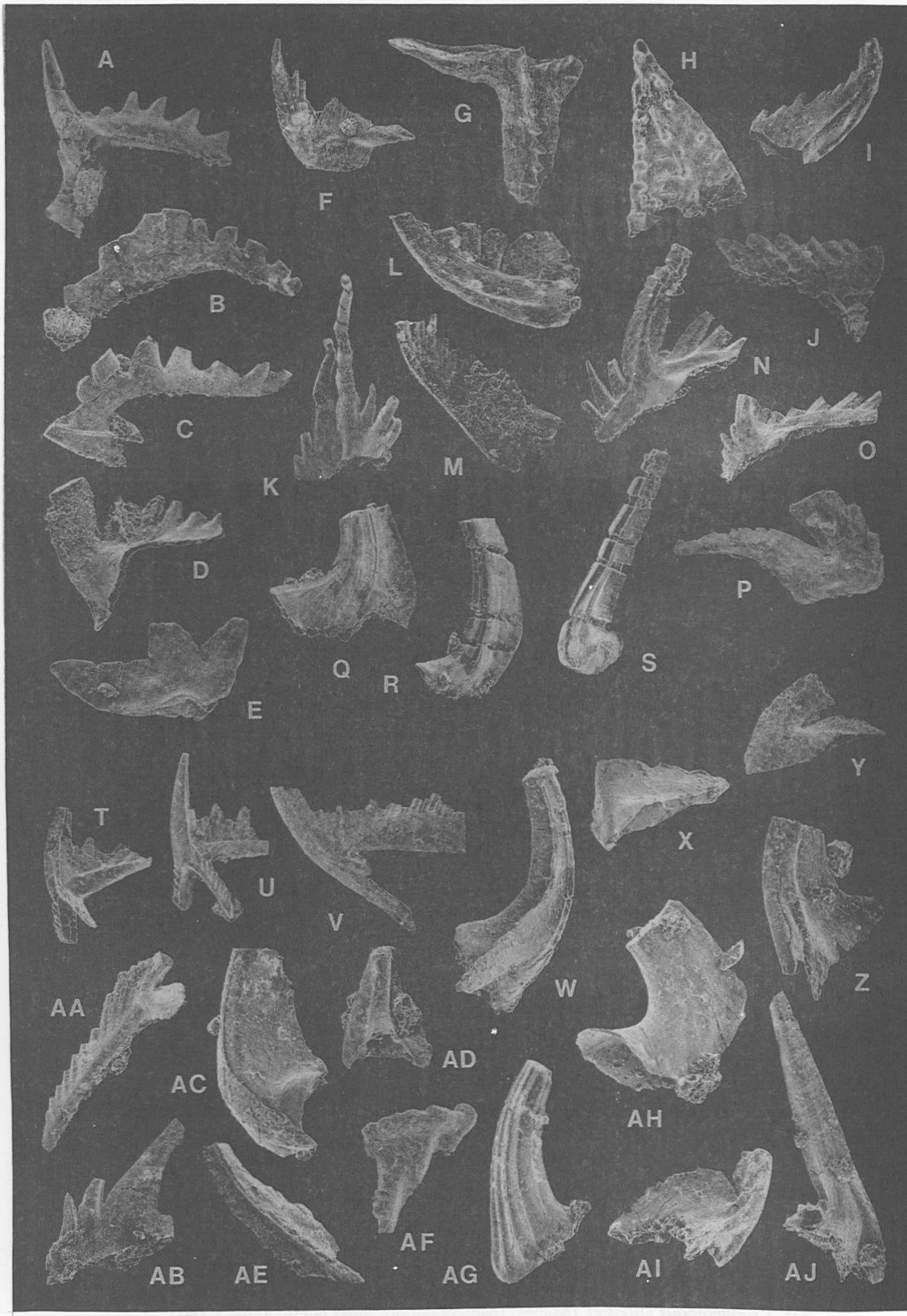


Figure 19. Conodonts from the Mazarn and Womble Shales.

Figure 19.

A-S: Conodonts from the Womble Shale. Specimens A-E are of penecontemporaneous taxa; considered to have been transported from adjacent warm, shallow platform facies. Specimens F-S are of cooler-/deeper-dwelling taxa; considered indigenous to Womble depositional regime. Samples CGS-12-93 [USGS loc. 11019-CO; NW 1/4, SW 1/4, SW 1/4, Sec. 6, T.2S., R.20W., Mountain Pine 7-1/2 minute quadrangle, Garland Co., AR.] and CGS-14-93 [USGS loc. 11020-CO; NE 1/4, SE 1/4, SW 1/4, Sec. 6, T.2S., R.20W., Mountain Pine 7-1/2 min. quad., Garland Co., AR].

A. *Erismodus* sp.; posterolateral view of Pb element, x 50, USNM 482921, sample CGS-14-93.
B. *Plectodina joachimensis* (Andrews); inner lateral view of Pa element, x 50, USNM 482922, sample CGS-14-93.
C, D. *Phragmodus flexuous* Moskalenko; inner lateral views of Sb (C), x 45, and M (D), x 60, elements, respectively; USNM 482923 and USNM 482924, both from sample CGS-14-93.
E. *Leptochirognathus* sp.; inner lateral view, x 60, USNM 482925, sample CGS-14-93.
F. *Goverdina* sp.; inner lateral view, x 65, USNM 482926, sample CGS-12-93.
G. *Cahabagnathus friendsvillensis* (Bergström); upper view of pastinate element, x 55, USNM 482927, sample CGS-12-93.
H-J. *Pygodus serra* (Hadding); H--upper view of P element, slightly offset tectonically near apex, x 50, USNM 482928, sample CGS-12-93; I--lateral view of Sb(?) element, x 60, USNM 482929, sample CGS-12-93; J--outer lateral view of Pb element, x 70, USNM 482930, sample CGS-14-93.
K. *Erraticodon balticus* Dzik; posterior view of Sb element, x 40, USNM 482931, sample CGS-14-93.
L. *Belodina monitorensis* Ethington & Schumacher; lateral view, x 80, USNM 482932, sample CGS-12-93.
M. *Ansella nevadensis* (Ethington & Schumacher); lateral view, x 60, USNM 482933, sample CGS-12-93.
N-P. *Periodon aculeatus* Hadding; inner lateral views of: Pa element (N), x 60, USNM 482934, sample CGS-12-93; Pb element (O), x 50, USNM 482935, sample CGS-12-93; and M element (P), x 50, USNM 482936, sample CGS-14-93.
Q-S. *Protopanderodus* cf. *P. varicostatus* (Sweet & Bergström); inner lateral views of asymmetrical costate elements (Q & R), x 60 and x 45, and costate scandodontiform element (S), x 40; USNM 482937, 482938, and 482939, respectively; all from sample CGS-14-93. Specimens R and S fractured and tectonically pulled apart, but held together by quatrz growths.

T-AJ: Conodonts from the Mazarn Shale. Specimens T-AI represent cooler- and (or) deeper-water taxa; considered indigenous to depositional regime. Specimen AJ represents a contemporaneous warmer- and (or) shallow-water taxon; considered transported into Mazarn depositional regime from adjacent carbonate platform. All from sample CGS4-8-16 [USGS loc. no. 11021-CO; SW 1/4, NW 1/4, SE 1/4, Sec. 28, T.2S., R.26W., Oden 7-1/2 minute quad., Montgomery Co., AR].

T-V. *Oepikodus smithensis* (Lindström) [= *O. evae* of authors]; lateral views of Pa, Pb, and S elements, x 50, x 35, and x 36; USNM 482940, 482941, and 482942, respectively.
W. *Tropodus australis* (Serpagli); asymmetrical multicostate element, x 50, USNM 482943.
X, Y. *Periodon flabellum* (Lindström); inner lateral views of Pb and M elements, respectively, both x 55; USNM 482944 and 482945.
Z. *Acodus gladiatus* Lindström; lateral view, x 60, USNM 482946.
AA, AB. *Bergstroemognathus extensus* (Graves & Ellison); inner lateral views of M and S elements, respectively, both x 40; USNM 482947 and 482948.
AC. *Reutterodus andinus* Serpagli; inner lateral view, x 65, USNM 482949.
AD. *Juanognathus variabilis* Serpagli; posterior view of symmetrical element, x 65, USNM 482950.
AE. cf. *Stolodus stola* (Lindström); lateral view, x 60, USNM 482951.
AF. *Polonodus*? *corbatoi* (Serpagli); upper view of P element, x 45, USNM 482952.
AG. *Scolopodus rex* Lindström; lateral view, x 55, USNM 482953.
AH. *Drepanodus arcuatus* Pander; inner lateral view of "pipaform" element, x 50, USNM 482954.
AI. New Genus?; anterolateral view of nearly symmetrical Sa(?) element, x 60, USNM 482955.
AJ. *Diaphorodus delicatus* (Branson & Mehl); inner lateral view of "vulgaris"-type oistodontiform M element, x 45, USNM 482956.

STOP 8. COMPLEXLY FOLDED BIGFORK CHERT AT VALLEY GRAVEL COMPANY QUARRY

This quarry is in the Bigfork Chert, of Middle and Late Ordovician age, south of Mountain Valley and is worked with minimal equipment for rock aggregate (Figure 20). We wish to acknowledge the kindness of Mr. Clyde Dickson, owner of the Valley Gravel Company, for letting us have access to the site.

The quarry is located on the "apparent" south flank of a southeastward-verging syncline near the northeastern margin of the Zigzag Mountains. The Bigfork Chert commonly forms lower 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 west. The less resistant Womble Shale underlies the valley to the north and the renowned Mountain Valley Spring issues from limestones within this Formation.

The Bigfork is complexly folded with both chevron and box-kinks typically inclined to the southeast. The strata dip gently to steeply to the north. The sequence is composed of many thin interbedded and often graded, calcareous (often decalcified), rather punky beds of silty brown chert, 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. Stylolites are often present in the calcareous silty chert and indicate a significant removal and thinning of the section.

The folds in the southern portions of the quarry are inclined southeastward, but many have a S and not a Z rotation as would be expected on the south limb of a syncline. Possibly there is a sizable anticlinal structure trending across the central part of the excavation? If not, then we may have another structural rotational problem that seems to happen occasionally in the Ouachita Mountains! There is a rather 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 very small thrust faults cut the sequences at places. It appears that these small displacements are associated with the late southward tectonic transport. Viele (1973) notes that in this area the fold hinges trend consistently toward the southwest, but the axial planes exhibit dips ranging from northwest to south.

The Bigfork Chert is the most reliable aquifer in the Ouachita Mountains. Small clear-to-chalybeate (iron-rich) springs are often present in the basal outcrops.

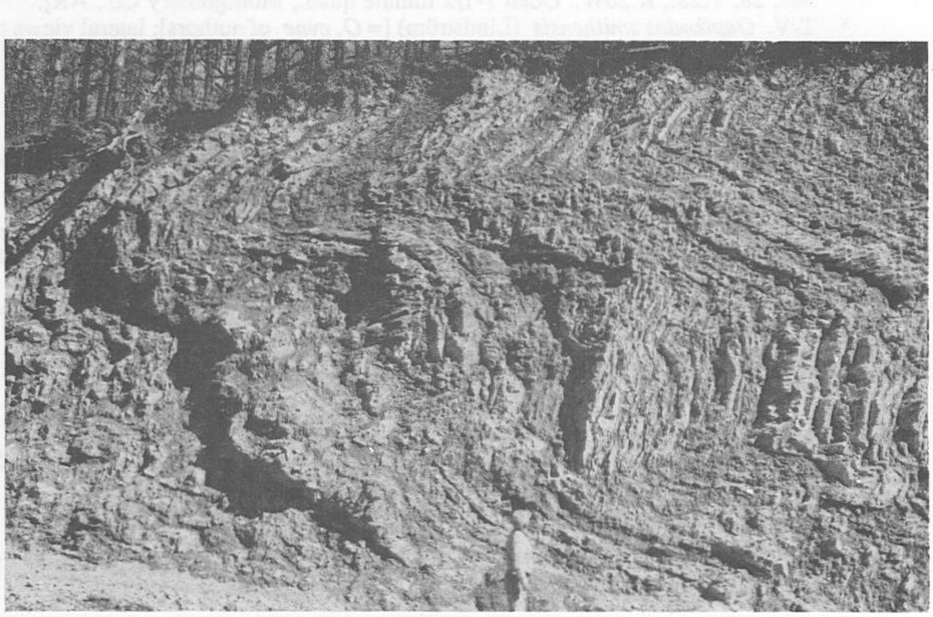


Figure 20. Stop 8. Chevron and kink folds in the Bigfork Chert at Valley Gravel Company quarry.

STOP 9. RON COLEMAN'S QUARTZ CRYSTAL MINE

We wish to thank Mr. Ron Coleman for his permission to visit this unique site!

Mining of quartz crystals in the Ouachita Mountains of Arkansas has been going on for many years,--the first miners probably being the Indians who shaped them into arrowheads and other weapons and tools. 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 were used to supplement the crystal supply from Brazil for the manufacture of radio oscillators. 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 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 successful mining.

In the Ouachita Mountains, there is a close association of quartz veins with some fault zones. It is believed that the quartz veins represent, in part, dewatering processes, notably from argillaceous strata, that took place along the fault zones. The increase in pore fluids may well have contributed to overpressuring and enhancing the overall faulting and folding process. The quartz veins with their associated minerals are 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 Ron Coleman Mine (Figures 21 and 22) are also known as the Geomex Mine, West Chance Area, Dierks No. 4 Mine, and Blocher Lead. The crystals occur in veins in lenticular channel-like lenses of weathered brownish-orange quartzitic to limy (decalcified) sandstone and conglomeratic sandstone of the Lower Ordovician Crystal Mountain Sandstone. Thick intervals 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 bodies were originally deposited as sediments in submarine upper-fan channels and were derived from a granite-rich terrain to the north-northeast.

It is our present belief that this unit represents a tremendous low-stand of sea level and that vast quantities of clastics from the shelf and slope to the north were deposited by retrogressive flows in upper submarine-fan channels and lower canyon systems along the northern flanks of the early Ouachita trough. We also believe that the erratic-bearing conglomeratic sandstones and lenticular sandstone masses exposed in this and other nearby pits are classic examples of upper submarine-fan deposition. We and others have also considered a lower submarine-canyon depositional site or combinations of both.

In this area we are crossing the main east-west axis of the Benton-Broken Bow uplift, which comprises many thrust-faulted "duplex-like" 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 westward plunging nose of a large, complexly-deformed anticline.

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 of removing overburden and loose rock with a bulldozer and scoop shovel 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.

Figure 21. Stop 9. Panorama of Ron Coleman's quartz crystal mine in the Crystal Mountain Sandstone.

Figure 22. Stop 9. Uncleaned quartz crystal cluster with halloysite (clay) at Ron Coleman's mineral shop and processing plant.

STOP 10. McEARL QUARTZ-CRYSTAL MINE

We wish to express our sincere appreciation to Mr. Jim Coleman for letting us visit this extraordinary site!

The McEarl quartz-crystal mine occurs in the middle and upper portions of the Lower Ordovician Crystal Mountain Sandstone on the north flank of an anticline about 1 mile north-northeast of Stop 9 (Figure 23). Clear quartz crystals, sometimes occurring as spectacular long "stove pipes" and weighing up to several hundred pounds each have been mined sporadically at this deposit since before World War II. Most of the quartz crystals have been sold as specimens, but some clear, optical grade quartz was used for radio oscillators. Small to large blocks of "fresh" blue-gray quartzite were also quarried recently for use as rock aggregate and decorative riprap.

The sequence of middle and upper Crystal Mountain Sandstone in the south portion of the excavation consists mostly of deeply weathered, thick-to thin-bedded, coarse-grained sandstone and sandy, decalcified, cherty, conglomerate that contains some exotic meta-arkose and granitic cobbles and pebbles. These strata are considered to represent a depositional product of a significant low-stand of the sea with proximal turbidites and debris flows being transported through and from submarine slope-scarp-channel systems to the north or northeast and forming large fans in the proto-Ouachita trough. Thin layers of maroon to light greenish-gray shale occur in the uppermost part of the Crystal Mountain Sandstone and they are overlain in turn (north) by greenish-gray to black banded shale, and laminated gray silty shale and siltstone of the overlying Lower Ordovician Mazarn Shale. It is not currently known whether these maroon to light greenish-gray shales represent bentonitic ash-falls and, as a consequence, "time" lines. Large reclined and apparently northward-verging folds occur within the Mazarn Shale along the highwall. These slaty rocks are dissected by pervasive cleavage that may be crenulated, may exhibit mullions, and may contain some boudins. A minor (?) thrust fault separates the Crystal Mountain from the Mazarn and a thin interval is sheared and, in places, mylonized. The offset on the fault is not thought to be significant, but this is uncertain. Further, the tectonic transport direction on the fault is unknown. Most of the other folds in this area are inclined southward and hinges rake to the east-northeast, further study at this site may ultimately resolve some other structural enigmas in the Ouachitas.

About seven miles northeast of this site, Bass and Ferrara (1969) obtained isotopic ages of between 214 and 287 m.y. (Late Pennsylvanian-Middle Permian or later) from adularia crystals at the Hamilton-Hill--Teal quartz crystal mine. These determinations thus confirmed the earlier conclusions by Miser (1943, 1959) and Engel (1952) that the quartz veins in the Ouachita Mountains of Arkansas are late Paleozoic in age.

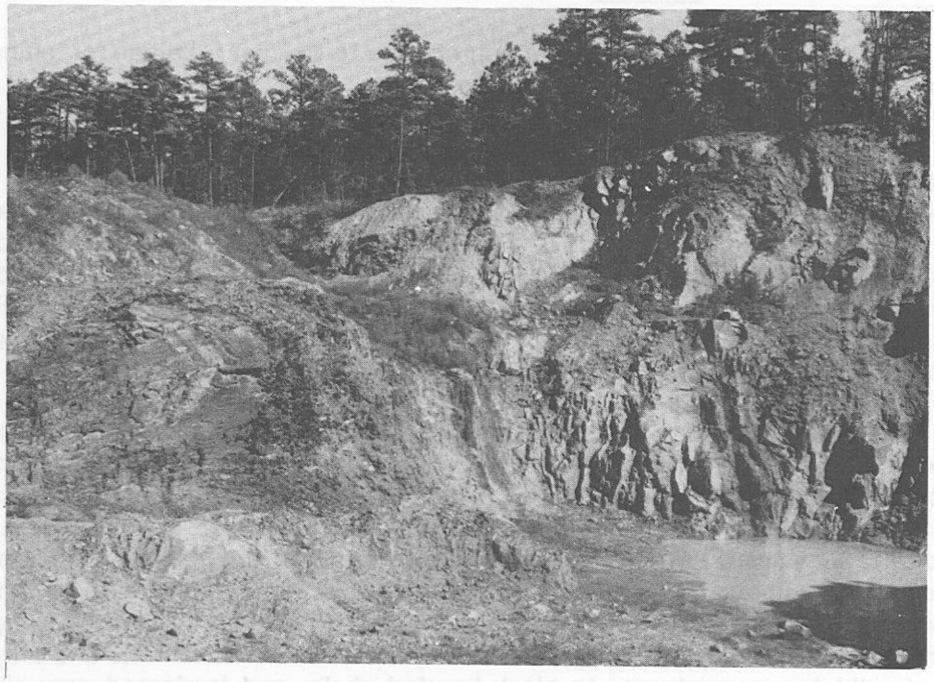


Figure 23. Stop 10. Vertical Crystal Mountain Sandstone (right) and recumbently folded and cleaved Mazarn Shale (left) at McEarl quartz-crystal mine.

STOP 11. COLLIER SHALE AND TRILOBITES AT MARBLE CHURCH LOCALITY

by

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At this stop we will examine exposures of the Collier Shale along Brushy Creek (Figure 24 and 25). At this locality (C--Figure 26)the Collier consists of deformed black shale containing clasts of dark limestone. Some of the clasts from this outcrop have yielded trilobites belonging to the Elvinia Zone of the Franconian Stage of the Upper Cambrian, and provide some of the evidence that the lower part of the exposed Collier Shale is Cambrian.

The Collier Shale was named by Miser and Purdue (1929) from exposures of black shale along Collier Creek in Montgomery County in the western part of the Benton uplift in the Ouachita Mountains. No fossils were recovered from the Collier, and it was assigned a Cambrian age on the basis of its stratigraphic position beneath strata containing Early Ordovician graptolites.

No fossils were discovered in the Collier until Repetski and Ethington (1977) reported Early Ordovician conodonts from the upper part of the Collier at the type area and from the Broken Bow uplift in southeastern Oklahoma. This suggested that the Collier was probably Ordovician in age rather than Cambrian.

William Hart (1985) discovered the presence of a large area of previously unknown exposures of the Collier Shale (Figure 26) during structural mapping in the northwestern part of the Goosepond Mountain 7.5' quadrangle in Saline and Garland Counties, Arkansas, which includes the outcrops at this stop. Subsequent mapping by Hart and Charles Stone of the Arkansas Geological Commission (Hart and others, 1986) extended this complexly folded area of Collier westward into the northeastern part of the adjacent Jessieville 7.5' quadrangle (Figure 26). The generalized stratigraphic sequence of the Collier Shale in the Jessieville area is shown in Figure 27. While no exact thicknesses are inferred, it is estimated that the exposed Collier is about 650 ft. thick.

Assignment of these black shales in the Jessieville area to the Collier was based primarily on faunal evidence. Specimens of the same species of Early Ordovician conodonts that were recovered from the Collier at the type area were also found in several thin limestone beds near the top of the Collier outcrops east of this Stop (Hart and others, 1987). Extensive collecting of clasts of dark limestone at this stop and at 13 other localities (Figure 26 shows the major localities) in the Jessieville area by Hart, Stitt, and Steven Hohensee has yielded over 8,000 trilobites assigned to 30 species characteristic of the Elvinia Zone of the Franconian Stage of the Upper Cambrian (Hohensee and Stitt, 1989). Figure 28 shows some of the more abundant species of trilobites, as well as the typical appearance of these trilobites on a broken surface of one of the limestone clasts). A few species of trilobites were recovered that are characteristic of the Taenicephalus Zone which overlies the Elvinia Zone in North America. The same species of trilobites that occur in the Collier are well known from light-colored, shallow-water shelf limestones that occur in the Davis Formation in Missouri (Kurtz, 1975), the Honey Creek Limestone in Oklahoma (Stitt, 1971, 1977), the Wilberns Formation in central Texas (Wilson, 1949), as well as in the same age strata in Pennsylvania, the upper Mississippi Valley, the Great Basin, and the Canadian Rocky Mountains (Hohensee and Stitt, 1989).

Figure 24. Stop 11. Northward dipping trilobite-rich limestone lenses in shales in the Collier Shale in Brushy Creek.

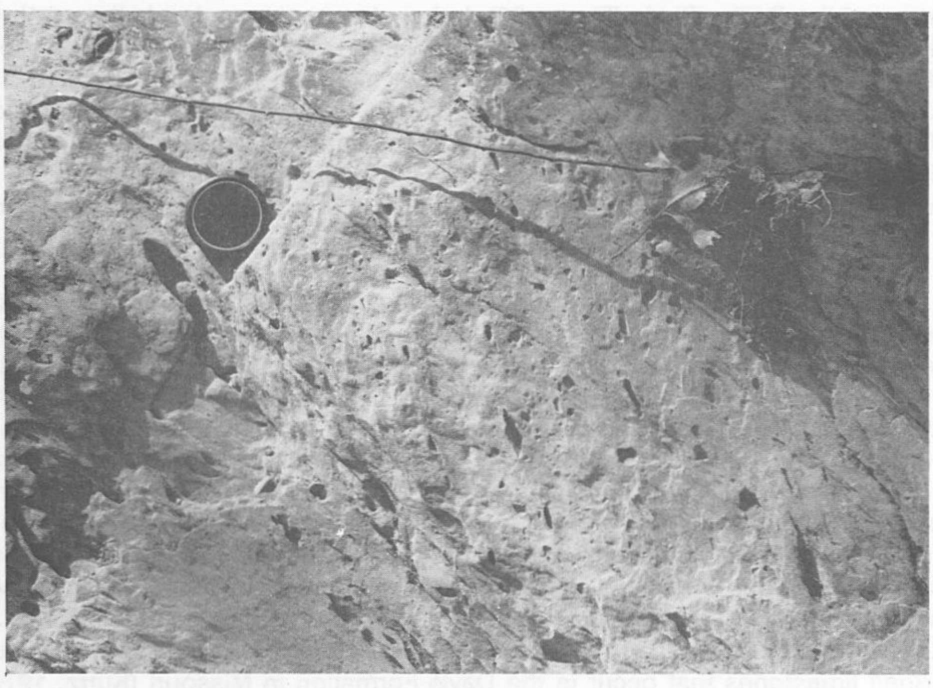

Figure 25. Stop 11. Closeup of Collier Shale showing solution pits formed by weathering of small limestone clasts.

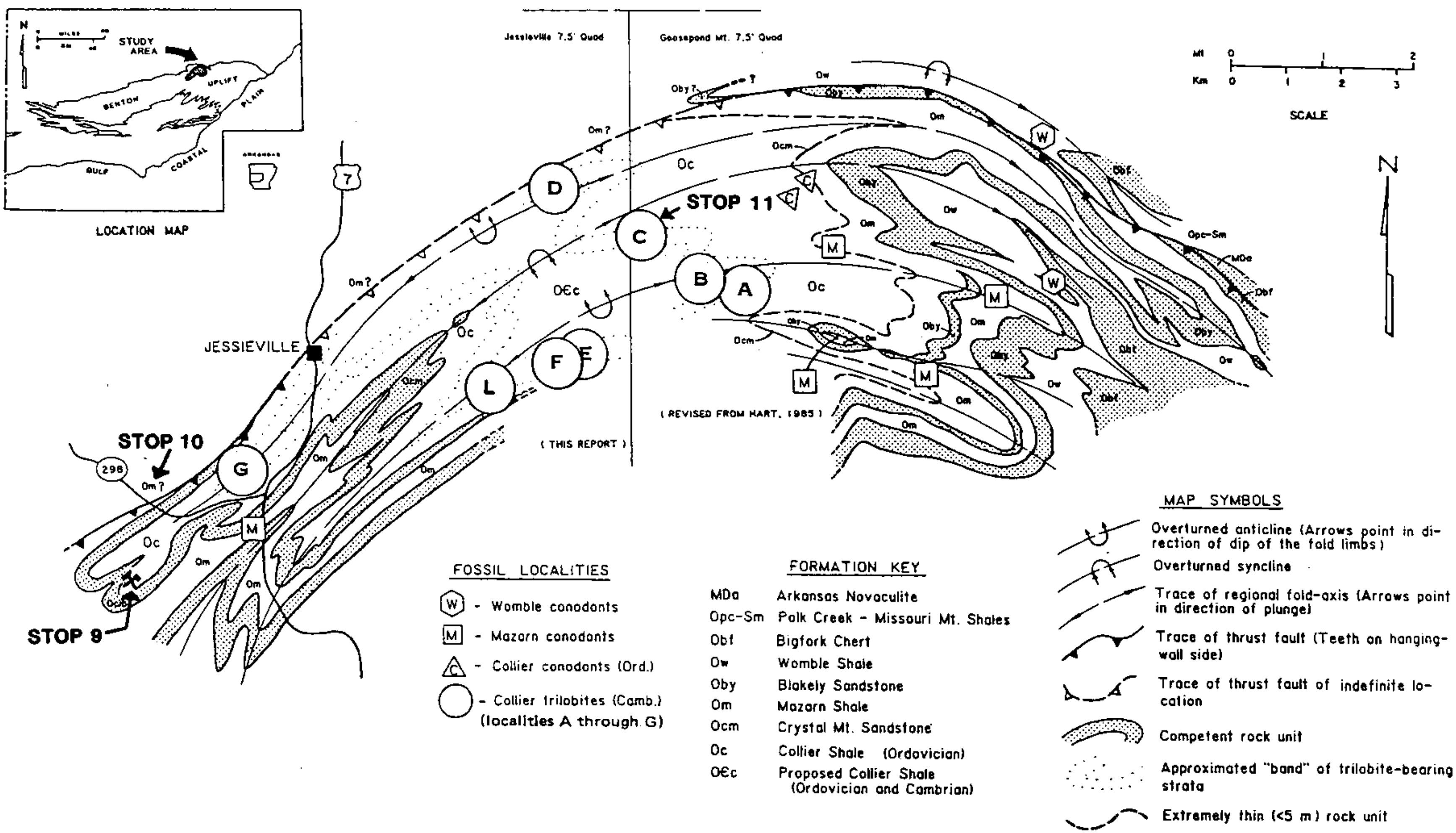

Figure 26. Geologic map of the Jessieville, Arkansas area in Garland County showing fossil localities. Goosepond Mountain quadrangle revised in part from Hart (1985).

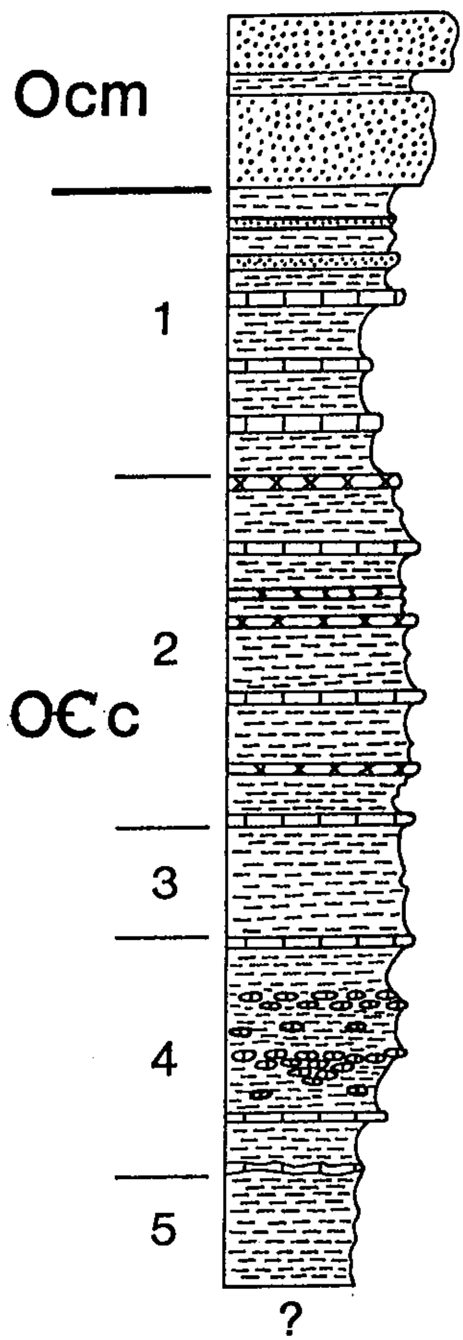

Figure 27. Generalized stratigraphic column for the Collier Shale in the vicinity of Jessieville, Arkansas. Ocm = Crystal Mountain Sandstone; O€c = Collier Shale, with 5 informal lithologic units.

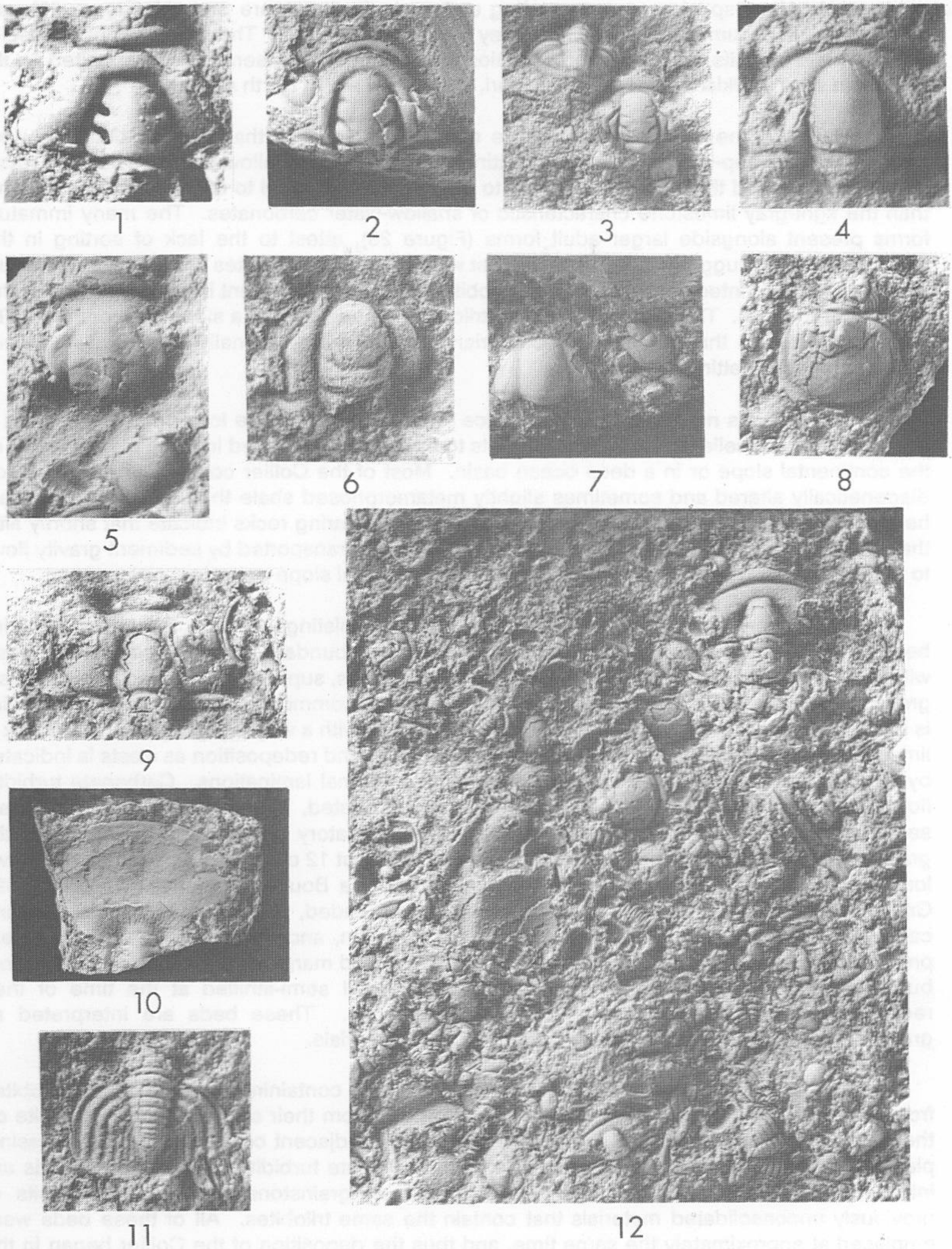

Figure 28. Trilobites of the <u>Elvinia</u> Zone (Late Cambrian), from the Collier Shale, Jessieville area, Arkansas. All specimens from locality D (Fig. 26) except 3 and 6, which are from locality G. All specimens are holaspids (adults) unless otherwise noted.

Most of these trilobites are very small (1-2 mm in length), disarticulated, unsorted, and unabraded. Many specimens representing early growth stages are present (Figure 28), and appear to have accumulated near where they were shed as molts. The fauna has high species diversity, and exhibits the style of preservation found in trilobite assemblages deposited on the Cambrian shelf in Oklahoma, Texas, Missouri, and elsewhere in North America.

However, the Collier trilobites have some characteristics that suggest that they were deposited in a deep-water, outer shelf setting, rather than in shallow water. They are found mostly in clasts and thin beds of dark-gray to black, pyritic, peloidal to micritic limestone, rather than the light-gray limestone characteristic of shallow-water carbonates. The many immature forms present alongside larger adult forms (Figure 28), attest to the lack of sorting in this environment, and suggests deposition in quiet water. Agnostid trilobites are very abundant, and Robison (1976) pointed out that agnostid trilobites were most abundant in outer shelf areas that faced open oceans. The absence of olenid trilobites argues against a slope environment. The evidence suggests that these Upper Cambrian trilobites were originally deposited in a deep water, outer shelf setting.

But this was not the final resting place for these fossils. The lower Paleozoic strata of the Ouachitas are believed by most geologists to have been deposited in deep marine water on the continental slope or in a deep ocean basin. Most of the Collier consists of gray to black, diagenetically altered and sometimes slightly metamorphosed shale that is inferred to have a hemipelagic origin. Field observations of these trilobite-bearing rocks indicate that shortly after the trilobites were deposited on the outer shelf, they were transported by sediment gravity flows to their final resting place in deeper water on the continental slope or basinal plain.

Several types of sediment gravity flows can be distinguished in the trilobite-bearing beds in the Collier. Channel-form debris flows contain abundant, lenticular, limestone clasts with tapered margins that occur in channel-form geometries, supported by a calcareous, bluish-gray shale/slate matrix. Sheet-form debris flows are very common (such as at this Stop, which is Locality C on Figure 26), and are tabular bodies of rock with a very high ratio of shale matrix to limestone clasts. Evidence of lithification prior to erosion and redeposition as clasts is indicated by angular fracturing of clasts and truncation across internal laminations. Carbonate turbidty-flow deposits are scarce, and consist of beds of brecciated, sometimes graded, carbonate sediment. The lower contacts of these beds are undulatory and sharply defined, and the graded intervals are overlain by laminated limestone. About 12 cm of this type of deposit at two localities are interpreted to represent parts A and B of a Bouma sequence (Bouma, 1962). Grainstone gravity-flow deposits consists of beds of ungraded, unsorted bioclastic debris and carbonate pebbles. The fossils show little or no abrasion, and numerous juvenile forms are present with the adult forms. Some pebbles have truncated margins suggesting prelithification, but most appear to have been burrowed and were still semi-lithified at the time of their redeposition, as indicated by their molded appearance. These beds are interpreted as grainstone gravity-flows of previously unconsolidated materials.

The evidence indicates that the limestone clasts containing Late Cambrian trilobites from the <u>Elvinia</u> and <u>Taenicephalus</u> Zones were eroded from their original depositional site on the outer shelf and redeposited in deeper water on the adjacent continental slope or basinal plain as channel and sheet-form deposits and in carbonate turbidites. These clast beds are interbedded with bioclastic limestones interpreted as grainstone gravity-flow deposits of previously unconsolidated materials that contain the same trilobites. All of these beds were emplaced at approximately the same time, and thus the deposition of the Collier began in the Late Cambrian.

Sampling of similar clasts of dark limestone in a black shale matrix by Hart, Stitt, Stone, and Ethington in a tightly folded anticline near Lena Landing (8 miles west of Jessieville) resulted in the recovery of species of trilobites from the Elvinia and Taenicephalus Zones, confirming the assignment of these black shales to the Collier Shale as mapped by Focht (1981). Near Buckville, Arkansas, 16 miles west of Jessieville, Early Ordovician conodonts have been recovered from the Collier. Near Paron, 18 miles east of Jessieville, conodonts indicative of the Cambrian-Ordovician boundary interval occur in outcrops of the Collier. Additional areas of Collier may be recognized in the Benton uplift in the future aided by paleontologic studies of conodonts and trilobites.

This information contributes to several important conclusions about the regional geology of the Benton uplift. The Collier Shale is a deep-marine deposit that contains clasts of dark limestone deposited as debris flows from the nearby Upper Cambrian outer shelf. Almost all of the trilobite species that have been recovered from the Collier are restricted to North America, which means that the Benton uplift is not an exotic terrain. The paleontologic evidence indicates that the deposition of the Collier was slow, and that it began in the Late Cambrian and, based on the conodont evidence, continued into the Early Ordovician.

STOP 12. ALUM FORK DECOLLEMENT WITH CRYSTAL MOUNTAIN SANDSTONE IN FAULT CONTACT WITH STANLEY SHALE, ARKANSAS NOVACULITE AND OLDER ROCKS.

The exposed sequence of shale, siltstone, and scattered beds of clean, quartzose sandstone belongs to the Crystal Mountain Sandstone. Locally there are some erratic granite and meta-arkose boulders and cobbles in the formation. Proceeding down the hill to the west, there are sequences of interbedded weathered limestone, calcareous siltstone, and shale probably in the Mazarn Shale. Near the base of the hill is a thin sheared interval representing the fault plane of the Alum Fork decollement (Figure 29). Below the fault are some exposures of the lower Stanley Shale. 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 accumulations of residuum are present in the older overthrust rocks, but are significantly less common in the underlying younger strata. As previously stated, a minimum of at least 8 miles of displacement can be measured along the fault in this area. In all likelihood however, this fault has a larger displacement. The true magnitude of the displacement is indicated by the presence of the central or southern facies of the Arkansas Novaculite a few miles northeast of this area, whereas here, the northern facies of the novaculite is present. It is interesting to note that most, if not all of the numerous thrust faults and related splays of the underlying plate are also covered by the overlying plate.

There have been numerous investigations in recent years to unravel the complex geology in the eastern part of the Benton uplift of the Ouachita Mountains. An incomplete summary 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 quantitative structural analysis mostly by Viele; later, the regional and detailed mapping by Haley and Stone; next, the studies by Viele and students, concurrently with more work by Haley, Stone, Ethington, Repetski, Stitt and others. Several publications by Viele have provided an explanation for the origin of the complex structure in these rocks. Haley and Stone and also Arbenz have offered alternative proposals, but until recently have published relatively little on this subject.

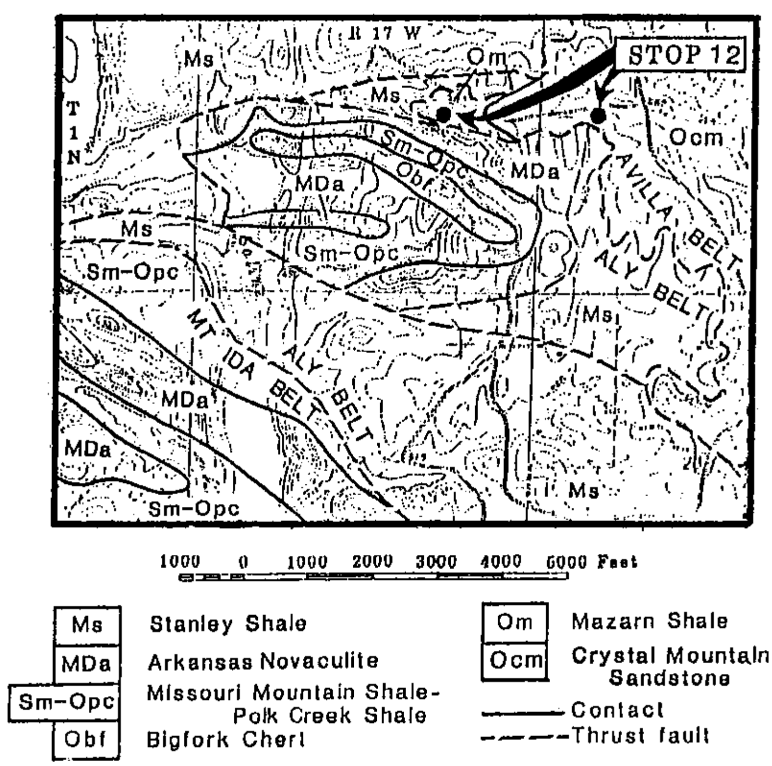

Figure 29. Geologic map of parts of the Alum Fork decollement in the vicinity of Stop 12.

STOP 13. WINDOWS AND KLIPPEN IN ORDOVICIAN ROCKS NEAR PARON

Near the bridge 0.2 miles southwest of Paron on Arkansas Highway 9, a thrust fault separates the covered lower Stanley Shale from the Bigfork Chert which is exposed to the south (Figure 30). The cherts and siliceous limestones of the Bigfork are intensely sheared. Traces of petroliferous minerals were noted in quartz-calcite veinlets cutting the unit. Continuing southwestward, thin-bedded, dense, gray limestone and shale of the upper Womble Shale are exposed. Next, along the north side (notice abundant cedar trees), a folded fault plane (thin white gouge zone) separates the Womble from banded slate, limestone, and siltstone of the Mazarn Shale. Some of the banded slates of the Mazarn contain a significant Lower Ordovician graptolite fauna which has been studied by Stan Finney. Several generations of horizontal to steeply plunging folds are present. Intense northward-dipping cleavage and large milky quartz veins are characteristic of this outcrop.

The structure in this area is complex and it goes without saying that interpretations continue to change. First, along Highway 9, the map trends indicate east-west or northwest-southeast striking beds. Dips are consistently to the north and the succession of the formations as a whole indicates a stratigraphic section that becomes progressively younger northward. Axial surfaces and cleavages are moderately inclined and dip north, but fold hinges are consistently of high rake, the folds are either raking folds or reclined folds.

Toward the west (Figure 30), there are two isolated areas of Bigfork Chert and Womble Shale lying across the Mazarn Shale. As they cannot be connected to any nearby outcrops of Bigfork, they do not appear to be the result of cross folding but are more probably klippen. Viele (1973), thinks they may be part of the nappe composing the Ellis Mountain-Ferndale trend. On the west side of the southernmost klippe, recumbent isoclinal folds having northward rotations are backfolded to Z patterns when viewed down plunge. Z folds on the lower libs are accented, S folds on the upper limbs are damped.

These relations along the highway and at the klippen suggest superposed folding, -- a northward direction of tectonic transport followed by backfolding to the south.

Thank you for your time and interest, now let's have a safe return trip to our Conference Headquarters!

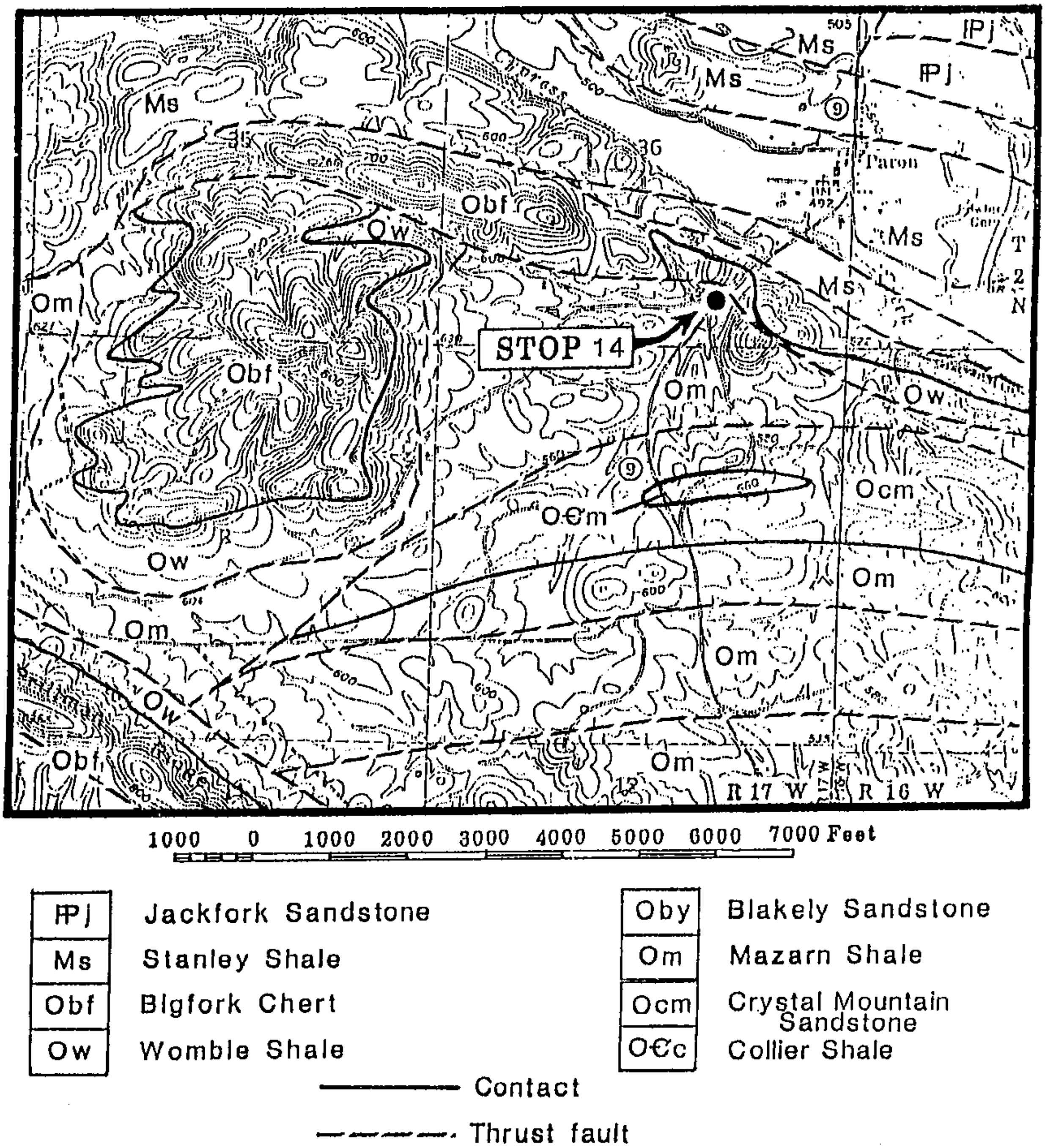

Figure 30. Geologic map of the Paron area.

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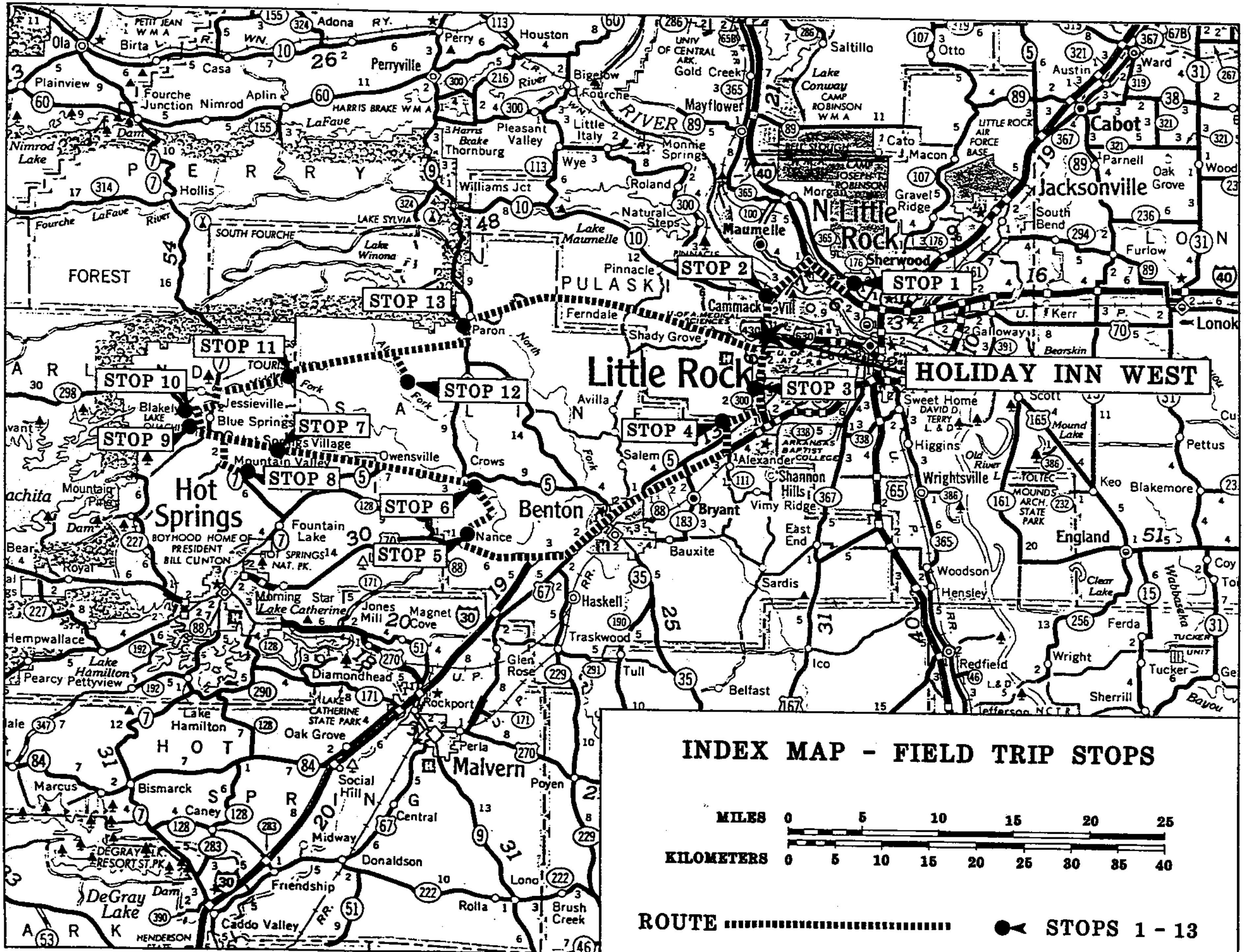
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