GUIDEBOOK 86-2

STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

William V. Bush, Director and State Geologist

SEDIMENTARY AND IGNEOUS ROCKS OF THE OUACHITA MOUNTAINS OF ARKANSAS

A Guidebook with Contributed Papers

Part 1

BY
CHARLES G. STONE, J. MICHAEL HOWARD, and BOYD R. HALEY

With Contributed Papers By
L. F. Berry, Curtis E. Breckon, J. Michael Howard, G. R. Keller,
Albert L. Kidwell, J. M. Kruger, Charles F. Mansfield,
Ellen Mullen Morris, and Haki Naz

Prepared for

THE GEOLOGICAL SOCIETY OF AMERICA

Annual Meeting
San Antonio, Texas
November, 1986

Little Rock, Arkansas
October, 1986
Reprinted September, 1996

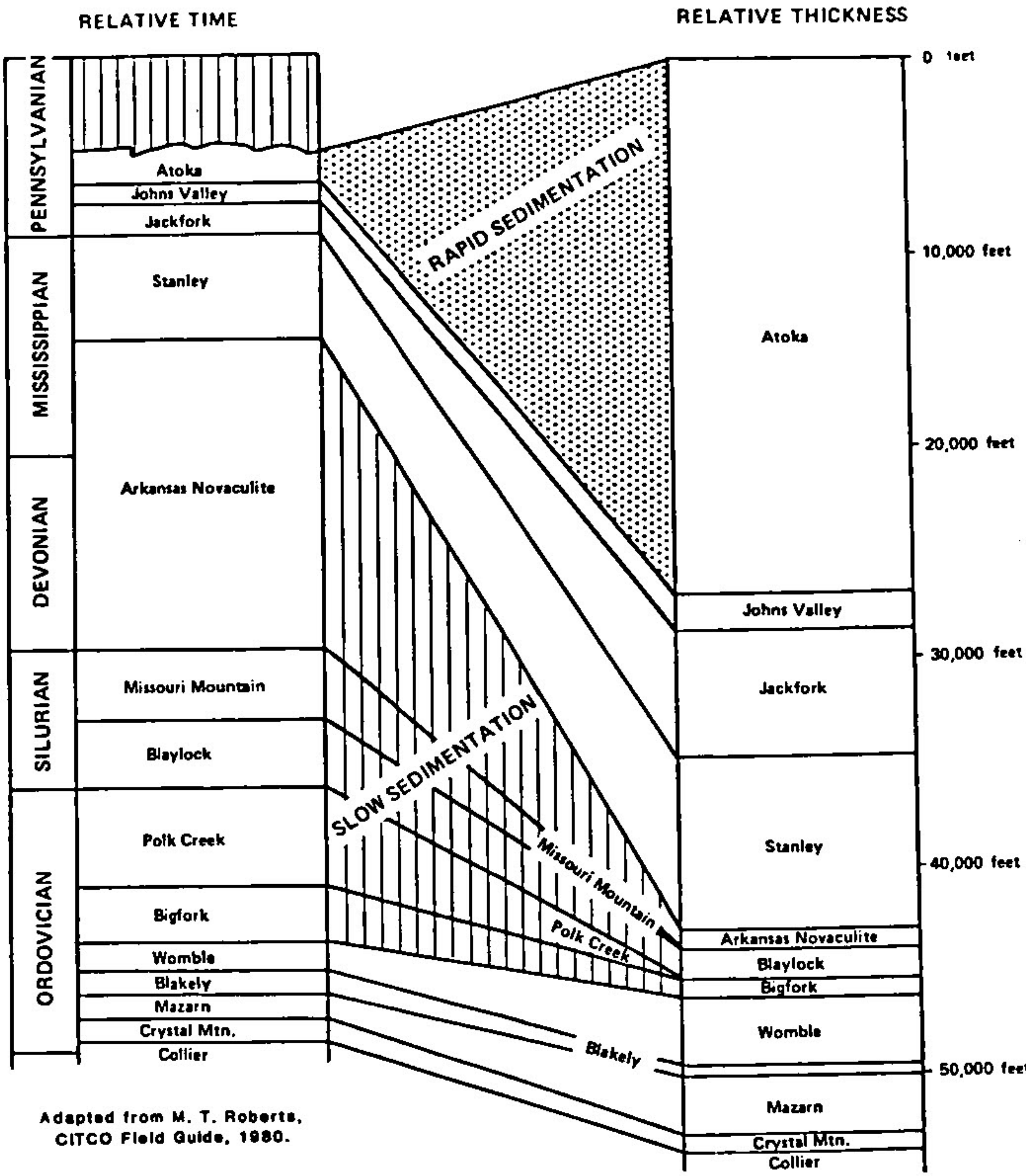

CHART SHOWING SEDIMENTATION RATES OF THE PALEOZOIC ROCKS IN THE OUACHITA MOUNTAINS, ARKANSAS

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COVER—Box fold in Ordovician age Bigfork Chert at City Quarry in Hot Springs, Arkansas (Stop 27).

Little Rock, Arkansas
1996

FOREWORD

The primary purpose of this guidebook is to examine the complex geologic environment of the rocks in the Arkansas portion of the Ouachita Mountains. Emphasis is placed on the depositional environment of the Upper Cambrian to Middle Pennsylvanian age rocks and on their subsequent deformation in late Paleozoic time. Much less emphasis is placed on the alkalic intrusive bodies of Cretaceous age and on the metallic minerals associated with them.

The main volume of the guidebook set was assembled for a field trip planned in 1985 by another society, — but subsequently canceled. Most of the stops are appropriate for the present field trip, but somewhat different goals and logistics require that some of them not be visited, including most of those where igneous rocks are present. By the same token, additional stops are desirable and they have been described in the supplemental volume. To avoid reformatting the main volume, the stop numbers and their order of presentation remain unchanged, although the order in which they will be visited during this field trip will be different.

Short papers contributed by other workers active in the area provide a sampling of recent types of studies being conducted in the Ouachita Mountains and an interpretive context for the geologic descriptions of the rocks at many of the stops. Our sincere thanks to those who have taken the effort to prepare these papers. Their names, which appear on the cover and title page as well as on the papers, will not be repeated here.

We are indebted to John David McFarland, III, who provided most of the photographs that accompany the stop descriptions, and George W. Colton, who assisted with some of the editorial chores. We also thank Albert L. Kidwell for preparing the description of Stop 7.

Special thanks are also expressed to Marie Arthur, Jim Cannon, Hurcil Cowart, Hewitt Harlow, Ralph Harrison, Henry deLinde, Garfield Lewis, Garland Milholen, and Ocus Stanley for their kind assistance. We thank Adrian Hunter, Virginia Snyder, Susan Young and other personnel of the Arkansas Geological Commission for their diligent efforts in the compilation of this volume.

Charles G. Stone
J. Michael Howard
Boyd R. Haley
April 11, 1986

CONTENTS

STOP DESCRIPTION – FIRST DAY

WEST GULF COASTAL PLAIN

CRATER OF DIAMONDS STATE PARK

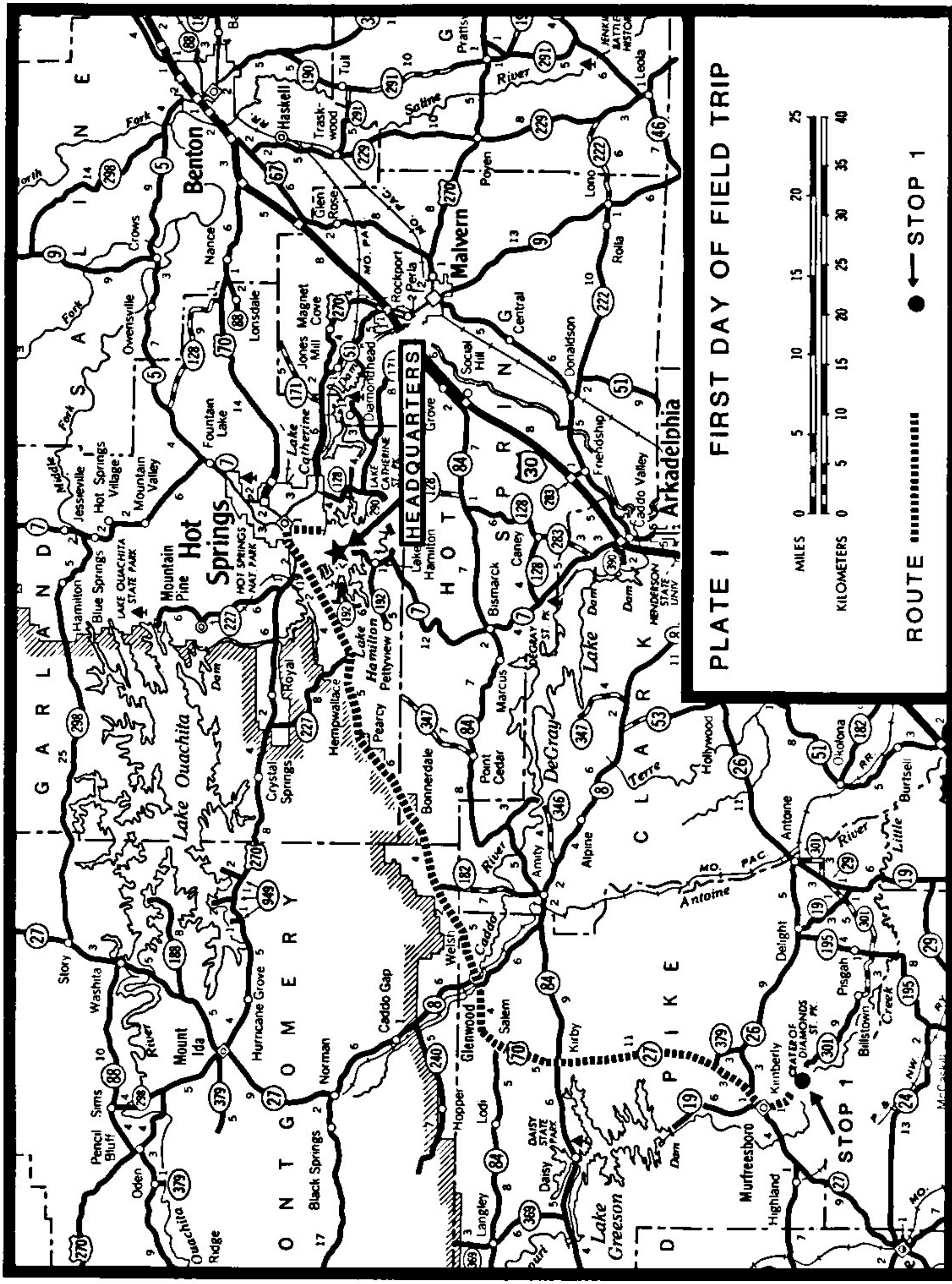


PLATE I FIRST DAY OF FIELD TRIP
MILES 0 5 10 15 20 25
KILOMETERS 0 5 10 15 20 25 30 35 40
ROUTE
STOP 1
HEADQUARTERS
Hot Springs
Benton
Malvern
Arkadelphia
Mount Ida
Lake Ouachita
Lake Catherine
Lake Hamilton
DeGray Lake
Lake Greeson
GARLAND
SALINE
HOT SPRING
CLARK
PIKE
MONTGOMERY
HOT SPRINGS NAT. PARK
LAKE OUACHITA STATE PARK
LAKE CATHERINE ST. PK.
DEGRAY ST. PK.
DAISY STATE PARK
CRATER OF DIAMONDS ST. PK.
HENDERSON STATE UNIV.
Murfreesboro
Kirby
Glenwood
Amity
Caddo Gap
Royal
Pearcy
Mountain Pine
Jessieville
Lonsdale
Magnet Cove
Donaldson
Friendship
Caddo Valley
Bismarck
Delight
Antoine
Okolona
Hollywood

STOP DESCRIPTIONS – FIRST DAY

SOUTHWESTERN ARKANSAS

MURFREESBORO

Stop 1. – CRATER OF DIAMONDS STATE PARK – PRAIRIE CREEK INTRUSIVE

The following summary of the kimberlite pipe was by Jerry Wilcox, a geologist formerly employed by the Arkansas Department of Parks and Tourism. From Bush, et al., 1977. See the enclosed report by Mullen for further information on the geology of the intrusive.

THE HUMAN HISTORY

The geologic formation was studied as early as 1889 by John C. Branner and R. N. Brackett. They realized that the formation was similar to diamond-bearing pipes found in Africa, but they failed to find any diamonds. It wasn't until 1906 that John W. Huddleston, a local farmer-woodsman-treasure hunter, found the first diamond.

Once the diamonds proved genuine, a Little Rock jeweler, a banker, and others bought the Huddleston property and organized the Arkansas Diamond Mining Company. But the Huddleston property covered only half of the kimberlite. The other half was purchased by Austin Miller, a competent geologist who spent years running tests to determine whether diamond mining would be profitable. The tests proved positive and in 1919, Miller constructed a full-scale diamond mining operation; but Miller's hopes were consumed by the fires of greed. Arsonists burned down his entire operation. And this was only the beginning!

As Austin Miller's son Howard A. Miller relates, "I became involved in a diamond drama that would bring on international intrigue, the deliberate destruction by fire of mine buildings and equipment, numerous lawsuits, and no telling how much undercover wheeling and dealing. . ." Commercial mining attempts were probably destroyed by greed rather than lack of diamonds.

GEOLOGY

The geology of the Crater is described in the excellent report U. S. Geological Bulletin 808, 1929, by Hugh D. Miser and A. H. Purdue. The following information is taken from that report:

The Prairie Creek peridotite area is roughly triangular in shape and comprises about 73 acres. It is adjoined on the east by clay and sand of the Trinity Formation and on the north and west and much of the south by alluvium. Outcrops of what is probably Carboniferous sandstone occur on the south, southwest, and east side of the mine. It is massive, very hard, and gray to greenish gray to brown.

Almost all of the peridotite exposed at the surface is weathered to soft earth or at least very soft rock and shows many shades of green, blue, and yellow. The surface soil is a gumbo tinted black by organic matter.

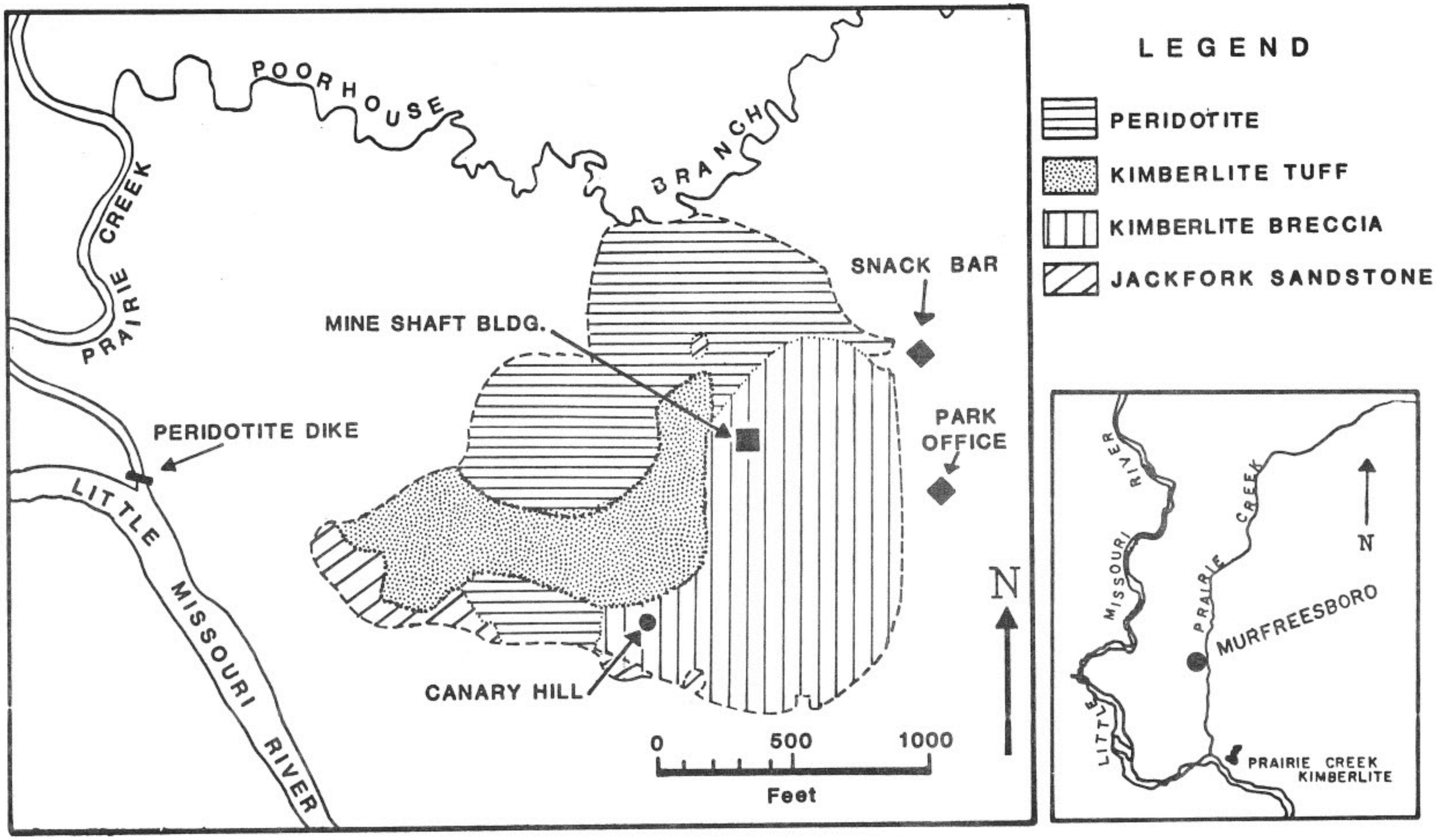


PLATE 2 —GEOLOGIC MAP OF THE PRAIRIE CREEK KIMBERLITE AREA

The rocks at the Crater may be divided into three catagories:

1. **Hardebank:** This is a hard, dense intrusive peridotite. It is greenish to brownish black. A good exposure may be seen on top of the small hump in the "search"area immediately to the northwest of the old mine shaft building. Only a few small diamonds have come from it.

The intrusive peridotite is composed mainly of phlogopite mica, olivine, serpentine resulting from weathering of the olivine, and small amounts of augite, perovskite, and magnetite. Except for texture, the next rock type described, breccia, is similar to the hardebank. This indicates that the intrusive peridotite is the hypabyssal equivalent of the breccia.

2. **Peridotite Breccia (Kimberlite).** Most of the mine presently cleared is pyroclastic breccia; in particular, the east-central part of the south half of the "search" area. Most of the diamonds come from this area. It contains fragments of shale and sandstone that have been carried upward hundreds or even thousands of feet from their source. The breccia ranges from fairly hard rock to material that has completely disintegrated into clay and ranges from yellow to gray and green and blue in color.

3. **Tuff and Fine-Grained Breccias:** Canary Hill is in the southwest corner of the grayish-blue rock. It is composed mainly of secondary chlorite. A few diamonds have been found in it.

THE DIAMONDS

The diamonds found here are, of coarse, pure crystalline carbon. They are distinguished by their hardness, high specific gravity, but most especially by their adamantine-greasy-metallic luster. A very peculiar character of the diamonds is their well rounded, highly polished surface. They look as though they have been polished in a rock tumbler.

Surprisingly, Crater diamonds are 20% harder than African diamonds and this, combined with their irregular crystal shape, makes them quite difficult to cut.

99% of the diamonds found at the Crater are various shades of brown, yellow, and white. A very few black, green, and even pink stones have been found. The average stone found is about one-half carat but gem quality diamonds of up to 40 carats have been found.

GEMS OTHER THAN DIAMONDS

Abundate agate, jasper, and amethyst and a few garnets and peridots are also found at the mine.

The following discussion on the origin of the diamond pipes and diamonds is by Mike Howard of the Arkansas Geological Commission.

Figure 1. — Stop 1. Searching for diamonds. The park personnel periodically plough the fields so that "good ground" is continually being brought to the surface.

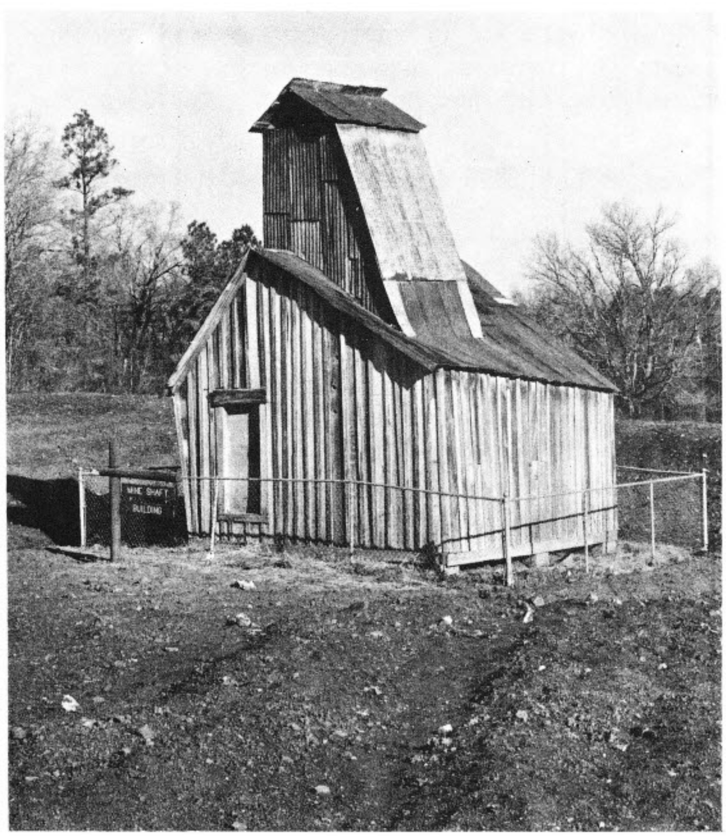


Figure 2. — Stop 1. Remains from an old diamond mill. This represents but one of the many intriguing ventures concerning the diamond mines.

ORIGIN OF DIAMOND PIPES AND DIAMONDS

Ever since the first diamonds were discovered and the art of cutting the stones began, men of science have attempted to explain their occurrence and origin. Early theories have fallen into disfavor in recent years as a result of information developed in the manufacture of synthetic diamonds and studies of natural stones.

Laboratory studies in growing diamonds indicate that they form only at temperatures above 1850°C and pressures above 66 kilobars. In order to shed further light on their origins, mineralogists recently began studying mineral grains contained in naturally occurring diamonds. These inclusions indicate the pressure, temperature, and chemical conditions at the time of the diamond formation. From a study of the inclusions diamonds appear to crystallize from molten rock chemically like that of peridotite or eclogite at upper mantle depths in the region of 93 to 125 miles (150 to 200 kilometers) and not in the kimberlite in which they are found.

The study of the rock type, kimberlite, that contains the stones gives the geologist a look deep into the earth that perhaps no other rock type allows. Kimberlite itself is a composite rock made of many finely ground angular fragments of highly altered magnesium-rich rock. The rock was apparently explosively intruded from some 93 to 125 miles (150 to 200 kilometers) depth by a carbon dioxide gas drive mechanism. Some geologists even think this happened at supersonic speeds in a matter of a few seconds. This accounts for the fantastic assortment of xenoliths (carried along fragments) of numerous other rock types from the upper mantle and lower crust. Furthermore, diamonds are metastable crystals at surface pressures and temperatures and eventually revert to a less dense form of carbon, i. e. graphite. If the stones were transported slowly to the surface, this transformation would already have taken place.

Interestingly enough, in reviewing many diamond pipes throughout the world, J. B. Dawson (1960) discovered that perhaps 90 percent of these pipes, including the Crater of Diamonds, were emplaced in Late Cretaceous time (about 90-100 million years ago). Geologists have yet to understand the conditions causing the sudden mobility of the upper mantle at this particular time in geologic history.

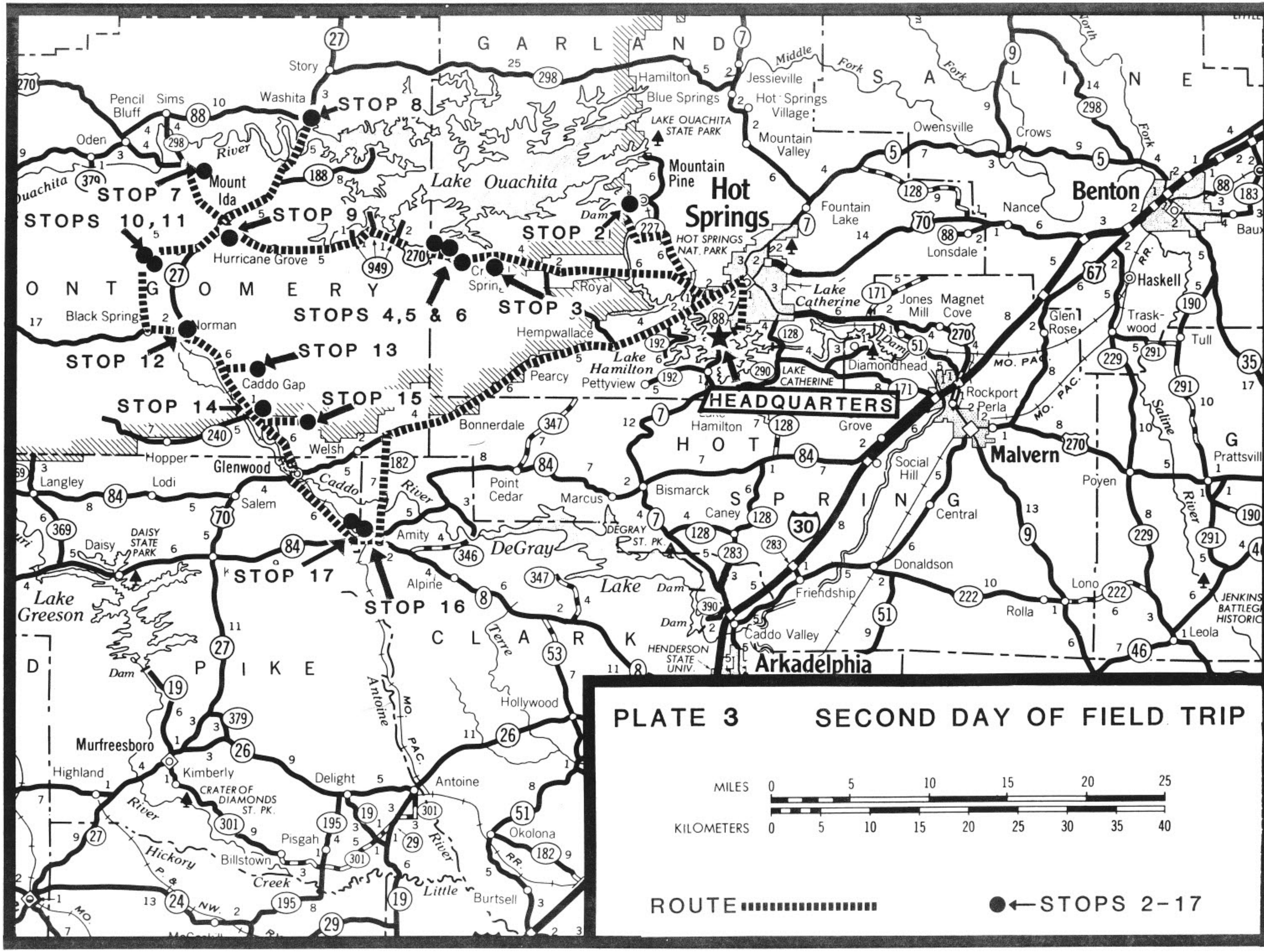


PLATE 3
SECOND DAY OF FIELD TRIP
MILES 0 5 10 15 20 25
KILOMETERS 0 5 10 15 20 25 30 35 40
ROUTE
STOPS 2-17
HEADQUARTERS
STOP 2
STOP 3
STOPS 4,5 & 6
STOP 7
STOP 8
STOP 9
STOPS 10,11
STOP 12
STOP 13
STOP 14
STOP 15
STOP 16
STOP 17
G A R L A N D
S A L I N E
H O T S P R I N G
C L A R K
P I K E
Hot Springs
Benton
Malvern
Arkadelphia
Mount Ida
Glenwood
Murfreesboro
Lake Ouachita
Lake Catherine
Lake Hamilton
DeGray Lake
Lake Greeson
Caddo Gap
Norman
Hurricane Grove
Black Spring
Amity
Story
Washita
Pencil Bluff
Sims
Oden
Mountain Pine
Fountain Lake
Jessieville
Hot Springs Village
Mountain Valley
Lonsdale
Jones Mill
Magnet Cove
Diamondhead
Rockport
Perla
Haskell
Pearcy
Royal
Hempwallace
Pettyview
Bonnerdale
Point Cedar
Marcus
Bismarck
Caney
Friendship
Caddo Valley
Donaldson
Salem
Lodi
Langley
Hopper
Welsh
Alpine
Antoine
Delight
Kimberly
Highland
Daisy
Okolona
Burtsell
Pisgah
Billstown
Hollywood
LAKE OUACHITA STATE PARK
HOT SPRINGS NAT. PARK
DAISY STATE PARK
DEGRAY ST. PK.
CRATER OF DIAMONDS ST. PK.
HENDERSON STATE UNIV.

STOP DESCRIPTIONS — SECOND DAY

CENTRAL OUACHITA MOUNTAINS

MOUNTAIN PINE — CRYSTAL SPRINGS — MT. IDA — NORMAN — GLENWOOD

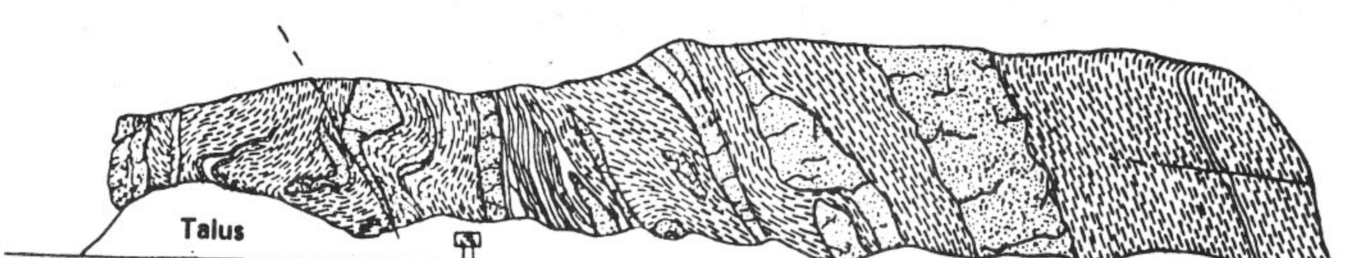
STOP 2 — BLAKELY SANDSTONE AT BLAKELY MOUNTAIN DAM

Rocks of the middle and lower Blakely Sandstone can be examined in two fine exposures at Blakely Mountain Dam. They consist of thin to massive bedded quartzitic sandstone (in part calcareous and conglomeratic), thin-to thick-bedded siltstone, and gray to black banded shale. Bottom marks, cross-laminations, and graded bedding indicate the tops of the beds are to the southeast, thus these beds are southward overturned. Cleavage in the shale dips northward and refracts across thin sandstone beds expecially near the fold hinge lines. This is especially well developed at the western end of both exposures. The sandstone divisions are thinning and fining upward and probably represent upper and middle submarine fan channel deposits derived from submarine scarps and slopes and possibly foreland facies to the north and northeast. Quartz veins of late Paleozoic age fill fractures in many of the sandstones. Graptolites are present in some of the shales.

The Hot Springs structural trend (northeast) as mapped by Purdue and Miser (1923) is the dominant structural feature in this area. Some anomalous directions of fold rotations in outcrops downstream indicate an older period of folding. At least two sets of cleavage are present. Most folds are overturned toward the southeast and hinge lines are near horizontal or rake gently northeast or southwest. Clastic dikes, in part parallelling cleavage, suggest deformation of soft water-saturated sediments. Sedimentary pull-aparts, debris flows, and soft-sediment slump features are present and may be mistaken for tectonic compressional features.

Riprap on the face of the dam is a gray, micritic and conglomeratic limestone quarried from the lower part of the Womble. The quarry is located in the NW¼ SW¼ NW¼ Sec. 34, T. 15 N., R. 22 W. a few miles northeast of the dam. This sequence of limestones represents a large sedimentary slurry deposit containing probable shallow-water pelletoidal and deep-water micritic materials. Repetski and Ethington (1977) made conodont collections from these limestones and indicate a Middle Ordovician age with affinities both to European and North American strata.

SOUTH END — BLAKELY MOUNTAIN DAM



From S.A.S.G.S Fall Field Trip Guidebook 1978

Figure 3 – Stop 2. Geologic sketch of the south end of Blakely Mountain Dam.

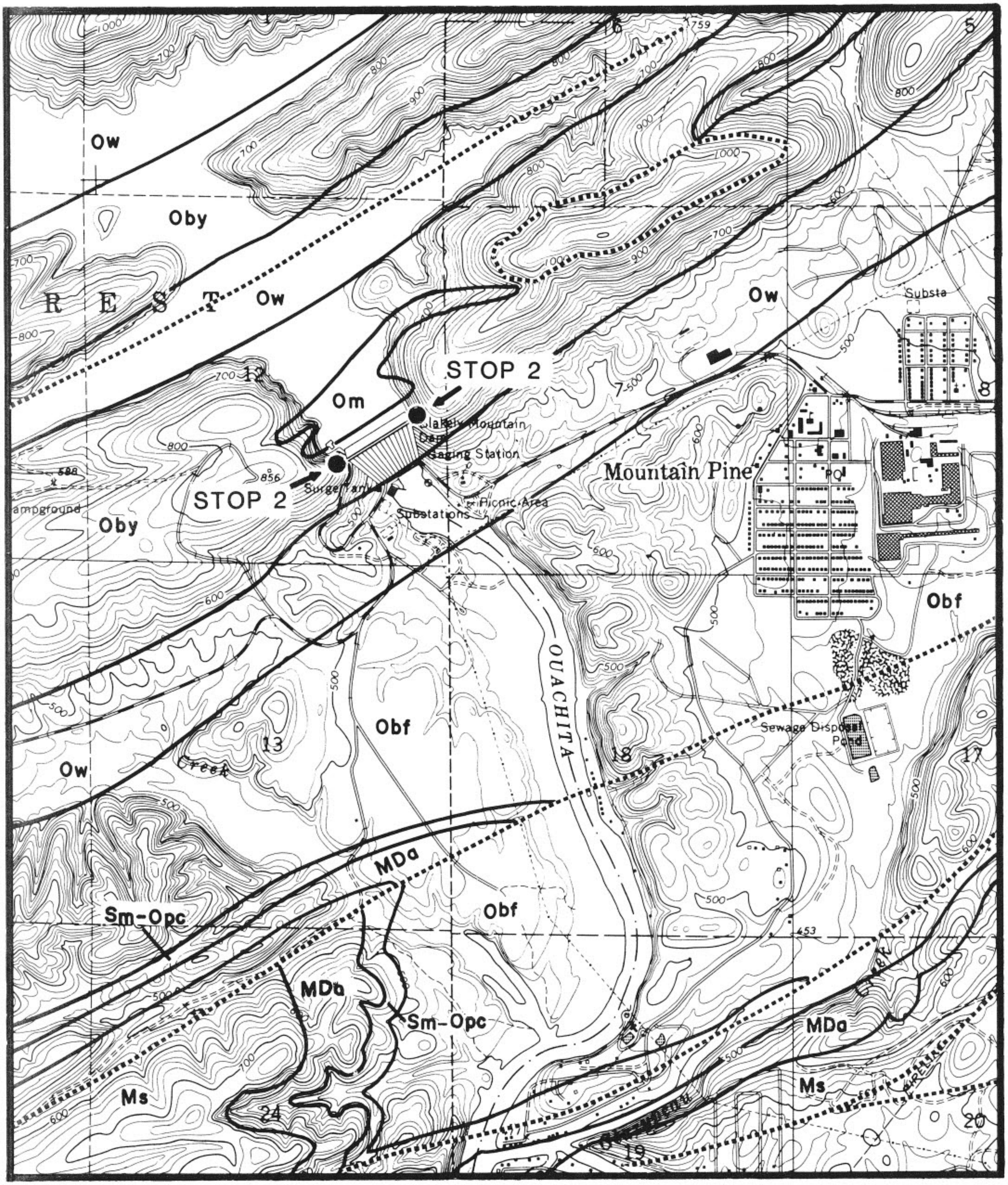


PLATE 4–GEOLOGIC MAP OF BLAKELY MOUNTAIN DAM – STOP 2

1000 0 1000 2000 3000 FEET

Ms	STANLEY SHALE	Oby	BLAKELY SANDSTONE
MDa	ARKANSAS NOVACULITE	Om	MAZARN SHALE
Sm-Opc	MISSOURI MOUNTAIN SHALE POLK CREEK SHALE		
Obf	BIGFORK CHERT	▪▪▪▪▪▪▪▪▪▪	THRUST FAULTS
Ow	WOMBLE SHALE	———	CONTACTS

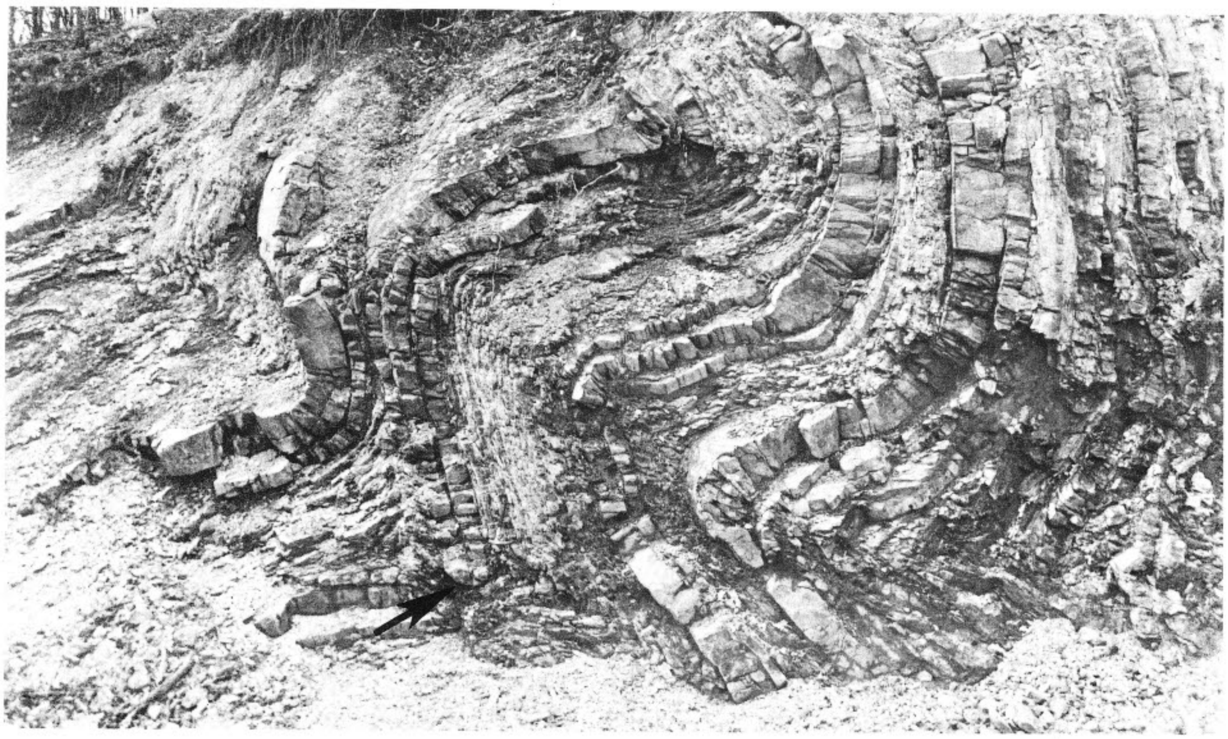


Figure 4. — Stop 2. Interbedded sandstone and shale forming southward-verging folds in the middle Blakely Sandstone at the south end of Blakely Mountain Dam. Arrow marks a small structure that has been interpreted variously as an earlier superposed fold, a sedimentary pull-apart, and as a tectonically "crowded" interval.

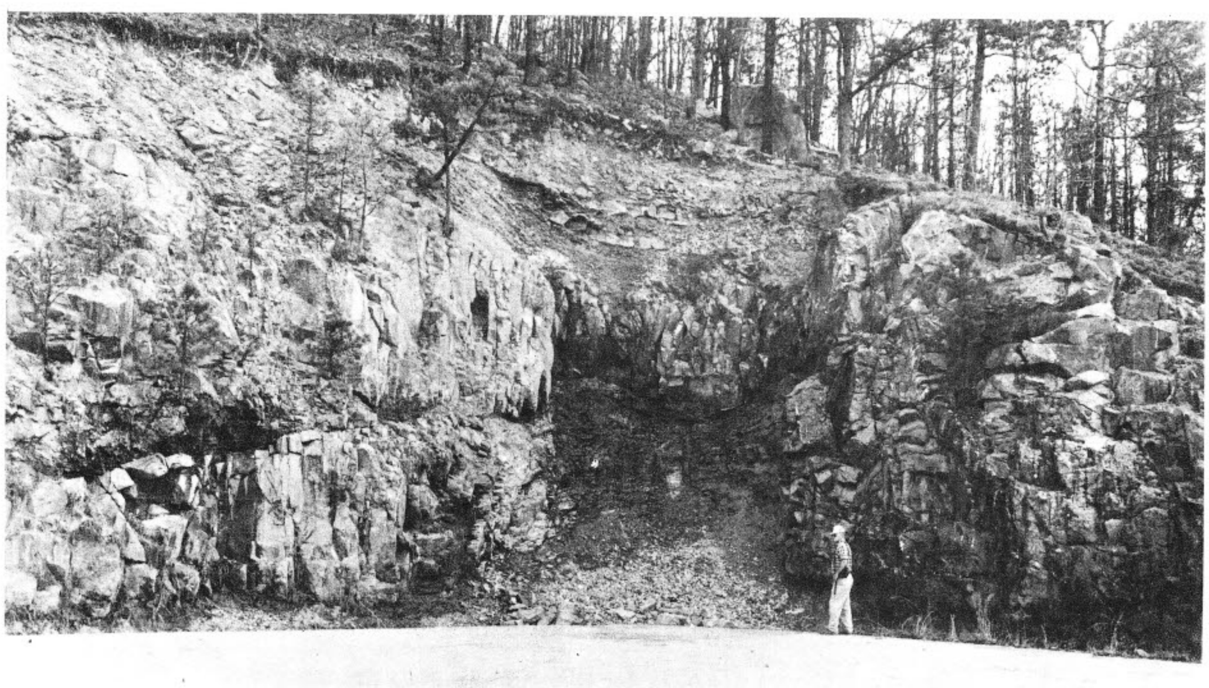


Figure 5. — Stop 2. Massive sandstones of the Blakely enclosing a mass of deformed shale ("the terrible corner") at the north end of Blakely Mountain Dam. The shale mass has been interpreted as tectonic boudinage, a faulted block, a clay plug in a submarine fan channel system, and as a sedimentary slump mass.

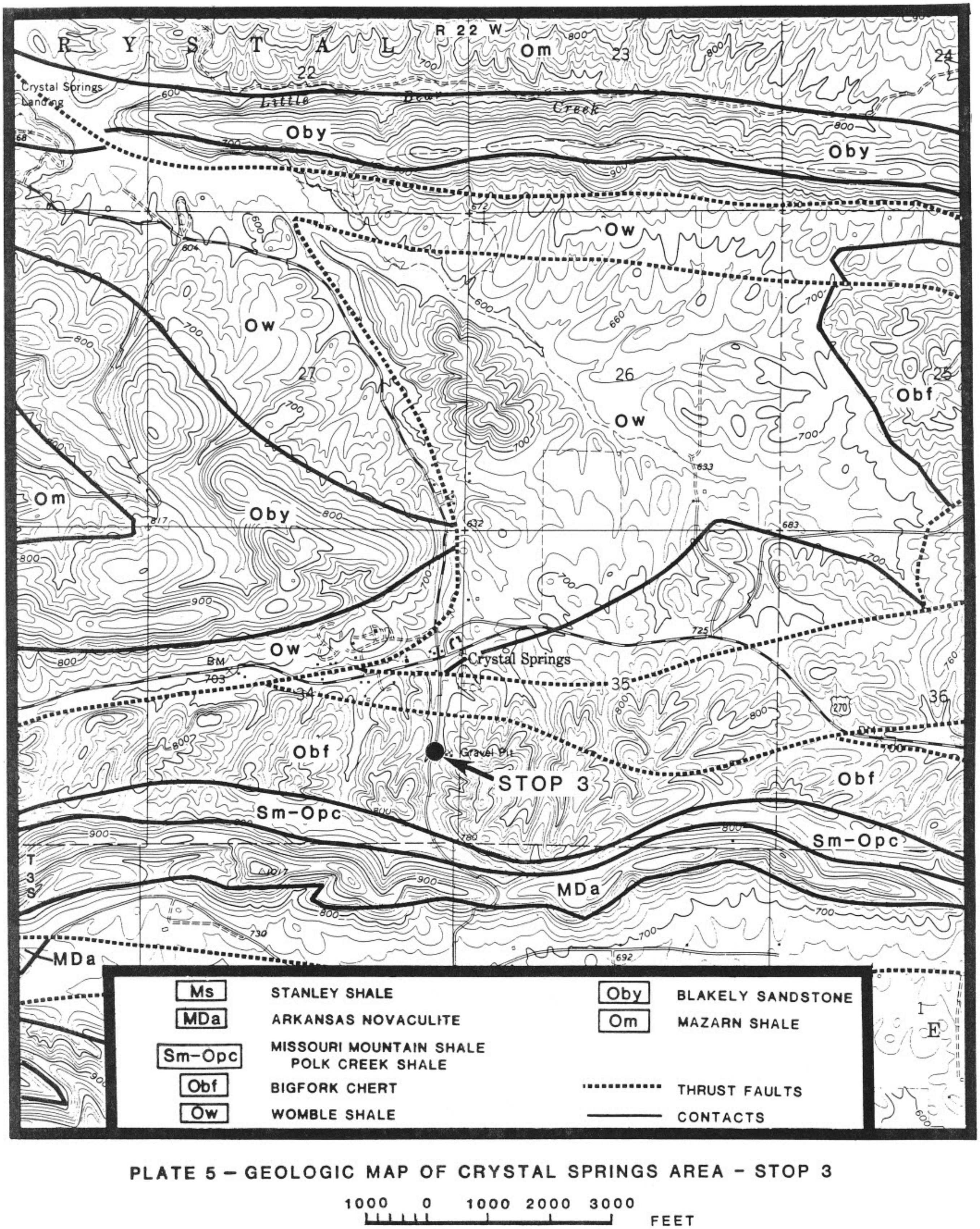


PLATE 5 – GEOLOGIC MAP OF CRYSTAL SPRINGS AREA – STOP 3

1000 0 1000 2000 3000 FEET

Geology from Haley and others (1976)

STOP 3. – FOLDED BIGFORK CHERT AT CRYSTAL SPRINGS QUARRIES

These two quarries are operated by Mr. Ralph Harrison in the Middle and Late Ordovician age Bigfork Chert south of Crystal Springs (Plate 5.) 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_2O_3 – 5.98%, MnO – 0.031%, CuO – nil, ZnO – 0.008 and PbO – 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.

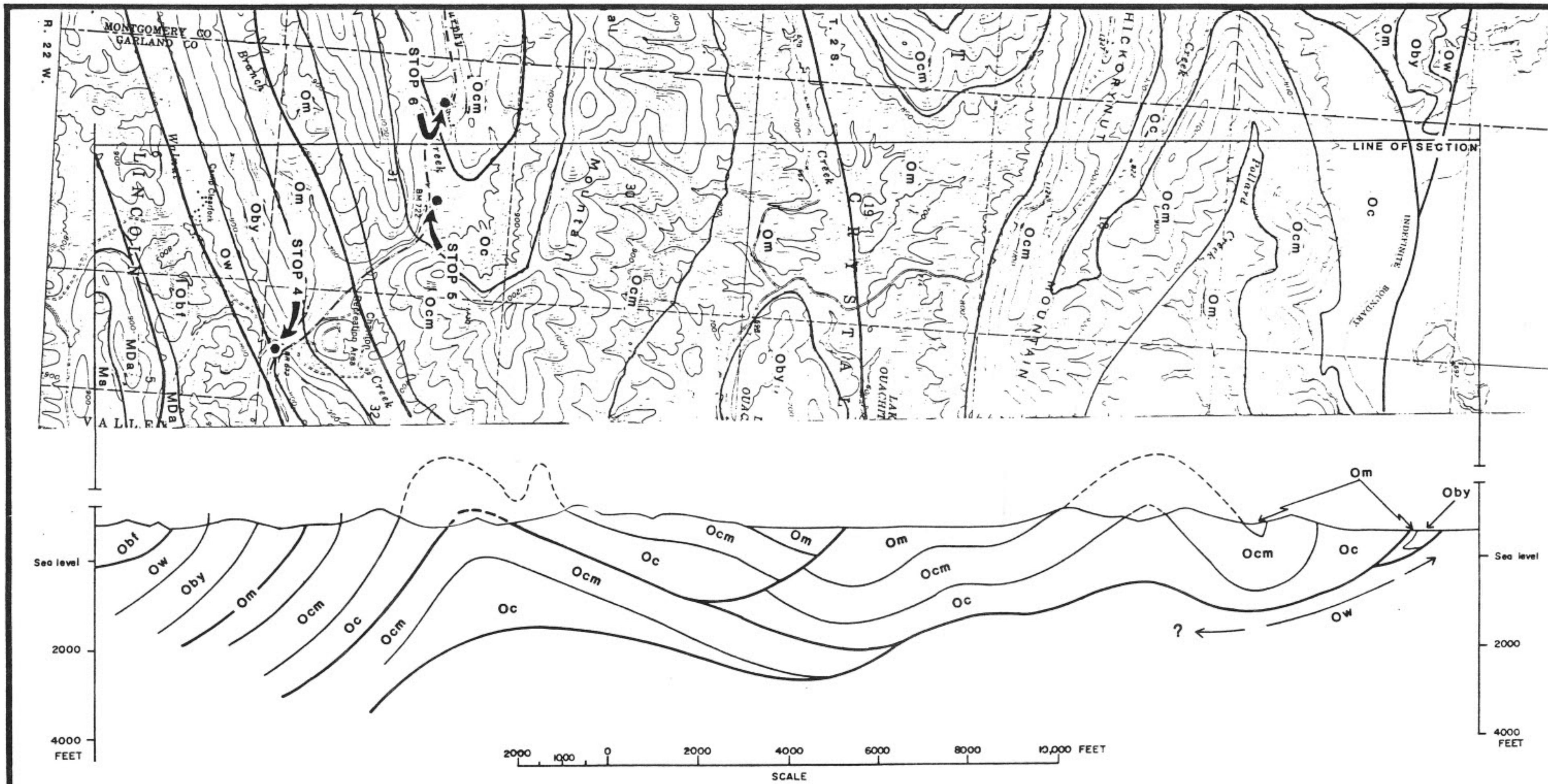


PLATE 6 — GENERALIZED GEOLOGIC MAP AND STRUCTURAL SECTION OF THE ROCKS NEAR AND NORTH OF STOPS 4,5 & 6.

STOP 4 — 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 6). 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. Stolarz and Zimmerman (1984) measured the section along Walnut Creek and compared it with other partial exposures east of the area (Plate 7).

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

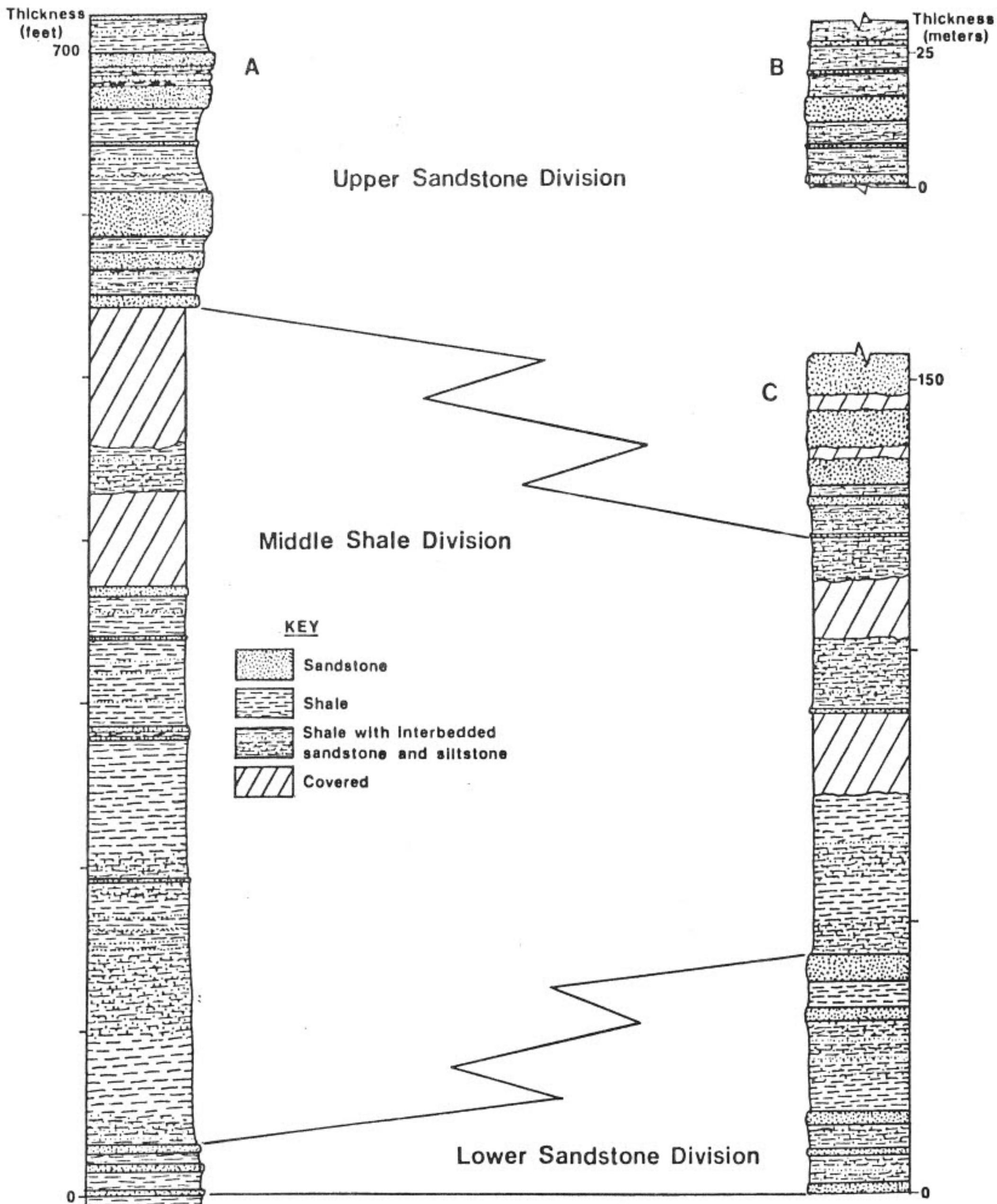
The lower part of the Womble is exposed above the upper Blakely in the roadcut. The rocks consist of black shale and thin lenses and beds of medium grained, slightly phosphatic sandy limestone. The shale weathers to a brown color and the limestone contains sponge spicules and other bioclastics. The bioclastic 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".

Figure 6 — Stop 3. Southward-verging chevron and box folds (top to left) in the weathered Bigfork Chert at a rock aggregate quarry south of Crystal Springs.

Figure 7 — Stop 4. 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.

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.



From Stolarz and Zimmermon 1984

Plate 7. — Measured sections in the Blakely Sandstone. A) Section along Walnut Creek in the Charlton Recreation Area, center of the SW¼, Sec. 32, T. 2 S., R. 22 W. B) Partial section from the upper sandstone division, E½, NE¼, SE¼, Sec. 17, T. 3 S., R. 23 W. C) Partial section measured in the center of the NW¼, SW¼, Sec. 20, T. 2 S., R. 21 W.

STOP 5 — 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 **6**). 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 *west* of Mount Ida (Stop **10**). 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

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 6. -- 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 6). 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.

Figure **8**. — Stop **5**. 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.

Figure **9**. — Stop **6**. Upright weathered quartzitic sandstones and shales with dissecting hydrothermal quartz veins in the Crystal Mountain Sandstone on U. S. Hwy. 270.

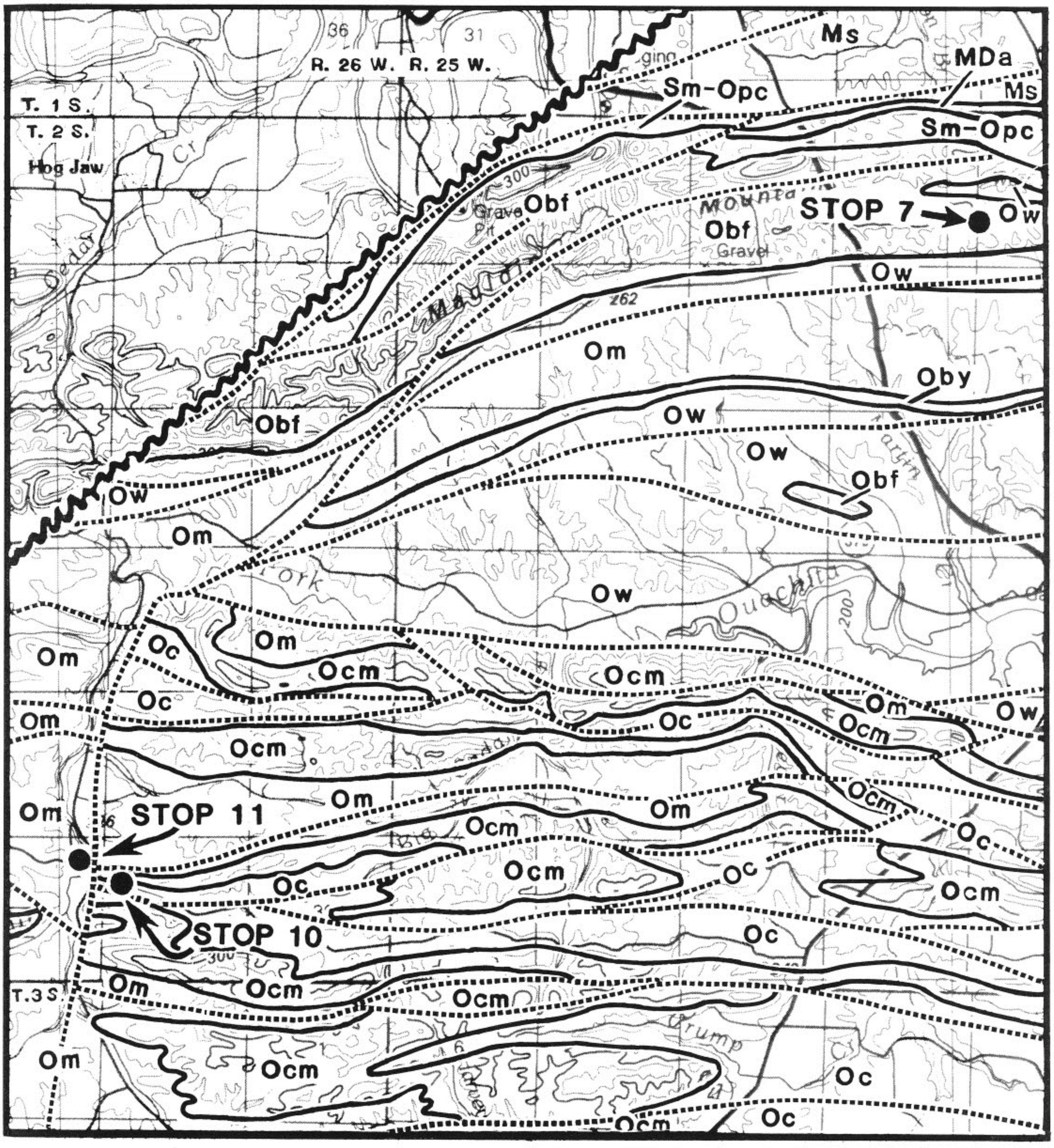


PLATE 8 – GEOLOGIC MAP OF THE SOUTH FORK OF THE OUACHITA RIVER AREA STOPS 7, 10 and 11.

Scale: 1 0 1 2 3 4 Miles

Ms	STANLEY SHALE
MDa	ARKANSAS NOVACULITE
Sm–Opc	MISSOURI MOUNTAIN SHALE – POLK CREEK SHALE
Obf	BIGFORK CHERT
Ow	WOMBLE SHALE
Oby	BLAKELY SANDSTONE
Om	MAZARN SHALE
Ocm	CRYSTAL MOUNTAIN SANDSTONE
Oc	COLLIER SHALE
-------	THRUST FAULTS
———	CONTACTS

STOP 7. – ALUMINUM PHOSPHATE MINERALS IN BIGFORK CHERT

The Montgomery County road quarry at Mauldin Mountain, about 3½ miles NW of Mt. Ida (Plate 8), is the most accessible location presently known for observing and collecting aluminum phosphate minerals. The quarry has been worked since about 1977 in highly fractured, tightly folded Bigfork chert and siliceous shale. The phosphate mineralization occurs in several stratigraphic zones in the lower part of the formation, but the most prolific one is within the lower ten feet of the quarry, where the minerals occur along both bedding plane breccias (faults?) and high-angle joints.

The three principal aluminum phosphate minerals at this location are planerite, variscite and wavellite (fig. 10). Other minerals identified are metavariscite, cacoxenite, illite and quartz.

Planerite is a name first used in 1852 for a poorly described Russian mineral which was never approved as a valid species. The name has recently been resurrected and applied to a newly described copper-free, turquoise-like mineral by E. E. Foord (personal commun., 1984) and approved by the International Commission of New Mineral Names. The description has not yet been published. The Mauldin Mountain material is generally light blue-green, but can vary from white to light green. It forms micro-botryoidal surface coatings and radiating masses up to 1 - 2 mm diameter. It tends to be the first phosphate mineral to form, but can also occur later.

Variscite, $Al(PO_4) \cdot 2H_2O$, occurs in the form of light-green micro-crystals coating planerite or chert and is most conspicuous along joint surfaces. It can form a complete coating or only microscopic hemispheres. It is easily distinguished from planerite in that it forms microscopic crystals whereas planerite does not.

Wavellite, $Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$, is generally the latest phosphate mineral and is most conspicuous in local chert breccias having adequate open space to allow the formation of the typical spheres and hemispheres composed of successive layers of light-green radiating needles. These "eyes" are coated by drusy wavellite crystals. During some of the earlier quarry operations, spectacular specimens were obtained from chert breccias with unusually large openings.

Metavariscite (a polymorph of variscite) has been identified in x-ray diffraction patterns, but has not been recognized in hand specimens.

Cacoxenite, $Fe_4(PO_4)_3(OH)_3 \cdot 12\ H_2O$, has been recognized as microscopic coatings of very tiny yellow spheres on other minerals. It is a very common mineral in the Arkansas iron phosphate localities.

Illite, the common potassium clay mineral, is the principal constituent of the gray shale present in the Bigfork Formation. Very pure illite is present in asbestiform layers along many shale partings and particularly around small openings where an unknown mineral has been dissolved. Identification was made independently by three laboratories using x-ray diffraction techniques.

Quartz is sparsely developed in veins which tend to follow bedding planes. Small crystals occur in cavities, and phosphate minerals also occur sparingly in some openings.

The phosphate minerals are believed to have been formed by warm waters which dissolved indigenous aluminum and phosphorus and redeposited them in available openings.

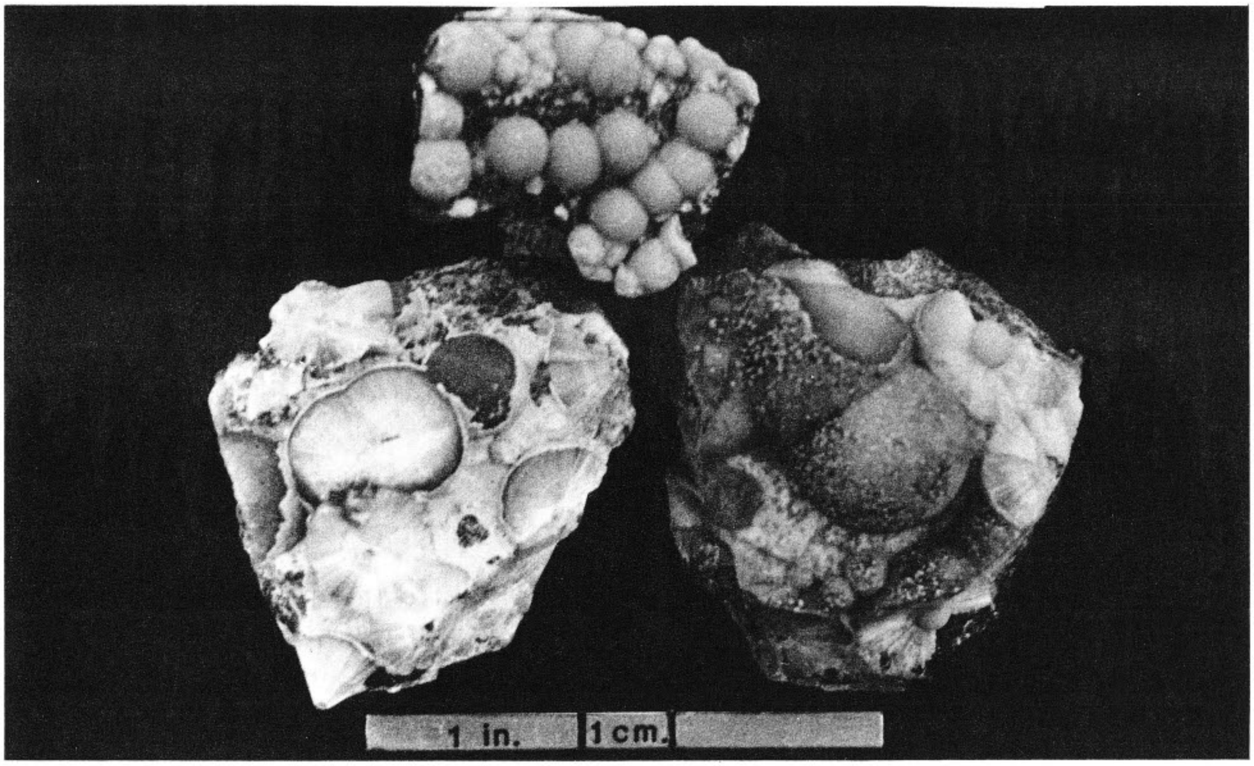


Figure 10. -- Stop 7. Different habits of wavellite from Montgomery County Quarry, Mauldin Mountain, Arkansas.

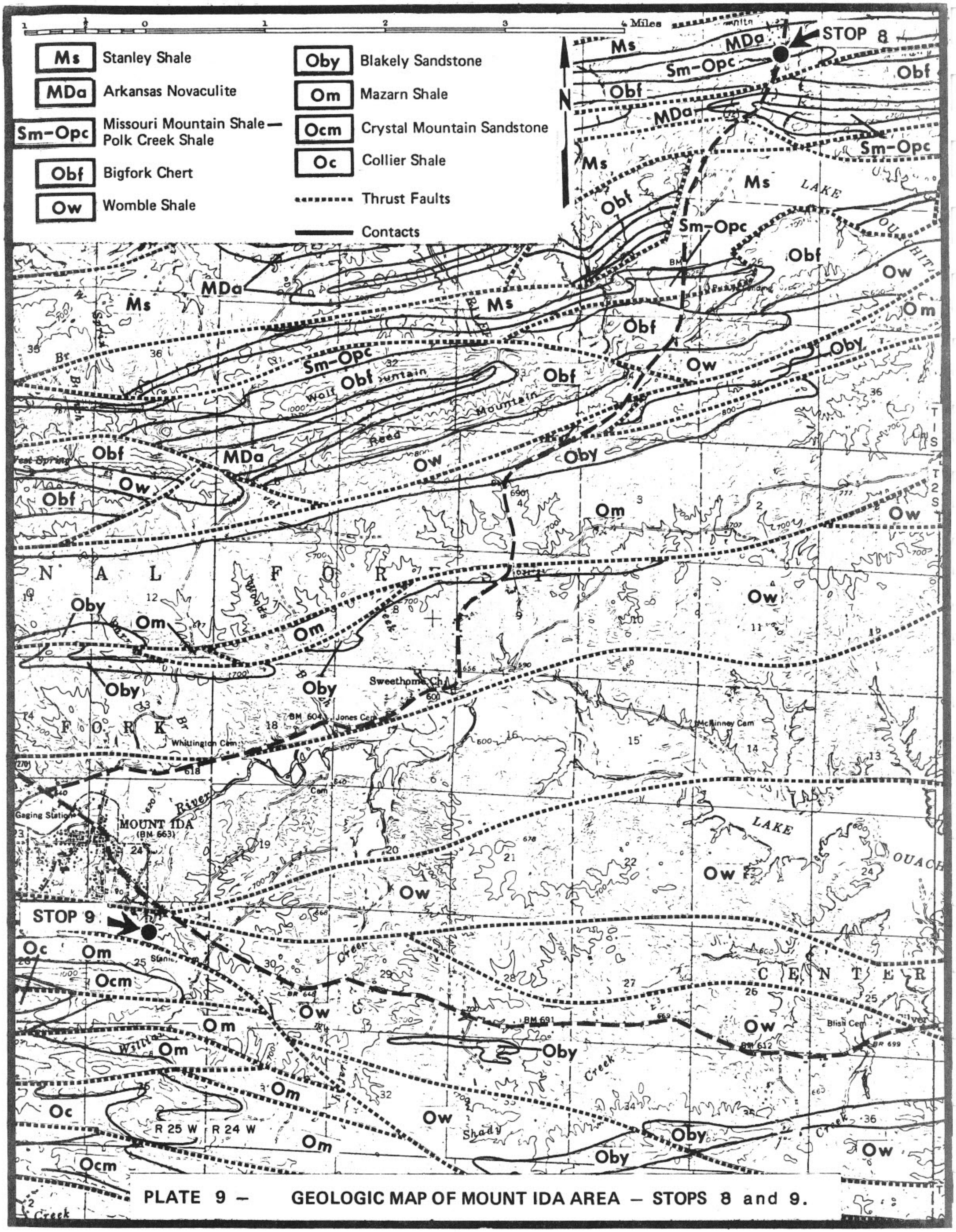


PLATE 9 — GEOLOGIC MAP OF MOUNT IDA AREA — STOPS 8 and 9.

STOP 8. – 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 9).

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 10).

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.

Figure 11. — Stop 8. . 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.

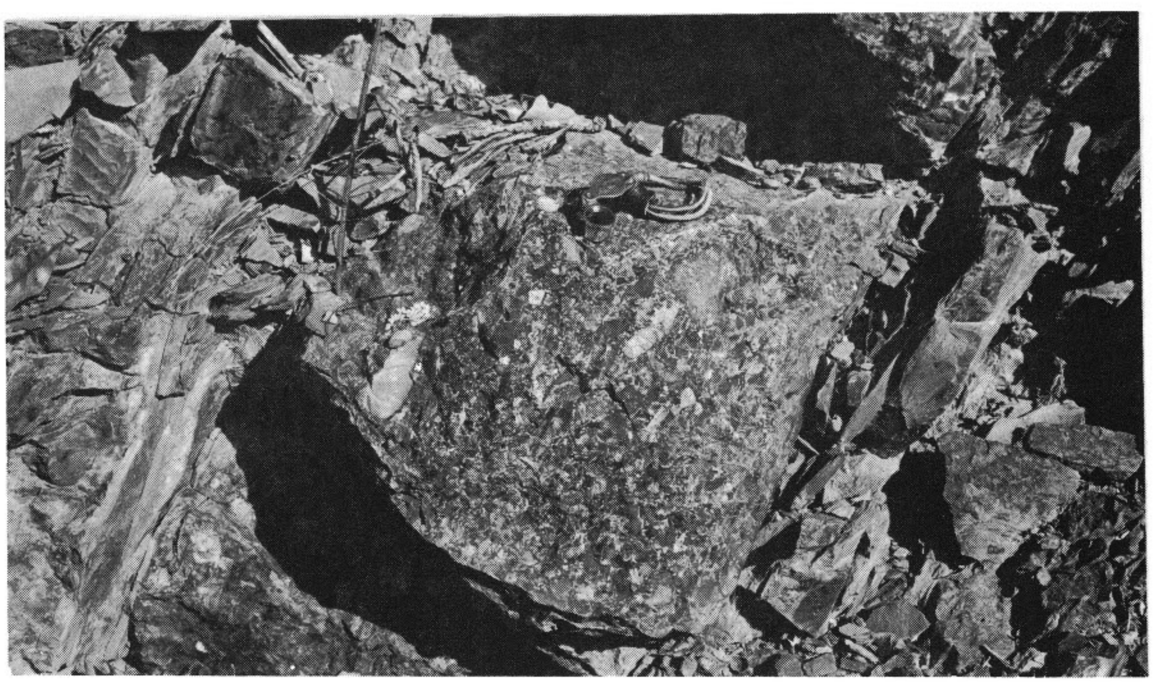


Figure 12. — Stop 8. Thin conglomerate interval containing chert, novaculite, sandstone and other clasts in the uppermost Arkansas Novaculite on Arkansas Hwy. 27.

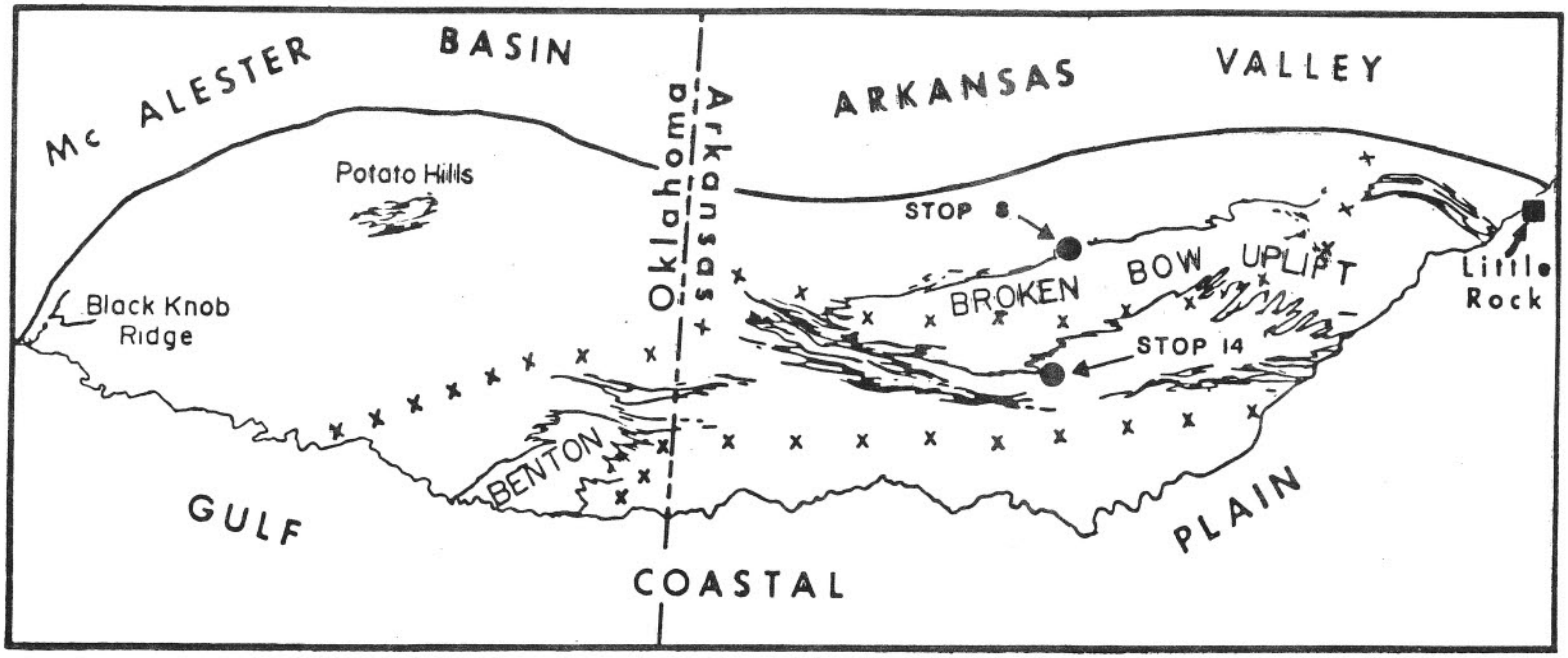


PLATE 10. MAP OF OUACHITA MOUNTAINS SHOWING OUTCROP OF THE ARKANSAS NOVACULITE (black area and lines) IN ARKANSAS AND OKLAHOMA. THICK SHALE-FREE PORTIONS OF THE NOVACULITE ARE WITHIN AREA OUTLINED BY X's.- STOP 8 and STOP 14.

STOP 9 – OCUS STANLEY MINERAL SHOP, MOUNT IDA (Plate 9).

Ocus, Irene, and Sonny Stanley are among the better known dealers in clear quartz crystals and other minerals generally common through the region.

Quartz crystals have been mined in the Ouachita Mountains of Arkansas for many decades, first by the Indians who shaped them into arrowheads. More recently quartz has been used for making optical and electrical equipment and jewelry. Stones that are cut from quartz crystals are sold in Hot Springs, Arkansas under the trade name "Hot Springs Diamonds". These should not be confused with genuine diamonds from the diamond mines at Murfreesboro, Pike County, Arkansas nor with "rock crystal" (glass). Most of the quartz crystals from Arkansas find their way into mineral collections of institutions and individuals, and a relatively large volume is used in construction of water fountains and religious or memorial shrines. The value of the natural crystals sold each year has ranged from a few hundred to many thousands of dollars.

During World War II, there was a great demand for oscillator quartz. At that time quartz crystal mining was greatly accelerated by individuals, the Diamond Drill Carbon Company, and the U. S. Government. Clear crystals of oscillator grade are, however, so scarce that only about five tons of this quality were produced during the war years. This quantity was very small in comparison with the wartime requirements of 2000 tons, nearly all of which was imported from Brazil. At the present time quartz crystals are marketed for transparent fused quartz which has many chemical, thermal, and electrical applications not met by glass. Some production of crushed milky quartz for precast concrete products has also been recorded. The quartz crystal deposits are numerous and are found in many localities in a wide belt extending from Little Rock, Arkansas westward to near Broken Bow, Oklahoma. They and their few associated minerals are hydrothermal deposits of probable tectonic origin formed during the closing stages of the late Pennsylvanian–early Permian orogeny in the Ouachita Mountians.

Milky quartz veins (up to 60 feet or more in width) have been noted in the shale sequences in the central "core area" of the Ouachita Mountains and commonly contain traces of adularia, chlorite, calcite, and dickite. Interestingly, these quartz veins locally contain lead, zinc, copper, silver, and antimony in this region.

In our work on the Ouachita Mountains we found that there was a direct association of quartz veins with fault zones. The suggestion is that the quartz veins represent, in part, dewatering processes that took place in the rocks along the fault zones. The increase in pore fluids may well have contributed to localized lubricating conditions and enhanced the overall faulting and folding processes.

Figure 13. — Stop 9. Water-clear quartz crystals in matrix from the Crystal Mountains, Montgomery County, Arkansas.

STOP 10. — 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 8). 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.

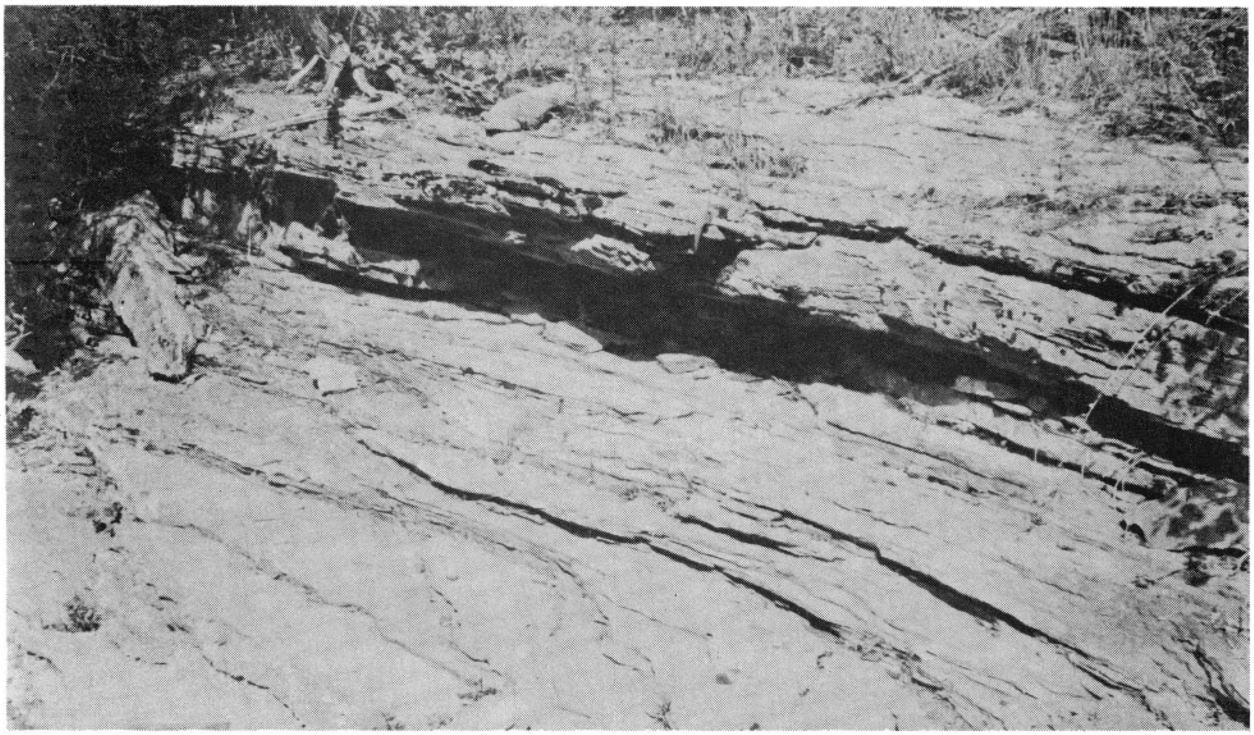


Figure 14. – Stop **10**. Thin-bedded, micritic limestones in the upper Collier Shale in creek adjacent to Lybrand Road. A few of the limestones have minor silt and sand fractions and a delicately graded bedding.

Figure 15. – Stop **10**. 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 11. — 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 8). 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.

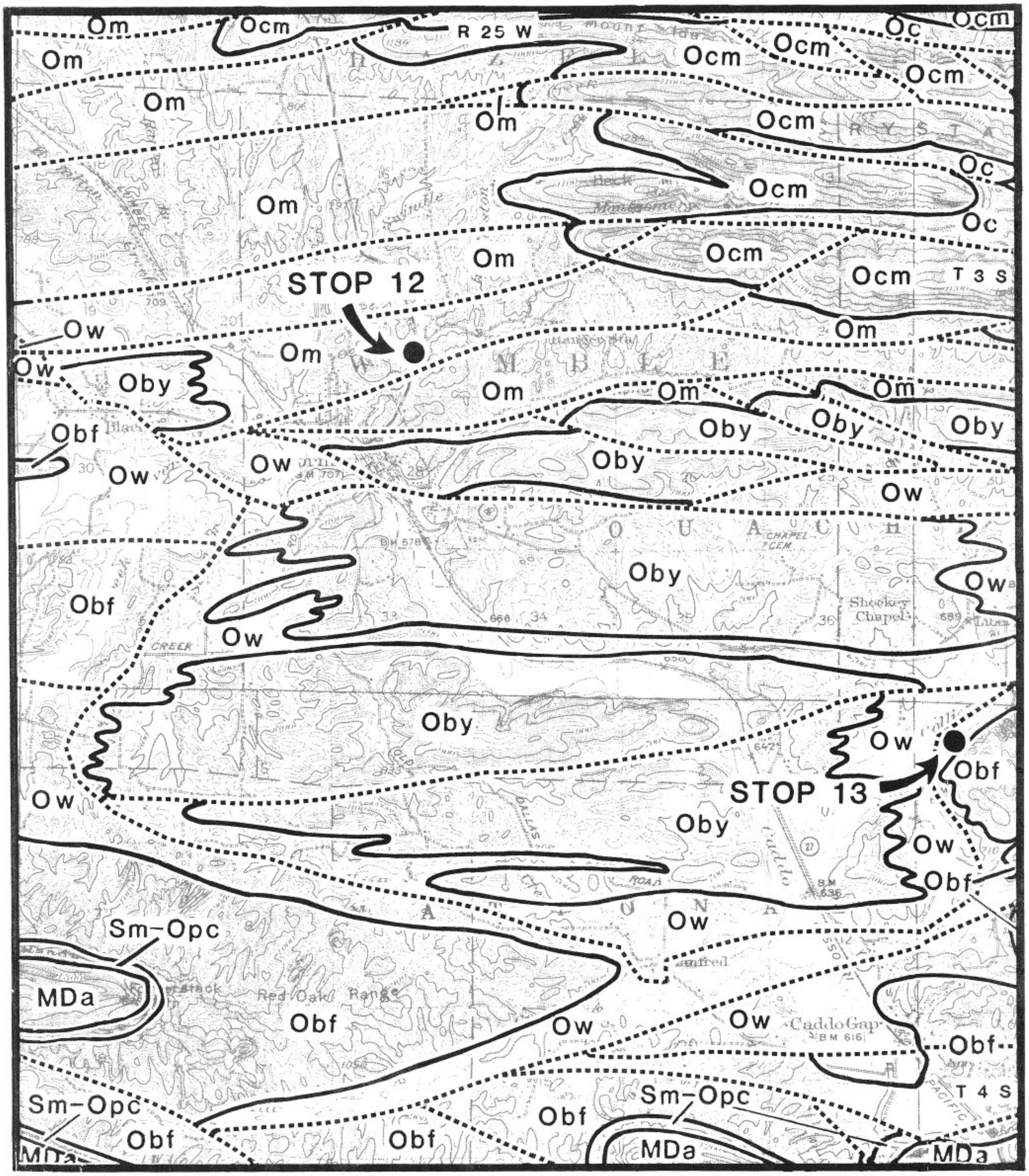


PLATE 11–GEOLOGIC MAP OF NORMAN AREA–STOPS 12 AND 13.

1 0 1 2 3 4 MILES

MDa	Arkansas Novaculite
Sm-Opc	Missouri Mountain Shale– Polk Creek Shale
Obf	Bigfork Chert
Ow	Womble Shale
Oby	Blakely Sandstone
Om	Mazarn Shale
Ocm	Crystal Mountain Sandstone
Oc	Collier Shale
- - - - - -	Thrust Faults
———	Contacts

STOP 12 — TYPICAL SEQUENCES OF UPPER MAZARN SHALE NORTH OF NORMAN (Plate 11).

The exposure on the east side of Arkansas Hwy. 27 contains interbedded banded green and black shale, laminated, fine-grained, gray siltstone, and minor lenses of fine-grained, brownish-gray quartzitic sandstone in the upper part of the Mazarn Shale. Small southward inclined folds with shallow northward dipping cleavage and some structural boudinage characterize the sequence. The southward overturning of the folds is confirmed by graded bedding, small cross laminations, and a few bottom marks (top of the beds are to the south). It is likely that the siltstones and sandstones are formed by fairly weak turbidity and marine currents causing grading of the silt and clay fractions. Trace fossils are fairly numerous in some intervals and, along with other data, suggest a deep-water origin. Small milky quartz veins fill fractures in the rock. As the vegetation on the ridge shows, cedar trees seem to prefer the Mazarn Shale.

Some intervals of bluish-gray, micritic limestone, gray sandy conglomeratic limestone and in places thin intervals of black chert are found in the lower Mazarn Shale north of this area as well as locally in the upper Mazarn.

It is thought that the Mazarn represents relatively quiet early trough deposition with minor fine clastics and some sedimentary slump and slurry masses being brought in from sources to the north or northeast.

Denison et al., (1977, p. 37) report a number of Devonian ages (358 to 378 m. y.) from some of the metasedimentary rocks in the Mazarn Shale to the west in the Broken Bow uplift of Oklahoma. It is further suggested that these age determinations indicate metamorphic-igneous activity during Devonian times in the Ouachita fold belt. The bulk of their age determinations from Collier and Mazarn surface samples, and from subsurface samples of the deep Vierson and Cochran No. 25-1 Weyerhaeuser Well, are Early Pennsylvanian to Early Permian, the time of major tectonic episodes in the Ouachita Mountains.

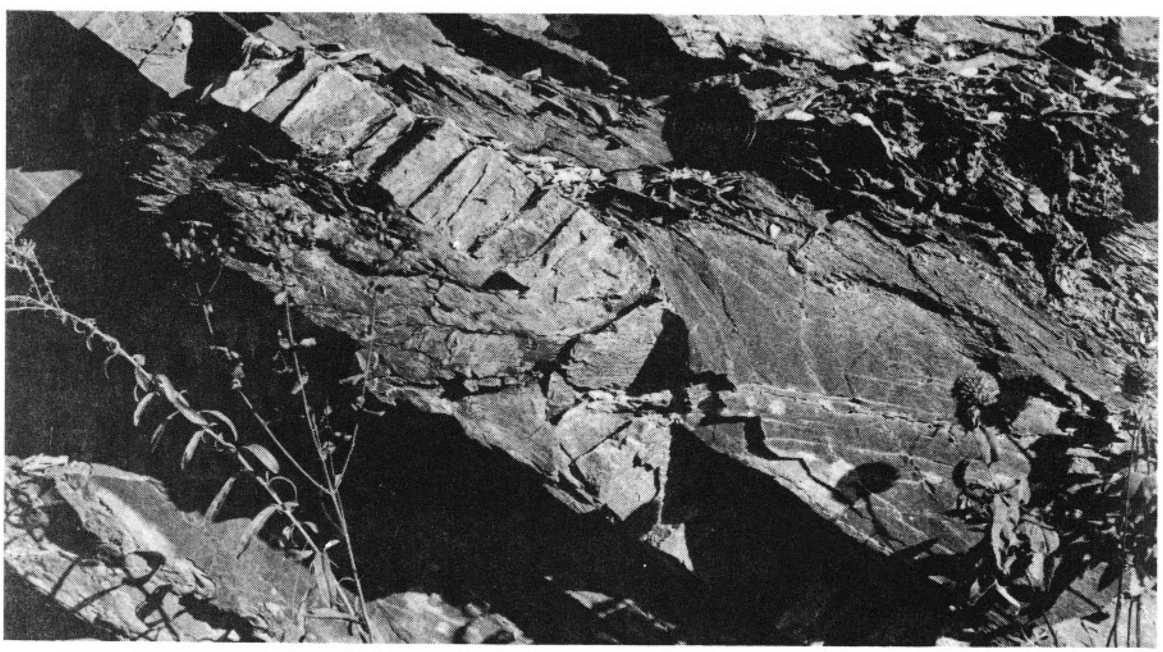


Figure 16. Stop 12. Closeup showing thin layers of banded shale and siltstone with a small southward-inclined fold exhibiting cleavage and internal crowding in the fold hinge. In the upper Mazarn Shale, in roadcut on Arkansas Hwy. 27 north of Norman, Arkansas.

STOP 18. – 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 **11**). 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.

Figure 17. — Stop 13. Interbedded, tightly-folded micritic limestone, carbonaceous shale, and chert in the uppermost Womble Shale and lowermost Bigfork Chert in abandoned quarry at Buttermilk Springs.

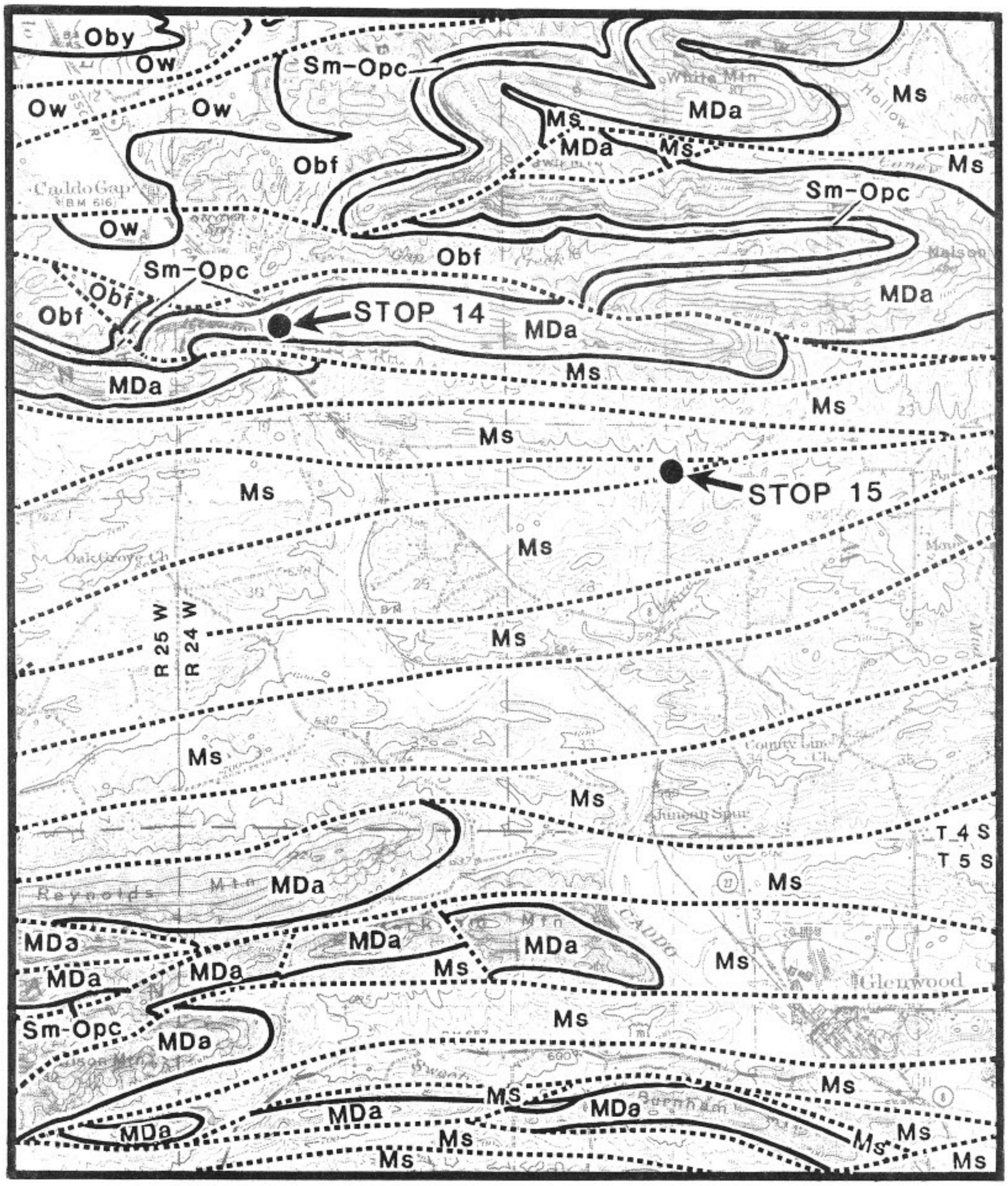


PLATE 12–GEOLOGIC MAP OF CADDO GAP AND GLENWOOD AREA STOPS 14 AND 15.

1 0 1 2 3 4 MILES

Ms	Stanley Shale	Ow	Womble Shale
MDa	Arkansas Novaculite	Oby	Blakely Sandstone
Sm–Opc	Missouri Mountain Shale– Blaylock Sandstone (south part)– Polk Creek Shale	--------	Thrust Faults
Obf	Bigfork Chert	———	Contacts

STOP 14 – 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! Plate 12.

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. 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 much of the surrounding region for a number of years. Plate 13 illustrates the exposed section of the structurally complex 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 suggest 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

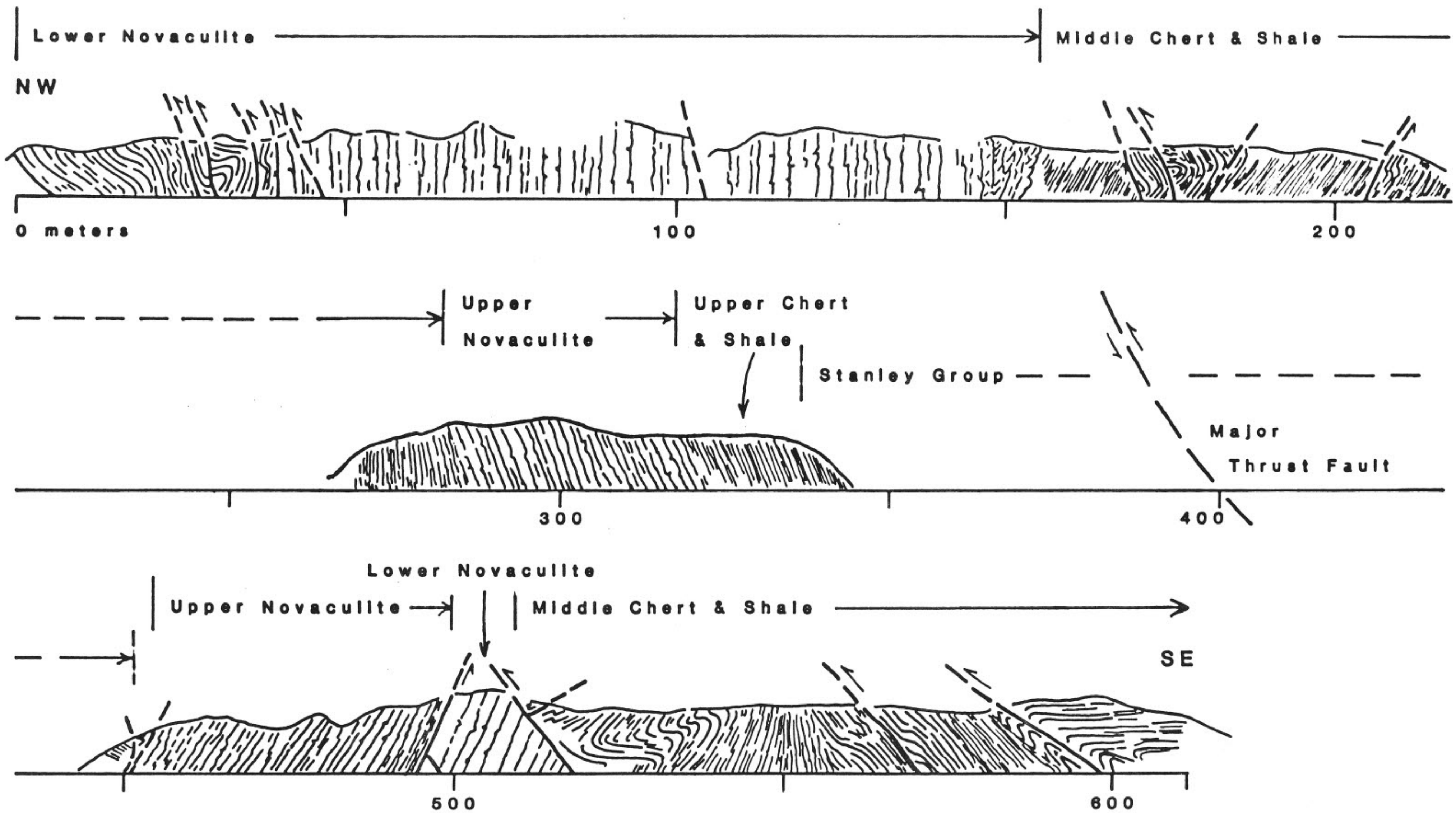


Plate 13. — Simplified cross section along Caddo Gap roadcut. Distances (in meters) are approximate owing to distortion in the photographic traverse from which this cross section was composed, and should be considered as only general guidelines. From Zimmerman (1984).

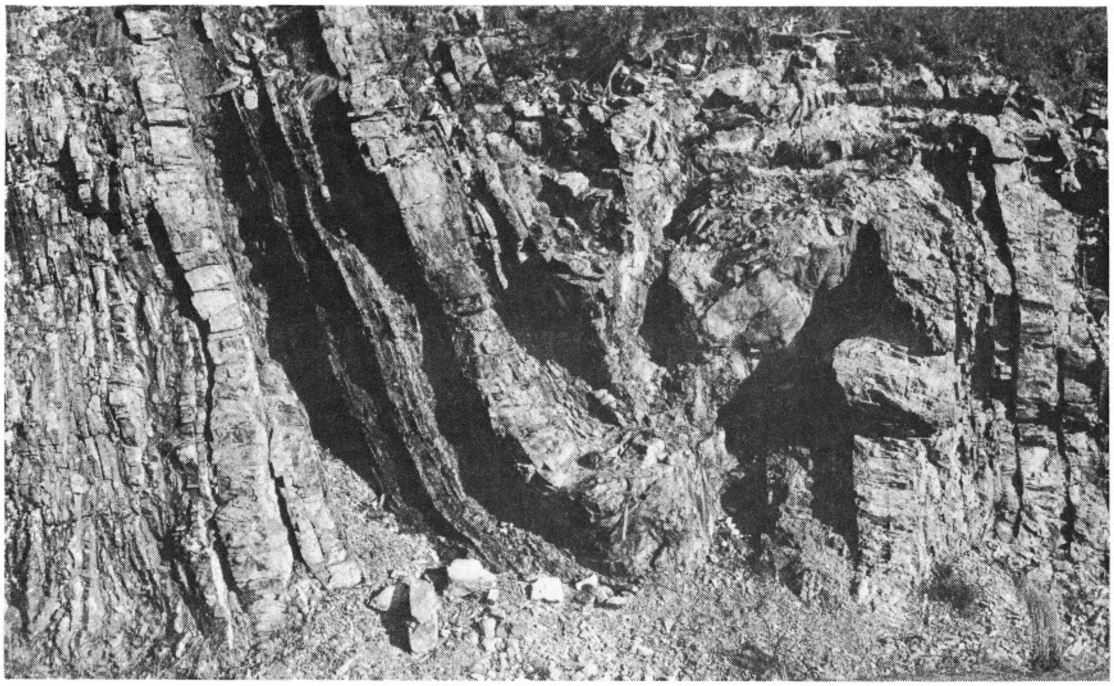


Figure 18. Stop 14. Steeply reclined kink folds with small faults in thick to thin intervals of very dense novaculites and some thin shales in the lower part of the Lower Division of the Arkansas Novaculite at the north end of the Caddo Gap section on Arkansas Hwy. 27.

Figure 19. Stop 14. 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.

STOP 15 — LOWER STANLEY SHALE IN THE GENSTAR ROOFING PRODUCTS CO. SLATE GRANULE PIT (Plate 12).

We wish to thank Hurcil Cowart and other members of his staff for permission to visit the site! **Please be careful** — and wear your hard hats!

Sheared shale and/or slate in the lower Stanley Shale is being mined and processed from this pit for roofing granules and as a filler. Most of the rocks are upright and are dipping rather steeply to the south. They consist of black shale or slate, black chert, with thin siltstone and graywacke.

Figure 20. — **Stop 15.** A view of the Genstar Co. slate granule pit north of Glenwood. Sheared and faulted shale with some siltstone, graywacke, and chert in the middle part of the lower Stanley Shale.

There are several thrust faults cutting the sequence and the fault zones exhibit numerous slickenside surfaces coated with dickite. The faulting has repeatedly shoved one sequence northward over another and some faults are, in part, slightly backfolded to the south. Small folds are formed in the chert interval on the east side of the pit. The thin, graded sandstone and siltstone layers are locally bottom-marked, thicken and coarsen upward and are believed to represent lobe sequences of an outer submarine fan or basin plain environment of deposition. The sandstones were likely derived from sources to the south and southeast. The sands were built out initially to the north and northwest as large deltas and deep-water submarine fans and subsequently directed by turbidity currents westward down the Ouachita trough. Close inspection of the clastic units shows that both structural boudinage and sedimentary pull-aparts are present. Two generations of cleavage are present and dip steeply to the north. The weathered Stanley Shale at the top of the pit shows a characteristic greenish-brown color. Small quartz veins with pyrite and calcite (some dog-tooth variety) fill fractures in the sandstone.

The middle and lower Stanley Shale are contained in the Tenmile Creek Formation of the lower Stanley Group in the Ouachita Mountains of Oklahoma. Both in Arkansas and Oklahoma there are chert intervals in the Stanley Shale that constitute reliable markers. The Battiest (Ba-teest') chert interval near the middle of the lower Stanley Shale is particularly definitive in portions of eastern Oklahoma. Due to the many structural complexities in this area and throughout the region, we are presently unable to make an exact correlation of the cherts in this pit with units elsewhere.

STOP 16. – 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 (Plate14). 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 15). 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 15). 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.

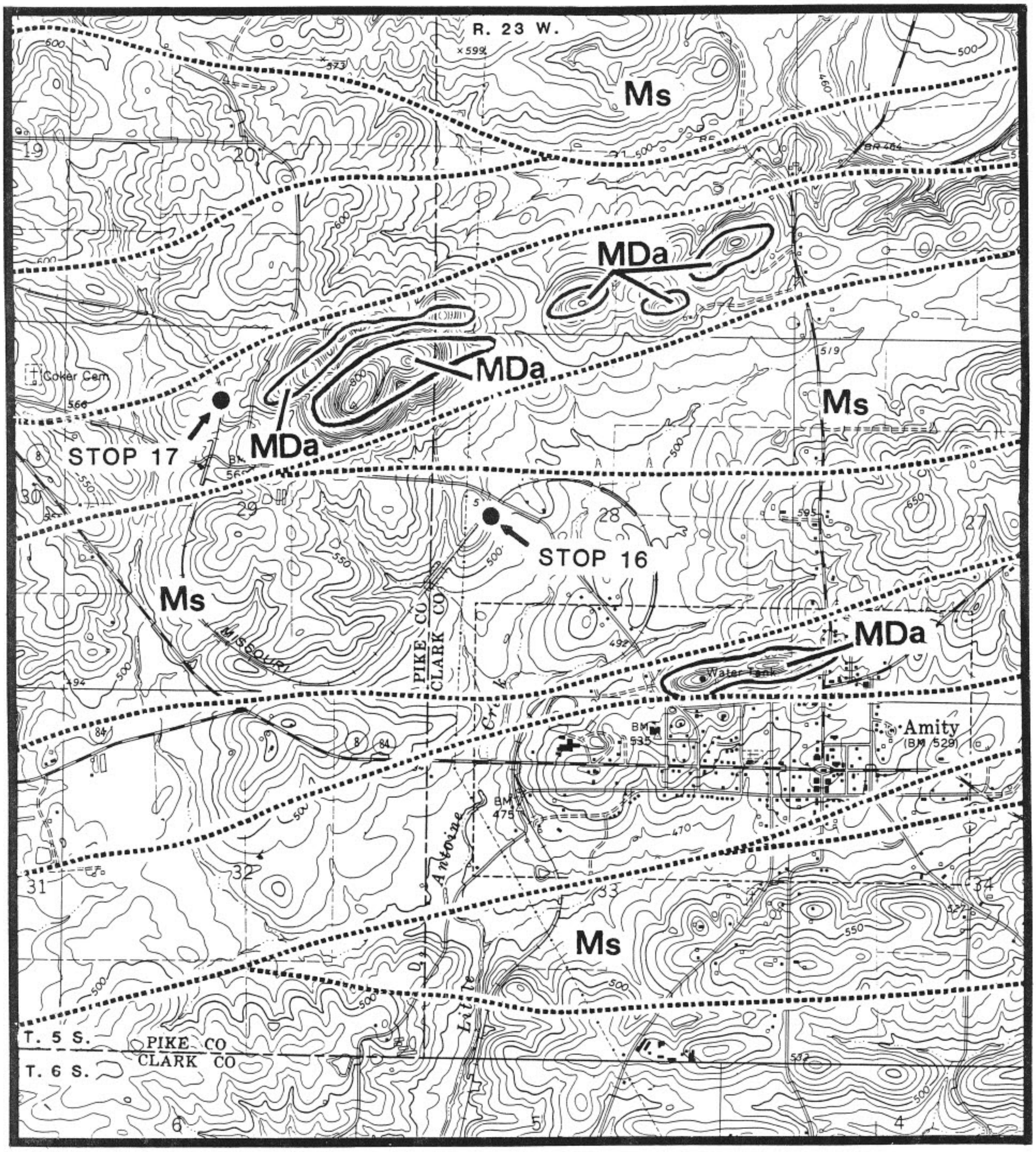


PLATE 14 – GEOLOGIC MAP OF THE AMITY AREA – STOPS 16 AND 17.

1000 0 1000 2000 3000 FEET

Ms	STANLEY SHALE	··············	THRUST FAULTS
MDa	ARKANSAS NOVACULITE	————	CONTACTS

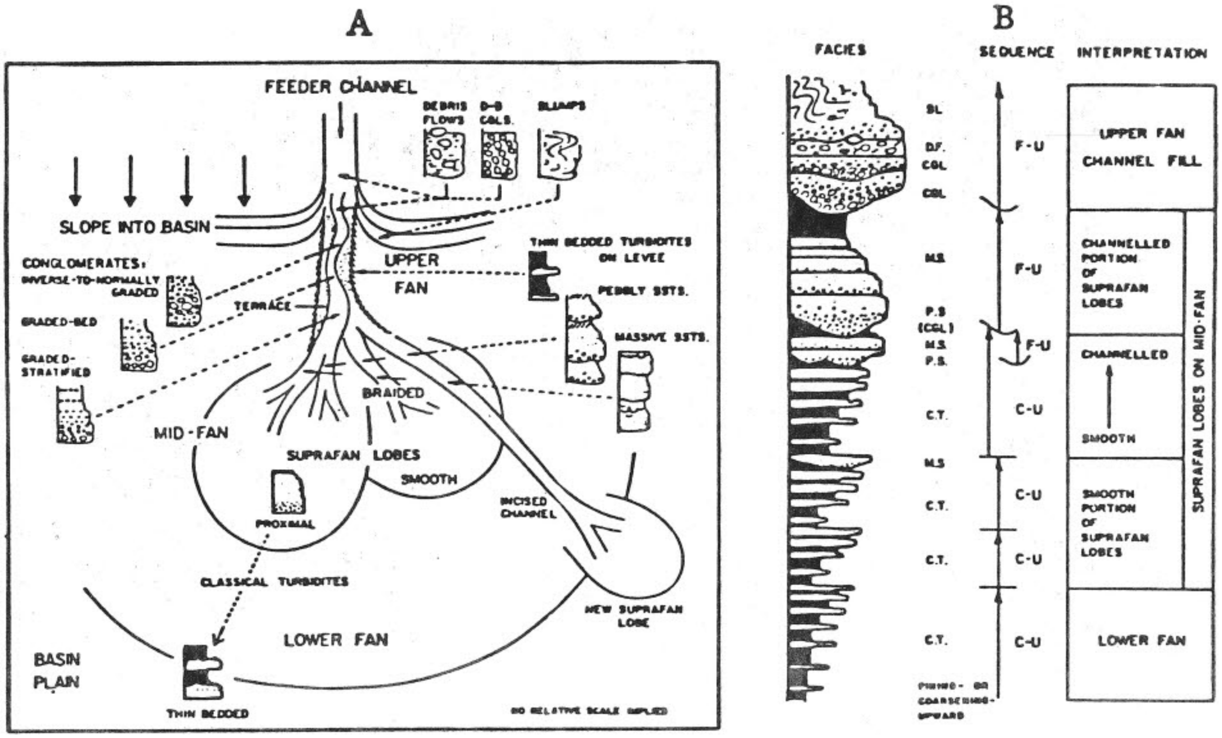


PLATE 15 A. — A. SUBMARINE—FAN MODEL AND ASSOCIATED TURBIDITE FACIES OF WALKER (1978).
B. HYPOTHETICAL STRATIGRAPHIC SEQUENCE THAT COULD BE DEVELOPED DURING FAN PROGRADATION: C—U., represents thickening—and coarsening—upward sequence; F-U., represents thinning—and fining—upward sequence; C.T., classic turbidites; M.S., massive sandstones; P.S., pebbly sandstones; CGL, conglomerate; D.F., debris flows; SL., slumps; from Walker (1978).

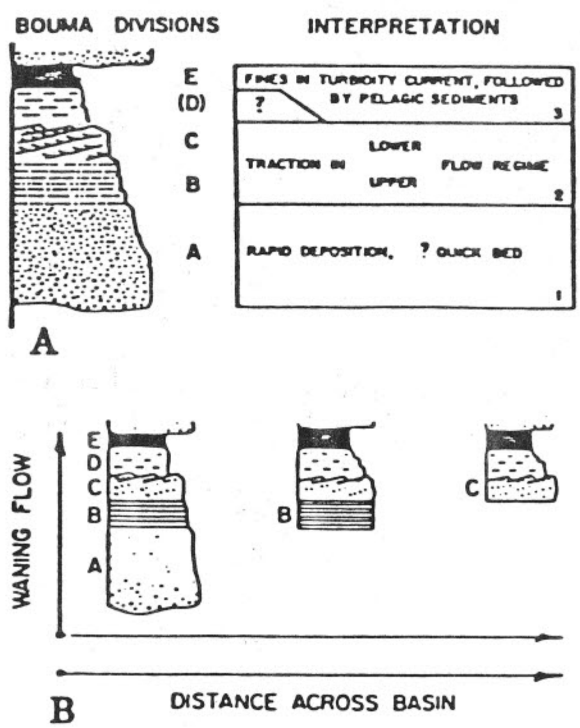


PLATE 15 B. — A. BOUMA MODEL FOR CLASSIC TURBIDITES: division A is massive or graded, B is parallel laminated, C is rippled, D consists of faint laminations of silt and mud, and E is pelitic after Walker (1978).
B. INTERPRETATION OF BOUMA SEQUENCE IN TERMS OF WANING GLOW: suggests that groups of turbidites beginning with divisions B and C represent deposition from progressively slower flows, presumably related to distance from source; after Walker (1978).

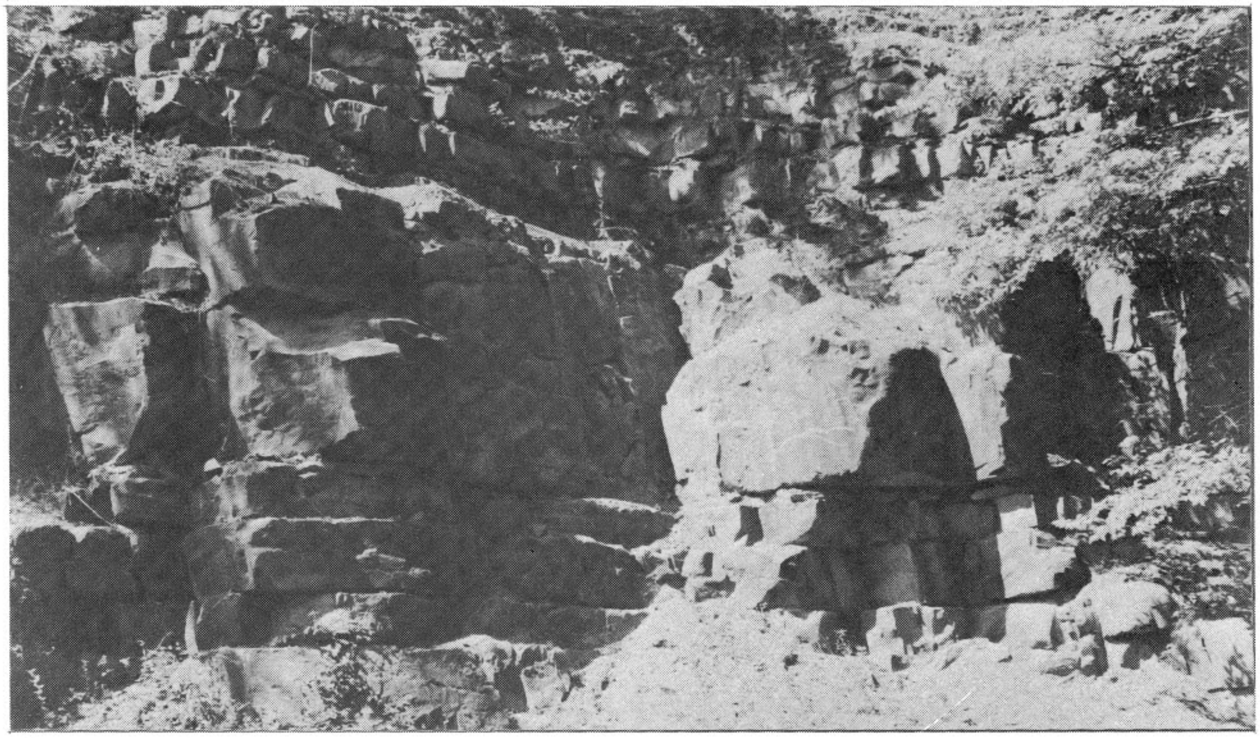


Figure 21. – Stop 16. Nearly flat-lying subgraywackes or graywackes and shales of the lower Stanley Shale along a Missouri Pacific Railroad cut northeast of Amity. The sandstone sequence thickens and coarsens upward, then reverses and thins and fines upward. It probably represents the development and gradual abandonment of a submarine lobe.

Figure 22. – Stop 16. 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 17 — 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 16 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 14). 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.

Figure 23 — Stop 17. 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).

STOP DESCRIPTIONS — THIRD DAY

EASTERN OUACHITA MOUNTAINS

MAGNET COVE — POTASH SULFUR SPRINGS — HOT SPRINGS

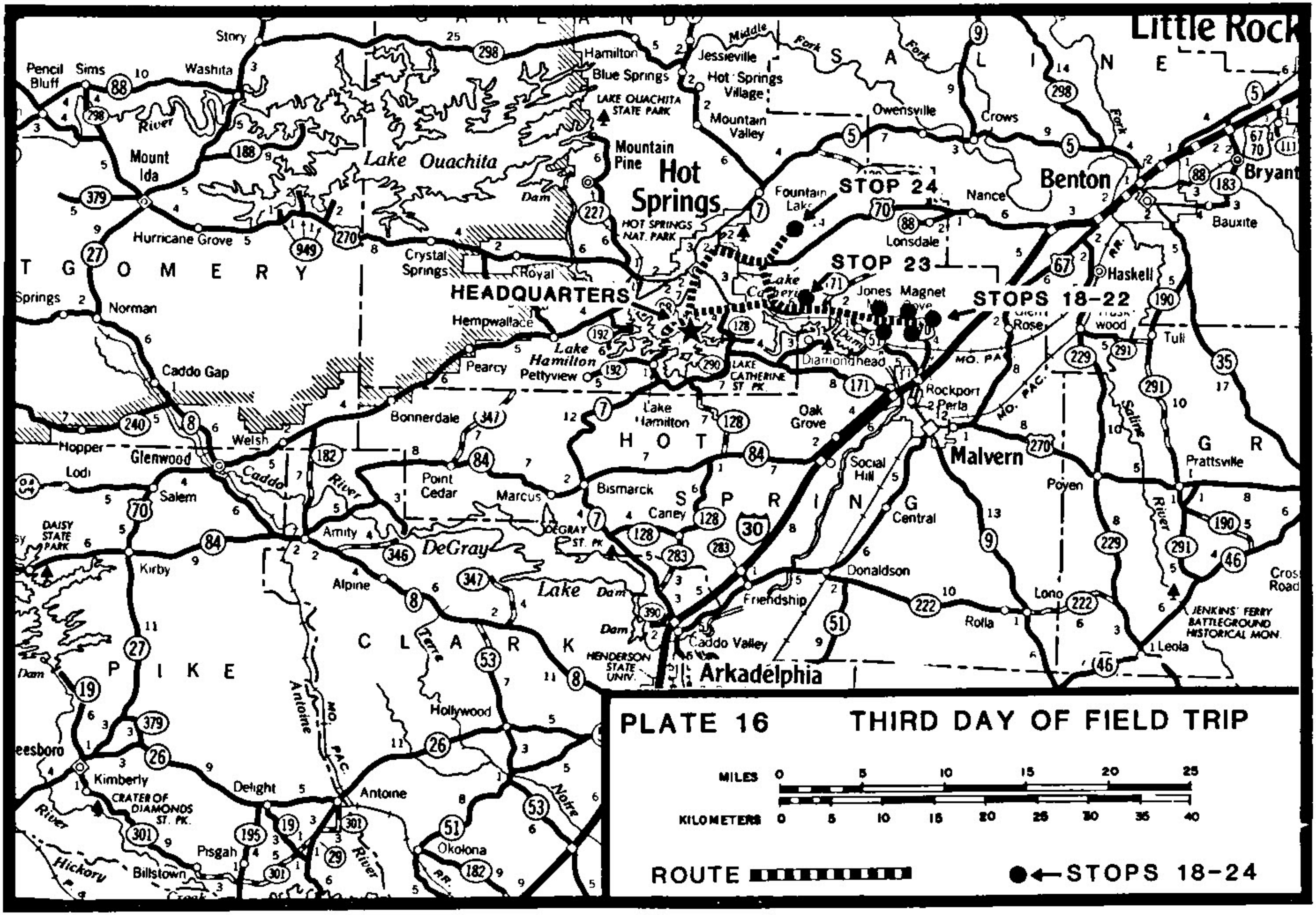


PLATE 16 THIRD DAY OF FIELD TRIP

STOP 18. – CHAMBERLAIN CREEK BARITE DEPOSIT

We wish to extend our sincere thanks to Mr. Joe P. Hill, plant manager, and Mr. A. J. Higgins of N L Baroid Division of N L Industries, Inc. for permission to visit this abandoned mine and for information pertaining to their operations.

The Chamberlain Creek barite deposit (Plate 17 and 18) is a stratiform deposit at the base of the Stanley Shale. The ore zone is conformable with the bedding and averages 60 feet in thickness. Structurally, the deposit lies in an asymmetrical northward-verging syncline which plunges southwest toward the Magnet Cove intrusion (one mile to the west) and is truncated at its eastern end by erosion, giving the orebody a spoon-like shape. The maximum length of the orebody is 3200 feet and its maximum width is 1800 feet. Some of the ore is nodular, but most ore has a dark gray, dense appearance resembling limestone. The barite is intimately mixed with minor amounts of fine-grained quartz, pyrite, and shale. A typical analysis of high-grade ore is 85 percent $BaSO_4$, 11 percent SiO_2, and 3 percent iron oxide and alumina. The average mill feed was about 60 percent $BaSO_4$. Inferred ore extends to the west in the Chamberlain Creek syncline to the contact of the Magnet Cove intrusion.

At the present time very little of the barite interval is exposed because the abandoned pit has gradually filled with a highly acid water. However, there are several good exposures of the pre-barite strata on both flanks of the syncline. During this stop our primary interests are the meaning and importance of the black, often pyritic, shales with discontinuous sandstone and minor chert masses of the Hot Springs Sandstone Member of the Stanley Shale that occur below the barite zone. It is thought that these beds represent an interval of very slow deposition with a high organic input interrupted by sporadic episodes of localized submarine slumping on the deep sea floor. These highly reduced strata likely aided in the ponding of the barium sulfates that were probably exhaled at places along the irregular, faulted margin of the Ouachita trough in earliest Chesterian (Late Mississippian) time. Slickensides commonly filled with small quartz veinlets occur in most of the small faulted intervals that are mostly related to the late Paleozoic orogeny that formed the Ouachita Mountains. Some faults and small alkalic-lamprophyric dikes are a product of the nearby Magnet Cove intrusion of early Late Cretaceous age.

Magnet Cove Barium Corporation (Magcobar) began mining and processing (flotation) operations of ore from this deposit in 1939, ending in 1973. Magcobar's mill was located in Malvern, Arkansas, about 7 miles south of the mine. Baroid Sales Division of National Lead Industries (N L Baroid) started their operations in 1941. Magcobar's headframe is on the north limb of the syncline and although their mining operation began with stripping on the northern limb, they soon went to an extensive underground operation. The office and mill of N L Baroid is on the southern limb of the syncline. N L Baroid's operation began as a major open pit, converted to both open pit and underground mining in 1961, and in 1977 went exclusively underground until ceasing operations in 1980. N L Baroid's mill remained active until 1982, processing a blend of high-grade mill tailings, low-grade stockpile ore from this deposit, and similar ore from deposits in Montgomery County in western Arkansas. Milling consisted of grinding to 200-mesh and concentrating by froth flotation. Final product grade was 98% $BaSO_4$. Nearly all of the barite produced from this deposit was marketed as a weighting agent for drilling fluids.

The origin of the barite in this and in similar barite deposits elsewhere in Arkansas has been the subject of much debate in the literature and on the outcrop. Scull (1958) classified the Arkansas barite occurrences as replacement deposits (most important volumetrically), cements, and fissure veins. He related all three types to hydrothermal fluids generated by Cretaceous alkalic intrusives. Zimmerman (1964) examined barite ores in the Stanley Shale (Scull's replacement type), primarily at the Chamberlain Creek deposit, and postulated a sedimentary origin, therefore a Mississippian age. Most of the recent studies have related the bedded ores to exhalative events during early Stanley deposition.

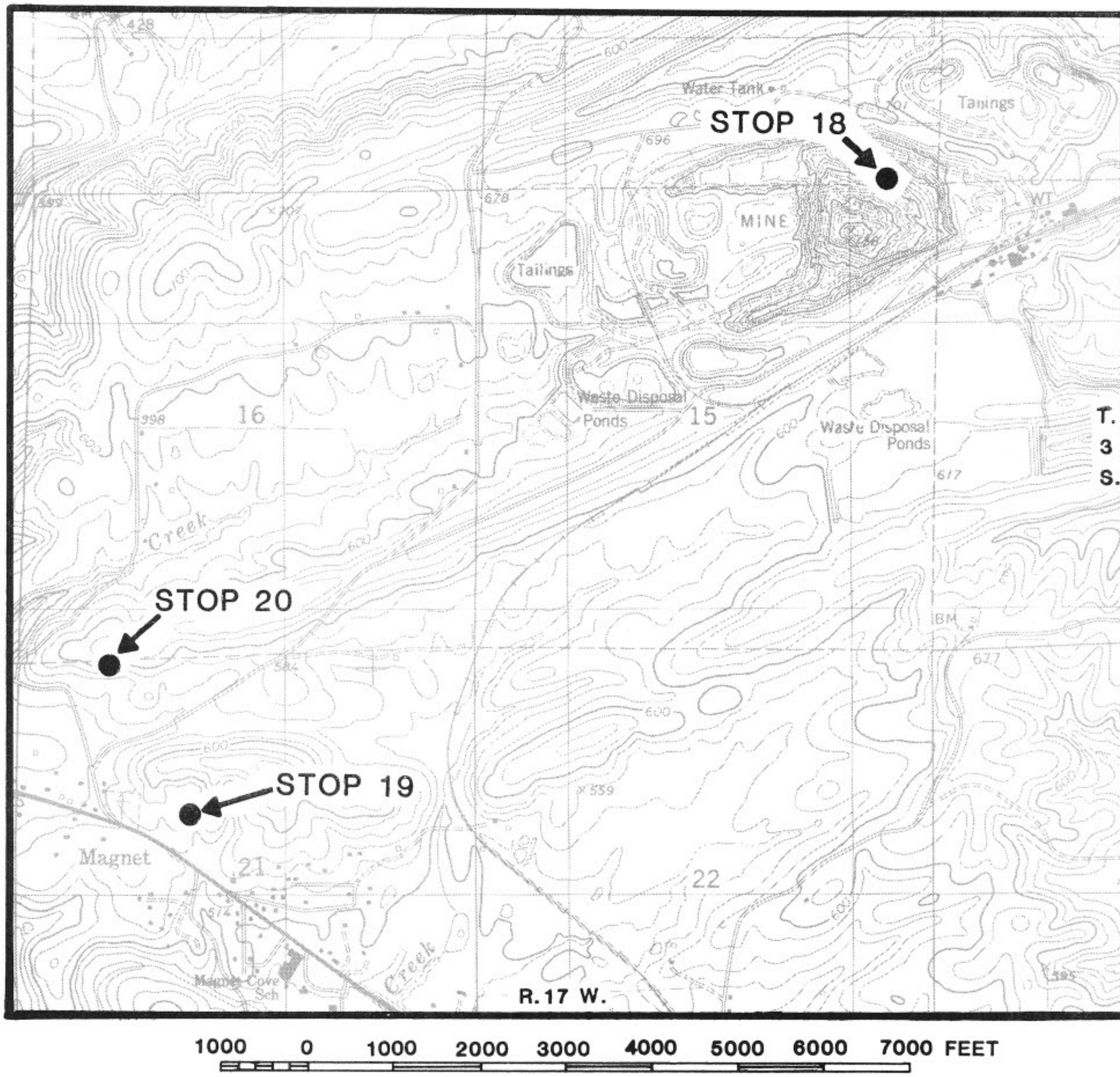
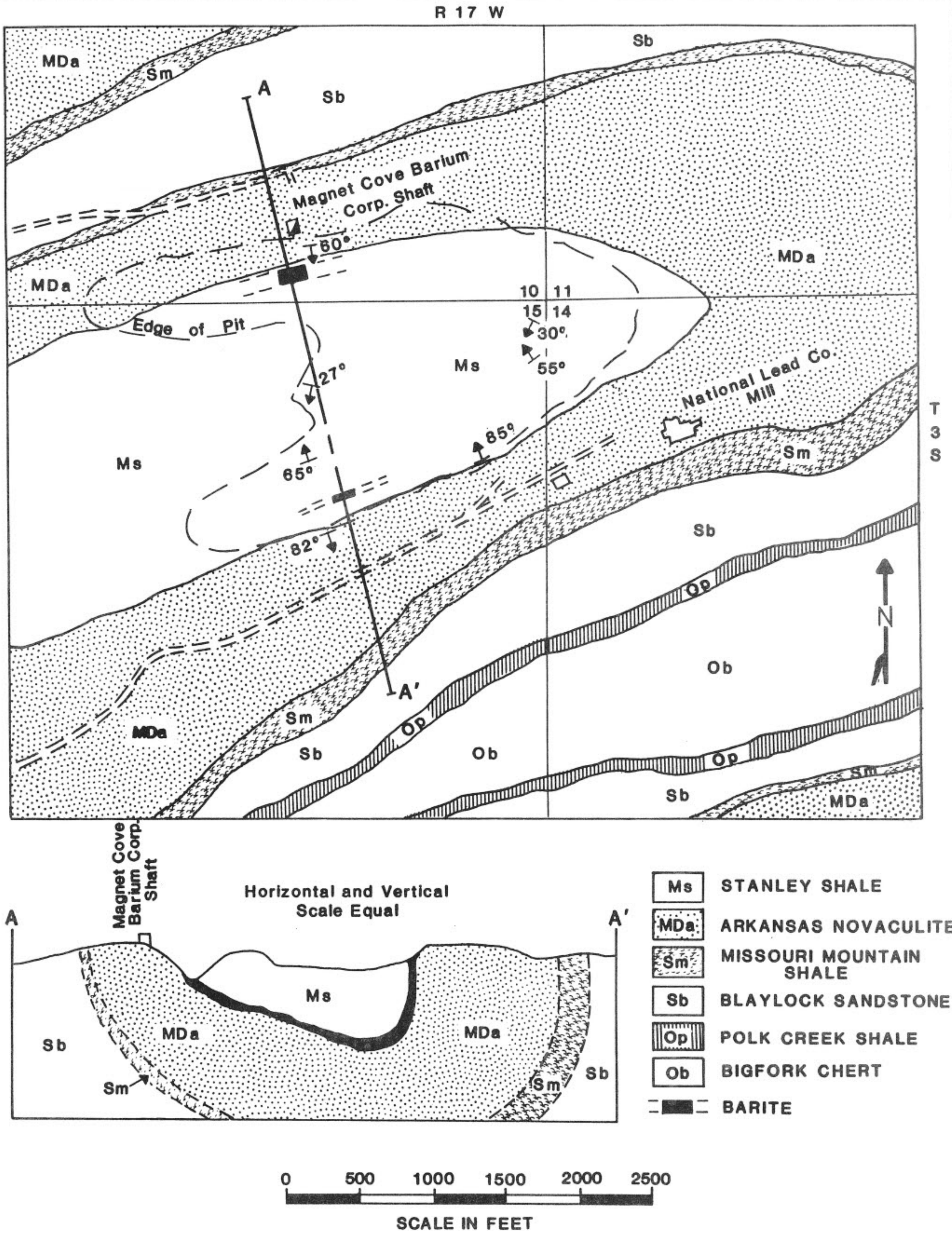


Plate 17. – Topographic map showing location of barite and vanadium–titanium mines (STOPS 18, 19, and 20).



After B. J. Scull 1956

ARKANSAS GEOLOGICAL COMMISSION

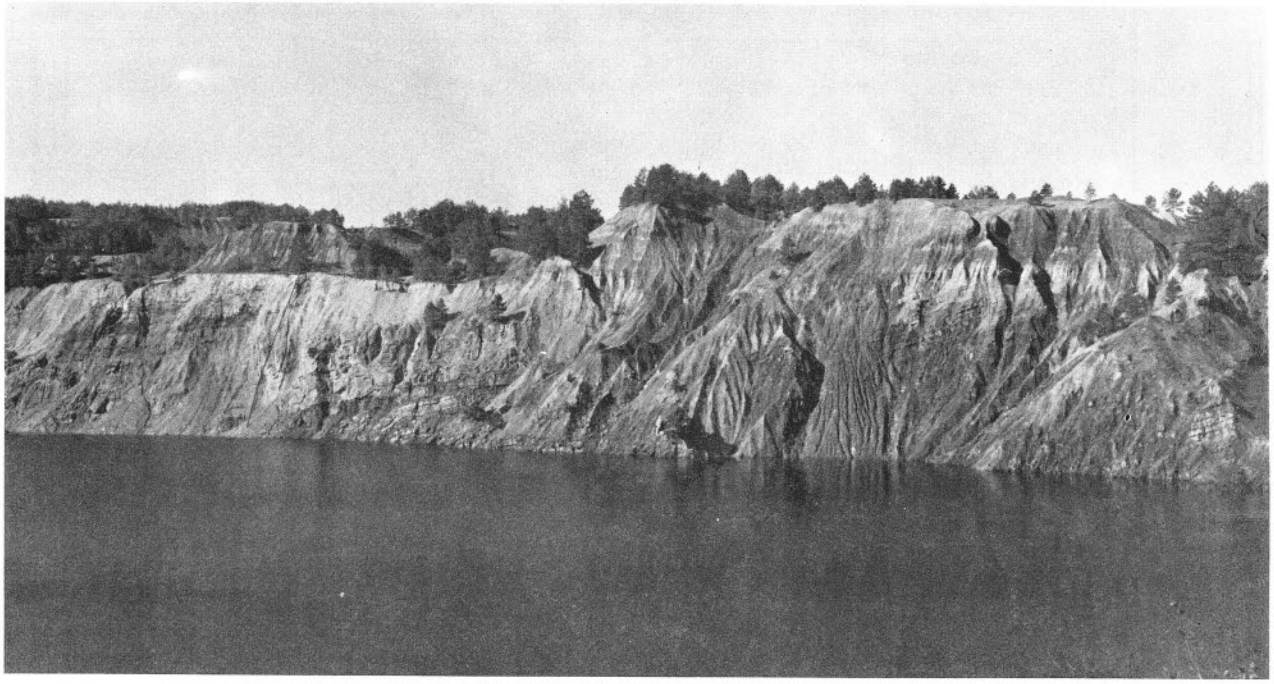


Figure 24. — Stop 18. Abandoned Chamberlain Creek barite pit near the center of the Chamberlain Creek syncline with lower Stanley shales and sandstones overlain by excavation materials. The thick interval of bedded barite formerly mined by open pit and underground methods is now below water level.

Figure 25. — Stop 18. Lenticular sandstone and some chert masses in black, often pyritic shales of the Hot Springs Sandstone Member of the basal Stanley Shale on the dip slope along north wall of the Chamberlain Creek barite deposit.

GEOLOGY OF MAGNET COVE

Magnet Cove is an area of unusual petrologic and mineralogic interest that derives its name from the presence of magnetite in the surface soil and from its basin-like shape. The Cove is located in northern Hot Spring County, Arkansas about 12 miles east of the city of Hot Springs. U.S. Highway 270 between Malvern and Hot Springs passes approximately through the center of the Cove.

The Cove lies at the eastern end of the Mazarn synclinorium about 1½ miles from where the Tertiary sediments of the Gulf Coastal Plain overlap the folded Paleozoic rocks. The parallel or almost parallel ridges and valleys adjacent to the Cove area are the topographic expression of plunging anticlines and synclines. The ridges are even-crested and are arranged in an unusual pattern that has given the name Zigzag Mountains to this subdivision of the synclinorium.

The sedimentary rocks cropping out in the immediate vicinity of Magnet Cove are Late Devonian and Mississippian in age. The oldest rocks belong to the Arkansas Novaculite and consist of novaculite with some interbedded shale. Overlying the novaculite is the Stanley Shale of Mississippian age. Two K-Ar ages of 97±5 m.y. and 99±5 m.y. and a Rb-Sr age of 102±8 m.y. from biotites in the Magnet Cove intrusion, show it to be contemporaneous with the Potash Sulfur Springs body.

The Cove itself is an elliptical basin with a maximum northwest-southeast diameter of about three miles and covers an area of about five square miles. The rim of the basin is broken through only at the two points where Cove Creek enters and leaves the Cove. The rim consists of an outer belt of light-colored nepheline syenites and an inner belt of phonolites. A large part of the Cove interior is covered by deep residual and alluvial soils that are presumed to be underlain by ijolite, a basic variety of nepheline syenite. Within the ijolite core are at least two large masses of carbonatite, one of which is exposed in the Kimzey calcite quarry.

There are three generalizations that may be made about the igneous rocks:

(1) They are all varieties of nepheline syenite.
(2) They contain a variety and abundance of titanium minerals.
(3) They become increasingly basic from the rim to the center of the Cove.

Several theories have been suggested for the emplacement of the Magnet Cove instrusives. J. F. Williams (1890) believed that the igneous rocks were formed during three different periods of igneous activity. The first period produced the basic nephelinitic rocks which constitute a large part of the interior basin. During the second period monchiquitic rocks filled the cracks in the first period rocks. The light-colored syenites of the Cove rim and numerous dikes were injected during a third period. H. S. Washington in 1900 suggested the differentiation of a magma in place.

R. L. Erickson and L. V. Blade of the U. S. Geological Survey made a detailed field and laboratory study of the Magnet Cove rocks. This project included the complete remapping of the Cove as well as intensive petrographic and geochemical studies of the igneous rocks. The work was published as U. S. G. S. Professional Paper 425, "Alkalic Igneous Complex at Magnet Cove, Arkansas". In revising the Cove map the authors used current terminology in naming the rock units and also made a number of significant corrections in the original map by Williams. The most important change was recognizing the band of rock lying on the Cove's inner rim, originally thought to be metasedimentary rock, as igneous rock – phonolite. They also correctly identified the so-called "tufa" in the Cove's interior as carbonatite residuum. In adapting this

Geological Survey map for field trip use, many of the smaller rock units were necessarily omitted and similar rock types were combined into single units. For a more detailed examination of the rock types of Magnet Cove, the reader is referred to the U. S. Geological Survey Professional Paper.

A description of the rock names used on the geological map of Magnet Cove is included here as the terms are unfamiliar to many geologists:

Carbonatite –

Dikes and irregular bodies of coarsely crystalline calcite. Locally contains concentrations of apatite, monticellite, magnetite, perovskite, and black garnet.

Ijolite –

Fine-to coarse-grained rocks composed chiefly of nepheline, diopside and black garnet. Contains biotite in some places but does not have any feldspar.

Phonolite –

Fine-grained, gray to greenish to black rocks locally brecciated and banded.

Garnet Pseudoleucite Syenite –

Light gray, medium-grained rock composed of white pseudoleucite, tabular feldspar, pyroxene and black garnet. The coarse-grained phase of this rock is composed of black garnet, nepheline, feldspar, and pyroxene.

The Magnet Cove intrusive complex and the surrounding host rock alteration zone, primarily the Arkansas Novaculite, have long been known for its unusual minerals. Over one hundred minerals are known to occur in the area. Some of the more outstanding minerals to the collector are: cyclic rutile eightling and sixling twins, paramorphs of rutile after brookite, brilliant lustered black brookite crystals perched on rusty smoky quartz crystals one foot long, plus black smoky quartz crystals, eighteen-inch long aegirine crystals in pegmatite matrix (originally mistaken for tourmaline), pink eudialyte crystals, a variety of crystal forms of perovskite, clusters of octahedral magnetite, massive lodestone, black to dark brown melanite crystals intergrown with apatite needles, lime-green vesuvianite crystals, pyrite crystals coated with molybdenite, mica books to six inches across, and trapezohedral pseudoleucite crystals. The micromount collector visiting Magnet Cove should look for any rock containing cavities. Depending on the rock type one may discover a variety of well crystallized minerals including kimzeyite (the only known location for this zirconium-bearing garnet), barite, pectolite, natrolite, labuntsovite, brookite, reticulated rutile, aragonite, diopside, orthoclase, brookite perched on rutile needles, aegirine, taeniolite (a lithium mica), and several newly discovered, not yet described species. The next 3 stops are shown on the bedrock geologic map of Magnet Cove (Plate 19).

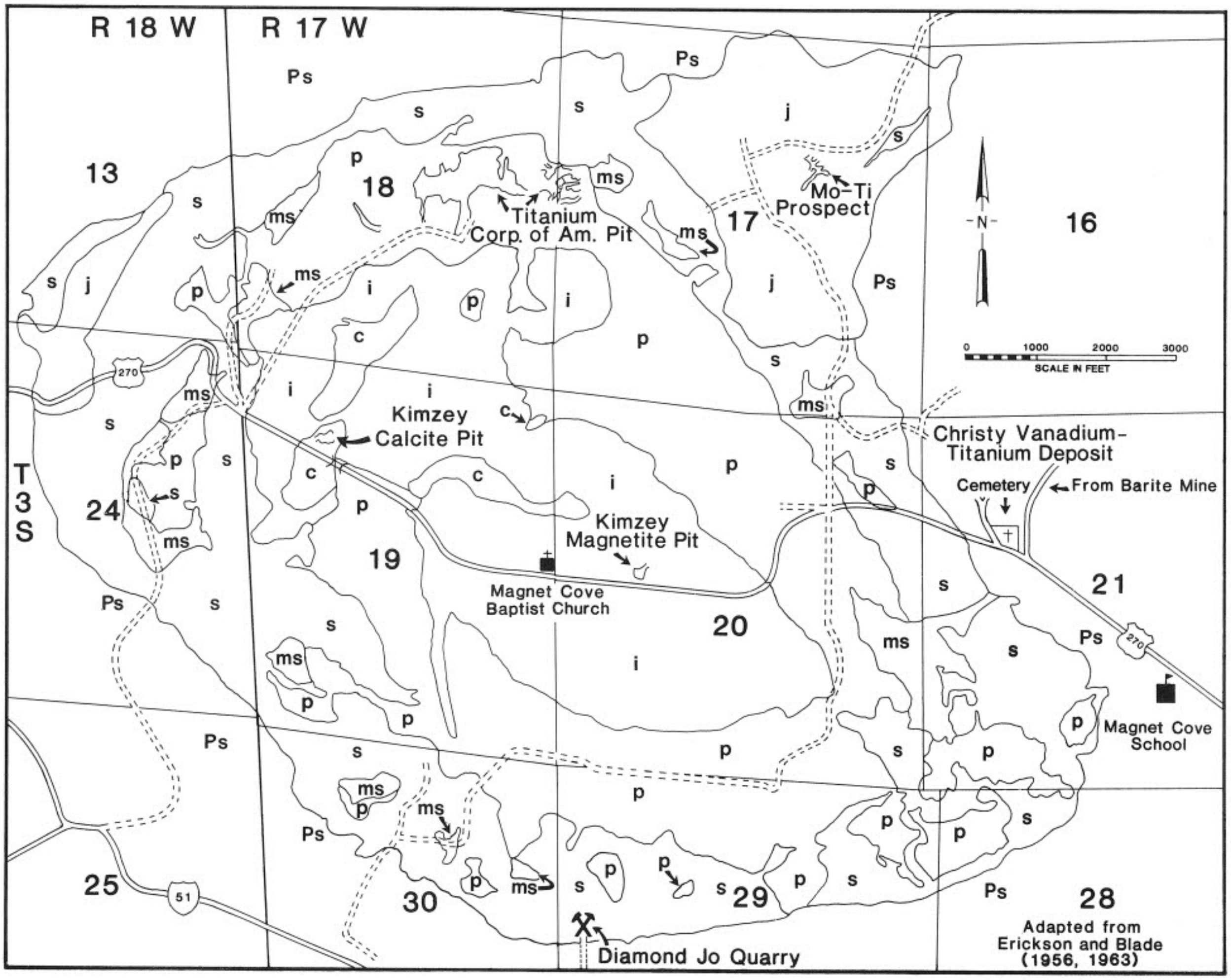


PLATE 19 – BEDROCK GEOLOGY OF MAGNET COVE INTRUSIVE, ARKANSAS

LEGEND

CRETACEOUS

c Carbonatite; residual and secondary phosphate rock derived from carbonatite.

j Jacupirangite and subordinant sphene pyroxenite.

i Garnet and biotite–garnet ijolite, undiff.; includes analcime–olivine metagabbro and minor lime silicate rock.

s Garnet--pseudoleucite syenite, sphene–nepheline syenite, and garnet–nepheline syenite, undiff.; minor garnet–biotite melteigite and small dikes of sphene–garnet–nepheline syenite intruding jacupirangite.

p Trachyte, phonolite, banded phonolite, and altered phonolite breccia, undiff.; small bodies of trachyte and tinguaite.

PALEOZOIC

ms Metamorphosed sedimentary rocks.

Ps Sedimentary rocks, undiff.; numerous igneous dikes are too small to be shown. An inner band, about 2000 feet wide, is a contact metamorphic zone.

Contact – approximate, indefinite, or gradational

Graded dirt road

Paved road

Open pit, trench, mine, or quarry.

Bridge

STOP 19. – SMOKY QUARTZ VEINS IN ARKANSAS NOVACULITE

Recent roadcuts along the east edge of the Magnet Cove Cemetery expose the Lower Division of the Arkansas Novaculite (Plates 17 and 19). They are approximately 800 feet east of the surface contact of the Magnet Cove intrusion with the Paleozoic sediments. The southernmost cut (west side of road) is in recrystallized novaculite (about 50 microns) which is crisscrossed by a network of smoky quartz veins. (Fig. 26). Here the Novaculite strikes N 55^{o} E and dips 24^{o} SE.

The smoky quartz veins may be vertical, along bedding planes, or anastomose through the novaculite. The veins contain not only simple zoned smoky quartz crystals with interstitial red clay, but often present are oxidized fine-grained drusy zones of quartz and brookite (TiO_2). In most cases the brookite-quartz druse is confined to the contact between the novaculite host rock and the simple smoky quartz veins. Introduction of titanium into the fractured novaculite is thought to have taken place in an alkaline fluid phase originating from the intrusive. Silica leached from the novaculite by these alkaline fluids was then deposited as coarse smoky quartz.

Locally the novaculite is recrystallized to as coarse as 100 microns and will crumble like a loosely cemented sandstone when struck with a hammer (outcrop south of the cemetery on U. S. Highway 270). Contact metamorphism is expressed as recrystallization, taking place at this location in an apparently "dry" environment.

STOP 20. – CHRISTY VANADIUM–TITANIUM MINE

We wish to thank Mr. Don R. Owens, geologist for United Metals Corporation (Umetco), a subsidiary of Union Carbide Corporation, for permission to visit the mine and for his assistance (Plates 17 and 19).

The Christy deposit is located on the east rim of Magnet Cove about half a mile northwest of the community of Magnet. Drilling by the U. S. Bureau of Mines in 1949 was undertaken to establish the extent of the titanium mineralization (brookite) in the deposit. The deposit lies on the top and partly on the south slope of an east-west ridge of metamorphosed Arkansas Novaculite. This ridge is the south limit of the Chamberlain Creek syncline, which is overturned so that the sediments dip about 45^{o} south. A few hundred feet to the west of the deposit the syncline is truncated by a coarse-grained nepheline syenite intrusive. Analyses of core samples from the USBM project varied from less than 1% to a maximum of 26% TiO_2, averaging about 5% TiO_2 for the orebody. Appreciable percentages of V_2O_5 (1 to 2%) were encountered in several core samples. Union Carbide Corporation obtained leases on this property during their vanadium-titanium exploration program in Arkansas in the mid-1960's. The deposit was drilled out by Union Carbide shortly thereafter. A test pit, dug in 1975, was developmental work to allow testing of the ore for both amenability to their present mill at Wilson Springs and blendability of Christy ore with those of Wilson Springs. The Christy vanadium ore consists of goethite-rich clay and brookite and averages slightly less than 1% V_2O_5. In December, 1981 developmental work began for ore stockpile sites and water control ponds. Stripping of overburden to expose the orebody began in the Fall of 1983.

Minerals found with the vanadium ores besides brookite, include smoky quartz, taeniolite, rutile, anatase, siderite, and pyrite.

Figure 26. -- Stop 19. Vein of coarsely crystalline smoky quartz with a small cavity of crystals, in Arkansas Novaculite, east of Magnet Cove Cemetery, Hot Spring County, Arkansas. Arrows demarcate the contact of wall rock with the vein.

Figure 27. – Stop 20. Kaolinized alkalic igneous dikes cutting recrystallized and chemically altered Arkansas Novaculite, east highwall, Christy vanadium-titanium deposit, Hot Spring County, Arkansas.

Fryklund and Holbrook (1950) suggested that the Christy deposit was formed by the introduction of mineralizing fluids from the Magnet Cove intrusion into the folded and metamorphosed Arkansas Novaculite, with subsequent erosion and weathering of mineralized rock. In a recent investigation of TiO_2 polymorph-bearing vein deposits adjacent to the Magnet Cove intrusion, Viscio(1981) discovered adularia at the Hardy-Walsh brookite deposit (approximately 2 miles to the N NW) on the northern limb of the Chamberlain Creek syncline, suggesting that the brookite deposits adjacent to Magnet Cove may be an aborted initial phase of alkali metasomatism (fenitization) by late fluids from the Magnet Cove intrusion.

STOP 21. – KIMZEY CALCITE QUARRY

We wish to express our appreciation to Mrs. Marie Arthur of Magnet Cove, Arkansas for permission to visit this famous mineral locality (Plate 19).

Originally opened to produce agricultural lime, the quarry is situated in one of several large carbonatite bodies that occur in and near the center of the Magnet Cove intrusive complex. Carbonatite is a rare intrusive igneous rock which is generally associated with nepheline syenite and more mafic alkaline rock types. Carbonatite, about 1.8 percent of the exposed igneous rocks of the complex, is expressed on the surface by two mappable rock units – carbonatite and residual phosphate. The carbonatite is composed dominantly of coarsely crystalline calcite with subordinate amounts of carbonate-apatite, magnetite, and monticellite. Other minerals present here include kimzeyite, perovskite (Nb-bearing variety dysanalyte) pyrite, biotite, aegirine and vesuvianite. Xenoliths of ijolite up to more than 50 feet across are present in the Kimzey calcite quarry. The larger blocks have reaction rims of varying thickness. The alteration of the xenoliths is similar to alteration noted along the contact zone of the carbonatite and ijolite and involved thorough replacement of nepheline by zeolite, partial to complete alteration of brown garnet to colorless garnet and vesuvianite, bleaching of biotite, and formation of other contact minerals. Weathering of carbonatite yields brown or black saprolite and residual phosphate. Recent work by M. L. Johnson (1975) on the carbon isotope ratios of the carbonate phases of the Magnet Cove intrusion supports the theory that most of the carbonate is mantle derived and represents a late stage of igneous activity.

On the south side of the highway, directly opposite the quarry, masses of eudialyte aegirine pegmatite are exposed. This pegmatite comprises less than 0.1 percent of the exposed igneous rocks of the complex and varies from a fine- to very coarse- grained phanerite. In thin section the fine- to medium-grained parts of the dikes are hypautomorphic-granular and are composed of aegirine; anhedral sodic orthoclase partially altered to cancrinite, calcite, pectolite, zeolite, or sodalite group minerals; nepheline partly altered to cancrinite and usually poikilitically included in the feldspar; euhedral to anhedral sphene; fluorapatite; magnetite; euhedral eudialyte; pyrite; and pyrrhotite. During construction of the bridge at Cove Creek, masses of this pegmatite weighing up to several hundred pounds were exposed yielding excellent specimens of eudialyte and aegirine.

Figure 28. — Stop 20. Late iron-carbonate dikelet in coarse-grained carbonatite, Kimzey calcite pit, Magnet Cove, Hot Spring County, Arkansas.

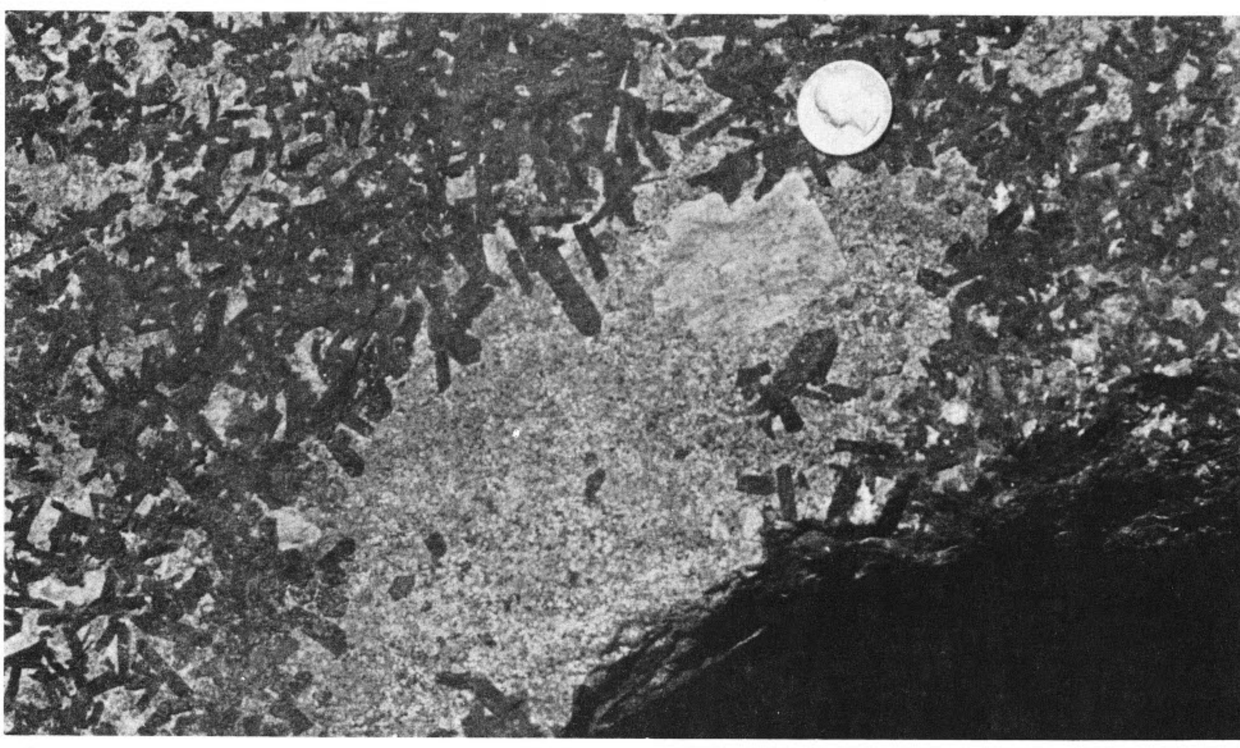


Figure 29. — Stop 21. Coarse-grained pyroxene in ijolite xenolith from the Diamond Jo Quarry, Magnet Cove, Hot Spring County, Arkansas.

STOP 22. – DIAMOND JO QUARRY

Our sincere thanks to Mr. Henry deLinde of Mabelvale, Arkansas for permission to visit this classic site (Plates 19 and 20). Mr. deLinde does request that we do not remove samples beyond our normal needs!

The Diamond Jo Quarry was opened in the 1870's to supply building materials and crushed stone for the "Diamond Jo Line", a narrow gauge track which connected Malvern with Hot Springs. The quarry was operated sporadically after 1890, but has been inactive for many years.

The Diamond Jo Quarry is developed in garnet pseudoleucite syenite and nepheline syenite pegmatite. Chemical composition and field relationships indicate that the garnet pseudoleucite syenite was emplaced before injection of nepheline syenite pegmatite (Erickson and Blade, 1963).

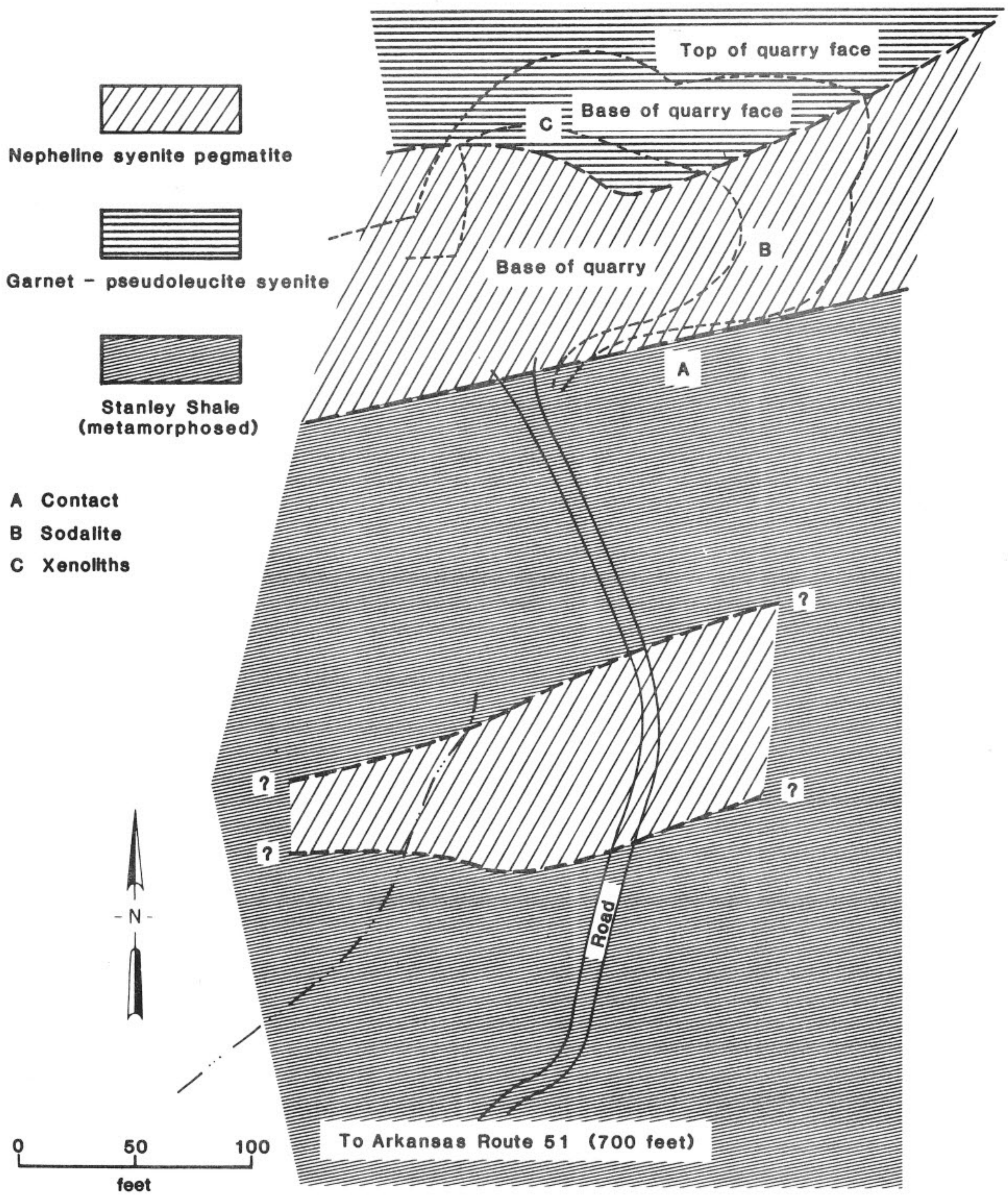
Garnet pseudoleucite syenite is a light gray medium-grained rock consisting of orthoclase, black titanium garnet, pseudoleucite, pyroxene, titanite, and nepheline. This rock contains many xenoliths of other igneous and sedimentary rocks. Miarolitic cavities, ranging from pinhead size to three inches across, occur in patches in this rock. Minerals commonly occurring in the larger cavities are orthoclase acmite, pectolite, and apophyllite. The smaller cavities contain a host of other minerals, including arfvedsonite, barite, barytocalcite, brookite, catapleiite, hematite, hornblende, labuntsovite, molybdenite, narsarsukite, pyrite, quartz, rutile, siderophyllite, sphalerite, and taeniolite.

The nepheline syenite pegmatite is lighter in color and coarser grained than the garnet pseudoleucite syenite. It is composed of barian sodic orthoclase, nepheline, cancrinite, black titanium garnet, and pyroxene. Joints developed in this rock type may be covered by fluorite or sodalite (visible in the east face). This rock also is in contact with the Stanley Shale at the southeast edge of the quarry. Little evidence of a chill zone is present at the contact which suggests that the country rock had not cooled from the emplacement of garnet pseudoleucite syenite before the injection of the nepheline syenite pegmatite. The Stanley Shale has been metamorphosed to a hornfels at the contact.

Howard (this volume) presents a summary of isotopic ages presently available for igneous rocks of Cretaceous age in Arkansas.

PLATE 20 - GEOLOGIC MAP OF DIAMOND JO QUARRY

MAGNET COVE COMPLEX, ARKANSAS



Stephen E. Kessler - 1967

STOP 23. – UMETCO'S VANADIUM MINE AT WILSON SPRINGS (POTASH SULFUR SPRINGS)

We wish to thank Mr. Don R. Owens, geologist for United Metals Corporation, a subsidiary of the Union Carbide Corporation, for permission to visit various mines and exposures at Wilson Springs and for his enlightening presentation on the geology.

The following article – GEOLOGY OF THE WILSON SPRINGS VANADIUM DEPOSIT, GARLAND COUNTY, ARKANSAS by J. S. Hollingsworth, Union Carbide Corporation (1967) was later revised by J. Michael Howard, *in* Stone, C. G., et al., (1982), and again for this volume.

INTRODUCTION

The vanadium deposits currently mined by Union Carbide Corporation at Wilson Springs, Garland County, Arkansas, are the only deposits mined specifically for vanadium in the United States. The geologic setting of these deposits is described in this report.

The Wilson Springs operation takes its name from Wilson Mineral Springs (formerly known as Potash Sulfur Springs), which is located near the edge of the small circular alkalic intrusive also named after these springs. J. F. Williams described the igneous rocks of the area in 1890 and noted that a large hotel existed near the springs. The building was first abandoned and later destroyed by a fire in the early 1930's.

Interest in the economic potential of the Wilson Springs area was primarily initiated in 1950 by the discovery of anomalous radioactivity and one boulder containing small amounts of uranian pyrochlore (Erickson and Blade, p. 83). Several investigations were conducted by the U. S. Geological Survey, the Atomic Energy Commission, the Arkansas Geological Commission, and private mineral interests. Only trace amounts of uranium were indicated by drilling and trenching adjacent to the "discovery boulder." Geochemical determinations by the U. S. Geological Survey and others indicated significant concentrations of niobium and vanadium in the vicinity of the uranium prospect (Beroni, 1955).

Union Carbide geologists first investigated the Wilson Springs area for vanadium in 1960. After obtaining mineral leases, a preliminary core drilling program during 1961-1962 disclosed vanadium ores. Development drilling was resumed in 1964, and by September, 1965, sufficient reserves were indicated to justify the construction of the Wilson Springs Vanadium Plant.

GEOLOGY

The location and general geologic setting of the Wilson Springs vanadium deposits are shown in Plates 21-23. The dominant feature of the area is the Potash Sulfur Springs igneous complex, which intruded folded and faulted Paleozoic rocks. The distribution and description of the various rock types are generalized, with modifications, from D. W. Pollock (1966), who performed field petrographic investigations of the intrusive. The highly variable contact rocks have been studied in detail by V. J. Hoffmann and D. M. Hausen of Union Carbide Corporation.

Igneous Rocks

The Potash Sulfur Springs intrusive is a circular alkalic igneous complex exposed for somewhat less than a mile in diameter, that probably was emplaced in early Late Cretaceous time (Zartman and Marvin determined the Magnet Cove

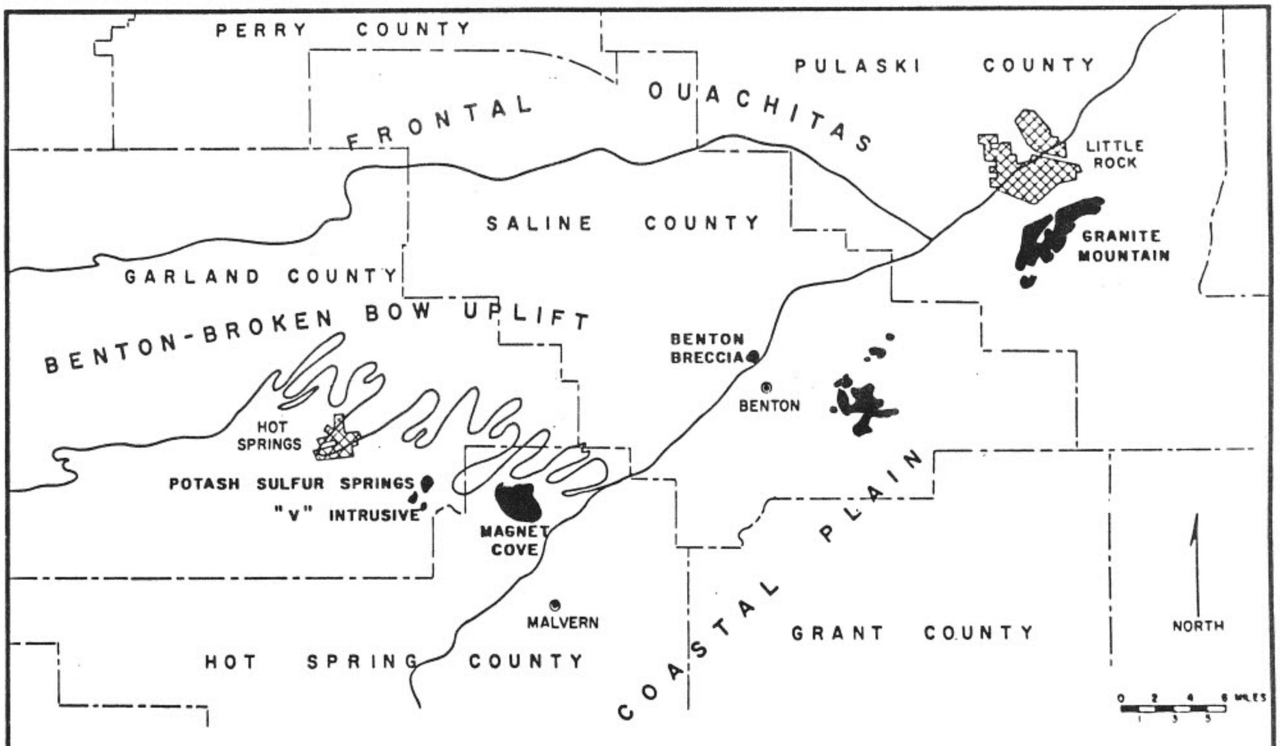


PLATE 21 – MAP OF EXPOSED ALKALIC INTRUSIVES IN CENTRAL ARKANSAS

Note: Modified for this volume (1985) by J. M. Howard

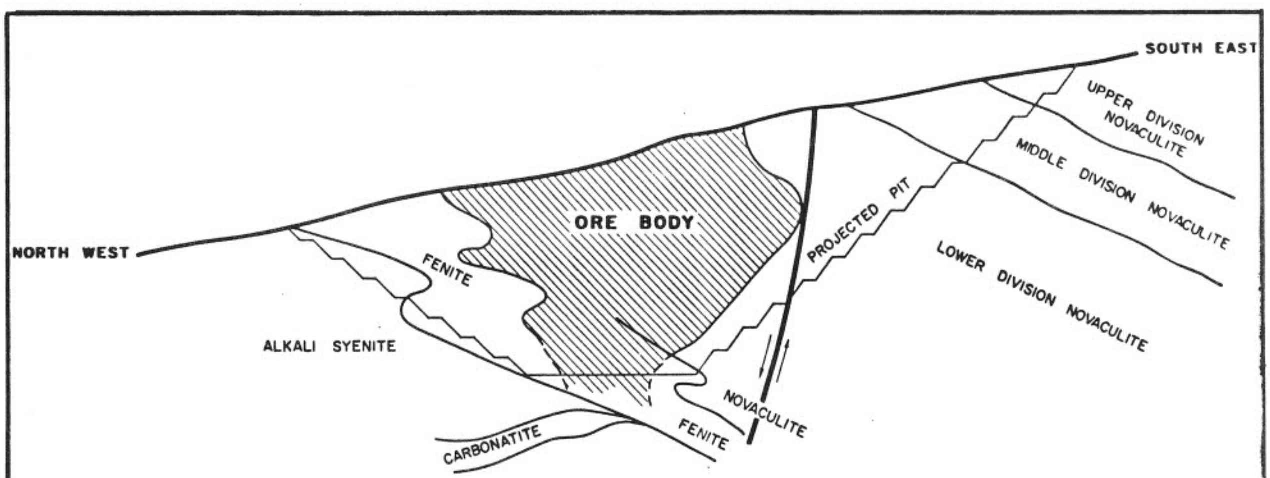


PLATE 22 – DIAGRAMMATIC CROSS SECTION OF THE EAST WILSON PIT

NOT TO SCALE

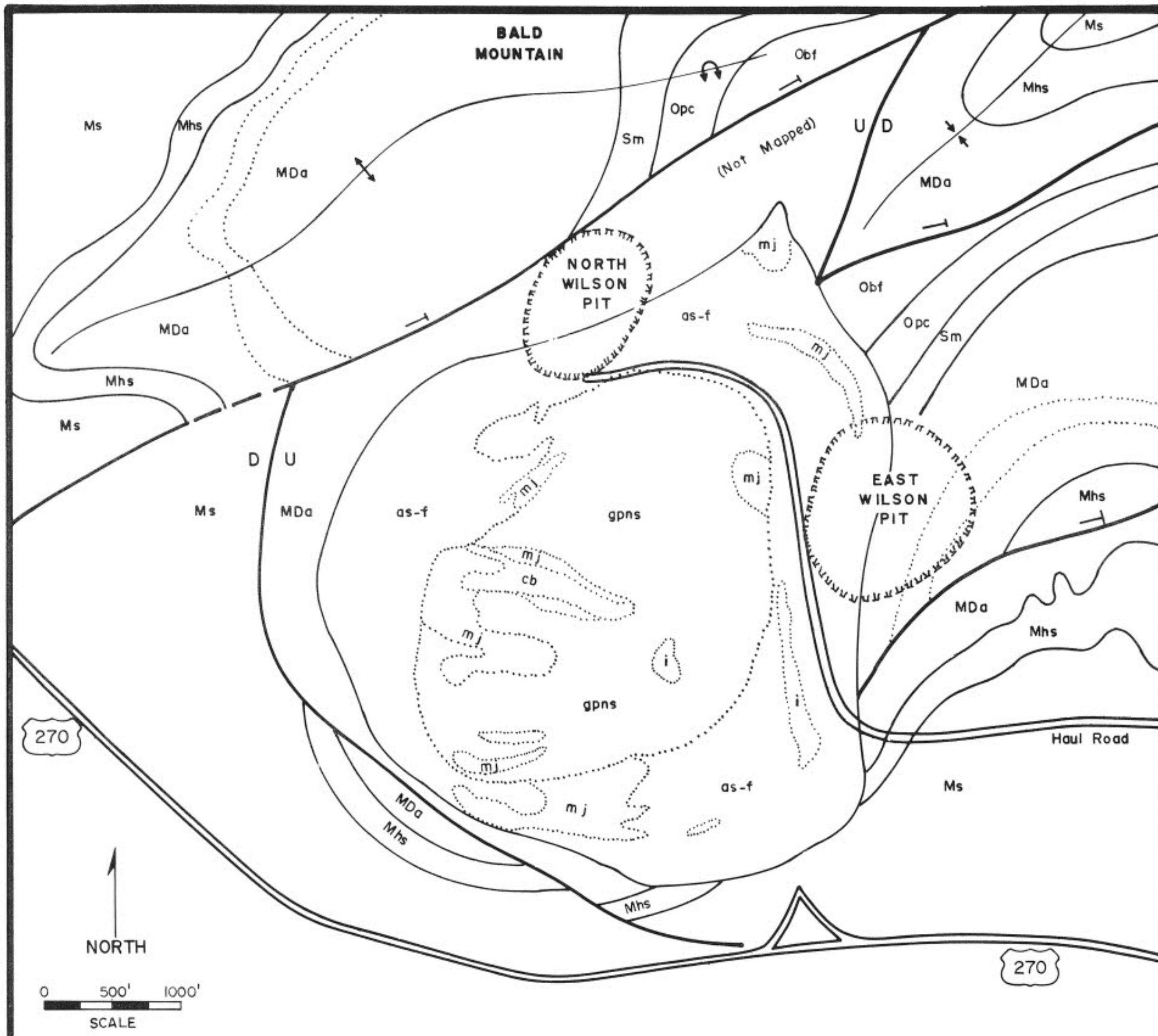


PLATE 23 - GENERALIZED GEOLOGIC MAP OF THE POTASH SULFUR SPRINGS INTRUSIVE AND VICINITY, GARLAND COUNTY, ARKANSAS

MODIFIED FROM PURDUE AND MISER (1923) AND POLLOCK (1966)

SEDIMENTARY ROCKS

MISSISSIPPIAN	Ms	STANLEY SHALE
MISSISSIPPIAN	Mhs	HOT SPRINGS SANDSTONE
DEVONIAN AND MISSISSIPPIAN	MDa	ARKANSAS NOVACULITE (upper, middle, lower)
SILURIAN	Sm	MISSOURI MT. SHALE
ORDOVICIAN	Opc	POLK CREEK SHALE
ORDOVICIAN	Obf	BIGFORK CHERT

IGNEOUS ROCKS

as-f	ALKALI SYENITE AND FENITE
gpns	GARNET PYROXENE NEPHELINE SYENITE
i	IJOLITE
mj	MELTEIGITE, PYROXENITE & JACUPIRANGITE
cb	CALCITE – CEMENTED BRECCIA

THRUST FAULT

U/D FAULT

ANTICLINE

SYNCLINE

intrusive to be 95 ± 5 million years). The complex has a crude ring structure similar to the Magnet Cove intrusive exposed about 6 miles to the east. The outer ring of the complex is alkalic syenite and fenite. Much of the central part of the complex is nepheline syenite. Disconnected exposures of jacupirangite, melteigite, and ijolite are present throughout the area. Near the center of the complex a calcite-cemented breccia crops out and carbonatite has been encountered in a few drill holes. Carbonatite is also present as dikes and as irregular masses in the subsurface near the margins of the intrusive. Several igneous and sedimentary rock breccias, commonly with feldspathic matrix, are present within and near the margins of the intrusive.

Saprolite, highly weathered rock averaging about 40 feet in thickness, is developed over much of the igneous area, but the outer portion of the nepheline syenite ring supports a low ridge.

The basic rocks of the Potash Sulfur Springs complex include jacupirangite, pyroxenite, and members of the melteigite-ijolite series. Nepheline content varies from traces in jacupirangite to a maximum of 60 percent in ijolite. Biotite jacupirangite contains small amounts of magnetite and titanite with biotite as the only major constituent. The pyroxenite contains aegirine-diopside, ferroaugite, and biotite. Locally these rocks have been intensely chloritized. The melteigites have aegirine-diopside with 14 to 40 percent nepheline. In one variety of melteigite, titanium-rich andradite (garnet) makes up 30 to 60 percent of the rock. Garnet and pyroxene are present in the ijolites. Secondary minerals such as calcite, orthoclase, zeolites, and pyrite may be up to 55 percent of these rocks.

The nepheline syenite contains 7 percent aegirine-diopside and 7 percent garnet with about 32 percent nepheline. Calcite, secondary orthoclase, and zeolites are present in variable amounts.

The alkali syenite and fenite ring represents 51 percent of the exposed complex. The alkali syenites are medium to coarse grained with 80 to 98 percent orthoclase. Much of the rock in this zone is a product of alkali-metasomatism and, therefore, should be termed fenite rather than syenite. The contact between the fenite and the surrounding sedimentary rock is irregular, and residual blocks and zones of metamorphosed sedimentary rocks are frequently found. Relict bedding can be seen in some fenite exposures. Aegirine is a common accessory mineral in the fenite, and occasionally makes up 80 to 90 percent of the rock. Locally, biotite, apatite, or siderite may be major constituents in the border fenite.

Calcite carbonatite has been encountered beneath the saprolite cover by several drill holes in the central part of the complex. Biotite, aegirine, pyrite, pyrrhotite, and magnetite are the most common accessory minerals. A few feldspar-carbonate veins, similar to the veins at Magnet Cove, have been encountered.

Dikes and sills of various sizes and attitudes are frequent within the igneous mass but appear to be more abundant in the surrounding sedimentary rocks. A large variety of rock types is present ranging from phonolites and trachytes to the very basic varieties including ouachitite, monchiquite, and fourchite. Outside the igneous complex, most of the dikes are partially or completely argillitized, often to depths of several hundred feet——only the texture remains to identify the origin of such clays. Many dikes are xenolithic; a large irregular dike mass in the North Wilson pit contains rounded as well as angular fragments of the adjacent rocks.

Stratigraphy

The sedimentary rocks in the immediate vicinity of the Potash Sulfur Springs intrusive range from Ordovician (Bigfork Chert) to Mississippian (Stanley Shale) in age. The approximate observed thicknesses of these units and a brief description are shown in the accompanying table.

Within 1000 feet of the igneous rocks, the Arkansas Novaculite has been recrystallized by thermal metamorphism to a very fine-to medium-grained quartzite. Closer to the intrusive, the siliceous units contain cristobalite, wollastonite, tremolite, aegirine, miserite, and calcite in a highly variable metamorphic rock suite. The shale units have been metamorphosed to hornfels. Large areas of shale have been argillitized, at least in part by hydrothermal solutions; thus many of the stratigraphic units cannot be distinguished in the immediate vicinity of the ore deposits.

Structure

The Potash Sulfur Springs intrusive is located on a southwest-plunging anticlinal nose of the Zigzag Mountains. The sedimentary rocks were intensely folded and faulted during the Late Pennsylvanian Ouachita orogeny. These structures trend about N 65° E. Several anticlines and at least three thrust faults are present in the area. The northernmost anticline at Bald Mountain is overturned to the north for much of its length.

The Potash Sulfur Springs intrusive considerably distorted the older Ouachita structural fabric. Minor faulting is quite common within 1,000 feet of the intrusive contacts. One large concentric fault is shown on the geologic map (Plate 23) and many others have been noted. Some of the older Ouachita faults were re-opened, altered, and mineralized by the intrusive, especially the thrust fault at the north edge of the North Wilson pit.

The high west wall of the North Wilson pit shown in Figure 30 displays the structural complexity of the near-contact areas. On the far right is a shattered zone probably representing an anticline. A broad fault zone left of the xenolithic dike cuts the bottom of a syncline. The contact between the Lower and Middle Divisions of the Arkansas Novaculite in the center marks the north limb of an anticline. Southward the Middle Division shales and cherts reappear in a syncline with two or three small faults and numerous dikes. Farther south fenite replaces the novaculite along an irregular contact.

ORE DEPOSITS

The vanadium ore deposits of the Wilson Springs area occur near the contact between the alkalic igneous rocks and the surrounding sedimentary rocks. Two ore bodies are being developed by separate open pits. Other deposits are present in the area that will be developed at a later date.

The vanadiferous ores occur as local concentrations within large, irregular areas of argillic alteration. Fenite, feldspathic breccias, and metamorphosed sedimentary rocks have all been altered and mineralized in such areas (Plate 23). Iron oxides are common near the present surface, and pyrite is present at depth.

TABLE I

STRATIGRAPHIC UNITS IN THE VICINITY OF THE POTASH SULPHUR SPRINGS INTRUSIVE

AGE	FORMATION	DESCRIPTION	APPROXIMATE LOCAL THICKNESS IN FEET
Mississippian	Stanley Shale	Dark gray platy shale with thick beds of fine-grained clayey sandstone.	over 1,000
Mississippian	Hot Springs Sandstone	Light gray, very-fine grained sandstone interbedded with dark gray shale.	90
Devonian and Mississippian	Arkansas Novaculite	Upper Division: medium to thick bedded white novaculite and ferruginous sandstones. Some gray shale interbeds are present and the base is marked by 1–2′ of conglomerate.	75
		Middle Division: thin bedded novaculite interbedded with dark gray fissile shale—strongly argillitized in the immediate area.	120
		Lower Division: white and black massive novaculite.	380
Silurian	Missouri Mountain Shale	Pale red to greenish gray shale, 1–2′ of ferruginous fine-grained sandstone at base may represent the Blaylock Sandstone.	100
Ordovician	Polk Creek Shale	Black, fissile, graphitic shale with thin beds of limy chert.	130 to 200
Ordovician	Bigfork Chert	Gray and black chert regularly interbedded with gray siliceous shale.	over 300

South

North

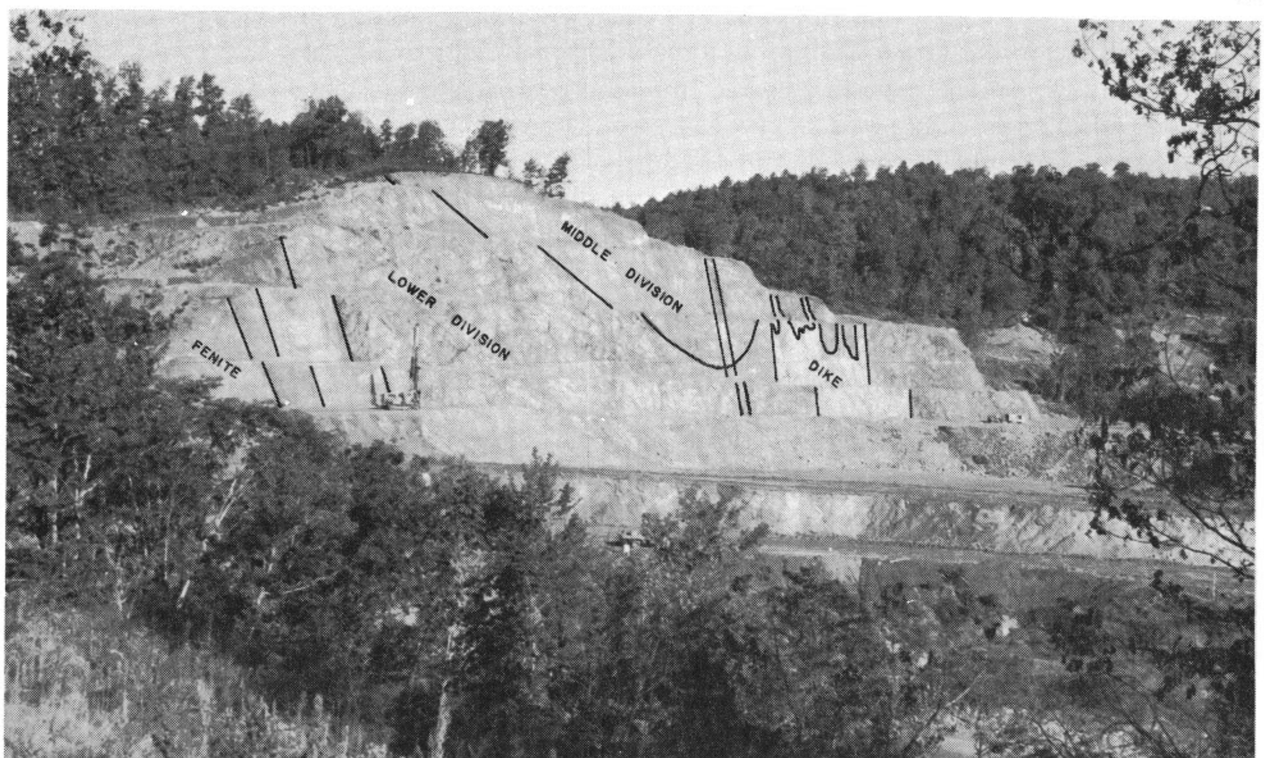


Figure 30. View of the North Wilson Pit looking northwest at the north-south high wall. Description in text.

The ores contain about one percent V_2O_5 as discrete clay-sized vanadium minerals. Bokite (?), duttonite, fervanite, navajoite, roscoelite, schoderite, and straczekite plus a number of presently undescribed mineral species are recognized in these ores (Arkansas Geological Commission, open file data from C. Milton, The George Washington University, Washington, D.C.). The vanadium occurs as a vicarious element in several rock-forming minerals and their alteration products.

Even though the Wilson Springs area has been investigated as a potential niobium deposit (Fryklund, Harner, and Kaiser, p. 55), the niobium content of the ores being mined is low, generally under 0.10% Nb_2O_5. Titanium occurs in minor quantities, mainly as anatase, which contrasts sharply with the higher values in the titanium prospects at the Magnet Cove intrusive.

Close control of the vanadium content must be maintained to derive optimum metallurgical results in the processing of the ore. The varying nature of the ore requires close-spaced test drilling, generally 20 foot centers, directly ahead of mining. Visual inspection is of limited value in ore control due to the variability of values and the nondescript nature of the ore.

Recent work by Howard (1975) characterized the intrusive rocks of Potash Sulfur Springs as a carbonated nephelinitic stock which was intruded by late mafic differentiates and high volatile residual carbonates. Heathcote (1979) reported on the alteration of masses of Arkansas Novaculite adjacent to the intrusion to felspathic fenite. Early carbonatite phases were implicated as the source of fenitizing fluids. Heathcote and Owens (1980) envisioned formation of the orebody to have proceeded according to the following scheme. Fenitizing fluids carrying Na, Al, Fe, V, and P permeated the country rock above ascending alkaline magma. These fluids altered the Upper and Lower Divisions of the Arkansas Novaculite to Or85Ab15 + apatite, while the argillaceous Middle Division fixed Na, Fe and V as it altered to Fe-sanidine bearing aegirine pyroxenite. Some aegirine also formed in the Lower Division as a replacement of feldspar. A later hydrothermal phase attacked the aegirine and deposited pyrite. Intense fracturing and brecciation of the country rock preceded injection of carbonatite and alkaline dikes. Vanadium ore was formed during weathering of the altered pyroxenite, probably in early to middle Tertiary time.

The Potash Sulfur Springs intrusive has been dated isotopically (see Howard, this volume).

STOP 24. – TRIPOLI MINE IN ARKANSAS NOVACULITE

We wish to thank Mr. Hewitt Harlow and Mr. Charles T. Steuart of the Malvern Minerals Company of Hot Springs for their assistance and permission to visit this presently inactive mine (Pl. 24, Fig. 31). This mine was operated primarily for tripolitic novaculite (Novacite®) in the Arkansas Novaculite. Tripoli is a microcrystalline silica (99.6%) used as a filler and extender in paints and plastics and as an abrasive. The Arkansas Novaculite here is overturned to the southeast and the rocks are dipping 32^o-45^o to the northwest. The tripolitic novaculite is mined

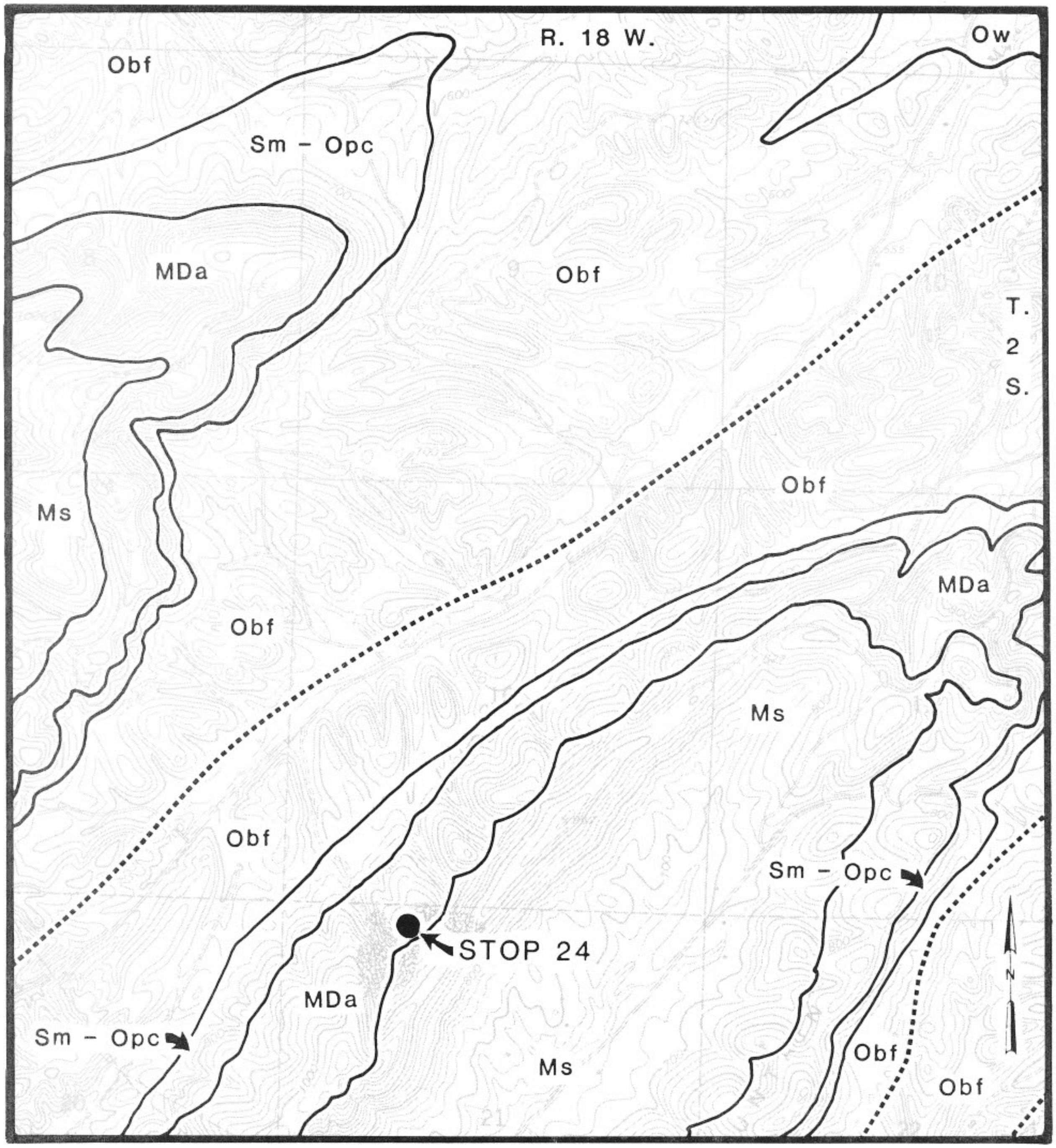


PLATE 24 - GEOLOGIC MAP EAST OF HOT SPRINGS-STOP 24

1000 0 1000 2000 3000 FEET

Ms	Stanley Shale	Obf	Bigfork Chert
MDa	Arkansas Novaculite	Ow	Womble Shale
Sm - Opc	Missouri Mountain Shale - Polk Creek Shale	....	Thrust Faults
		———	Contacts

from the Upper Division of the Arkansas Novaculite which is about 60 feet thick. It is overlain by the Middle Division (about 20 feet thick) and the Lower Division (about 400 feet thick). The Upper Division is white and friable with an average particle size of 7 microns. The Middle Division consists of a highly siliceous, carbonaceous black shale which the company mines and markets under the trade name Ebony® for use as an extender pigment and other purposes. Typical analyses of the Novacite® and Ebony® are:

		Novacite®	Ebony®
Silica	SiO_2	99.49 %	60.40 %
Carbon	C	0.00 %	3.37 %
Sulfur	S	0.00 %	0.07 %
Aluminum oxide	Al_2O_3	0.102 %	22.40 %
Ferric oxide	Fe_2O_3	0.039 %	2.15 %
Titanium oxide	TiO_2	0.015 %	1.70 %
Calcium oxide	CaO	0.014 %	2.00 %
Magnesium oxide	MgO	0.021 %	0.38 %
Loss on Ignition		0.190 %	9.75 %

The tripoli in the Upper Division is probably formed by the leaching of calcium carbonate cement from the novaculite. Scanning electron micrographic studies of the novaculite and tripoli by Keller et al. (1977) confirm that the silica has been slightly recrystallized at this locality and that polygonal triple-point texture is present.

At the top of the Lower Division at this locality there is about a 20 foot interval of sedimentary slurried boulder-like novaculite, minor sandstone, and other materials forming a very coarse conglomerate or breccia. Minor granitic fragments are present in similar rocks about ten miles to the north. Honess (1923) reports igneous and volcanic debris in the Arkansas Novaculite in the Broken Bow area of Oklahoma. These deposits likely represent slurries derived from submarine scarps and ridges to the north that, in part, had active extensional faulting and igneous activity in Devonian times. Richard Lane of Amoco Production Company tentatively identified Middle Devonian conodonts from the shales about 18 feet stratigraphically below the boulder interval. Other interesting geologic features in or near the quarry are:

1. Secondary oxides, often forming manganese and iron dendrites, coatings, and discolorations on fracture surfaces;
2. Unusual development of grooved-like curtains or sheets of tripoli are present on the wall face;
3. Some of the fractures are filled with weathered to fresh igneous intrusives (alkalic dikes, early Late Cretaceous);
4. Novaculite in the Lower Division that is of very high quality for whetstones, including both hard (Arkansas) and soft (Washita) types;
5. Minor thrust and tear faults with slickensides;
6. The ridge south of the quarry is formed by the overlying Hot Springs Sandstone of the lower Stanley Shale. It is about 75 feet thick and is composed of quartzitic sandstone and shale with sandy chert-novaculite conglomerate typically near the base;
7. Thin films of gorceixite (barium phosphate) coating novaculite fractures;
8. And minor amounts of chalcocite and pyrite.

STOP DESCRIPTIONS – FOURTH DAY

SOUTHEASTERN OUACHITA MOUNTAINS

HOT SPRINGS – BISMARCK – ARKADELPHIA

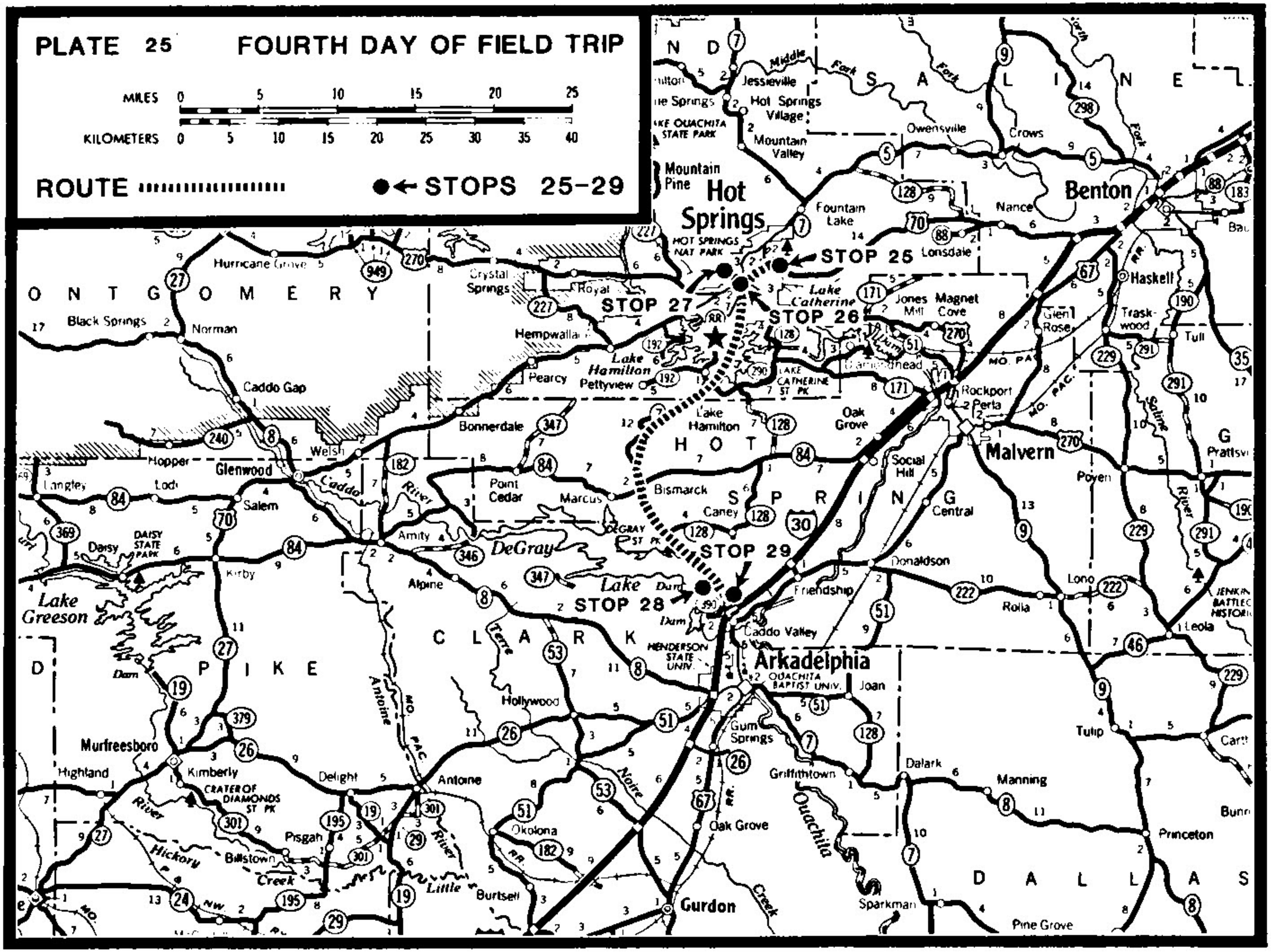


PLATE 25
FOURTH DAY OF FIELD TRIP
MILES 0 5 10 15 20 25
KILOMETERS 0 5 10 15 20 25 30 35 40
ROUTE
STOPS 25–29
STOP 25
STOP 26
STOP 27
STOP 28
STOP 29
Hot Springs
HOT SPRINGS NAT PARK
Mountain Pine
Jessieville
Hot Springs Village
Mountain Valley
Fountain Lake
Lake Catherine
LAKE CATHERINE ST PK
Lake Hamilton
Pettyview
Pearcy
Hempwallace
Royal
Crystal Springs
Hurricane Grove
Black Springs
Norman
Caddo Gap
Glenwood
Hopper
Langley
Lodi
Salem
Daisy
DAISY STATE PARK
Lake Greeson
Kirby
Amity
Alpine
DeGray Lake
DEGRAY ST PK
Point Cedar
Marcus
Bonnerdale
Bismarck
Caney
Lake Hamilton
Oak Grove
Social Hill
Central
Donaldson
Friendship
Caddo Valley
Arkadelphia
HENDERSON STATE UNIV.
OUACHITA BAPTIST UNIV.
Joan
Gum Springs
Griffithtown
Dalark
Manning
Princeton
Tulip
Sparkman
Pine Grove
Gurdon
Oak Grove
Okolona
Burtsell
Hollywood
Antoine
Delight
Pisgah
Billstown
Kimberly
CRATER OF DIAMONDS ST PK
Murfreesboro
Highland
Malvern
Rockport
Perla
Magnet Cove
Jones Mill
Glen Rose
Haskell
Traskwood
Tull
Benton
Nance
Crows
Owensville
Lonsdale
Poyen
Rolla
Lono
Leola
Prattsville
Welsh
Caddo River
Antoine
Terre Noire
Ouachita
Little River
Hickory Creek
Saline River
MO. PAC.
M O N T G O M E R Y
G A R L A N D
S A L I N E
H O T S P R I N G
C L A R K
P I K E
D A L L A S

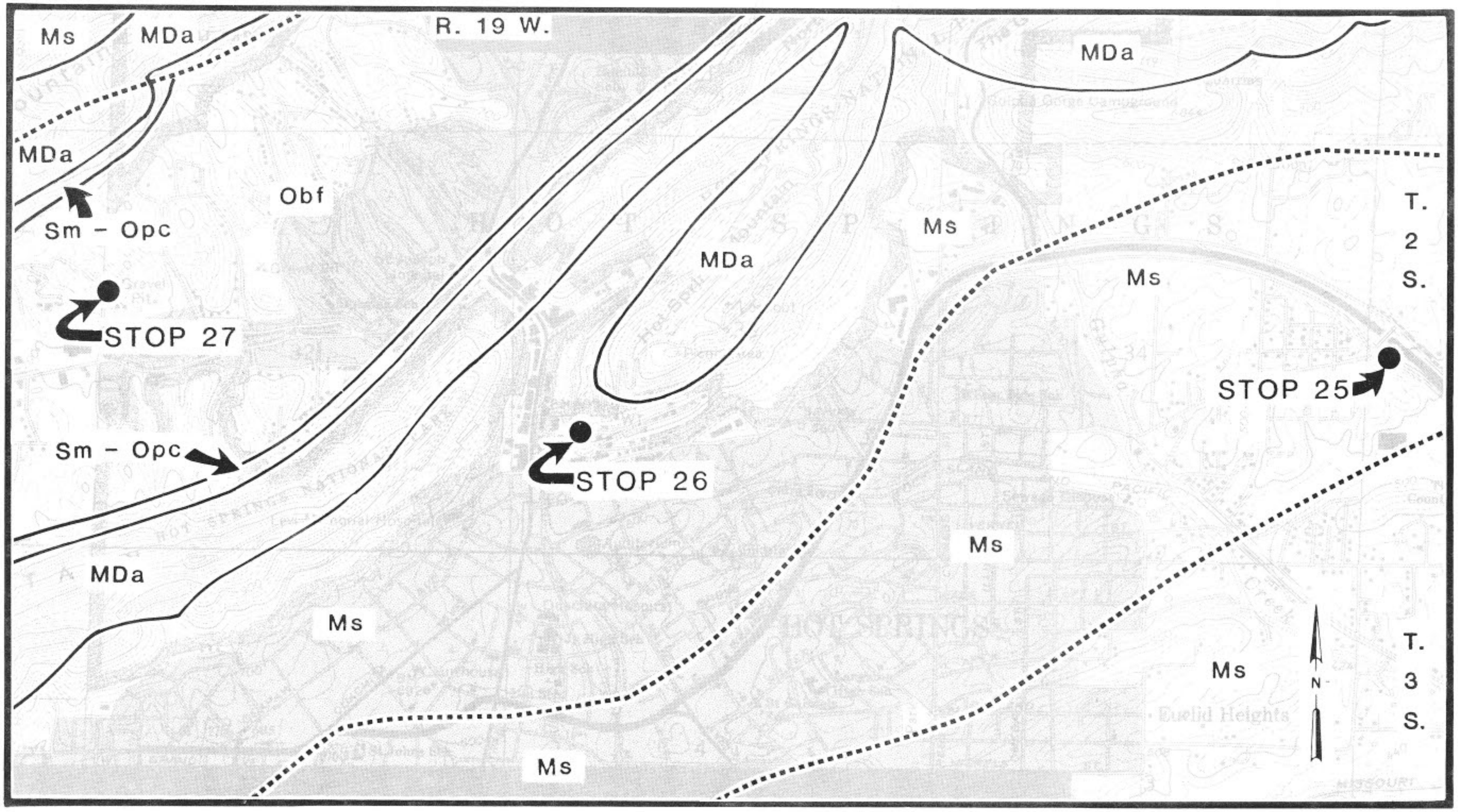


PLATE 26 - GEOLOGIC MAP OF HOT SPRINGS AND VICINITY - STOPS 25, 26 AND 27

1000 0 1000 2000 3000

FEET

Ms — Stanley Shale

MDa — Arkansas Novaculite

Sm - Opc — Missouri Mountain Shale - Polk Creek Shale

.... Thrust Faults

Obf — Bigfork Chert

——— Contacts

STOP 25. – LOWER STANLEY SHALE EAST OF HOT SPRINGS

The lower part of the Stanley Shale is well exposed at several localities east of Hot Springs along U. S. Hwy. 70. At this outcrop the rocks consist of black shale or slate, thin bedded siltstone, thin- to thick-bedded subgraywacke and graywacke, chert, and a few cone-in-cone concretions. The maximum thickness of the Stanley is approximately 9500 feet; these rocks are about 1200 feet above the base. Most of the rocks are overturned to the south into the Mazarn Basin and dip steeply to the north. The lower Stanley is complexly folded, with both flexural-flow and slip types, and exhibits at least two generations of cleavage. Thrust faults cutting the sequence are indicated by numerous slickenside zones with quartz veins and dickite coating on the rock surface.

Sedimentary features include bottom marks, ripple marks, graded bedding, cross-laminations, debris flows, loading and slumping, and bioturbations. Many of the beds thicken and coarsen upward and are believed to represent lobe sequences of an outer submarine fan depositional environment. Some sandstone packets thin upward, indicative of a submarine fan channel depositional environment. These sands were likely derived from sources to the south and southeast. The sands were initially carried to the north and northwest down deep-water submarine fans and subsequently carried by turbidity currents to the west down the Ouachita trough. The clastic units show both structural boudinage and sedimentary pull-aparts. The weathered Stanley Shale at the top of the roadcut is characteristically greenish-brown.

The middle and lower parts of the Stanley Shale are in the Tenmile Creek Formation on the lower part of the Stanley Group in the Ouachita Mountains of Oklahoma. In Arkansas and Oklahoma there are chert intervals in the lower, middle and upper parts of the Stanley that represent reliable markers. Sandstones in the Stanley are often tuffaceous in Arkansas, but the acidic volcaniclastic beds of the Hatton and Mud Creek Tuff lentils, which are prominent in the lower 1500 feet in southwestern Arkansas and Oklahoma, are rarely present in this area. Miser (1934) and Niem (1977) have shown that the tuffs were derived from a source south or southwest of Broken Bow, Oklahoma.

STOP 26. – HOT SPRINGS NATIONAL PARK TOUR

This is a brief walking tour of the hot springs located off Central Avenue in downtown Hot Springs, Arkansas (Plate 26). The Grand Promenade Trail provides convenient access to hot springs, and exposures of tufa rock and sandstone. Nearby there is a fine museum at the Hot Springs National Park Headquarters. This was the first Federal Reservation (1832) and became the eighteenth National Park (1921) in the United States.

The U. S. Park Service regulates the use of the water from the world famous hot springs which issue from fractures and joints in the Hot Spring Sandstone along the base and slope of East Mountain.

East Mountain is a westward plunging, faulted, southward overturned anticlinal ridge of the Zigzag Mountain subprovince. Early American Indian tribes, Spanish conquistadors, early settlers and modern man have all exploited the therapeutic properties of the springs. "Tah-ne-co", the place of the hot waters, was the Indian name for the site. About 50 of the

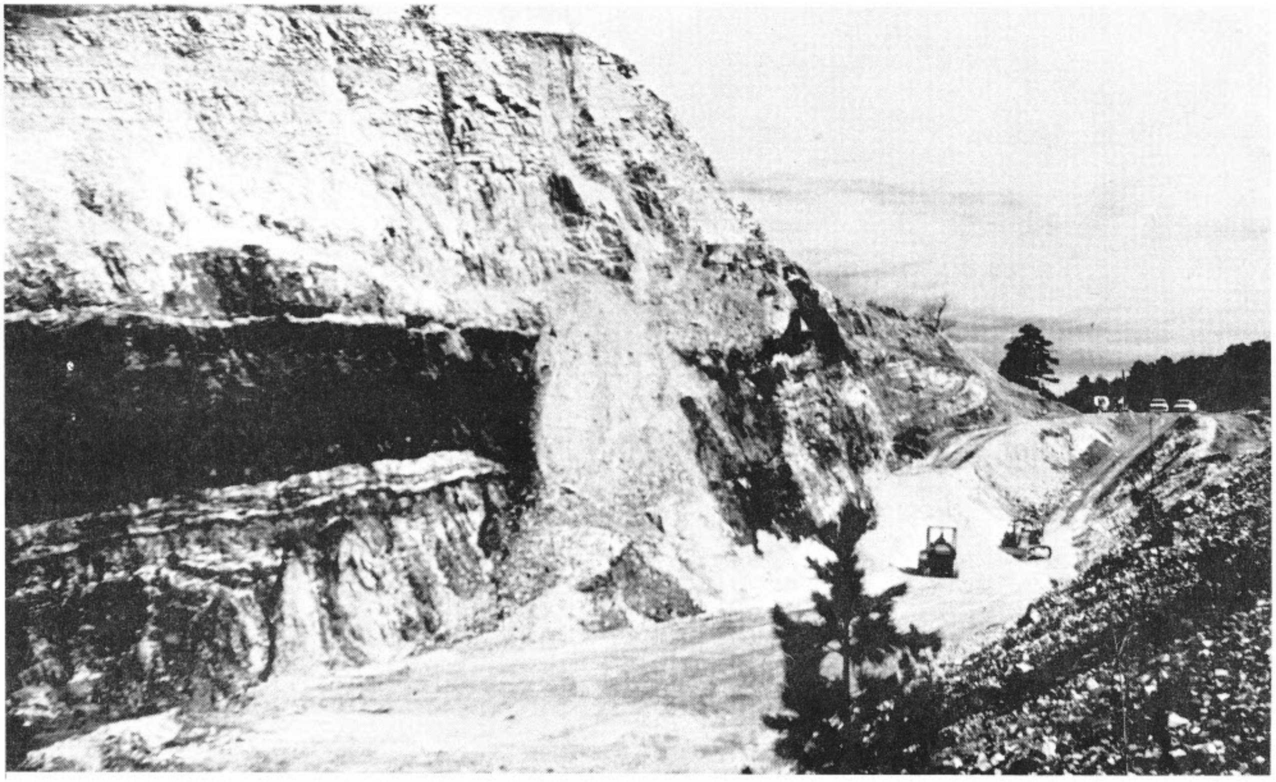


Figure 31. - Open-pit, tripoli ("Novacite®") mine of the Malvern Minerals Company, Garland County, Arkansas. The stratigraphic section is inverted here; the white, tripolitic upper member of the Arkansas Novaculite is at the base of the deposit, the dense novaculite of the lower member is at the top, and the dark shale of the middle member is between them.

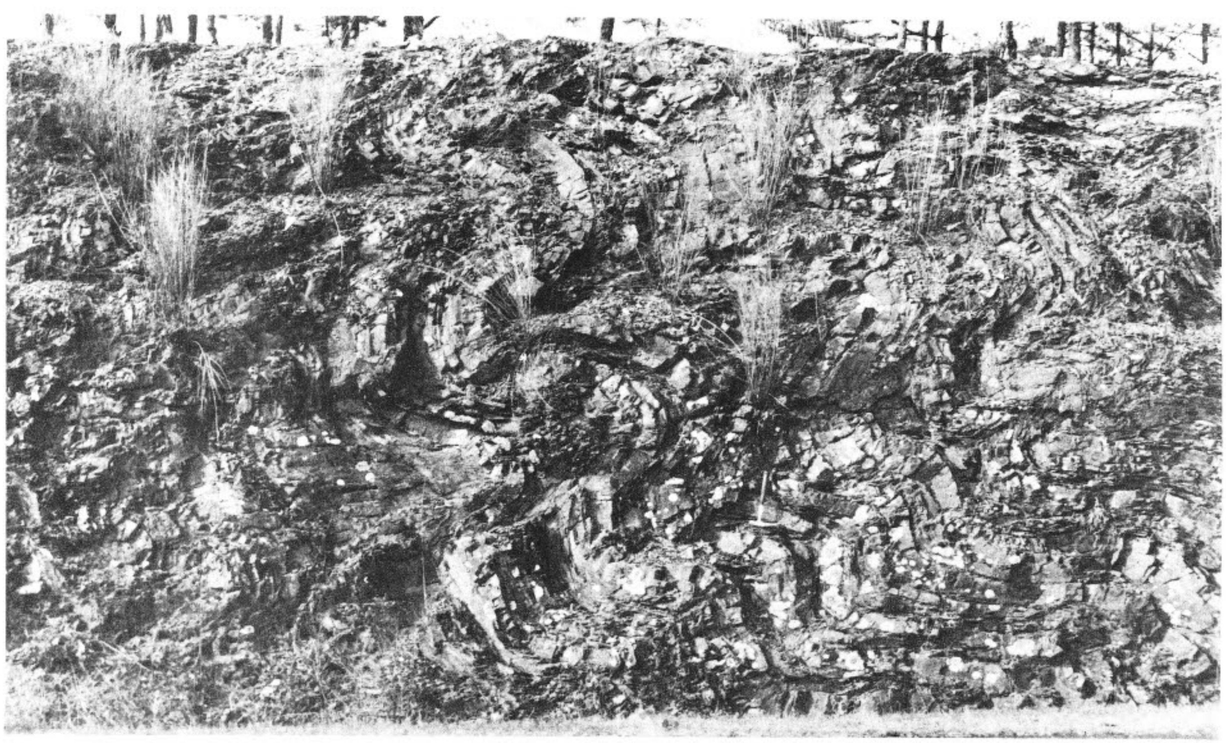


Figure 32 - Stop 25. Flexural-flow folding and well developed cleavage in overturned, southward-verging, interbedded graywackes and shales of the lower Stanley Shale.

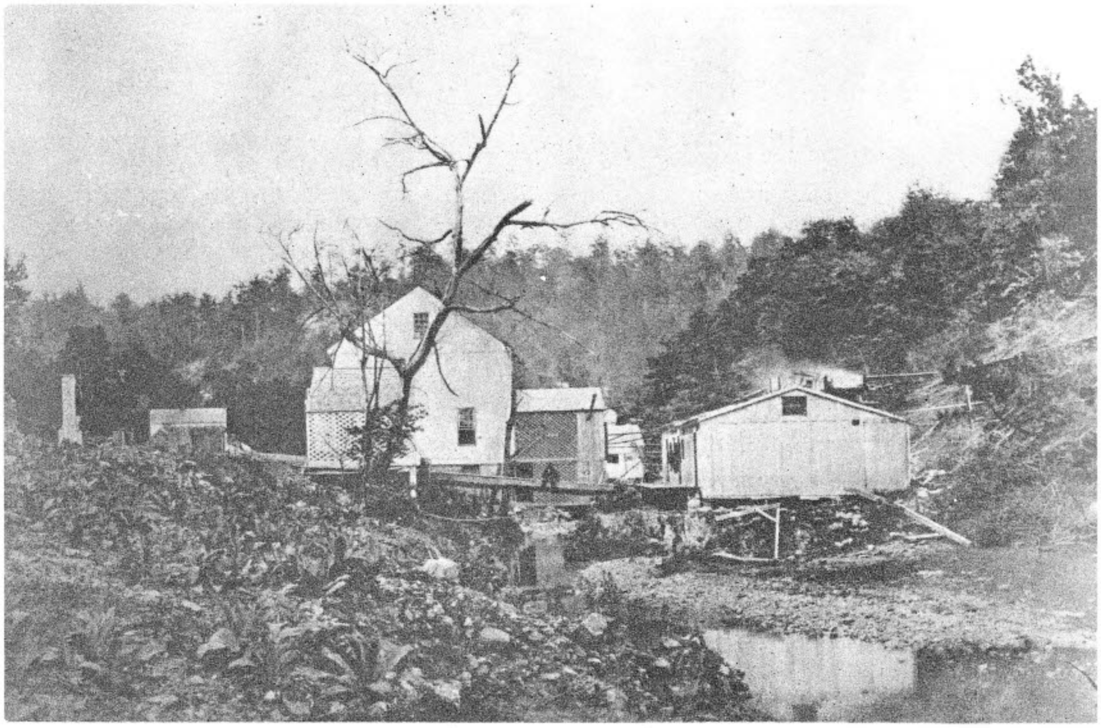


Figure 33 – Stop 26. The celebrated old Hale Bath House, east of and adjoining the present site of the Arlington Hotel, Hot Springs.

Figure 34 – Stop 26. The Earl Bath House at Hot Springs, opposite Hale Bath House.

Photographic copy courtesy of Bobby A. Campbell of Little Rock; from the 1919 Centennial edition of the Arkansas Gazette.

original 71 springs produce hot water. According to J. K. Haywood and W. H. Weed (1902) the daily flow aggregates 850,000 gallons with the largest spring yielding a little over 200,000 gallons. The temperature range is from 95.4^{o} to over 147^{o}F. The hot spring water is slightly radioactive, apparently caused by radon gas. A soil-and-vegetation-covered gray calcareous tufa formed by the hot springs covers an area of 20 acres and in places is 6 to 8 feet thick. Measurements of the hot springs' flow to the central collection reservoir have been made periodically since 1970 by the U. S. Geological Survey. These measurements indicate a range in spring flow of 750,000 to 950,000 gpd with an average flow of about 825,000 gpd.

The tritium and carbon 14 analyses of the spring water indicate a mixture of a very small amount of water less than 20 years old and a preponderance of water about 4,400 years old.

Bedinger et al. (1979) state that the geochemical data, flow measurements, and geological structure of the region support the concept that virtually all the hot springs water is of local meteoric origin. Recharge to the hot springs artesian flow system is by infiltration of rainfall in the outcrop areas of the Bigfork Chert and the Arkansas Novaculite. The water moves slowly to depth where it is heated by contact with rocks of high temperature. Highly permeable zones related to jointing or faulting collect the heated water in the aquifer and provide avenues for water to travel rapidly to the surface.

STOP 27. – CITY QUARRY IN BIGFORK CHERT AT HOT SPRINGS

Folded and faulted rocks in the middle part of the Bigfork Chert are exposed in a quarry north of Weyerhaeuser office on Whittington Avenue. The quarry is near the axis of the southwestward plunging Hot Springs anticline (Plate 26). Massive novaculite of the Lower Division (Devonian) of the Arkansas Novaculite forms the ridges to the north and south.

In the quarry the Bigfork consists of very thin-bedded and often graded, calcareous (often decalcified) siltstone, gray chert, and minor beds or laminations of siliceous to carbonaceous shale. The basal silty part of each interbedded sequence likely represents minor influxes of fine clastics and bioclastics transported into the Ouachita trough by turbidity and bottom currents and the overlying cherts and siliceous shales represent slowly deposited deep-water pelagic accumulations. Stylolites are often present in the calcareous siltstones and indicate a significant removal and thinning of the section.

The Bigfork is complexly folded in the quarry with a large box fold and associated kink, chevron, and buckle folds inclined both to the south and north. Most of the strata dip to the north, indicating a dominant southward vergence. North-dipping cleavage often refracts across the cherts and calcareous siltstones. Flowage of rock can be seen in some of the tight fold hinges. Several apparently small reverse faults dissect the rocks and they often contain gouge (dickite?)-impregnated chert breccia.

The Bigfork Chert is the most reliable aquifer in the Ouachita Mountains. Clear or small chalybeate (iron-rich) springs are often present in the basal outcrops. The water moves along joints, fractures, and bedding planes in the thin-bedded basal sequence.

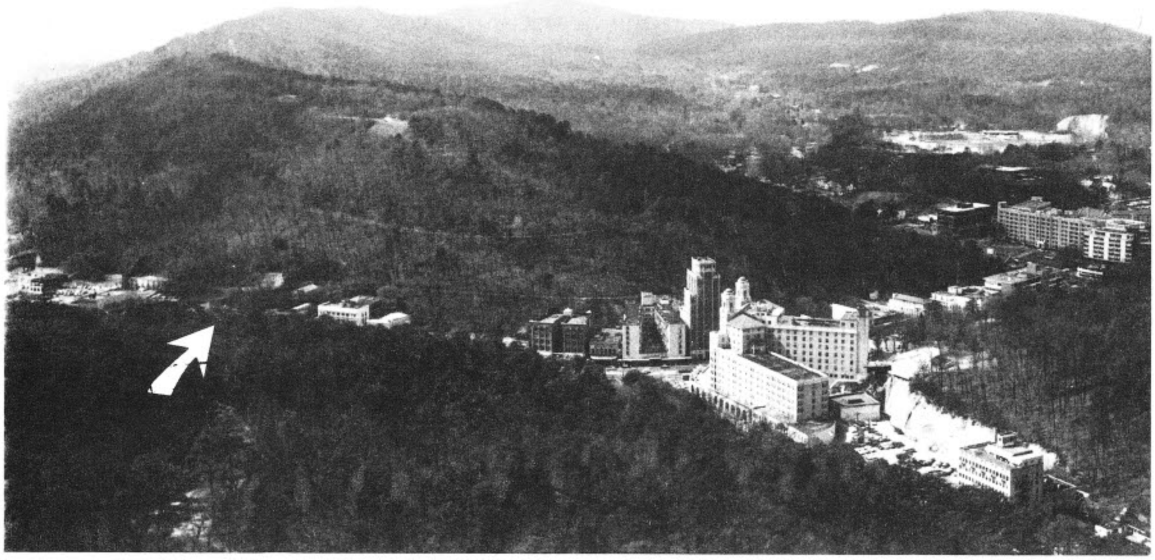


FIGURE 35 – STOP 26. Downtown Hot Springs as viewed westward from Hot Springs National Park tower. The hot springs (arrow) issue from fractures in the Hot Springs Sandstone along nose of small southwestward plunging anticline forming hill in nearground. More distant ridges are underlain by the Arkansas Novaculite and outline part of the larger Hot Springs anticline.

FIGURE 36 – STOP 27. Classic box and kink folds in cherts and siltstones of the Bigfork Chert at a quarry north of Whittington Avenue.

STOP 28. – SEQUENCE OF UPPER JACKFORK SANDSTONE AT DEGRAY LAKE SPILLWAY (PLATE 27).

Park at DeGray Lake access area; walk to the east and then to the south across the one-thousand-foot sequence of southward dipping, fine-grained, quartzitic sandstone, subgraywacke, gray siltstone, and black shale in the middle and upper Jackfork Sandstone. The sandstones contain Bouma sequences, graded bedding, load structures, dish and pillar structures, bottom marks, ripple marks, broad scours, clay balls, and other features. Slurry and slump intervals of probable intra-formational origin are present and one unusual zone contains small sandstone cobbles, chert pebbles, iron carbonate concretions, clay balls, and other lithologies in a shale matrix. Sandstone olistoliths ("glumps and gloops") occur in a few intervals, especially in the shale sequences below the upper more massive sandstone at the south end of the spillway. Coalified plant fragments are quite common in some of the debris flow deposits represented by the siltstone "blue beds". A few invertebrate fossil remains can be found at various places along the exposure.

At the south end of the spillway there are at least 15 cycles of granule or "grit" deposition in a 200-foot sequence. These "grit" beds are commonly graded and have some small to rather large scour features. The granules are composed of quartz and metaquartzite.

The north end of the spillway contains mostly upward-thinning sandstone sequences and are thought to represent middle submarine fan channel deposits. Near the middle of the spillway there are several thickening and upward-coarsening fan lobe sequences. At least one upward-thickening sequence proceeds into a upward thinning dying lobe sequence. These intervals in the middle of the spillway represent a thick regressive or prograding section of outer fan lobe or possible midfan interchannel deposits. The exposures at the south end of the spillway represent upward-thinning, high-energy, probable middle fan channels. It is thought that these deposits were supplied from deltas and through submarine canyons down the slopes from two major areas: (1) to the northeast (Illinois basin); and, (2) to the east (southern Appalachians).

Some small tear faults cut the rocks and contain milky quartz, dickite, and traces of cinnabar. In this southern Ouachita Mountain area pervasive shearing, cleavage, boudinage, and other structural deformation features are absent. Viele (1973) notes that along the northern margin of the Ouachita Mountains there is evidence for northern tectonic transport. Here on the south side there is evidence for the same direction of movement. However, in the lower Paleozoics, we have abundant evidence of southward movement. This is but one of the many Ouachita problems.

In recent years the DeGray spillway cut has served as one of many educational geologic stops for groups interested in flysch and submarine fan deposition. Plate 28 is extracted from a report by R. C. Morris (1977), who performed a detailed sedimentological study of the units at this exposure. Some additional deep-sea fan models and concepts have been applied to these rock units by a number of workers, including Breckton and Mansfield (this volume).

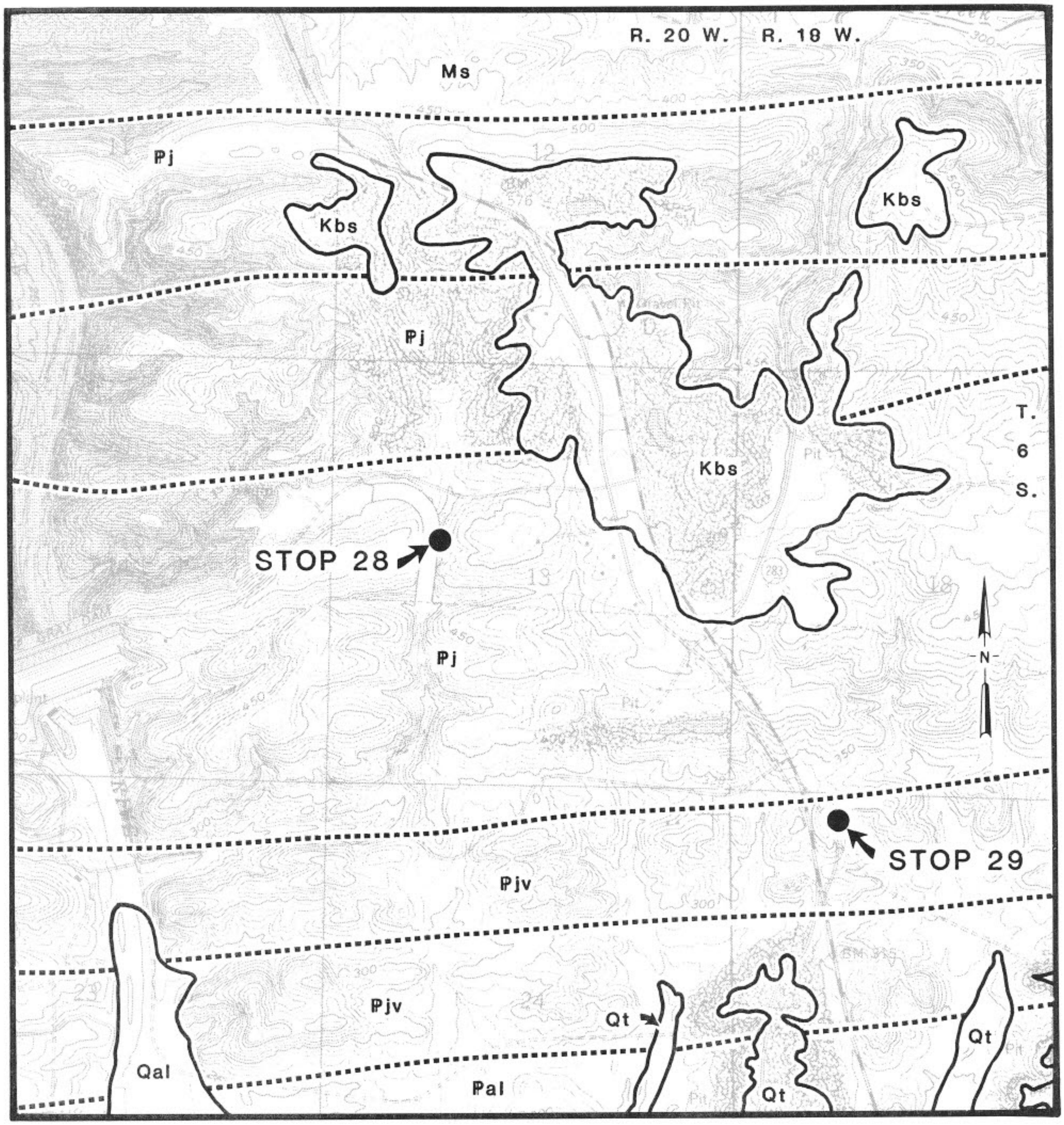


PLATE 27 - GEOLOGIC MAP OF DeGRAY DAM AREA - STOPS 28 AND 29

1000 0 1000 2000 3000 FEET

Qal	Alluvium	Pjv	Johns Valley Shale
Qt	Terrace Deposits	Pj	Jackfork Sandstone
Kbs	Brownstown Marl	Ms	Stanley Shale
Pal	Lower Atoka Formation	....	Thrust Faults
		———	Contacts

Figure 37 - Stop 28. An exposure of the upper Jackfork Sandstone near the middle of the DeGray spillway cut. The interbedded sandstones and shales exhibit both thickening and thinning upward sequences. A cobble-bearing slurried interval is present where the figure is standing. These deposits represent either submarine outer fan lobe or possibly midfan interchannel facies.

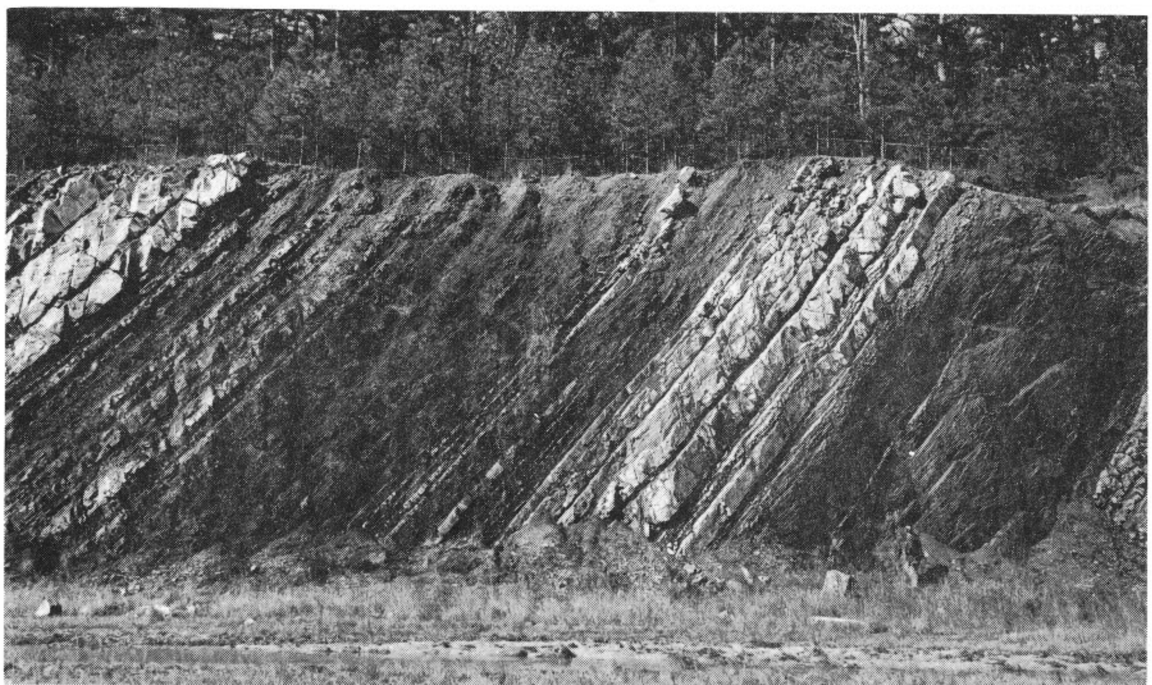


Figure 38 - Stop 28. Several thinning and fining upward intervals of southward-dipping, quartzitic sandstone and shale representing probable middle submarine fan channels in the upper Jackfork Sandstone near the middle of the DeGray spillway cut.

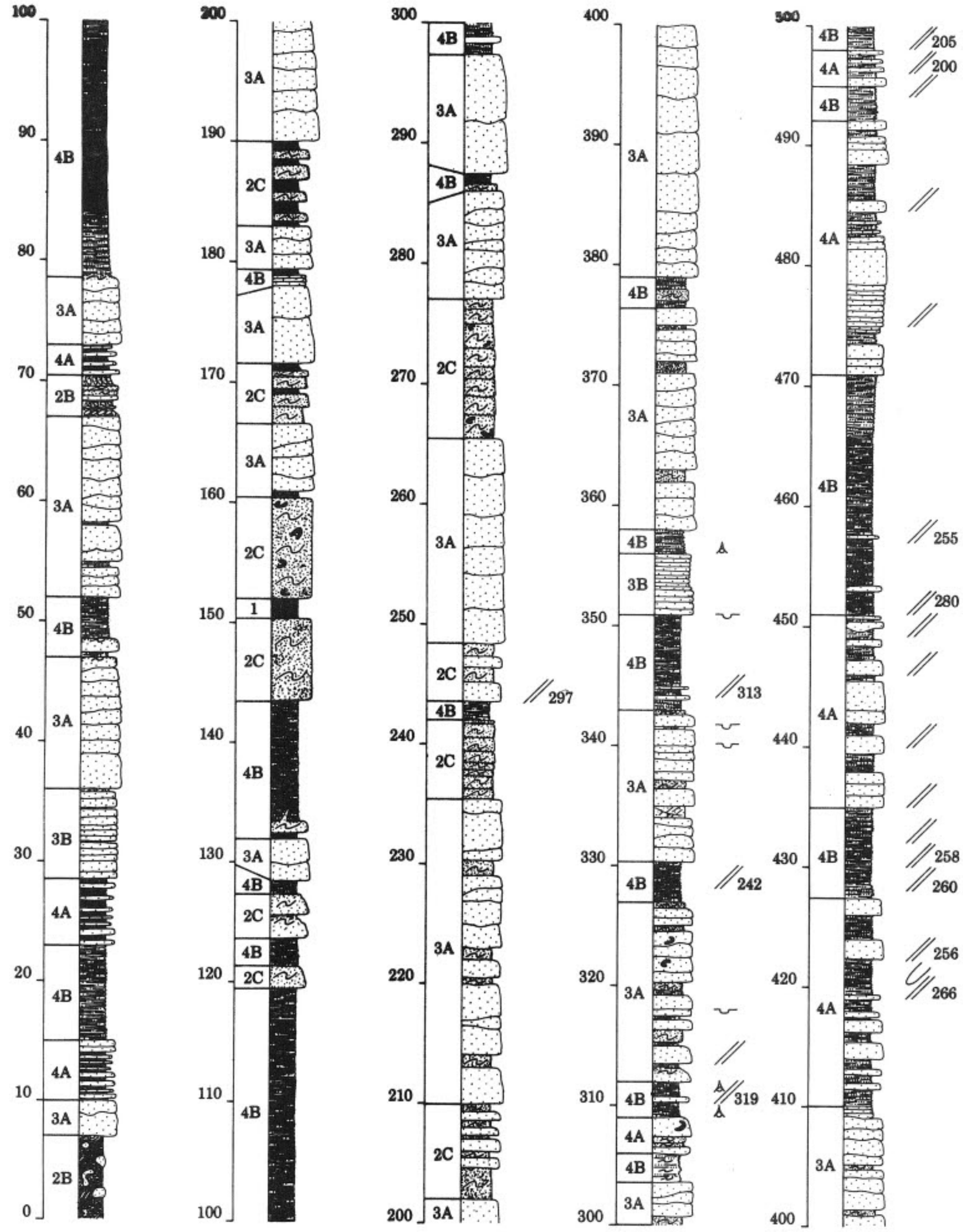
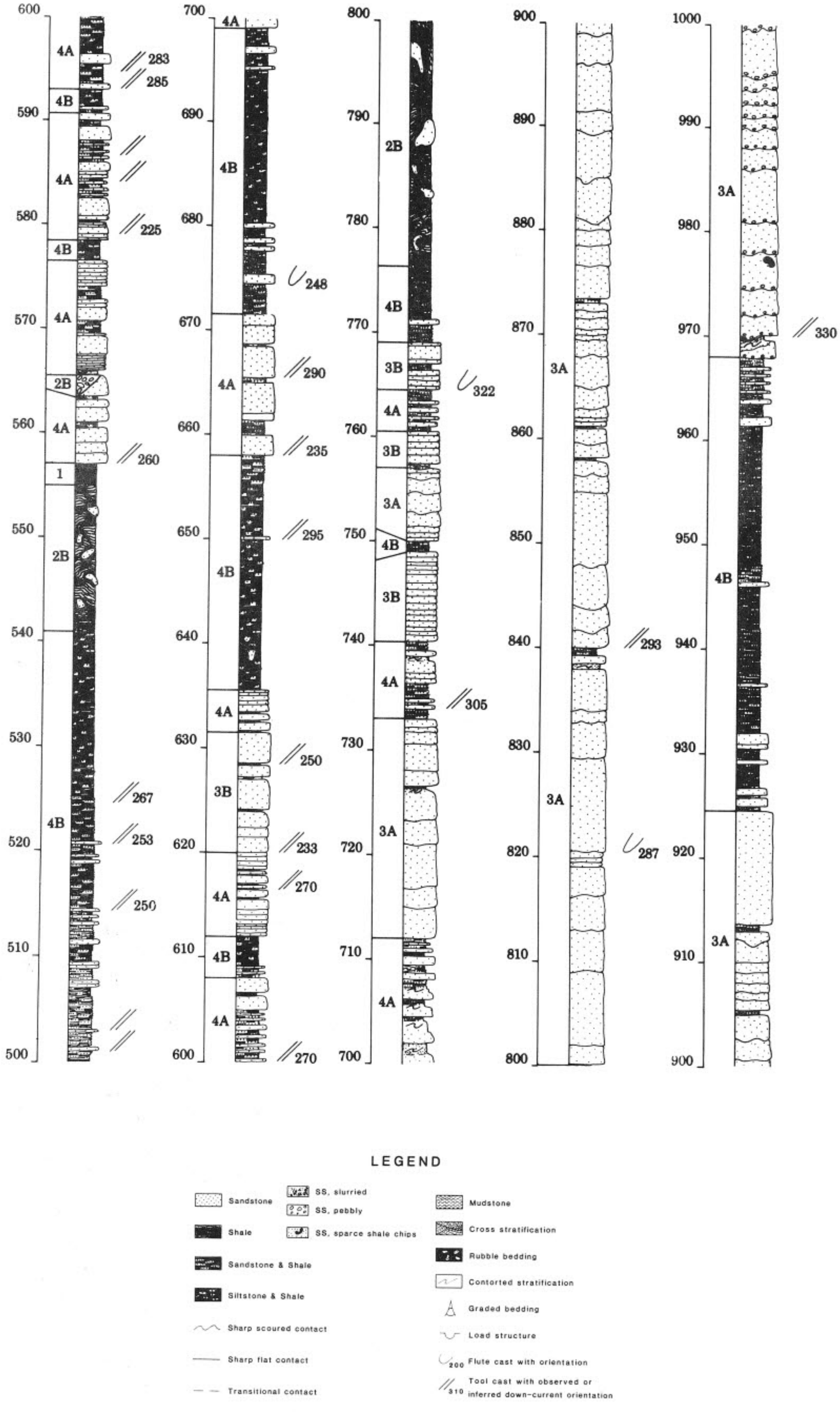


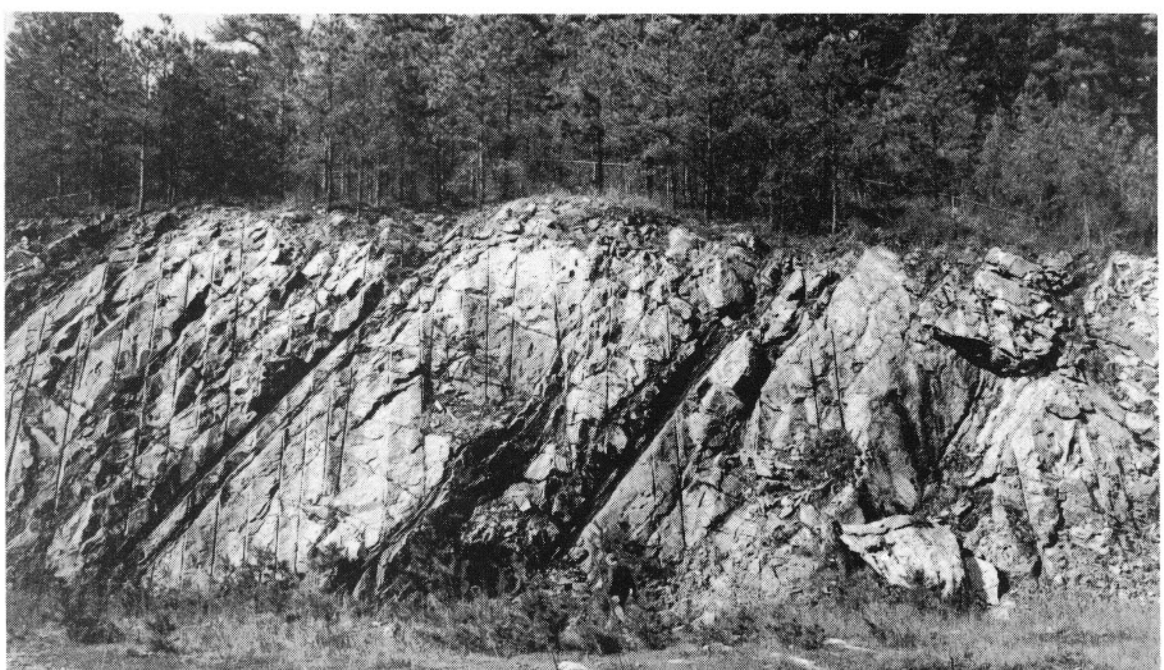
Figure 39. (Above and facing page.) Partial stratigraphic section of upper part of Jackfork Sandstone exposed along spillway at DeGray Dam. Numbers at left of each column are feet above bed where study began. Numbers and letters in central column designate flysh facies described in an earlier paper by Morris (1977).



LEGEND
Sandstone
SS, slurried
SS, pebbly
Shale
SS, sparce shale chips
Sandstone & Shale
Siltstone & Shale
Sharp scoured contact
Sharp flat contact
Transitional contact
Mudstone
Cross stratification
Rubble bedding
Contorted stratification
Graded bedding
Load structure
Flute cast with orientation
Tool cast with observed or inferred down-current orientation

Figure 40 - Stop 28. Parallel laminated granule-bearing "grit" interval in the upper Jackfork Sandstone at the south end of the DeGray spillway cut. The granules are composed, for the most part, of rounded quartz and metaquartzite.

Figure 41 - Stop 28. An interval of quartzitic sandstone formed by three probable middle submarine fan channels or three cycles or pulses of a single migrating channel in the upper Jackfork Sandstone at the south end of the DeGray spillway cut.



STOP 29 -- JOHNS VALLEY SHALE NORTH OF CADDO VALLEY (PLATE 27)

This exposure on the side road about 100 yards southeast of Arkansas Hwy. 7 is in southward dipping lower Johns Valley Shale. The north end of the roadcut is a few hundred feet from the apparent contact with the underlying Jackfork Sandstone, but there is a thrust fault between the two units. At the north end the rocks consist of several thinning and fining upward sequences of brown, silty, micaceous subgraywacke with some thin beds of siltstone and silty gray shale. Near the middle of the roadcut there are contorted and rubbly sandstone sequences, some with sandstone, chert, and other exotic clasts that, for the most part, represent sedimentary slumps. It is our belief that the slumping of these rocks was from the south to the north. There are also some later tectonic faults dissecting these slumped beds that have slickensides and dickite. At the south end of the exposure there are many thin-bedded intervals of sandstone and shale. Bottom marks, Bouma sequences, graded bedding, ball and pillow structure, and other features are common. Trace fossils are present and appear to be of a deep-water type.

REGIONAL GRAVITY ANOMALIES IN THE OUACHITA MOUNTAINS AREA

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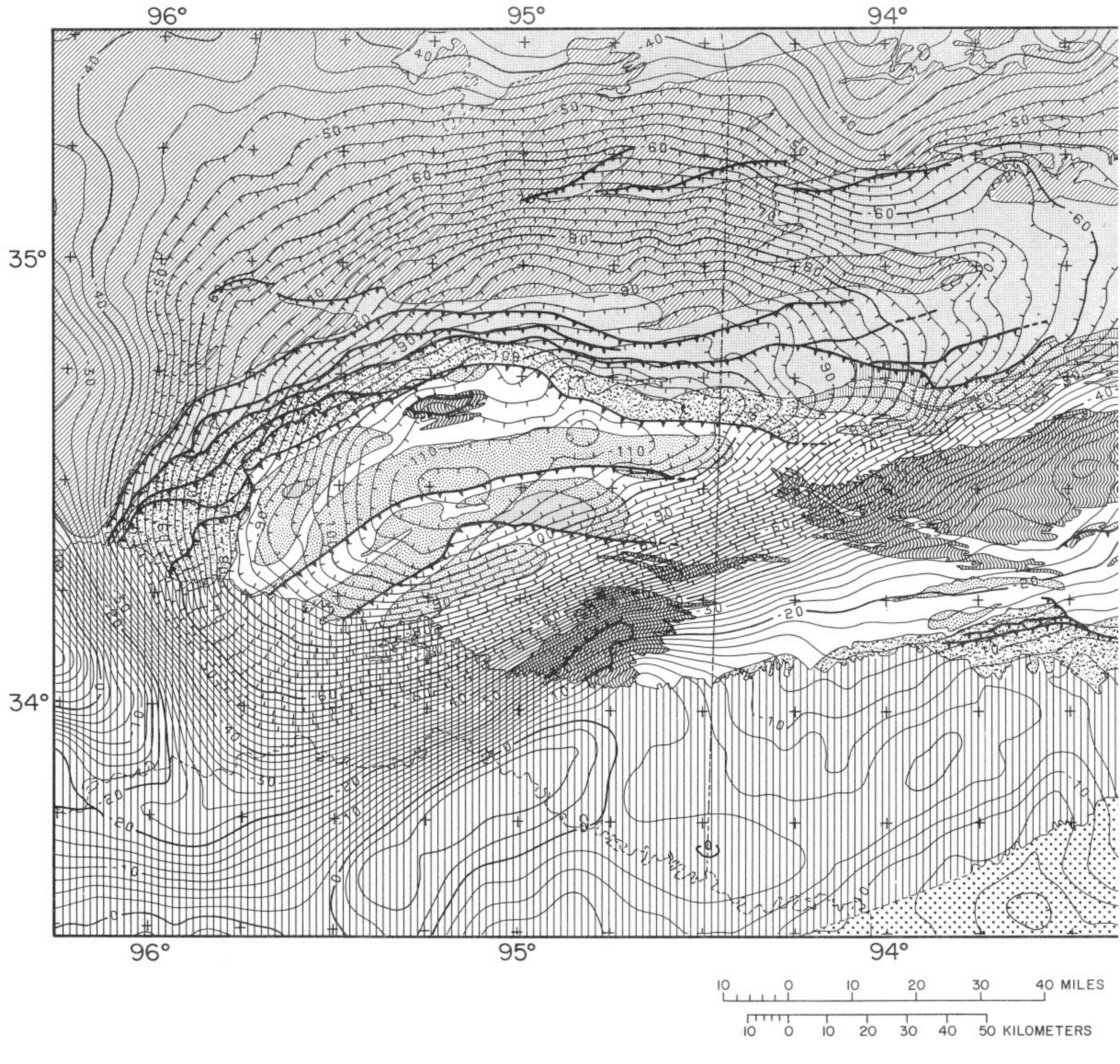
INTRODUCTION

The Ouachita Mountains area poses not only many interesting geological questions but also many equally interesting geophysical questions. We have been compiling gravity data in the area for a number of years and have been able to amass a considerable data base. This data base is the result of the efforts of many individuals and groups and contains approximately 35,000 readings. Many of the data have been donated by Mr. and Mrs. Hart Brown. Additional help in generation of this data base has been provided by Dr. W.J. Hinze (Purdue University), Dr. Carlos Aiken (University of Texas at Dallas), Don Scheibe (Defense Mapping Agency), Dr. Bill Strange (National Geodetic Survey), and Lindrith Cordell and Dr. Tom Hildenbrand (U.S. Geological Survey).

In our data base, gravity readings are edited and maintained in a standard format and are tied to a common gravity datum (IGSN-71; Morelli, 1976). In this study, sea level was used as an elevation datum and a density of 2.67 gm/cm^3 was used in the Bouguer corrections to compute Bouguer anomaly values using the formulas of Cordell and others (1982). The anomaly values were used to generate Bouguer anomaly maps of the area (Figures 1 and 2) as well as a series of filtered maps. The filtered maps are particularly important because such maps aid in the interpretation of various gravity anomalies by removing interfering effects.

For the purpose of this discussion, the most interesting filtered map is the strike-filtered map which was constructed using a computer program developed by Coultrip (1982). This map is shown in Figure 3 and was designed to reject trends parallel to the Ouachita System. This filter rejected trends ranging from N0^{o}E to N85^{o}E in the spatial domain.

Four gravity profiles (A-A' through D-D', Figure 2) were constructed using gravity readings projected (parallel to the contour lines of the Bouger anomaly map in Figure 2) to intersect with the profile lines shown in Figures 2 and 4. None of the stations were projected greater than 7 km (4.4 mi), and most were projected much less. Only profile


96°
95°
94°
35°
34°
10 0 10 20 30 40 MILES
10 0 10 20 30 40 50 KILOMETERS

GEOLOGIC MAP EXPLANATION

STRATIGRAPHY

Tertiary rocks

Cretaceous rocks

Bloyd Shale and Prairie Grove Member of the Hale Formation (Pennsylvanian)

Hartshorne Sandstone and younger Pennsylvanian rocks (Pennsylvanian)

Stanley Shale, Jackfork Sandstone, Johns Valley Shale, Atoka Formation: undivided

Atoka Formation (Pennsylvanian) (including some older rocks in the frontal zone of Oklahoma)

Johns Valley Shale (Pennsylvanian)

Jackfork Sandstone (Pennsylvanian)

Stanley Shale including Chickasaw Creek Chert, Hatton Tuff lentil, and Hot Springs Sandstone (Mississippian)

Arkansas Novaculite and older rocks (Cambrian - Lower Mississippian) (includes Stanley Shale in Potato Hills Uplift)

Igneous rocks (Cretaceous ?)

GEOLOGIC SYMBOLS

Contact (dashed where hidden or inferred)

Thrust fault

◀ **Figure 1.** (facing page) Simple Bouguer anomaly and generalized geologic map of the Ouachita Mountains area. See explanation (above) for description of patterns and geologic symbols. Geology after Miser and others, 1954; and Haley and others, 1976; geologic divisions modified from Miser, 1959.. Gravity contour interval = 2.5 mgal; long-short dashed lines = state boundaries.

station locations were surveyed in and terrain corrections were made.

A detailed version of profile A-A' is shown in Figure 5. However, due to the regional nature of this study, it was determined that not all of the stations shown on this profile were needed to adequately represent it.

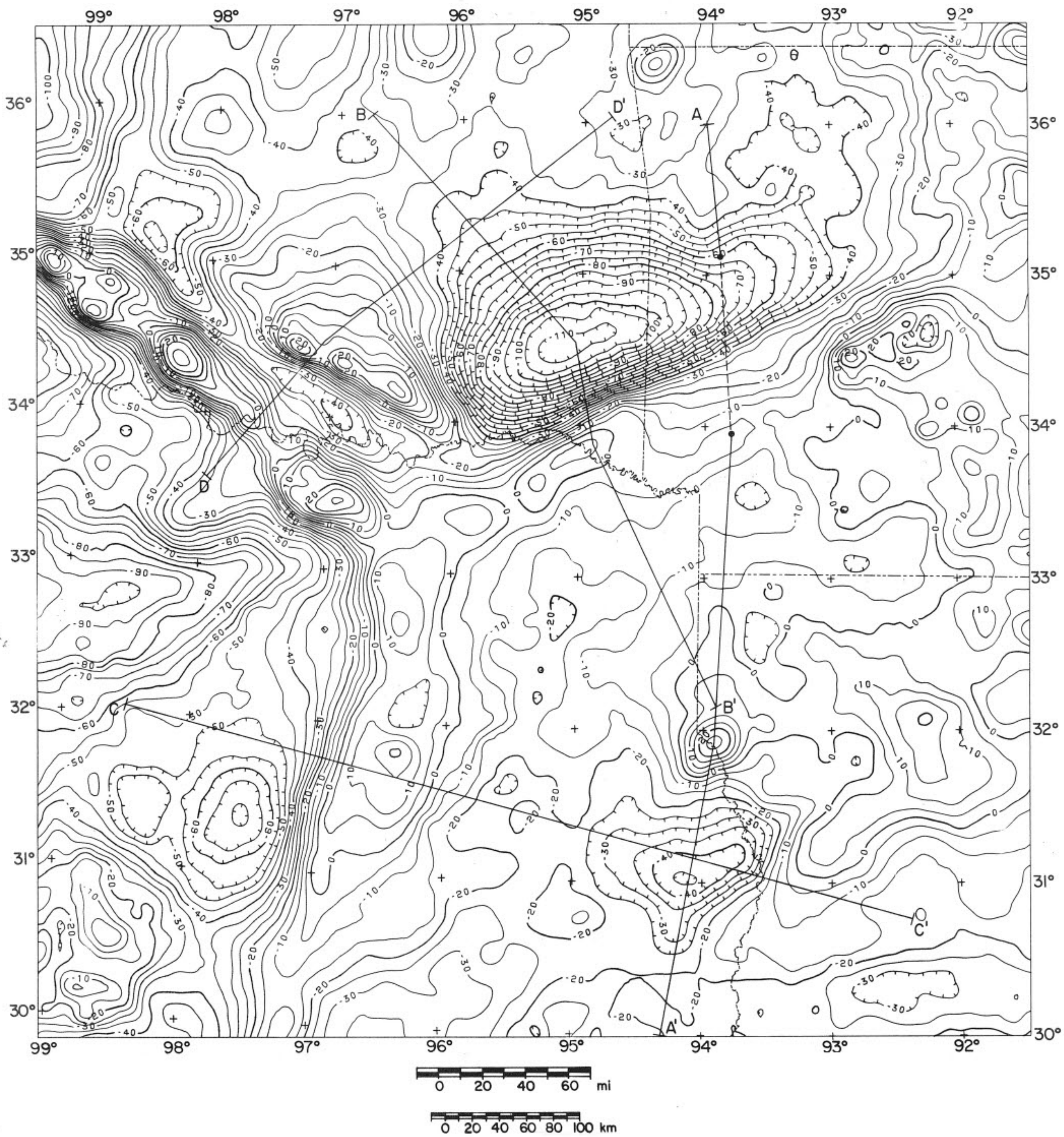


Figure 2. **Simple Bouguer anomaly map with gravity profile locations. Contour interval = 5 mgal; short-long dashed lines = state boundaries; dashed line = approximate line on which COCORP line gravity stations are projected.**

Another consideration was the saving of computer time. Thus, some of the stations shown in Figure 5 were deleted for the purpose of modeling. The gravity stations that were used in the modeling are shown as the purged version of the profile (Figure 5) which can be seen to sufficiently delineate all regional anomalies.

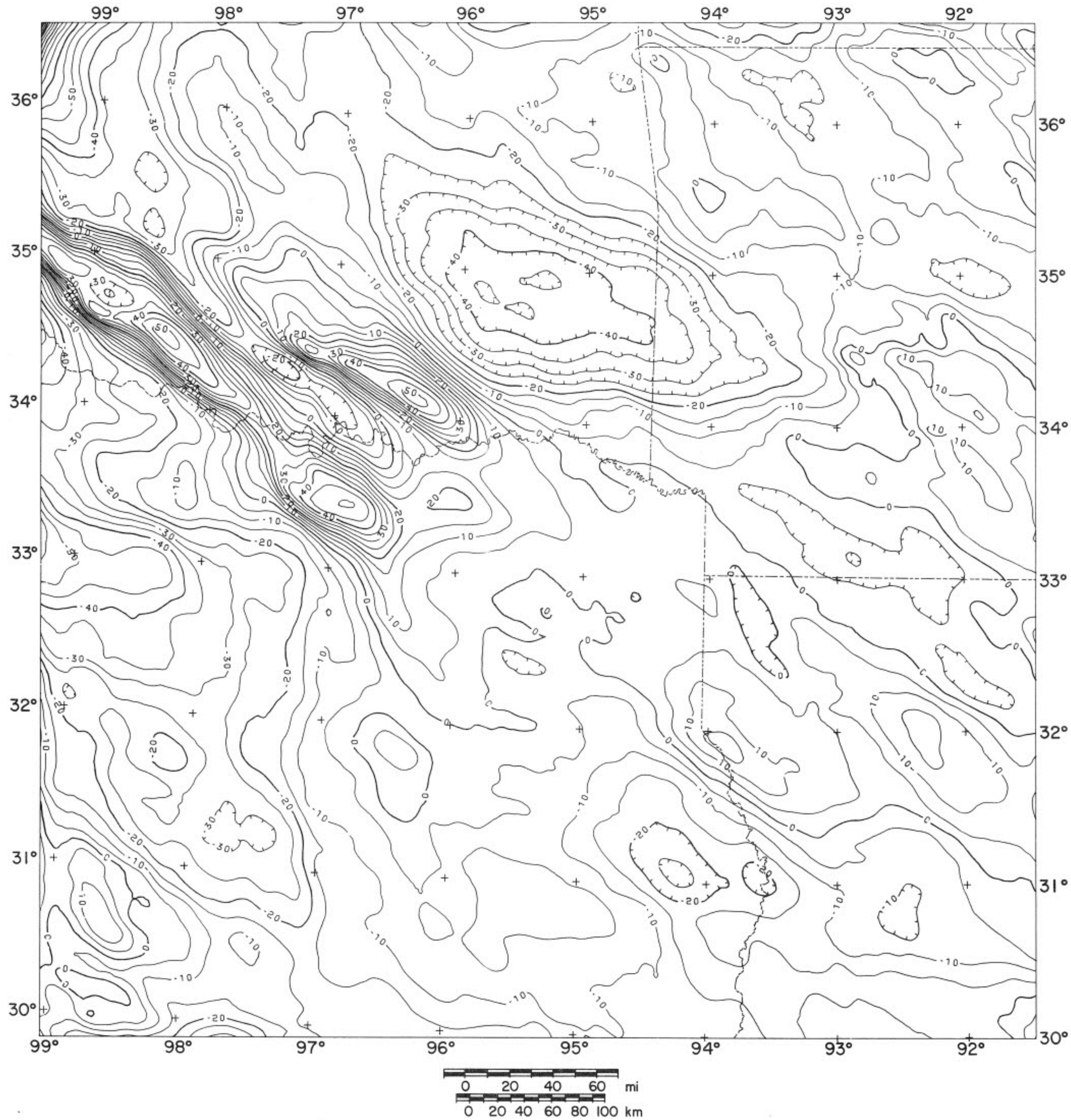


Figure 3. Strike filtered gravity map rejecting Ouachita system trend (reject linear trends in space domain from N O° to N 85° E). Contour interval = 5 mgal; dashed lines = state boundaries.

The modeling was carried out using a two-dimensional gravity modeling program based on methods developed by Talwani and others (1959). Starting models were based on geological and geophysical observations by various authors, along with well information and other ideas derived from qualitative interpretations of the regional gravity anomalies

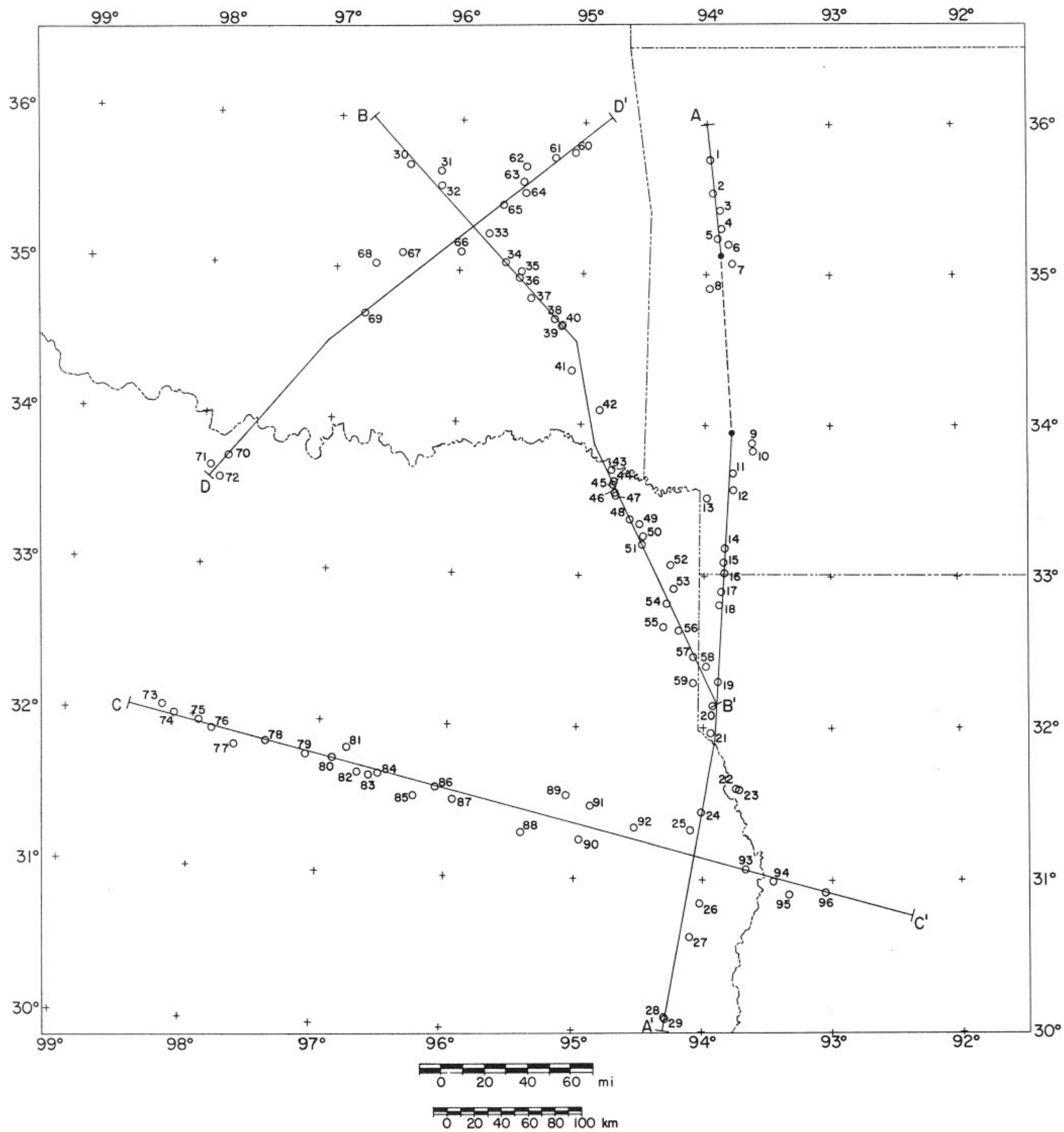
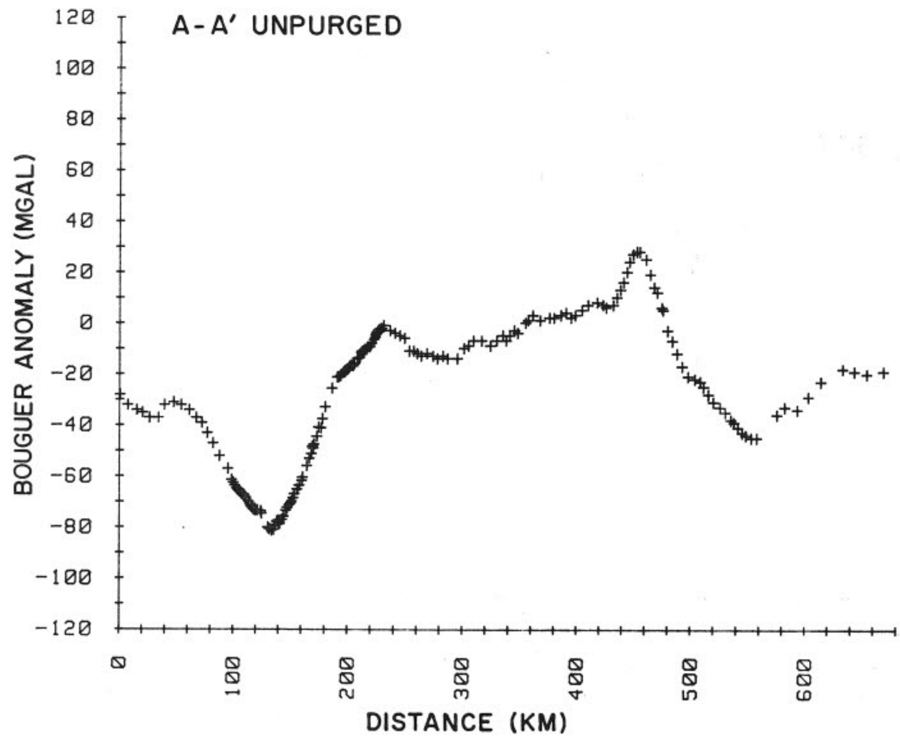


Figure 4. Location map for gravity profiles and wells used in modeling. Open circles with numbers = locations and index numbers (see Kruger, 1983 for description of wells); short-long dashed lines = state boundaries; dashed line = approximate line on which COCORP line gravity stations are projected.

being modeled. In profile A-A' the starting model for the upper crust, from a distance of 98 to 229 km (61 to 143 mi) south of A, was based on results from the COCORP seismic profile in Arkansas (Nelson and others, 1982; Lillie and others, 1983). The



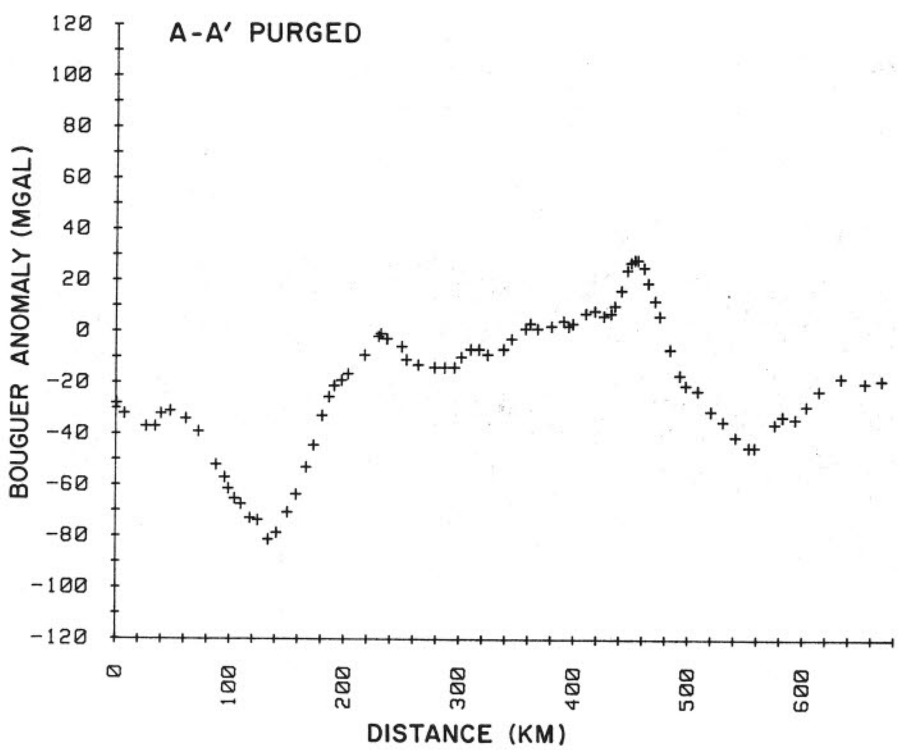
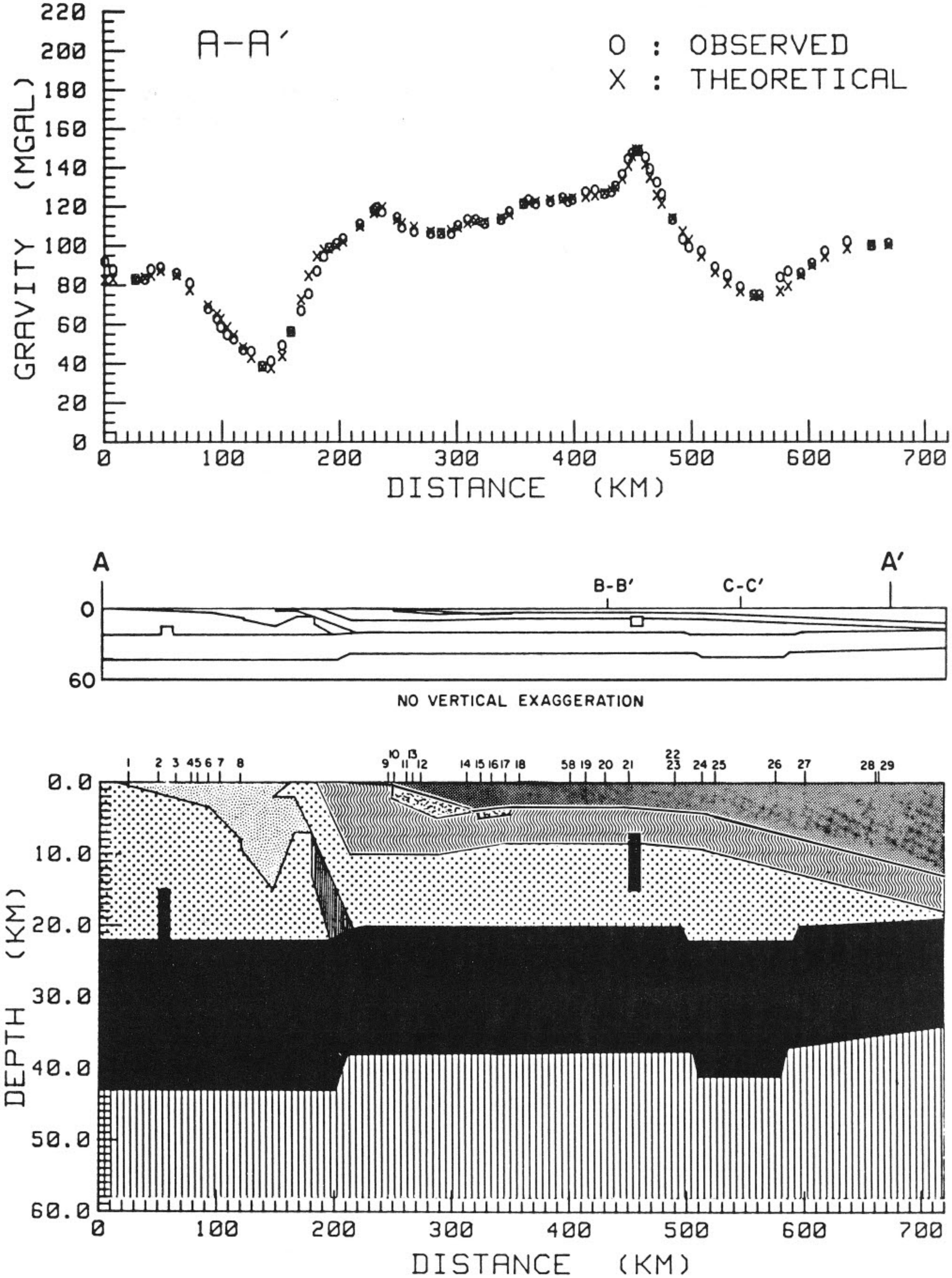


Figure 5. Gravity profile A-A'.


A-A′
O : OBSERVED
X : THEORETICAL
GRAVITY (MGAL)
220
200
180
160
140
120
100
80
60
40
20
0
0 100 200 300 400 500 600 700
DISTANCE (KM)
A
A′
B-B′
C-C′
0
60
NO VERTICAL EXAGGERATION
1 2 3 4 5 6 7 8
9 10 11 13 12
14 15 16 17 18
58 19 20 21
22 23 24 25
26 27
28 29
DEPTH (KM)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
0 100 200 300 400 500 600 700
DISTANCE (KM)

well data used as constraints are shown on Figure 4 as numbered circles and on Figure 6. A detailed listing of these data is available in Kruger (1983).

GRAVITY ANOMALIES

Arkoma Basin Minimum. - A large gravity minimum underlies the Ouachita Mountains and Arkoma basin of Arkansas and Oklahoma (Figures 1 and 2). The most detailed version of this minimum is shown in Figure 1. which includes a geologic overlay. This anomaly has been modeled in profile A-A' (Figure 6). Bouger anomaly values within the trough are the lowest in the map area (>-110 mgals) and suggest a great thickness of sediments in conjunction with an

EXPLANATION FOR MODELS

2.5 g/cm^3 Post Smackover Formation Mesozoic and Cenozoic sedimentary rocks

2.5 g/cm^3 Eagle Mills Formation (Triassic ?) graben fill

2.58 g/cm^3 Post Arbuckle Group Paleozoic sedimentary rocks (predominantly Mississippian through Pennsylvanian flysch and molasse)

2.65 g/cm^3 Paleozoic sedimentary and metasedimentary rocks including Smackover Formation and older Mesozoic rocks

2.7 g/cm^3 Metamorphosed Lower to Middle Paleozoic off-shelf clastic or volcanic rocks ?

2.7 g/cm^3 Upper continental crust including Arbuckle-Ellenburger and older sedimentary, metasedimentary, and volcanic rocks. Also including lower through middle Paleozoic Ouachita facies metasedimentary rocks in A-A', B-B' and possibly C-C'

3.0 g/cm^3 Lower continental crust and mafic intrusions

3.3 g/cm^3 Upper mantle

22 Well location and ID number

◀ Figure 6. (facing page) Gravity profile and model A-A' with projected well locations and identification numbers. See explanation (above) for description of patterns and Fig. 4 for well locations.

upper and/or lower crustal downwarp towards the south.

As can be seen in Figures 1 and 2, the minimum is elongated in two directions that are approximately perpendicular to one another. The primary axis of elongation is ENE-WSW, approximately parallel to the NE-SW trend of structures in the westernmost Ouachita Mountains and Arkoma basin of Oklahoma, but diverges from the more E-W trending Ouachita structures in Arkansas. The other axis trends NW-SE (Figure 3) and extends from the northwest corner of the minimum (35.5°N, 96°W).

The gravity model of profile A-A' (Figure 6) suggests that the ENE-WSW trending gravity minimum in the vicinity of the profile may be due solely to a thick sequence of upper Paleozoic sediments (flysch and molasse), assuming that an average density of 2.58 g/cm^3 for the rocks is reasonable and that the structural configuration of the basin as determined by COCORP (Nelson and others, 1982; Lillie and others, 1983) and well information is valid. This thick sedimentary pile agrees with the findings of Lillie and others (1983) but does not preclude the possibility of a thinner or denser sedimentary pile in conjuntion with an upper and/or lower crustal downwarp towards the south.

One striking feature of the northwest arm of the Arkoma basin minimum is its parallelism with the trend of the southern Oklahoma aulacogen (Figures 1, 2 and 3). Because of this parallelism, it seems reasonable to suggest this anomaly may delineate a Cambrian basin which formed during the rifting episode which initiated development of the southern Oklahoma aulacogen. It may also have been formed, or deepened, by the NE-SW directed compression that deformed the aulacogen in the late Paleozoic. This compression may also have resulted in the downwarping of the upper and/or lower crust.

The relationship between the Arkoma basin minimum and the surface geology is complex (Figure 1). This is particularly true in Arkansas and easternmost Oklahoma where the E-W structural trends are discordant with the ENE-WSW trend of the gravity minimum. The reason for this discordance may be differences between the orientation of the Paleozoic cratonic margin, which probably ran parallel to the gravity gradient to the south, and the compressional directions(s) during the Ouachita orogeny. Another possibility is that deep-seated stresses during the Ouachita orogeny were oriented differently than the shallower stresses due to decoupling between two or more layers. This decoupling would have resulted in different deformational orientations at depth as compared to the surface. An allocthonous nature for the upper levels of the crust in the Southern Appalachian-Ouachita orogen has been proposed by numerous authors (e.g., Cook and others 1979; Harris and Bayer, 1979; Harris and others, 1981; Nelson and others, 1982; Lillie and others, 1983; Seeber, 1983). A clockwise rotation of the principal compressional stress direction between formation and final deformation of the basin may also have created this discordance.

Ouachita System Gradient -- As can be seen in Figures 1 and 2 a steep gravity gradient occurs between the frontal zone and interior zone of the Ouachita system. This gradient is in part due to the juxtaposition of the Arkoma basin minimum cratonward of the gradient and the interior zone maximum gulfward of the gradient. However, these factors alone do not totally explain the existence of the gradient.

As shown in the model of profile A-A' (Figure 6), this gradient is also due to a major crustal structure transition between the craton and the Gulf costal plain. Thus, an abrupt rise in the Moho and/or upper crust-lower crust boundary also contributes to the gradient. This observation agrees with work of Keller and Cebull (1973) and Lillie and others (1983). Another piece of evidence in favor of a major crustal structure transition (zone of weakness?) in the area of this gradient is the coincidence between its trend and the trends of the Mexia-Talco, southern Arkansas, and Pickins-Gilbertown fault zones. The northern rim of the Gulf coastal plain also roughly coincides with this gradient.

Ouachita System Interior Zone Maximum -- An arcuate, elongated, gravity maxiimum, which is composed of several interconnected maxima, lies gulfward of and parallel to the Ouachita system gradient. This maximum has been interpreted to be due to a variety of phenomena such as metamorphic effects (densification) in the Ouachita system interior zone, basement uplifts (ie. Broken Bow and Waco), the orogenic core of the Ouachita system, and a major crustal structure transition (e.g. Flawn and others, 1961; Watkins, 1961a, b; Fish, 1970; Nicholas and Rozendal, 1975; Keller and Cebull, 1973; Lillie and others, 1983; Lillie, 1984). All of these interpretations may well be valid locally, but it seems unlikely that a single interpretation is valid along the entire length of this anomaly (Arkansas to Mexico).

In some parts of the study area, for example along profile A-A', the crustal structure transition, basement uplifts, interior zone metamorphic rocks, and Mesozoic basins south of the maximum are enough to explain the observed gravity anomalies. However, these features alone are not enough to model the maximum in other parts of the orogen (in the vicinities of profiles B-B' and C-C'). Thus in general, an anomalously dense body in the upper crust may be needed to explain the discrepancy. Such a body could represent an upwarp of the lower continental crust, mafic intrusions, accreted island arc material, obducted oceanic crust, or relatively undeformed oceanic crust. Because of the location of this body with respect to the major crustal transition between the craton and the coastal plain and because of its location within a possible zone of weakness (old continental margin), we would like to suggest that this body (not the entire anomaly) could be the result of an aborted rift which formed during Eocambrian extension in the area. Aborted Mesozoic rifting may have also followed this zone of weakness and partically created this body.

Note that an offeset occurs in the maximum near the Arkansas-Oklahoma border. This offset may have formed during the Ouachita orogeny or during Mesozoic or Cambrian rifting.

Regional Minimum Gulfward of the Ouachita System Maximum -- A regional, arcuate, elongated minimum lies gulfward of the Ouachita system maximum. This anomaly extends from the Monroe uplift, counterclockwise around the northen and western portions of the Sabine uplift, through the east Texas salt basin and northwestern arm of the Gulf Coast salt dome province, and into the southeast Texas Gulf Coastal Plain region.

As shown in Figure 6, this regional low has been modeled as a zone of attenuated upper and lower continental crust underlying a series of Triassic and younger basins. It is believed that this region was originally normal continental crust that became attenuated during Triassic and later Mesozoic rifting. This extension stretched and thinned the lower continental crust, and lower part of the upper continental crust in a ductile manner, while fracturing and attenuating the upper part of the upper continental crust in a brittle manner.

DISCUSSION AND CONCLUSIONS

Although the exact nature of deep-seated features in the Ouachita Mountains area cannot be resolved with certainty until more deep seismic results become available, gravity anomalies provide considerable insight into the structural relations present. We would like to stress the following points.

1. The Cambrian continental margin was almost certainly in the vicinity of the Ouachita system gradient and interior zone maximum. This conclusion is based on the obvious triple junction where the Ouachita System and southern Oklahoma aulacogen intersect (Figure 2) and the fact that the large anomalies present require major variations in crystal structure regardless of how they are interpreted.

2. There is an NW-SE structural trend associated with the Arkoma basin. If this trend at least in part represents a Cambrian basin, it may be an interesting exploration target. This interpretation would also explain the magnitude of the Arkoma basin minimum as being due to the superposition of a Cambrian basin (NW trending) and a late Paleozoic basin (primarily NE to E trending.)

3. The Benton, Broken Bow, and Potato Hills uplifts produce very minor gravity anomalies and are not consistently positioned with respect to the major gravity anomalies in the area. Thus, it seems that these features may not be deeply rooted.

ACKNOWLEDGEMENTS

Many colleagues have provided valuable information and insight through conversations over the years. We would particularly like to acknowledge R.E. Denison, W.A. Thomas, R.L. Nicholas, C.G. Stone, R.L. Lillie and G.W. Viele.

We would also like to thank Javier Adame, Wayne Basden and Robert Schneider for their aid in conducting gravity surveys along the COCORP seismic line in Arkansas. Thanks are also extended to the following people and organizations who helped in one way or another with the computer work on this project: James Lance, Robert Coultrip, Murry Voight, Cheng-Lee Wen, John Rater, Bill Costello, Harold Gurrola, Ellen Kass, and the University of Texas at Dallas, Program in Geosciences. Linda Marston, Cynthia Renteria, and Doug Madden should also be acknowledged for their very professional cartographic work.

This study was partially funded by the Atlantic Richfield Company (ARCO Exploration). Other funding was provided by Standard Oil of Ohio (SOHIO), Cities Service Company, Sun Oil, and the National Science Foundation.

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GEOLOGY AND PETROLOGY OF THE PRAIRIE CREEK INTRUSIVE, MURFREESBORO, ARKANSAS

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The alkalic peridotite complex of Prairie Creek, Pike County, is significant not only because it contains diamonds, but also because it is a key to the genesis of the Arkansas alkalic province. The mantle-derived rocks of Prairie Creek are linked to the alkalic ring dikes and related intrusives (Magnet Cove, Potash Sulfur Springs) and syenites (Saline County, Granite Mountain) to the northeast by fractionation and possible crustal contamination. Because the Prairie Creek rocks are the most primitive, they best indicate the nature of the mantle source which produced the wide spectrum of alkalic rocks found along the west edge of the Mississippi Embayment in Arkansas.

The diamondiferous nature of the Prairie Creek intrusive was discovered in 1906 by John Huddleston as he was plowing a field. Since that time, an estimated 100,000 diamonds have been found, mostly white, yellow, or brown, with approximately 10% of gem quality (Bolivar, 1984). Diamond mining was a more-or-less continuous enterprise from 1907 through the early 1930's, involving four companies and two private owners. The Prairie Creek area was acquired by the State of Arkansas in 1972 and is now protected as Crater of Diamonds State Park.

The principal exposure of diamondiferous peridotite in Arkansas is the Prairie Creek complex. It covers about 0.3 km^2 and consists of three different lithologies: hypabyssal peridotite, tuff, and breccia. There are numerous other small exposures of diamondiferous peridotite in the area, including the Black Lick, American, and Kimberlite prospects (Fig. 1). However, only the Prairie Creek intrusive has produced a significant quantity of diamonds.

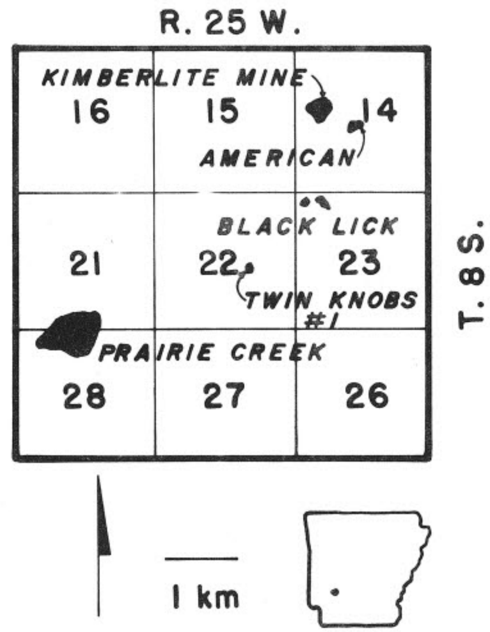

Figure 1. Map of the Murfreesboro area showing principal peridotite localities.

THE ROCKS OF PRAIRIE CREEK

Three igneous lithologic units are recognized in the Prairie Creek complex. Although they have been subdivided somewhat by recent workers, the accompanying map (Fig. 2) is essentially the same as that produced by Miser and Ross (1923).

The most abundant lithology is hypabyssal peridotite, which comprises slightly more than half the area. Fresh rock outcrops are plentiful on the "middle hill" to the east of the plowed "diamond mine". The rock consists of a glassy groundmass,

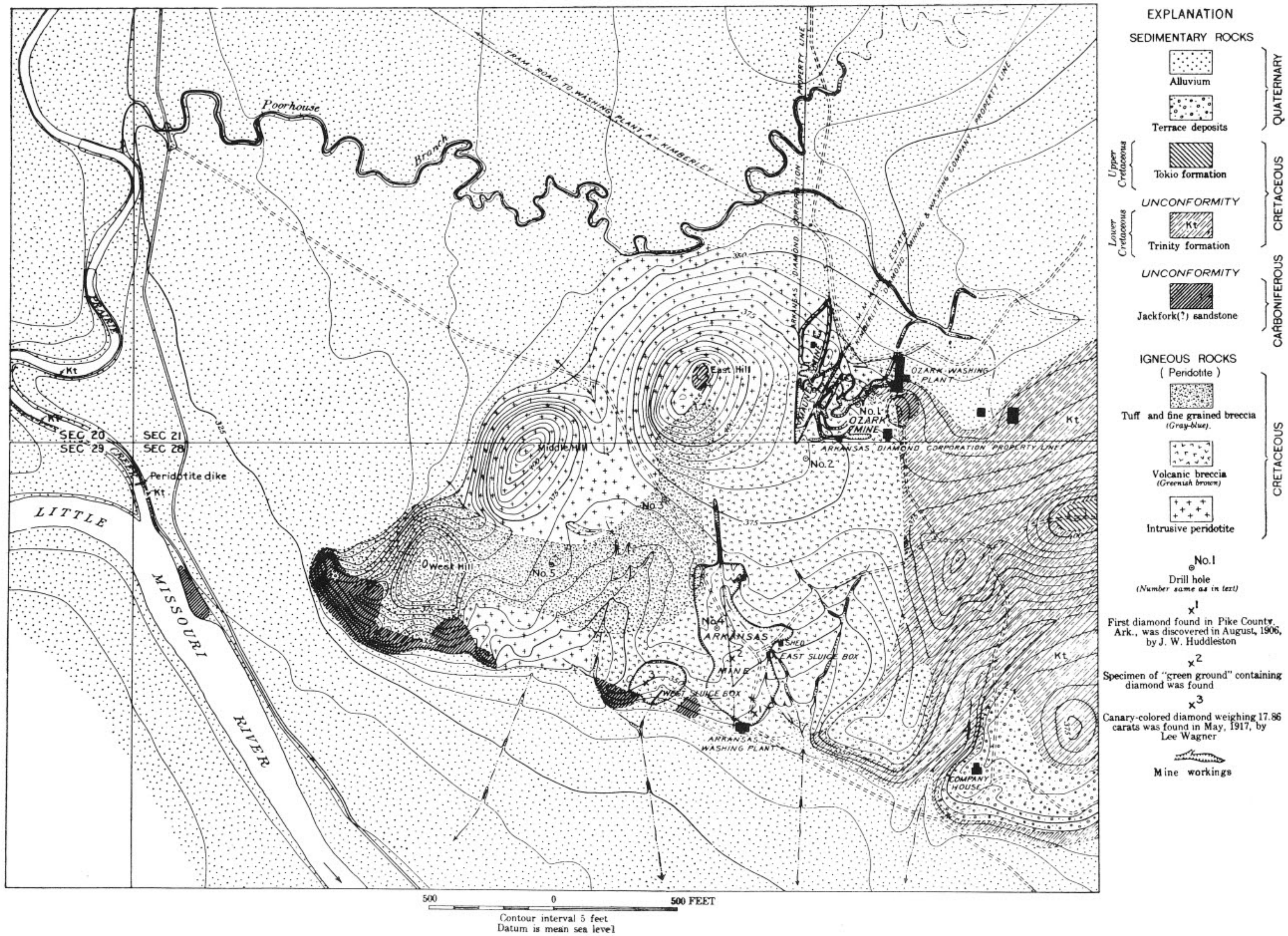

Figure 2. Map of the Prairie Creek complex from Miser and Ross, 1923.

now substantially altered to serpentine and/or chlorite, with poikilitic phlogopite. Small (< 1 mm) crystals of diopside, apatite, Cr spinel, and perovskite are considered part of the groundmass (Fig. 3, Table 1). Olivine occurs most commonly as embayed macrocrysts with serpentine reaction rims. Amphibole (potassic richterite), priderite, and both high Cr and low Cr garnet (Lewis et al., 1976) are rare phases. Ilmenite and orthopyroxene have not been reported from the Prairie Creek locality, although they are common in kimberlites.

Mineral compositions are characteristic of alkali-rich ultramafic rocks, but somewhat different from kimberlites. Diopside is extremely calcic (Ca–50; Fe–4; Mg–46), and plots above fields for groundmass diopside of kimberlite on the pyroxene quadrilateral (Fig. 4). It can best be compared to clinopyroxene of some carbonatite complexes. The poikilitic phlogopite has high contents of SiO_2 and Al_2O_3 compared to most kimberlites (Fig. 5) and plots on a wolgidite

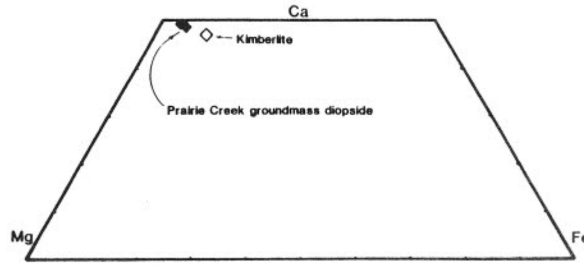

Figure 4. Pyroxene compositions, Prairie Creek.

trend of low Al_2O_3 increase with FeO* or TiO_2, indicating a primitive mantle source rather than an evolved, fractionated source. However, this same phlogopite has a pleochroic scheme characteristic of low-pressure crystallization, rather than the high-pressure scheme characteristic of most kimberlites. The overall compositions of Prairie Creek phlogopites are distinct from most kimberlites. Olivine (Fig. 5) is very magnesian (Fo_{86-92}) and overlaps the compositional field for olivine macrocrysts in kimberlites. Two generations of olivine have been recognized (Scott-Smith

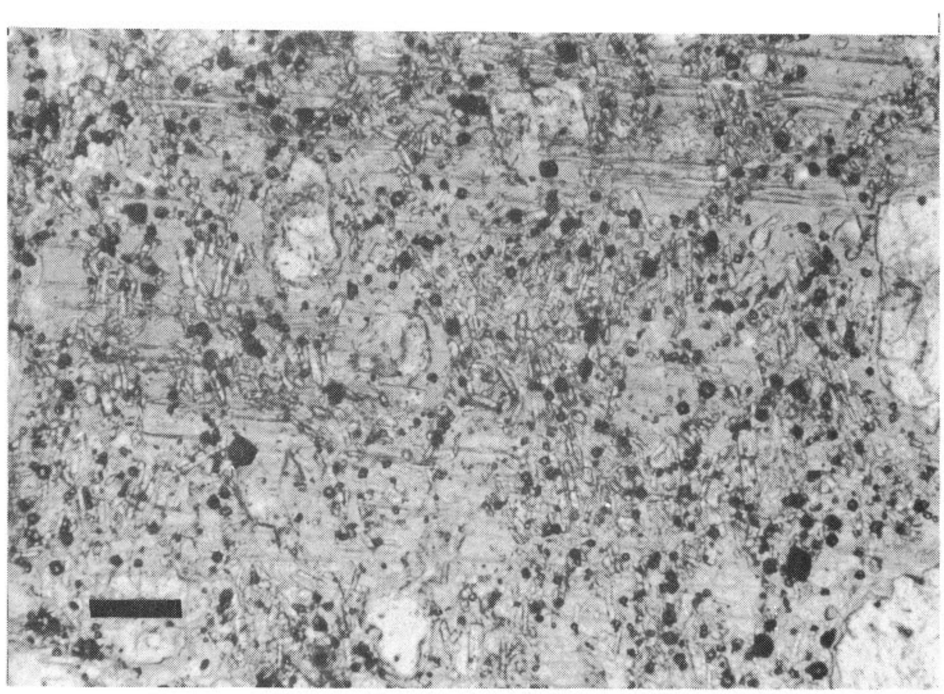

Figure 3. Photomicrograph of ultramafic rock, Prairie Creek. X50.

Table 1. — Mineral compositions: Prairie Creek peridotite

	OLIVINE					DIOPSIDE			PHLOGOPITE	
SiO_2	42.30	42.20	41.70	41.30	42.20	53.00	53.00	53.20	42.90	43.00
TiO_2	0.00	0.00	0.00	0.00	0.00	1.20	1.60	0.90	6.20	6.40
Al_2O_3	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	8.00	8.70
FeO*	8.30	8.10	8.50	8.30	7.90	3.30	3.00	2.60	6.80	6.50
MgO	49.60	48.80	49.10	49.10	50.30	16.70	16.60	16.60	0.00	0.00
CaO	0.10	0.10	0.20	0.10	0.10	25.10	25.30	25.10	22.30	22.30
Na_2O	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.40	0.60	0.50
K_2O	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	9.50	9.50
NiO	0.38	0.39	0.34	0.41	0.37	0.03	0.02	0.03	0.00	0.00
Cr_2O_3	0.04	0.05	0.05	0.05	0.04	0.46	0.35	0.20	0.10	0.10
TOTAL[1]	100.70	99.60	99.90	99.30	100.90	100.50	100.50	99.30	96.40	97.00
						Ca	50.00	50.00	50.00	
Fo	86.00	86.00	85.00	86.00	86.00	Mg	46.00	46.00	46.00	
						Fe	4.00	4.00	4.00	

[1] Totals rounded to 0.0%

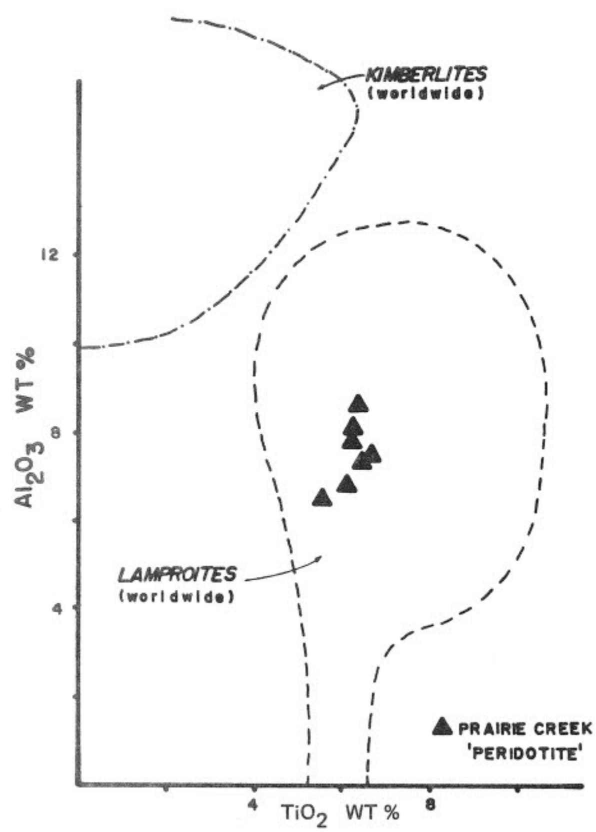

Figure 5. Phlogopite compositions, Prairie Creek peridotite.

and Skinner, 1984a); a euhedral form and a much more common embayed morphology (Fig.6) of larger macrocrysts (<1 mm). Both generations have the same compositional range. Accessory minerals show little compositional variations from their occurrence in any other rock type.

The breccia unit constitutes about 40% of the Prairie Creek exposure. It is intruded by a dike of the hypabyssal peridotite in the southeast, so is somewhat earlier than the peridotite. The breccia is substantially altered and deeply weathered so that its pristine character is difficult to determine. In general it is an easily fragmented rock which contains a highly variable combination of juvenile lapilli, ultramafic (mantle) and crustal xenoliths, and olivine macrocrysts in an (serpentinite + chlorite) altered matrix (Fig. 7). Bolivar (1984) divides the breccia into six units based upon degree of alteration, and speculates that some units may represent different phases of intrusion.

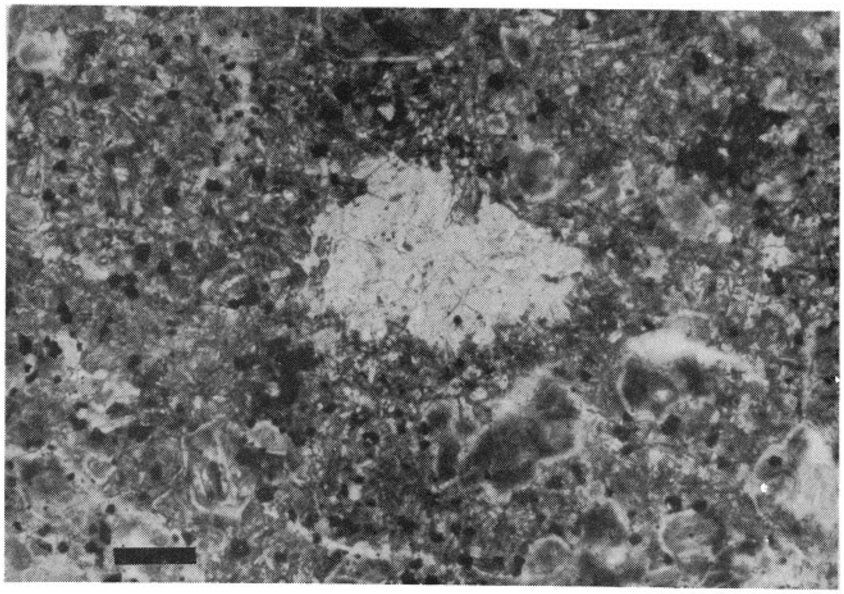

Figure 6. Embayed olivine in Prairie Creek peridotite. Photomicrograph, X50.

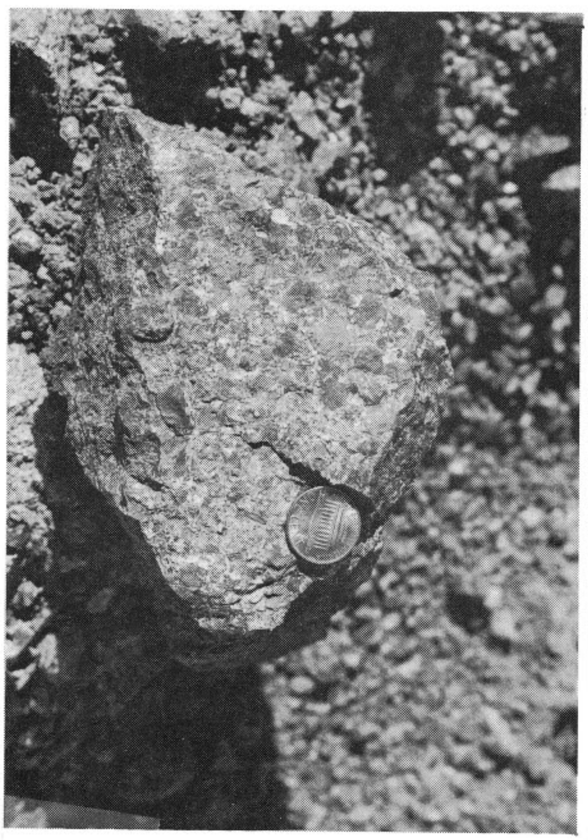

Figure 7. Prairie Creek breccia.

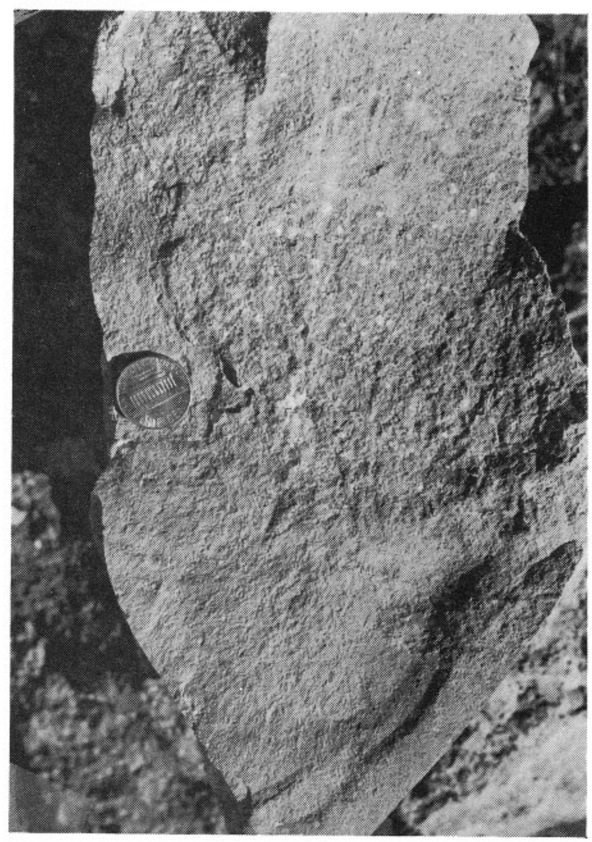

Figure 8. Tuff unit, Prairie Creek.

The tuffs are the finest-grained and most altered lithology. They are principally blue in color, and contain rock fragments, lapilli, and a highly chloritic matrix. Quartz grains, probably derived from the underlying Jackfork Sandstone, are a principal constituent of some tuffs. Graded bedding occurs in some tuffs (Fig. 8), suggesting for those tuffs a waterlaid origin.

OTHER DIAMONDIFEROUS PERIDOTITES, SOUTH–CENTRAL ARKANSAS

Diamondiferous peridotites occur in several other localities near Murfreesboro. The best known of these are the Black Lick and American mines which were prospected for only a short time. Both localities are represented by only a single lithology, highly altered hypabyssal peridotite. Mineralogy of the American mine is similar to that of Prairie Creek. However, the Black Lick contains 15% modal secondary nepheline as fillings in vugs, indicating a probable less Mg-rich but more volatile magma than was present at Prairie Creek. A recently discovered diatreme, Twin Knobs #1, covers approximately 13 acres 1.1 miles ENE of Prairie Creek (Fig. 1), and consists of tuffs, epiclastics, and intrusive breccia (Waldman et al., 1985). Breccias at the TK1 have yielded small, low-grade diamonds.

GEOCHEMISTRY

Whole rock geochemistry of the Prairie Creek intrusives is undoubtably affected somewhat by the variability and alteration of the rocks. Fresh samples of hypabyssal peridotite are available for the central hill, and the rocks of this area have good uniformity.

Major element analyses (Table 2) indicate that the rocks are depleted in SiO_2, have 2–3% TiO_2, are Mg rich, and contain about 10% H_2O with a significant content of CO_2 (0.20%). In general, their major element geochemistry is comparable to kimberlites. On an AFM plot the Prairie Creek samples fall on the trend of other alkalic rocks of Arkansas (Fig. 9), suggesting that they are, indeed, the most primitive portion of the Arkansas alkalic province.

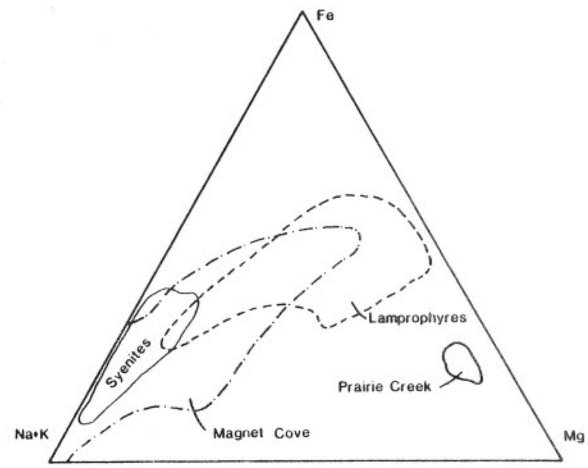

Figure 9. AFM plot, Arkansas alkalic province.

Trace element data are broadly similar to data from kimberlites, with some significant differences. A plot of Nb vs Zr (Fig. 10) indicates that the Prairie Creek samples are intermediate between kimberlites and lamproites (Scott-Smith and Skinner, 1984a). The 87/86 Sr ratio of 0.707 reported by Scott-Smith and Skinner is compatible with data from kimberlites and other mantle-derived, uncontaminated alkalic rocks.

IS THE PRAIRIE CREEK COMPLEX A KIMBERLITE?

The rocks of the Prairie Creek complex bear a strong resemblance to kimberlite – the classical mother lode of diamonds. They have much the same lithologic grouping – hydrated hypabyssal peridotite plus breccia plus tuff – and seem to have been associated with ultravolcanian (explosive non-magnetic) emplacement. They certainly, unequivocally, contain diamonds. They contain olivine macrocrysts, calcic diopside and perovskite.

Table 2. Major element analyses, Prairie Creek peridotite

	1	2	3
SiO_2	49.90	39.46	38.40
TiO_2	2.48	2.61	2.36
Al_2O_3	3.45	3.53	3.47
FeO*	7.73	8.78	8.65
MgO	27.50	26.67	26.31
CaO	4.20	5.14	4.60
Na_2O	0.28	0.29	0.73
K_2O	4.00	2.56	3.07
P_2O_5	1.01	0.29	0.81
CO_2	5.00	0.21	0.18
H_2O^+	0.54	7.70	8.10
TOTAL	106.09	97.24	96.68

1. Bolivar, 1984: 87/86 Sr = 0.7066.

2.,3. Scott-Smith and Skinner, 1984a.

They are low in SiO_2 and are Mg rich. They have a rare earth element pattern (extreme LREE enrichment) which resembles kimberlites. And last, but not least, their 87/86 Sr ratio is low, indicating a primitive mantle source, as we would expect in kimberlites.

However, there is considerable evidence to indicate that the Prairie Creek rocks are not true kimberlites. The hypabyssal intrusive contains no ilmenite or orthopyroxene and almost no garnet — common minerals in kimberlites. The rocks *do* contain amphibole and priderite, which are unknown in kimberlites. No other known kimberlite has a glassy matrix. Furthermore, mineral chemistry is not the same as that of kimberlites. Clinopyroxenes of Prairie Creek contain more CaO than kimberlites, olivines are more iron-rich, and phlogopites are more TiO_2 and FeO* rich and show a pleochroic scheme which is the reverse of the mica of kimberlites. Geochemistry also indicates that the Prairie Creek rocks should not be classified as kimberlite. Major element abundances, and rare-earth element plots are inconsistent with categorization as a kimberlite.

CLASSIFICATION OF THE PRAIRIE CREEK COMPLEX: LAMPROITE

The classification which best fits the rocks of Prairie Creek seems to be that of lamproite as recognized by Scott-Smith and Skinner (1984b). Lamproites as defined by Niggli (1923), Wade and Prider (1940), and Mitchell (1970) are potassium-titanium-magnesium-rich lamprophyric rocks characterized by the presence of high Ti, low Al phlogopite, diopside, amphibole, and olivine with diamond, sanidine, leucite, priderite, perovskite, Cr-spinel and apatite as possible accessories. Garnet and ilmenite are not present. Glass may occur as a groundmass in lamproites. Furthermore, lamproite intrusions have a flared, "champagne glass" cross-section, whereas kimberlites have a very narrow and pipe-like morphology. The cross-section of Prairie Creek determined by drilling and field evidence is much more like the "champagne glass" lamproite geometry.

SIGNIFICANCE OF LAMPROITES

The lamproite of Prairie Creek is a mantle-derived rock, as indicated by the presence of high-pressure phases (diamond, perovskite) and low 87/86 Sr ratio. (Its true nature is probably between kimberlite and lamproite, but nonetheless, it represents a primitive mantle melt.) No *kimberlites* are associated with the variety of rocks — ring complexes and syenites — which appear in the progressively more leucocratic sequence northeastward from Prairie Creek.

The following model is purely speculative until it can be substantiated by data and investigations in progress. The presence of some lower pressure phases (phlogopite, priderite, amphibole) suggest that the lamproites were generated at *somewhat* shallower depths than true kimberlite. The temporal and petrologic association of the Prairie Creek intrusions with the ring complexes and syenites indicates that a similar mechanism was responsible for the generation of all rock types. Possibly, a slightly wider continental rifting along an ancient fracture zone (now expressed as the New Madrid Zone) in the North American craton would allow a greater volume of shallower source magmas to reach the surface than is possible in situations where only kimberlites – commencing at great depth, but driven by very high volatile pressure–breach the surface.

Whatever the source, cause, and significance of the Prairie Creek intrusives, they are significant to the petrology of the Arkansas alkalic province.

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SUMMARY OF ISOTOPIC DATES OF CRETACEOUS IGNEOUS ROCKS OF ARKANSAS

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Figure 1 presents published isotopic dates (mostly by Zartman, 1977) for igneous rocks of Cretaceous age in Arkansas. When arranged geographically as on the figure, from southwest (left) to northeast (right), it is apparent that the intrusion sequence of these genetically related rocks began in the southwest and proceeded to the northeast over a time span of approximately 15 million years. R.E. Denison (written commun., 1976) obtained a K/Ar age of 83 ± 8 m.y. from biotite concentrates from a lamprophyre in Pope County. Howard (1974), Howard and Steele (1975), and Robinson (1976) have contended that the lamprophyres were not only comagmatic with the kimberlitic and syenitic rocks of Arkansas, but were derived from the same parental magma source. It is proposed that when dates of other lamprophyres in Arkansas are obtained, the ages will span the entire time range of the major intrusions.

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(Figure 1, over.)

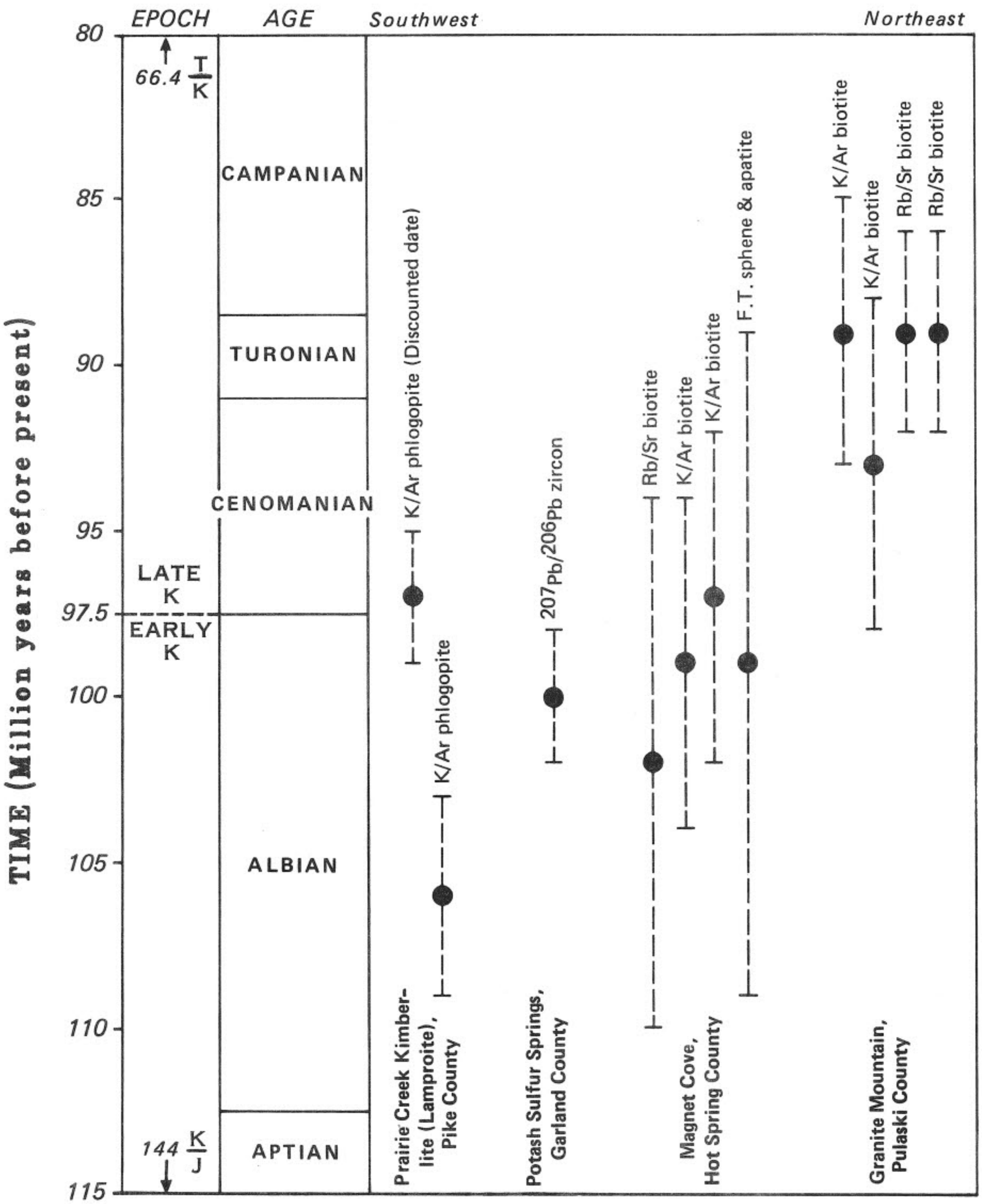

Figure 12. Isotopic dates of Cretaceous igneous rocks in Arkansas. Time scale from Palmer (1983).

PHOSPHATE MINERALS OF ARKANSAS

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INTRODUCTION

The author first became associated with the mineralogy of Arkansas in 1948 while working on an economic mineral survey for Arkansas Power & Light Company. Many samples of phosphate minerals were encountered, and it soon became obvious that although the deposits had no direct economic importance, there were some fascinating problems in the occurrence and detailed mineralogy of these minerals. The collection and study of the phosphate minerals have been pursued intermittently up to the present time, with the active assistance of other collectors and geologists too numerous to mention.*

LOCATION AND GEOLOGIC SETTING

The phosphate minerals of interest occur within the central part of the Ouachita Mountains in western Arkansas (Fig.1). They are largely restricted to fractures and breccia zones within the two principal siliceous formations in the pre-Stanley section – the Arkansas Novaculite and the Bigfork Chert.

The iron phosphates occur only in the Arkansas Novaculite and specifically in the upper part of the Lower Member, below the shaly Middle Member, and invariably associated with iron and/or manganese oxides.

Aluminum phosphates are the characteristic varieties in the Bigfork Chert. The principal exception to this is at Potash Sulphur Springs in the vanadium mines of Union Carbide Company. Here the novaculite has been metamorphosed by alkaline igneous intrusions to a coarser siliceous rock, and exposed in the pits are a variety of both aluminum and iron phosphates.

MINERALOGY

The Arkansas phosphate minerals can be conveniently subdivided into three chemically similar groups – ferrous-ferric, ferric, and aluminum. They are listed in Table 1 and will be discussed by these groups.

Table 1 – List of Arkansas Phosphate Minerals

Ferrous-Ferric Iron	
Rockbridgeite	$(Fe^{+2},Mn)Fe_4^{+3}(PO_4)_3(OH)_5$
Laubmannite	$Fe_3^{+2}Fe_6^{+3}(PO_4)_4(OH)_{12}$
Lipscombite	$(Fe^{+2},Mn)Fe_2^{+3}(PO_4)_2(OH)_2$
Dufrenite	$Fe^{+2}Fe_4^{+3}(PO_4)_3(OH)_5 \cdot 2H_2O$
Beraunite	$Fe^{+2}Fe_5^{+3}(PO_4)_4(OH)_5 \cdot 4H_2O$
Ferric Iron	
Kidwellite	$NaFe_9^{+3}(PO_4)_6(OH)_{10} \cdot 5H_2O$
Strengite	$Fe^{+3}PO_4 \cdot 2H_2O$
Phosphosiderite	$Fe^{+3}PO_4 \cdot 2H_2O$
Cacoxenite	$Fe_9^{+3}(PO_4)_4(OH)_{15} \cdot 18H_2O$
Aluminum	
Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O$
Planerite	Al-Fe phosphate
Wavellite	$Al_3(PO_4)_2(OH,F)_3 \cdot 5H_2O$
Crandallite	$CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$
Variscite	$AlPO_4 \cdot 2H_2O$
Gorceixite	$BaAl_3(PO_4)_2(OH)_5 \cdot H_2O$

*Many of these individuals are members of the so-called "Coon Creek Group" who gather informally for a few days each fall to collect minerals and compare notes on recent discoveries in Arkansas mineralogy.

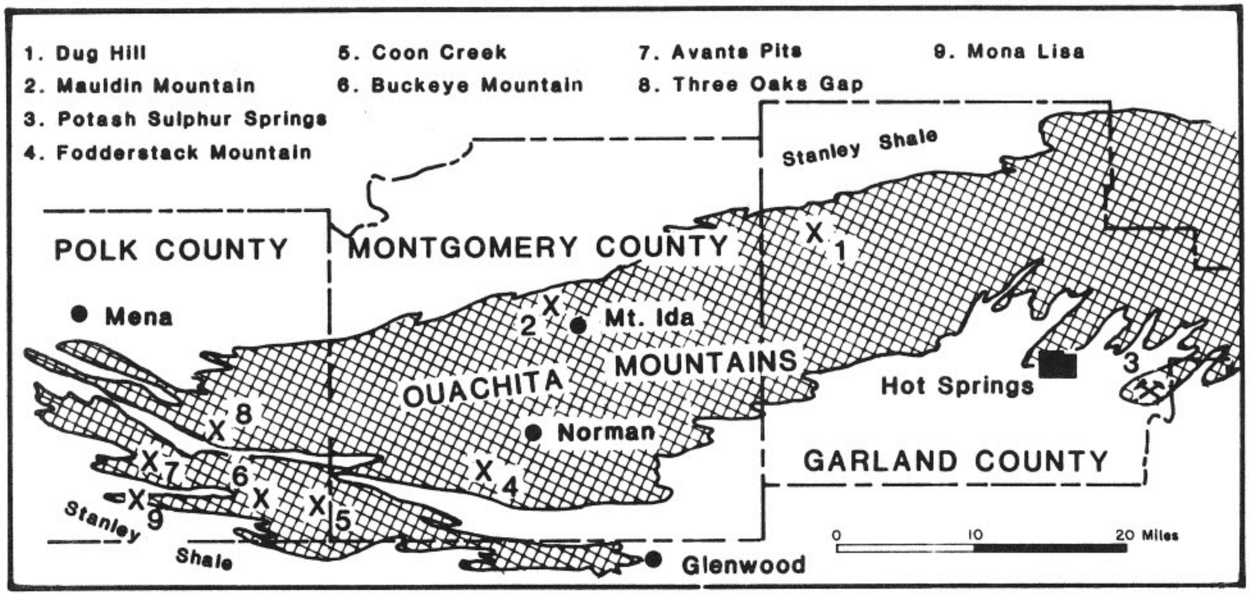

Figure 1. Location of phosphate occurrences, Ouachita Mountains, Arkansas. Pre-Stanley formations shown by pattern.

Ferrous-Ferric Phosphates

The most distinctive of these minerals is beraunite, which is reddish brown and forms lustrous monoclinic tabular crystals that generally occur in either radiating or parallel aggregates. In the absence of crystals, the color alone is sufficient for field identification.

Dufrenite, rockbridgeite and laubmannite are somewhat difficult to distinguish because they are all some shade of green or brown and all occur in banded botryoidal masses or crusts with a radial fibrous or fine-columnar structure. The surface of the crusts is composed of indistinct crystals. Any or all of them can also occur together as distinct layers of different color shades in the fibrous masses. The exact color also depends upon the state of oxidation. Dufrenite is the easiest to distinguish because it tends to be a darker color than the others (often almost black) and often forms sub-rounded blocky crystals in subparallel or sheaf-like crystals within openings. Rockbridgeite and laubmannite can appear very similar, but rockbridgeite tends to be olive green when fresh but oxidizes easily to a brownish green or dark reddish brown. Laubmannite is generally a grayish green and tends to form finer, more silky fibers. It is relatively rare, the best examples occurring at Buckeye Mountain, which is the approximate locality from which the type samples came. Lipscombite was identified by Moore (1970) from Fodderstack Mountain, but has not been definitely identified by the writer. It typically has more of a bluish color than the others. The most definitive method for positive identification of these minerals is x-ray diffraction.

Ferric Phosphates

The ferric phosphates are generally distinctive enough for sight identification. The one exception is kidwellite, which can occur in a variety of forms. Its most typical occurrence is as the last mineral to form in a banded mass of ferrous-ferric phosphates. This probably represents an alteration rim. It also typically forms aggregates of fibrous microcrystals and spheres up to a few millimeters in diameter along fractures or microbreccias. The true color is light yellowish green, but it often appears much darker when present on a dark matrix. The mineral was described and named by Moore and Ito (1978). Since then it has proved to be a very common mineral in these types of deposits and has worldwide occurrence.

Another mineral which typically occurs with kidwellite may be a higher hydration product of that mineral. It forms white to very light-green tufts and coatings of extremely fine, fibrous crystals and gives a well defined x-ray diffraction pattern.

Cacoxenite forms very distinctive yellow, hair-like crystals which are generally in radiating micro-spheres. However, individual crystals may reach lengths greater than one centimeter at localities such as Potash Sulphur Springs and Three Oaks Gap. Often associated with cacoxenite are red microspheres which sometimes form the nuclei of cacoxenite aggregates. The material was identified as amorphous iron phosphate by Moore (1970) and has been referred to as diadochite by others.

Strengite and phosphosiderite (metastrengite) are dimorphous. Strengite is by far the more common and typically occurs as very attractive radiating sheaves of pink, violet or gray, well-terminated orthorhombic prisms. Phosphosiderite, where present, occurs with strengite in stout, plum-colored crystals lacking the bipyramids so typical of strengite. Phosphosiderite may represent a period of slightly higher temperature solutions.

Aluminum Phosphates

A blue to green material which commonly coats fracture and joint surfaces in both the Arkansas Novaculite and the Bigfork Chert has generally been identified as turquoise or a turquoise-like mineral. However, the only true turquoise occurs as sparse micro-crystals with iron phosphates and as the only phosphate mineral at the Mona Lisa Mine. It is greenish blue to sky blue, contains more than trace amounts of copper, and has a characteristic x-ray diffraction pattern. The other turquoise-like mineral has been shown by Eugene Foord (U.S.G.S., Denver) to be a different mineral species which he is naming planerite (personal commun., 1984). This is a name originally proposed for a turquoise-like mineral in the mid-1850's, but was inadequately defined and had not been accepted as a valid mineral species. Planerite is blue to blue-green, forms micro-spheres and botryoidal coatings on joint and fracture surfaces, and has not yet been found as distinct crystals. It contains iron but no copper and has other distinctive properties which will be discussed by Foord in a forthcoming paper on turquoise family minerals.

Wavellite typically occurs in radiating, needle-shaped crystals which, if they grow unobstructed, often form perfect spheres, with each fibrous crystal having a termination. Generally the aggregates grow in narrow fractures where complete spheres cannot form and, when broken, show a characteristic radiating structure. In addition, wavellite can and does occur in single micro-crystals or simple aggregates in some deposits. The color of wavellite ranges from colorless in the micro-crystals to white, yellow or most commonly some shade of green. The most prolific wavellite localities are Avant and Mauldin Mountain, but it is also known from the novaculite at Potash Sulphur Springs and from a number of places where the Bigfork Chert occurs.

Variscite is another aluminum phosphate which typically forms coatings of green drusy crystals on joints and fracture surfaces in the Bigfork Chert. It commonly coats planerite at Mauldin Mountain. It can be distinguished on the basis of the green color and the drusy coatings of pseudo-octahedral crystals. This is one of the few areas, worldwide, where variscite occurs as recognizable crystals.

Crandallite occurs as an alteration product of wavellite, and is relatively common in the Avant area. It is buff to tan, generally porcellaneous, and shows the same crystal form as the wavellite it replaces. However, magnification reveals that the crandallite is in parallel fibers normal to the c-axis of the original crystal.

Gorceixite is a rare barium-aluminum phosphate first reported by Young (1958) from Arkansas. It occurs sparingly as white to colorless, radial, fibrous coatings along fractures in novaculite about 6 miles east of Hot Springs.

Two non-phosphates minerals commonly associated with the iron phosphates are goethite and hyalite opal. Goethite is generally the base upon which the iron phosphates have formed. It is usually present as botryoidal coatings and micro-stalactites on novaculite in fracture zones. Hyalite opal forms colorless, bubbly crusts on any of the other minerals, since it was the last to form. In contrast to many hyalite occurrences, it is not fluorescent, since there is no uranium associated with any of these deposits.

INDIVIDUAL DEPOSITS

Most of the known deposits of phosphate minerals were found as an adjunct to mining, prospecting or road building, primarily for manganese. There are undoubtedly many other mineralized places which have not been recognized because fresh cuts or excavations have not been made. Some of the principal locations are shown on the index map (Fig. 1) and are discussed briefly as follows:

1. Dug Hill, sec. 11, T. 1 S., R. 22 W., is a long known location for wavellite and variscite. It is located about 1½ miles north of a village variously known as Avant or Buckville. The area is public land administered by the U. S. Army Corps of Engineers, due to the proximity to Lake Quachita. Hand digging of shallow pits for non-commercial collecting is allowed, except for private leases which are well marked. Wavellite, variscite, and crandallite occur in fractures and brecciated masses of Bigfork Chert near the surface.

2. Mauldin Mountain Quarry, sec. 3, T. 2S., R. 25 W., actually consists of two adjacent quarries operated for road material by the state and county respectively. Only the eastern one (county quarry) is of mineralogical interest. Wavellite, variscite, and planerite are moderately abundant along fractures and bedding planes. Occasional spectacular specimens of wavellite have been found wherever the fractures widen. The quarry is open to the public for collecting.

3. Potash Sulphur Springs, sec. 17, T. 3 S., R. 18 W., is the location of the vanadium mine of Umetco, a subsidiary of Union Carbide Corporation. Here a complex of alkaline igneous rocks has intruded novaculite, causing extensive contact metamorphism which has been further modified by later geologic processes. Wavellite, variscite, strengite, and cacoxenite have been found in the altered novaculite. Several rare phosphates have also been found by Dr. Charles Milton in the altered igneous material, some of which are being described as new minerals. The location is closed to individual collectors.

4. Fodderstack Mountain, secs. 7 & 12, T. 4 S., R. 25 & 26 W., is an outcrop of fractured novaculite and local float containing strengite, phosphosiderite, dufrenite, kidwellite, and some unidentified iron phosphates. This is the type location for kidwellite, although better material has since been found in other areas. Part of the area is under claim, and is further complicated by very difficult access.

5. Coon Creek (also known as the York mine), sec. 13, T. 4 S., R. 28 W., was opened up as a manganese prospect and

abandoned in the late 1950's. It is presently under claim by Mr. Meredith York, Stephens, Ark. Many of the better specimens of kidwellite, rockbridgeite, dufrenite, strengite, phosphosiderite, and cacoxenite have come from here. Other minerals present are beraunite, laubmannite, turquoise, and planerite. The mineralization occurs within a major fracture zone and in boulders derived from it. Permission should be obtained before collecting.

6. Buckeye Mountain, sec. 18, T. 4 S., R. 28 W., produced fine specimens of laubmannite, beraunite, and kidwellite in 1948 when blasting was done for a mine road. Planerite is locally abundant in an old surface prospect within brecciated novaculite. This area has been included in the Caney Creek Wilderness Area and is closed to mineral entry.

7. Avants pits, secs, 1 & 2, T. 4 S., R. 30 W., were dug by the Avants brothers during the 1940's and 1950's while prospecting for anything interesting. These are the original spots where iron phosphate minerals were found by the writer in fractured novaculite. Most of the area lies within the National Forest and is a good area to prospect for iron phosphate mineralization.

8. Three Oaks Gap, sec. 27, T. 3 S., R. 29 W., was discovered in 1983 by a company prospecting for manganese. Extraordinary specimens of kidwellite, dufrenite, strengite, beraunite, and cacoxenite were found here within unusually large openings in novaculite breccia. The area has reportedly been staked as a claim for mining mineral specimens. Little is available here at present.

9. Mona Lisa Mine, sec. 23, T. 4 S., R. 30 W., comprises a series of pits which were worked for turquoise along the top of Porter Mountain. The mineral is associated with kaolinite as veins, nuggets and coatings in a hydrothermally altered, fractured novaculite. This is the only important known occurrence of true turquoise in Arkansas and has been worked intermittently for a number of years. The most recent operation was by Mr. Chuck Mayfield, Mena, Arkansas, who shipped hand cobbed material to New Mexico, where it was treated and used for making turquoise jewelry. Collecting was possible as recently as spring, 1984.

ORIGIN

The origin of these deposits has not been studied in detail, but certain constraints are evident. The virtual restriction of the phosphate minerals to specific formations or parts of formations suggests that the phosphorous was indigenous either to the siliceous beds in which the minerals occur, or to adjacent shales from which it could have moved. It seems likely that the phosphorous was leached and redistributed in fracture zones by hot waters similar to those issuing as hot springs at present. The ferrous-ferric phosphates formed first from solutions depleted in oxygen. The ferric phosphates formed later and at shallower depths from water with a somewhat higher oxygen content which either altered the earlier deposited phosphate minerals or was continuing to carry phos--phorous from the indigenous source. The ferric phosphates are notably more stable under surface conditions of oxidation than are the ferrous-ferric ones which alter readily to goethite. The formation of aluminum phosphates took place where there was abundant aluminum available but relatively little iron.

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JACKFORK GROUP SANDSTONES ALONG THE TALIMENA TRAIL, ARKANSAS AND OKLAHOMA

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The Jackfork Group[1/] is a 1400-meter thick sequence of deep-marine, Pennsylvanian sandstone, siltstone and shale, exposed along the northern and southern flanks of the folded and thrust-faulted Ouachita Mountains of southeastern Oklahoma and west-central Arkansas (see Morris 1971, 1974). The Jackfork and enclosing Carboniferous strata were deposited in an east-west trending, elongated, submarine-fan and basin system that, according to Graham *et al.* (1975), was similar to the modern Bengal submarine fan in terms of fan geometry and tectonic setting. On the basis of hafnium content in zircons and cathodoluminescent color of detrital quartz, Owen (1984a, 1984b) showed that sand grains in the upper part of the Jackfork Sandstone in southwestern Arkansas have little affinity with Carboniferous sand grains in the Illinois basin. Instead, they are quite similar to those in the Parkwood Formation of the Black Warrior basin, Alabama, and were most likely derived from a southern, not a northern, source.

Jackfork strata dip southerly and are discontinuously exposed along the 40-km long, east-west strike section of Rich Mountain, which extends from Polk County, Arkansas, into LeFlore County, Oklahoma, (Figure 1) and lies between the Honess fault on the north and the Windingstair fault on the south. The Talimena Trail — Arkansas route 88 and Oklahoma route 1 — follows the crest of Rich Mountain and is joined by Arkansas route 272 from the northeast at Queen Wilhelmina State Park. The section nearly parallels the west-southwesterly paleocurrent trend shown by contained sedimentary structures; thus it presents an excellent, current-parallel view of Jackfork turbidites and associated deposits.

[1/] Recognized as the Jackfork Sandstone in Arkansas by the Arkansas Geological Commission.

LITHOFACIES

Detailed observations of individual beds, their texture, fabric, sedimentary structures, and internal and external geometry, were recorded in the field at a scale of 1:20 and drafted into columnar sections at a scale of 1:100. Vertical sequences of beds form descriptively and genetically similar units, best described by the lithofacies terms introduced by Mutti and Ricci Lucchi (1978). They described 7 lithofacies, designated by the letters A through G. Six of these occur within the Jackfork Group at Rich Mountain. Lithofacies A of Mutti and Ricci Lucchi is subdivided here into lithofacies A-1 and A-2 on the basis of texture, bed geometry, and presence or absence of mudrock. Salient attributes of the lithofacies are summarized in Table 1.

Lithofacies A-1 (Fig. 2) Comprises structureless sandstone with some interleaved mudrock. The sandstone is fine to medium grained, poorly to very poorly sorted and so weakly indurated that it is often called the "friable sandstone". It occurs in beds 1 to 3 meters thick. Granules and mud clasts occur randomly throughout the sandstone. The mudrock is clayey, laminated and from a few up to 200 centimeters thick; it contains some disconnected, sand-filled, load casts.

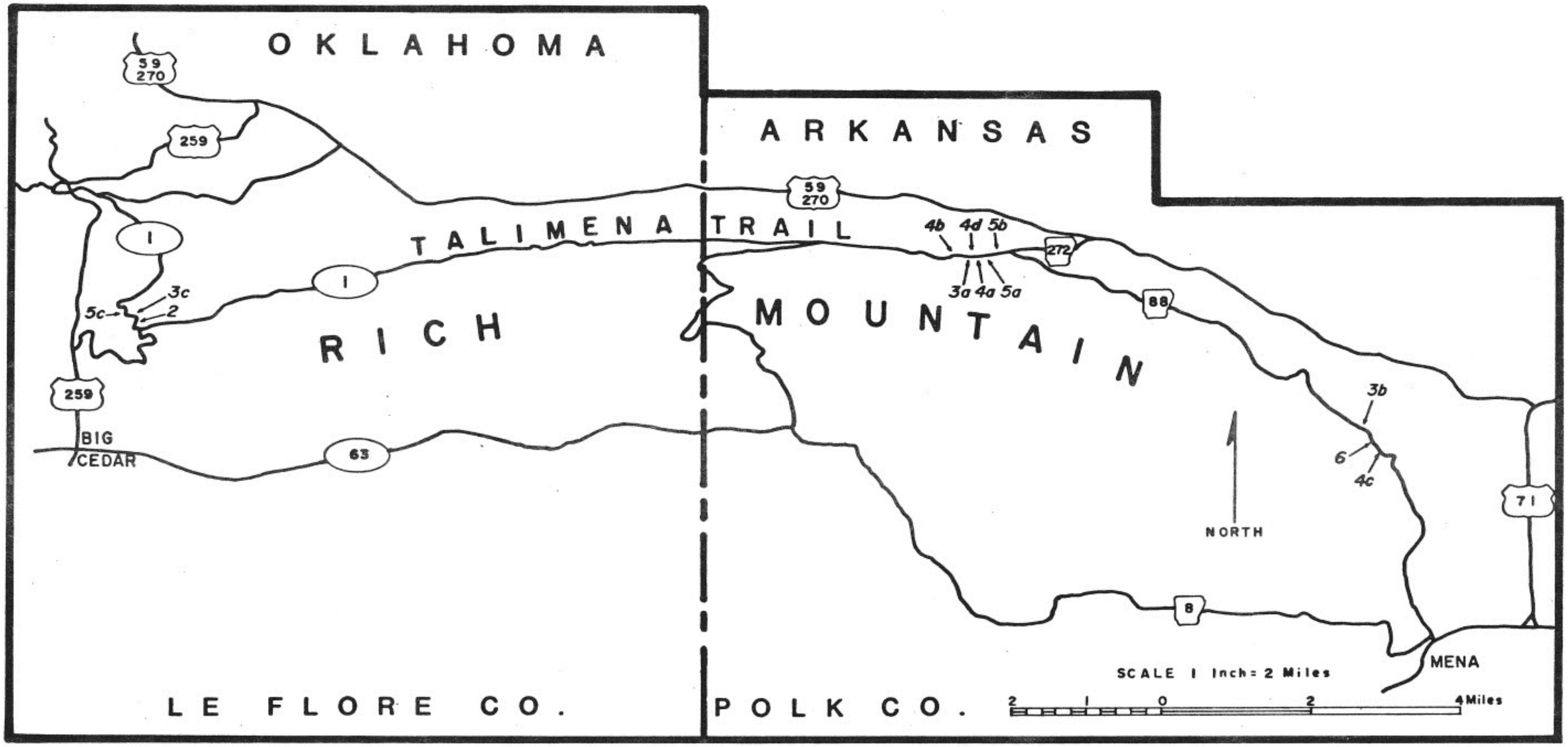

Fig. 1. Sketch map of the Talimena Trail — Rich Mountain area of Arkansas and Oklahoma showing location of sections (italic numbers) illustrated in figures 2 through 6.

TABLE 1. CHARACTERISTICS OF COMMON LITHOFACIES ALONG THE TALIMENA TRAIL. ADAPTED FROM MUTTI AND RICCI LUCCHI (1978).

	A-1	A-2	B	C	E
LITHOLOGY	Sandstone-mudrock	Sandstone	Sandstone	Sandstone to mudrock (L.C.)[1]	Sandstone, siltstone to mudrock (L.C.)[1]
TEXTURE	Sandstone: fine to medium, granule and rip-up clasts, poorly sorted, weakly indurated. Mudrock: clayey.	Locally sparse granules, rip-up clasts, well sorted, well. indurated.	Fine to medium, well sorted, well to moderately indurated, rip-up clasts.	Sandstone: fine to medium, well sorted, well indurated; pebbles and rip-up clasts. Mudrock: clayey to silty; siltstone intercalations.	Sandy part: fine-grained sand to silt, sorting variable (poorly to well), moderately to well indurated. Muddy part: silt to clay. Pure siltstones: coarse silt.
BED THICKNESS	Sandstone: thick to very thick, (mostly 1 m) Mudrock: intervals up to 2 m.	Thick to very thick (mostly 0.90 – 2m).	Thick to very thick (mostly 0.65 – 1m).	Medium to very thick (mostly 60 – 150 cm). Lower sandstone part generally thicker.	L.C.: thin to medium (mostly 10 – 20 cm). Pure siltstones: thin to medium.
BED GEOMETRY	Even-parallel at outcrop; erosional truncation of mudrocks prevalent but no channeling.	Continuous at outcrop; flat, parallel; wavy diffuse, convex basal contacts; channels not deeper than 3 m; sole markings rare to absent; load casts rare.	Continuous at outcrop; sharp, flat-parallel base, wavy top. Scour marks predominate.	Continuous at outcrop; sharp, flat-parallel base and top. Scour marks predominate; load casts present.	L.C.: discontinuous at outcrop; sharp, flat base and top; wedging, lensing, pinching, swelling common. Tool marks predominate; some beds are truncated; trace fossils common. Siltstone: discontinuous to parallel.
SAND:MUD RATIO	High; average 70:30	Indefinite, amalgamated.	Very high; 95:5	High; generally 60:40. Some beds coalesce.	L.C.: 40:60. Siltstones: indefinite.
INTERNAL SEDIMENTARY STRUCTURES	Sandstones: structureless. Mudrocks: thin to thick, parallel laminated.	Structureless	Thick horizontal laminae, dish structures, parting lineation, current ripples.	Step grading, diffuse current laminae, ripples and dish structures present; convolute bedding common.	L.C.: normal grading, step grading, current laminae of transition and lower flow regime. Siltstones: structureless.
BOUMA SEQUENCES	Not applicable (or T_{ae})	Not applicable (or T_a)	T_{abc}, T_{bc}	T_{abcde}, T_{abce}, T_{ace}, T_{bcde}, T_{bce}, T_{ae}	T_{acde}, T_{abde}, T_{ade}, T_{ae}
DEPOSITIONAL MECHANISM	Slurry-like mass flow or grain flow.	Grain-flow	High- to moderate-energy turbidity flow.	High- to moderate-energy turbidity flow.	Low-energy turbidity flow.

[1] L.C.: Lithologic couplet.

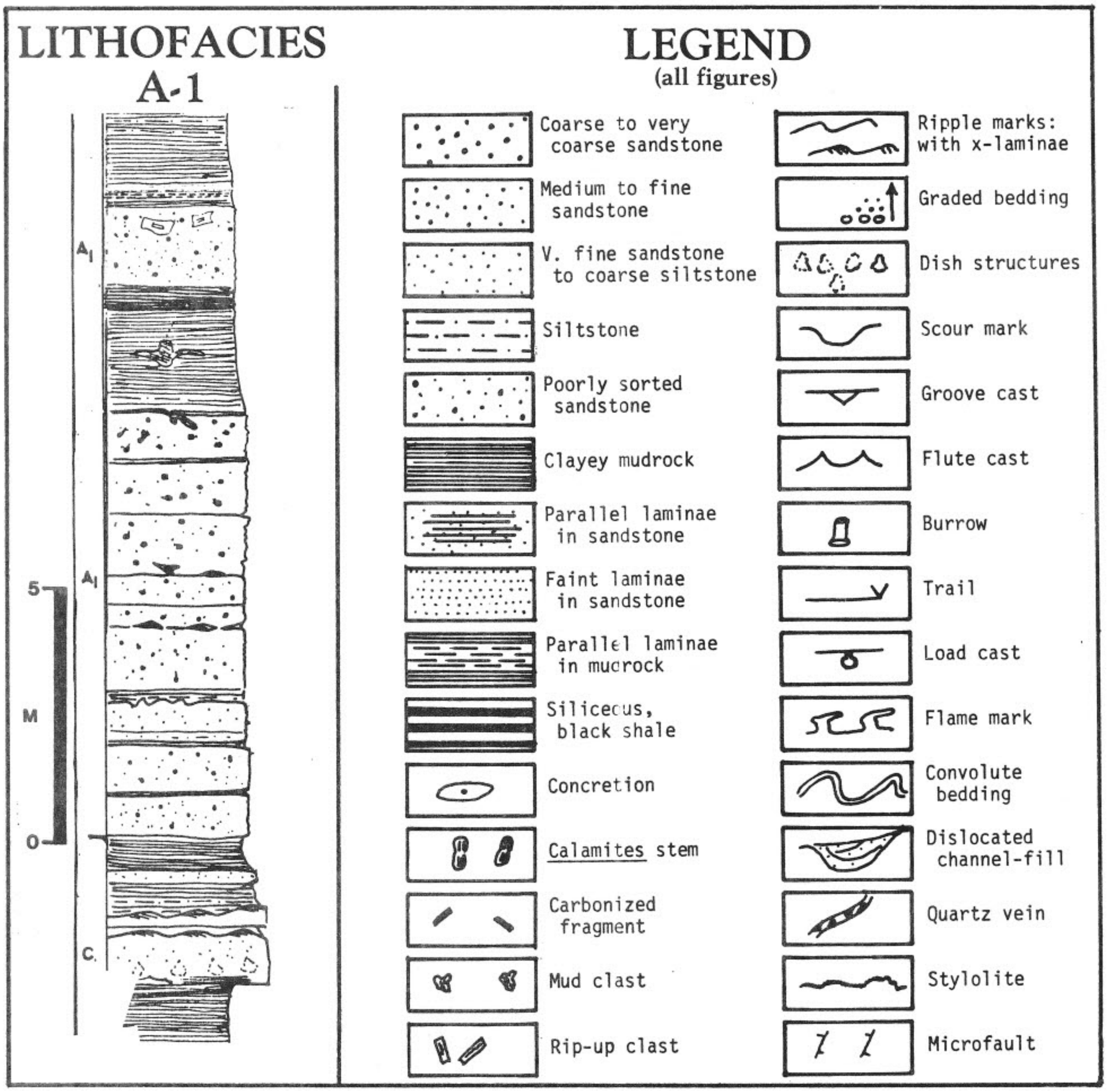

Fig. 2. Columnar section typical of lithofacies A-1 and associated beds. Legend applies to figures 2 through 6.

A complete bed consists of mainly structureless fine- to medium-grained sandstone and overlying, laminated mudrock. Many of the beds are normally graded from sandstone into mudrock and present no descriptive problem where the grading is regular. However, abrupt step grading also occurs, causing one bed to look as though it comprised two—one of sandstone, one of mudrock. These paired layers are referred to as lithologic couplets and are herein described as one bed. These are slurry-like, mass-flow or grain-flow deposits, distinguished from the similar, structureless sandstones of lithofacies A-2 by their weaker induration, poorer sorting, and greater number of granules.

Lithofacies A-2 (Fig. 3, a and b) comprises medium to very thickly bedded (terminology of Ingram, 1954), fine- to medium-grained, well sorted, very well indurated, structureless, mostly nongraded sandstone. It is distinguished from sandstones of lithofacies B, C and E by its thicker bedding, somewhat coarser grain size, presence locally of sparse granules and mud clasts, absence of interleaved mudrock, and the general absence of sedimentary structures. Beds are 0.9-2 meters thick, and bedding contacts are mostly sharp and flat. Some are irregular, due to amalgamation and local scour-and-fill structures up to 1 meter wide and 50 cm deep. Basal beds include randomly scattered, very coarse, quartz sand-grains and granules along with rare, angular mud-clasts up to 20 cm across. These sandstones, like

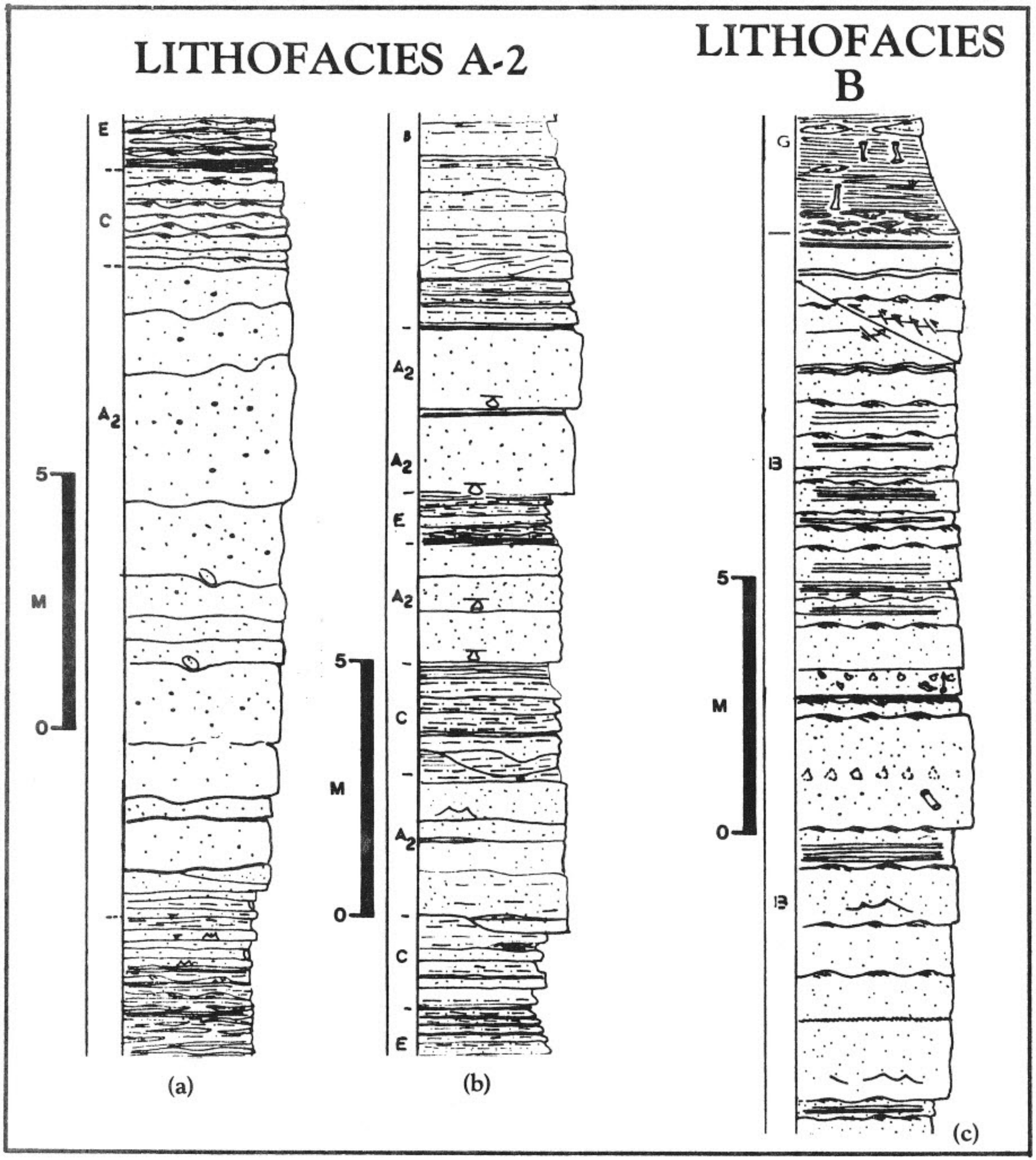

Fig. 3. Columnar sections typical of lithofacies A-2 (columns a and b) and lithofacies B (column c). Column a also typifies proximal-lobe deposits. See figure 1 for location of columns and figure 2 for legend.

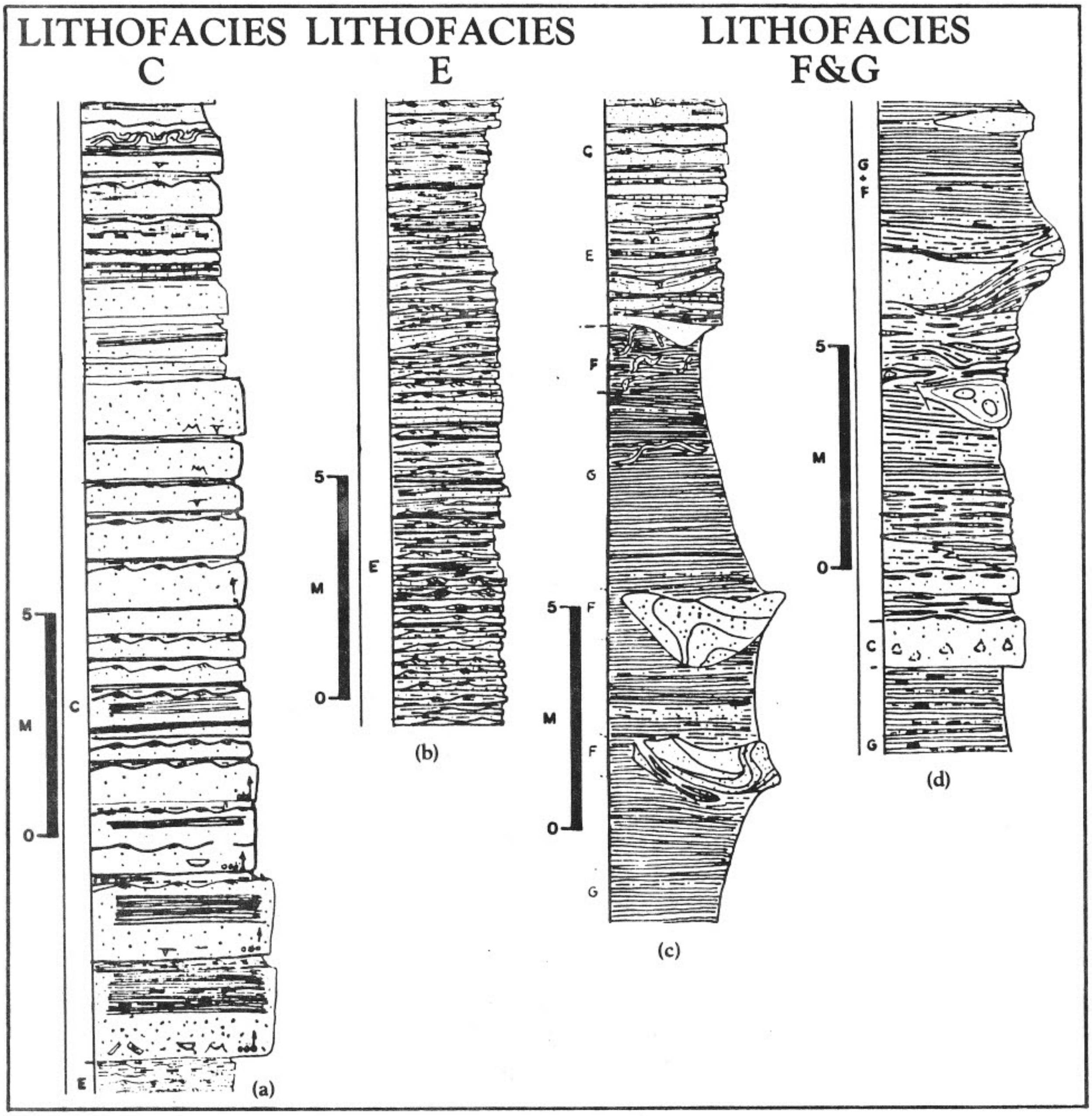

Fig. 4. Columnar sections typical of lithofacies C (column a), lithofacies E (column b), and lithofacies F and G (columns c and d). See figure 1 for location of columns and figure 2 for legend.

those of lithofacies A-1, appear to be grain-flow deposits.

Lithofacies B (Fig. 3c) comprises normally graded, fine- to medium-grained, well sorted sandstone in beds 30-220 cm thick. Classically developed Bouma abc sequences predominate, and Bouma bc sequences are common. This sandstone is thinner bedded and has better developed syndepositional sedimentary structures than those of lithofacies A-1 and A-2. The absence of an upper, muddy interval distinguishes it from lithofacies C.

Lower bedding contacts are flat and parallel to enclosing beds; scour and tool marks are common with flutes and grooves predominant. Upper bedding surfaces are wavy, due to asymmetric ripples. Beds appear to be laterally continuous beyond the outcrop with little variation in individual bed thickness. These sandstones are turbidity-current deposits and are a transitional facies between lithofacies A-2 and C or E. They occur downcurrent from lithofacies A-2 beds and also overlie them in upward-fining sequences.

Lithofacies C (Fig. 4) contains medium to very thick beds of sandstone-to-mudrock lithologic couplets, comprising a lower sandstone and an upper mudrock. The sandstone is generally well to very well indurated, fine to medium grained, normally graded and well laced with sedimentary structures, including abundant scour marks. The upper, fine-grained part is mostly thinner than the lower sandstone, is also normally graded, and contains clayey to silty mudrock with intercalated siltstone. The internal boundary between sandstone and mudrock can be either sharp or gradual.

Most beds are laterally continuous and traceable for several hundred meters. Thickness is between 60 and 150 cm and, for most beds, does not change markedly across outcrops. A few beds, however, vary in thickness because of local scours up to 50 cm deep and several meters across and because some beds coalesce. These are turbidity-current deposits and have nearly complete Bouma a-through-e sequences with the a or e interval missing from some beds.

Lithofacies D may be present but can not be distinguished from lithofacies E in this area. According to Mutti and Ricci Lucchi (1978), lithofacies D is finer grained than E; the beds are lithologic couplets that display more parallelism and greater lateral persistence, and most are base cut-out sequences with the Bouma a, b and c intervals missing. Within the Jackfork strata at Rich Mountain, lithologic couplets having fine-grained sand or silt in the lower part tend to be laterally discontinuous, irregularly bedded and base complete; thus they are interpreted as lithofacies E.

Lithofacies E, shown in Figure 4b in association with thicker and sandier beds of lithofacies C, comprises two types of beds: (1) thin- to medium-bedded, normally graded, lithologic couplets of fine-grained sandstone or siltstone and overlying mudrock and (2) relatively pure, nongraded siltstone. The lower sandstone or siltstone is generally well indurated, moderately to poorly sorted, and poorly graded to nongraded. The upper part contains clayey mudrock and intercalated siltstone.

Beds are 10 to 20 cm thick. Most beds are irregular and do not persist laterally more than about 100 meters. Bedding contacts are sharp, flat and erosional with the soles displaying scour marks and abundant tool marks. These are low energy turbidity-current deposits and are commonly associated with lithofacies C, F and G at Rich Mountain.

Lithofacies F (Fig. 4, c and d) comprises those deposits of other lithofacies that have undergone post-depositional, soft-sediment deformation. Volumetrically these are of minor importance and include disrupted sandstone blocks and dislocated, channel-fill deposits. The disrupted sandstone blocks are angular, up to 5 meters across, and generally sharply surrounded by mudrocks of lithofacies G. The dislocated channel-fill deposits are well amalgamated and show no internal sedimentary structures. Several display characteristic semi-circular, scoured bases. These deposits apparently underwent gravity-induced sliding and deformation shortly after deposition because overlying beds are undeformed.

Lithofacies G shown in the same columns with lithofacies F (Fig. 4, c and d) comprises thick sequences of laminated to bedded shale and associated mudrock that, in some localities, have been formally mapped as members. These mudrocks generally separate the different submarine-fan lobe sequences.

DEPOSITIONAL FACIES

Most of the lithofacies described occur in more than one depositional facies at Rich Mountain. The vertical sequence and, to a degree, the lateral associations identify five, submarine-fan depositional facies. Three occur within what Mutti and Ricci Lucchi (1978) call the outer-fan lobe, and we designate them as (1) proximal-lobe, (2) distal-lobe, and (3) lobe-fringe deposits. There are also (4) outer-fan channel and (5) hemipelagic or starved-basin deposits. These five types of deposits correspond with what

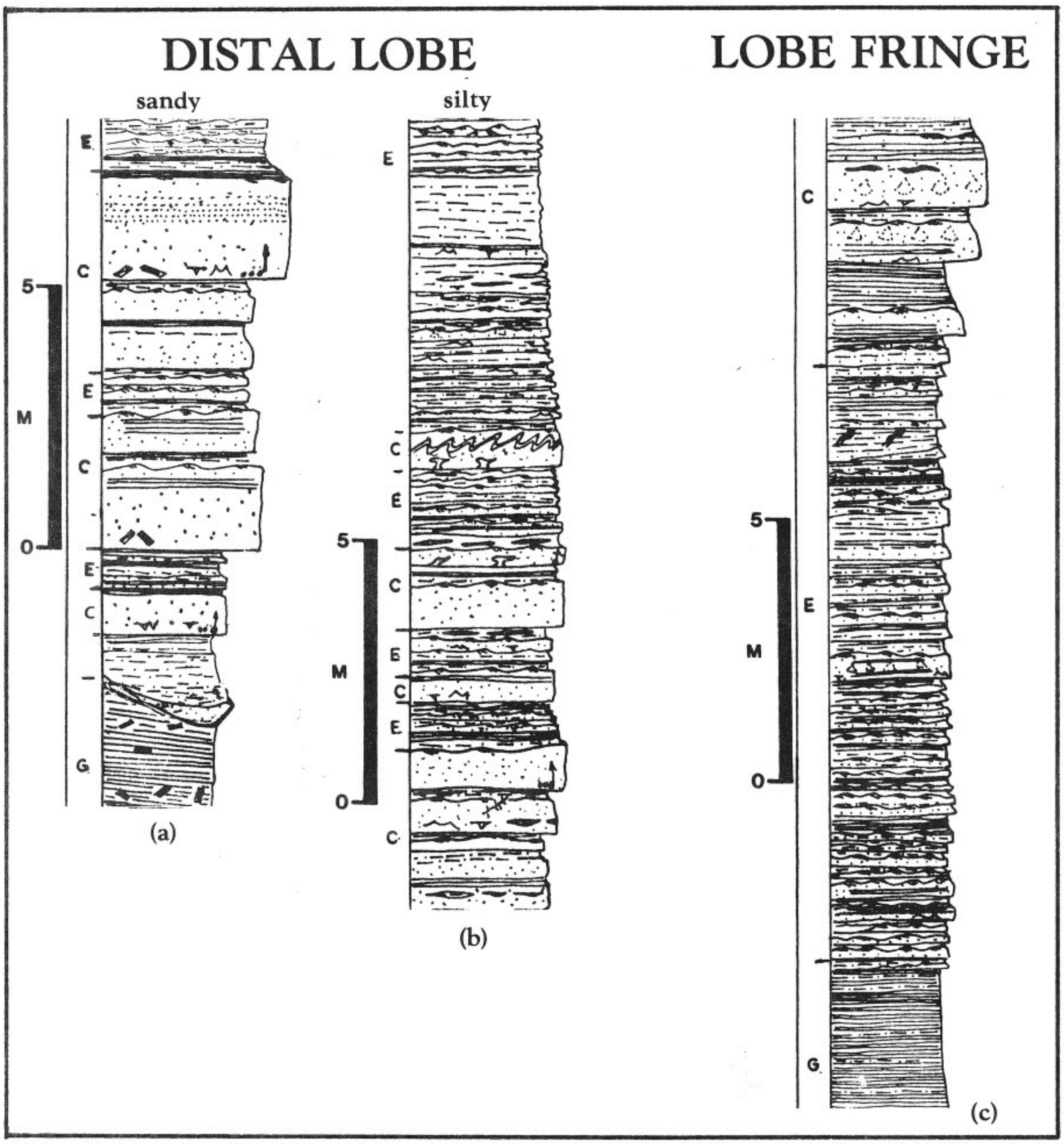

Fig. 5. Sandy distal-lobe deposits (column a), silty distal-lobe deposits (column b), and lobe-fringe deposits (column c). See figure 1 for location of columns and figure 2 for legend.

Normark (1978) has termed suprafan-lobe and lower-fan deposits. Although these names were first applied to semicircular fan systems, they can also be applied to the elongated, Carboniferous, submarine fans of the Ouachita trough.

Proximal-lobe deposits occur in the central and upcurrent parts of lobes, and all contain lithofacies A-2, along with B, C and/or E. Figure 3a shows an A2-C-E sequence approximately 15 meters thick. Proximal-lobe deposits exhibit both vertically symmetrical (upward increase in grain size and bed thickness, topped by an upward decrease in grain size and bed thickness) E-A2-E sequences and positive (upward fining and thinning) A2-B-C±E sequences. This latter sequence suggests slower abandonment of a lobe than the E-A2-E sequence and may even identify retrogradation.

Distal-lobe deposits (Fig. 5, a and b) are downcurrent of and peripheral to proximal-lobe deposits. They consist of lithofacies C and E in negative (upward increase in grain size and bed thickness) E-C sequences and in symmetrical E-C-E sequences. The E-C sequences may identify prograding distal-lobes that were abruptly abandoned. Conversely the E-C-E sequences may identify a prograding then slowly abandoned lobe or a series of laterally migrating, interfingering lobes.

Lobe-fringe deposits (Fig. 5c) comprise mostly lithofacies E and rare beds of lithofacies C. These deposits are closely associated with distal-lobe deposits: (1) as downcurrent facies equivalents, (2) as an enclosing facies, and (3) interleaved with distal-lobe deposits in vertical sequences.

Outer-fan channel deposits (Fig. 6) are rare and comprise one or two beds of lithofacies A-2 sandstones in scoured channels up to 2.5 m deep and up to 100 meters or more across. They commonly cut into lithofacies G shales and are overlain by lithofacies E beds of the lobe-fringe facies. Channel-fill deposits

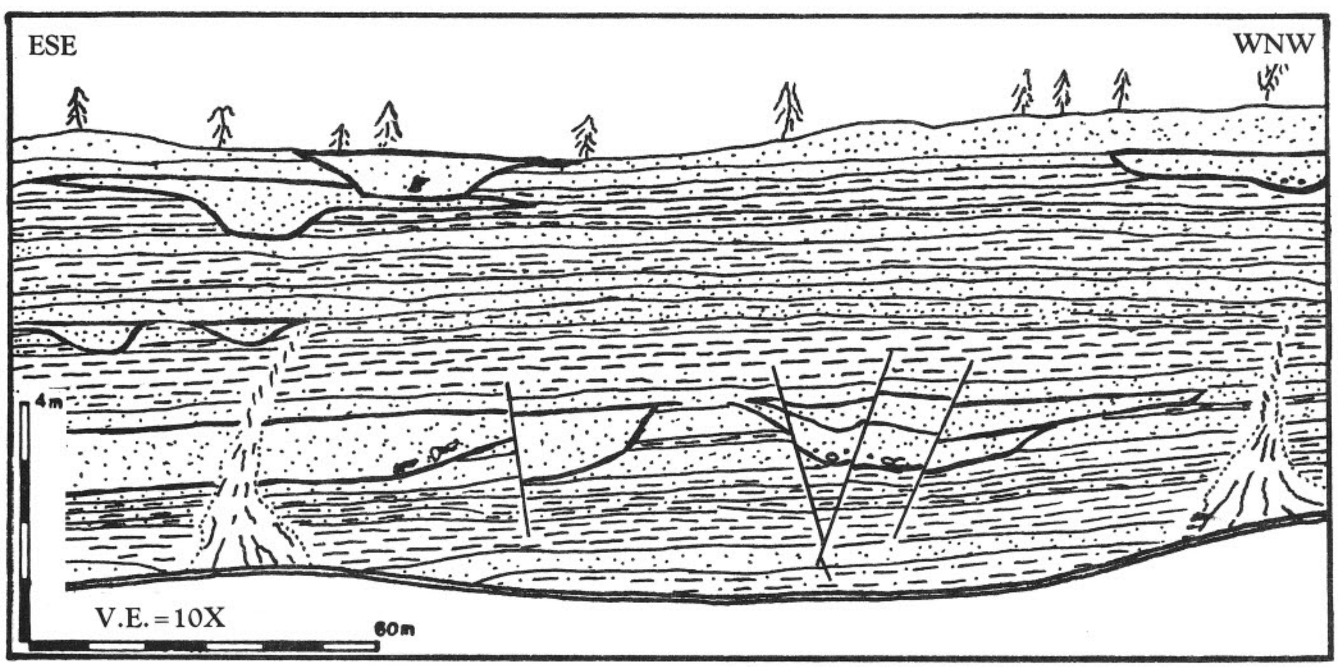

Fig. 6. Geologic sketch of sand-filled channels in a silty, clayey sequence along the southwest side of the Talimena Trail (SE ¼, sec. 25, T1S, R31W, Ark.). See figure 1 for location of section and figure 2 for legend.

are generally asymmetrical with one steep bank and one gentle bank, suggesting the channels were curved. There are no associated natural-levee deposits, per se, although some of the sandstones do taper to a thin edge within a few tens of meters.

OUTER-FAN DEPOSITIONAL LOBES

Facies-correlation diagrams along strike, which nearly parallels the paleocurrent heading, and observations across the paleocurrent heading suggest that the outer-fan lobes are elongate. They comprise proximal-lobe, distal-lobe, and lobe-fringe deposits enclosed by hemipelagic mudrock. In longitudinal section these outer-fan lobes display three different shapes. Most are bow-tie shaped; one is lens shaped, and two are wedge shaped.

There are at least 15 bow-tie shaped lobes at Rich Mountain. The proximal lobe and the distal lobe are both thicker than the transition zone between them. The proximal lobe is the locus of sand deposition and contains a few thick to very thick beds of medium- to fine-grained sand but little mud. Conversely the distal lobe contains numerous thin to moderately thick beds of fine-grained sand and mud. Consequently the proximal-lobe and distal-lobe deposits are about equally thick. However, the transition zone is thinner because sandy beds from the proximal lobe are thinner but not supplemented by the more numerous, thin-beds of the distal lobe. This bow-tie shaped pattern may also reflect concurrent aggradation of the proximal lobe and progradation of the distal lobe.

The one lens-shaped lobe thins to both east and west and probably represents a tangential slice through the margin of a proximal-lobe deposit. The two wedge-shaped outer-fan lobes show the transition from proximal lobe to distal lobe to lobe fringe and also occur along sections oblique to the lobe axis. Several of the proximal-lobe deposits resemble channel-fill deposits in terms of the facies and facies changes they display across paleocurrent heading. For example, lithofacies A-2 passes laterally across a lobe into lithofacies B within 1.5 km (SW ¼, sec. 30, T1S, R30W to NE ¼, sec. 6, T2S, R30W). This distance of transition is many times shorter than the same A-2 to B transition along the lobe axes. Most channel deposits display equally marked facies changes across the channel axis. Thus, outcrop sections across a channel and across a lobe appear similar. These sharp lithofacies changes within such short distances across the lobe are likely indicative of the extreme east-west elongation of the Carboniferous, Ouachita, submarine-fan system.

ACKNOWLEDGEMENTS

Financial assistance from the Arkansas Geological Commission and Turkish Petroleum Corporation is acknowledged. We especially thank Charles G. Stone and Boyd R. Haley for their advice, assistance and encouragement.

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EXPOSURES OF JACKFORK GROUP SANDSTONES NEAR DE GRAY LAKE, ARKANSAS

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The Pennsylvanian Jackfork Group [1/] is well exposed at several locations around and near DeGray Lake. Figure 1 shows the location of some of the more accessible exposures in the area. R. C. Morris (1974) has published measured sections of the Jackfork along the DeGray spillway and in a roadcut along Highway 7 south of the DeGray Lake Dike. D. M. Stone (1981) and Stone et al. (1984) have published 440 feet of section described and measured along a roadcut near milepost 81 on Interstate 30, about three miles east of DeGray Lake (east of Fig. 1). About 80 feet of sandstone is exposed at a quarry just west of Highway 7 in the SE ¼ of section 13, T6S, R19W.

Near DeGray Lake the Jackfork Group is a 6,000-foot thick turbidite sequence which is about 70% wackes and arenites (Morris, 1971). Morris (1971) also found the sandstones had a mean grain size of 2.8 phi (0.14 mm) and an average standard deviation of 1.0 phi unit. He found the average composition to be 96% siliceous resistates, 1.3% feldspars, and 2.7% unstable lithic fragments (total equals 100% of framework grains). Morris found an average 14% matrix content and noted carbonaceous plant remains, crinoid columnals, shale chips, and molds containing ferric clay residue. A study of the clay-mineral suite of the Jackfork Group (Davis, 1968) revealed (in decreasing abundance) illite, mixed-layer clay, chlorite, and kaolinite. A gradual but persistant increase in the percentage of illite upwards within the section was also noted. Lepidocrocite was also found in one interval.

Strata of the Jackfork Group were deposited mainly by turbidity currents flowing westerly down the axis of an elongate, marine trough (Morris, 1974). The beds have common turbidite features including sole marks and repeated Bouma sequences. Chaotic beds and hemipelagic strata are also present.

Near the south end of the spillway is an interesting exposure of about 60 feet of sandstone, conglomeratic sandstone and conglomerate (Fig. 2). These beds are thick bedded to thin bedded (terminology of McKee and Weir, 1953), are medium light gray on fresh surfaces, weather to moderate yellowish brown, range in grain size from fine sand to pebbles, contain shale clasts up to 30 cm in length, and are moderately well sorted to poorly sorted. Larger grains are generally well-rounded quartz pebbles with a smaller number of angular to rounded shale clasts. Sedimentary features present include normal grading, scour marks, and less commonly undulose to planar laminations. This assemblage of beds is interpreted as being transitional between lithofacies A and B of Mutti and Ricci Lucchi (1978), representing a middle-fan, channel-fill deposit. This assemblage of beds has been traced and correlated along strike for a distance of 3.5 miles using aerial photographs

[1/] Recognized as the Jackfork Sandstone in Arkansas by the Arkansas Geological Commission.

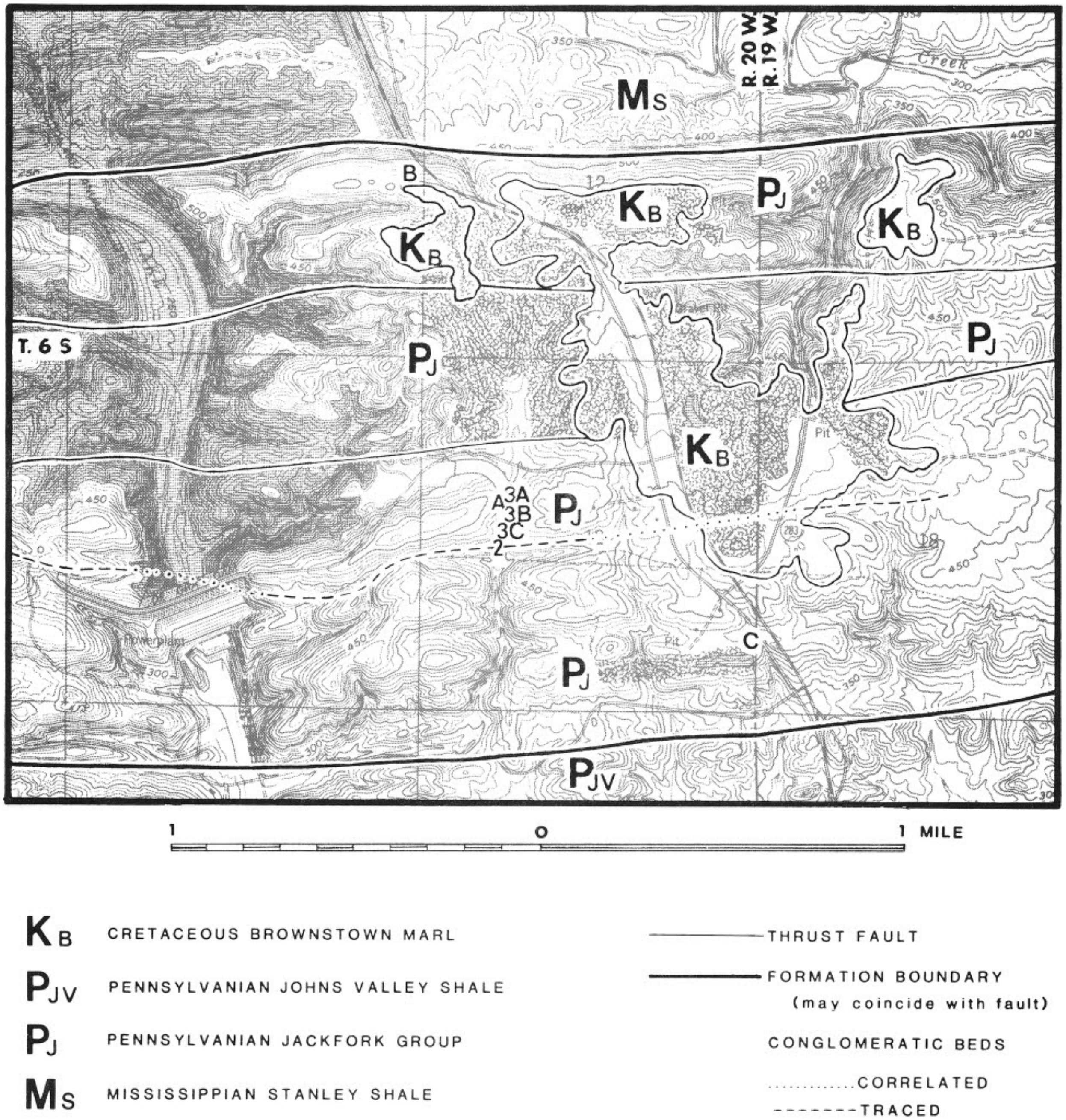
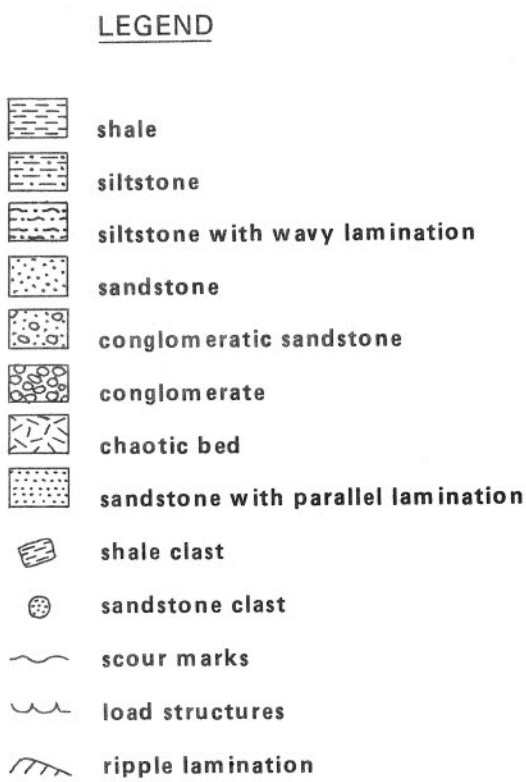


Figure 1. Jackfork Group and associated strata, DeGray Lake, Arkansas. The strata strike nearly east-west and dip southerly at 42° to 52°. Selected outcrops are located and identified as follows: A, DeGray Lake spillway including the columns in Figure 2 (2) and Figure 3 (3A, 3B, and 3C); B, Highway 7 south of DeGray Lake as described by Morris (1974); and C, the quarry in SE¼, sec. 13, T6S, R19W. Faults and contacts from Haley et al. (1976).

and by field tracing of nearly continuous exposures.

Typical beds and bedding sequences at the DeGray Lake spillway are shown in Figure 3. These sequences are stratigraphically lower than that of Figure 2. Column A depicts predominately sandy sequences, comprising thin to thick beds of generally fine-grained sandstone interbedded with and enclosed by thin-bedded siltstone and very fine-grained sandstone. Column B depicts a chaotic, 3.5 m-thick bed of mudrock containing a few sandstone clasts and concretions near the top of a mostly shaly interval with some siltstone interbeds. The upper 9 meters comprises thin-bedded, fine- to medium-grained sandstone with interbedded siltstone and shale. Column C depicts a sequence of mostly shale, siltstone, and very thin-bedded, very fine-grained sandstone interrupted by intervals of thin- to thick-bedded, fine-grained sandstone.



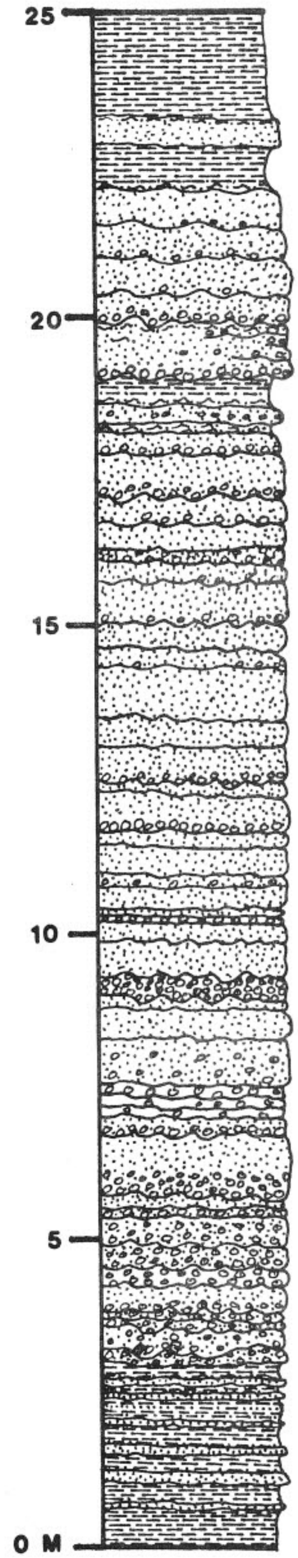


Figure 2. Sandstone, conglomeratic sandstone and conglomerate exposed at south end of the DeGray Lake spillway.

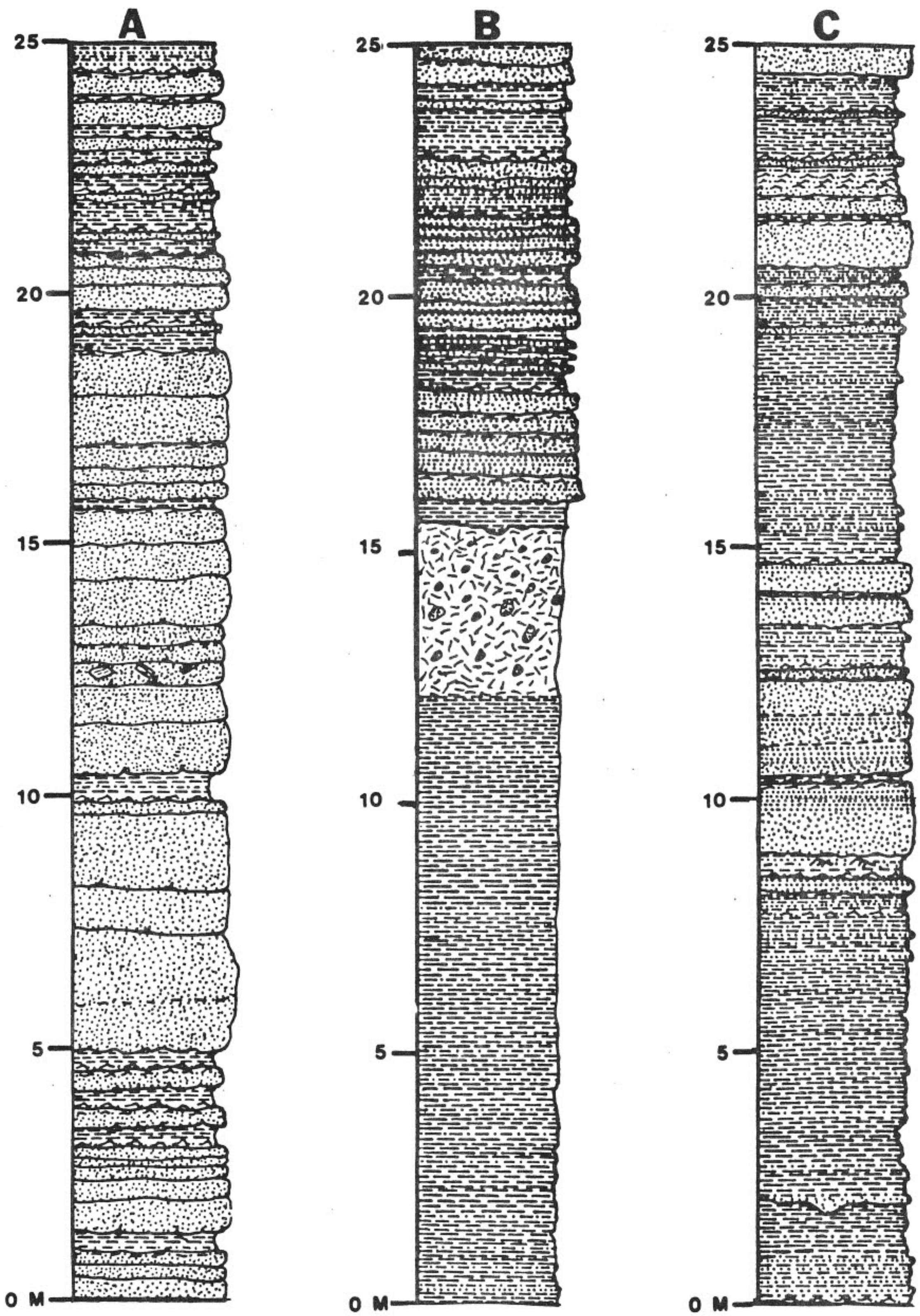


Figure 3. Typical beds and bedding sequences at the DeGray Lake spillway. See Figure 2 for explanation of symbols and patterns.

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REELFOOT RIFT
ILLINOIS BASIN – OUACHITA GEOSYNCLINE CONNECTION[1/]

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ABSTRACT

This paper recounts efforts to reconstruct the lower reaches of the ancestral Illinois basin Chesterian deltas and their probable relationship to the Ouachita geosyncline. The ultimate aim was to locate the most likely position of the Chesterian continental slope where large submarine fans, genetically related to these Chesterian deltas, were postulated to have formed. Once this was accomplished, refinement of the prospective area by subsurface and geophysical means in the search for oil and gas could be mounted.

INTRODUCTION

The economic significance of submarine fans, or turbidites, has been well documented for years. In southern California, the most noteworthy are the Los Angeles basin, 8 BBO produced, and Ventura basin, 2 BBO produced. Southeast Texas/southwest Louisiana host the Hackberry Sands (Fig. 1), the deep Anadarko basin (Fletcher basin) in southwest Oklahoma, the Woodbine in east Texas, the lower Tuscaloosa in central Louisiana; Frigg, Ekofisk, Magnus in the North Sea, and the Cisco Sands of west Texas all add to the growing list of significant discoveries in the last decade contained in deep-water clastics.

To vividly illustrate the size (thus potential) of submarine fans, I have shown the Laurentian fan (Fig. 2) south of Newfoundland as an example. Observe also the "delivery system" that supplied clastics to the fan, the Lawrence rift to the north. In real terms, this fan is several times larger in area than the state of Pennsylvania!

RIFT INFLUENCE ON SEDIMENTATION

While fans themselves are fairly well known, little light, until recently, has been shed on the enormous influence rift systems have upon submarine fans, and/or deltaic systems. Several cases in point are the Benue rift in Nigeria, site of the Niger River and delivery system to the Niger Delta; the aforemenioned Lawrence rift, site of the St. Lawrence River delivery system supplying the Laurentian fan; the Viking graben, localizing submarine fans that produce at Frigg, Ekofisk, Magnus and other North Sea Fields; and the Anadarko aulacogen (Fig. 1), concentrating tens of thousands of feet of clastics. Simply put, rifts are structural troughs, rivers flow in troughs, and rifts on the cratonic margins often are failed-arm aulacogens, thus connected to open seas, dumping loads of clastics at their mouths.

RECONSTRUCTION OF THE CHESTER PALEOGEOLOGY

Sloss, et al. (Fig. 3) depict the Illinois basin as an enclosed half-basin during Chester time.

1/ Reprinted, with minor revisions, by permission from the 1984, Kentucky Geology Oil and Gas Association, June volume, p. 20-38.

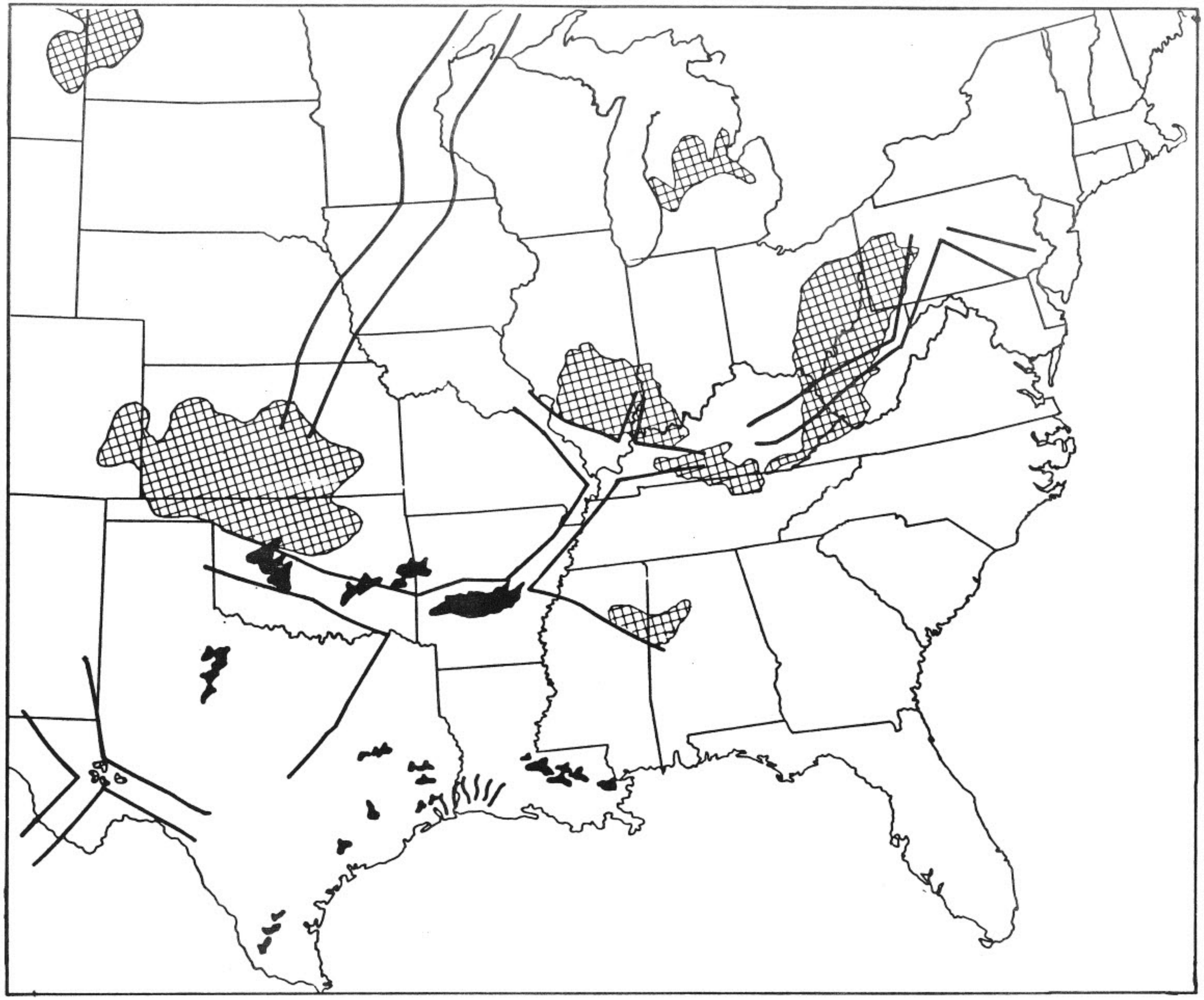

Figure 1. Eastern United States showing areas of deep-water clastics (black) and Chesterian (i.e. Mississippian) hydrocarbon production (cross-hatched).

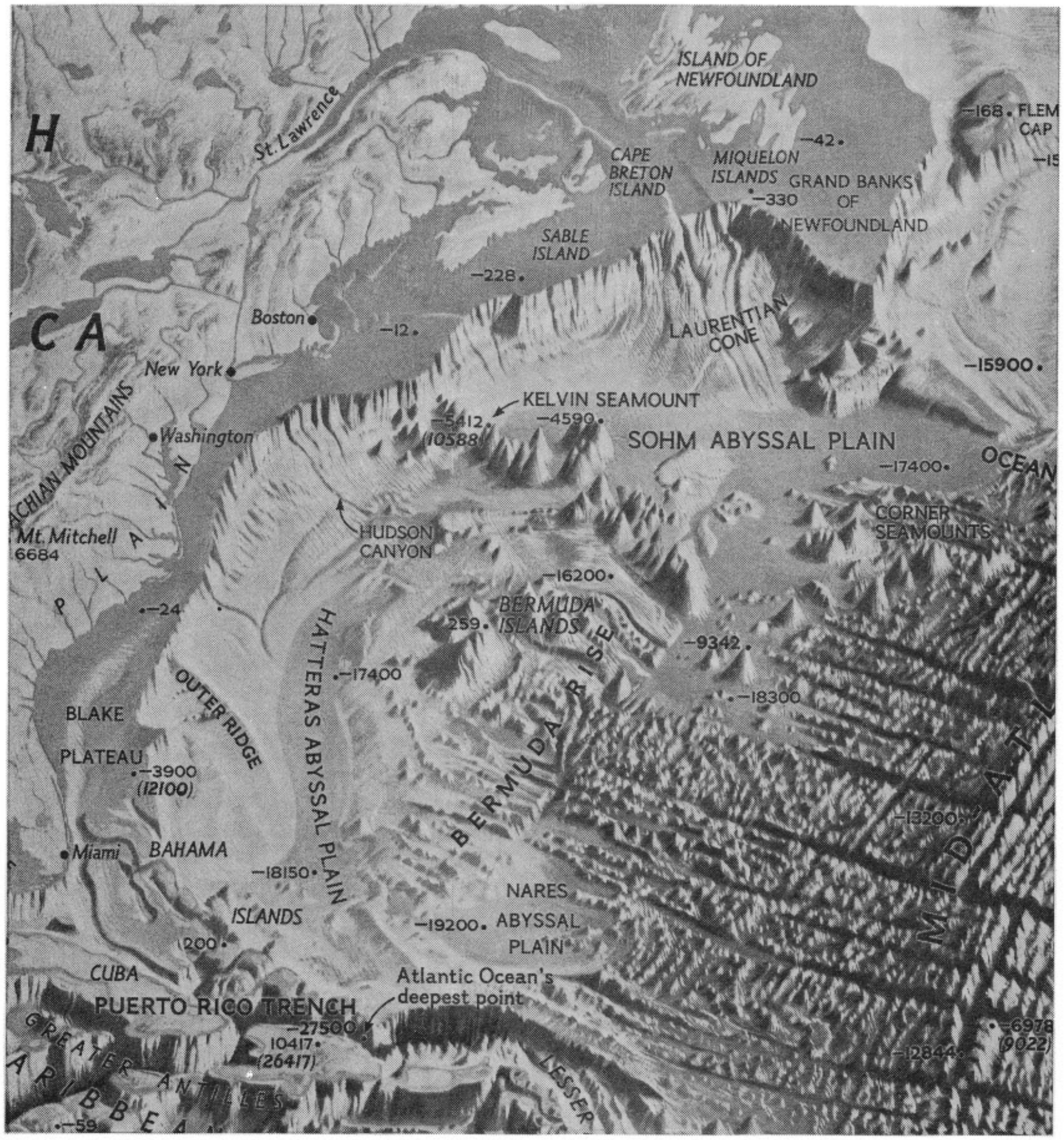

Figure 2. A part of the National Geographic Society's map, "Atlantic Ocean Floor," 1973, used here with the Society's permission to show the extent of the Laurentian fan off the Maritime coast of Canada. Fan complex extends from the top of Laurentian Cone southward to a line about one half the distance along the southern arm of the Sohm Abyssal Plain. Scale approximately 380 miles per inch at the latitude of Kelvin Seamount.

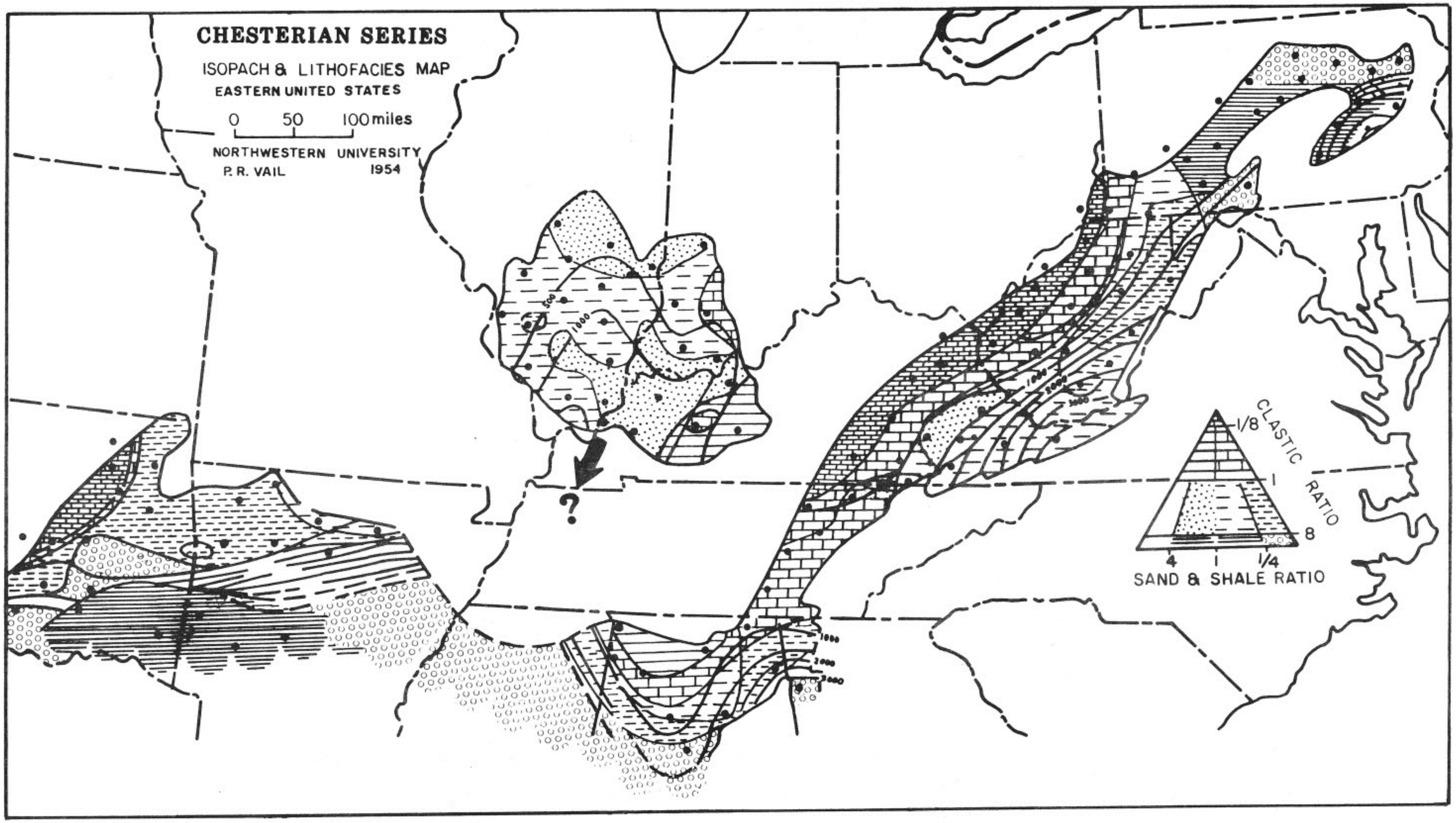

Figure 3. Isopach and lithofacies map of the Chesterian Series (Sloss, Dapples, and Krumbein, 1960).

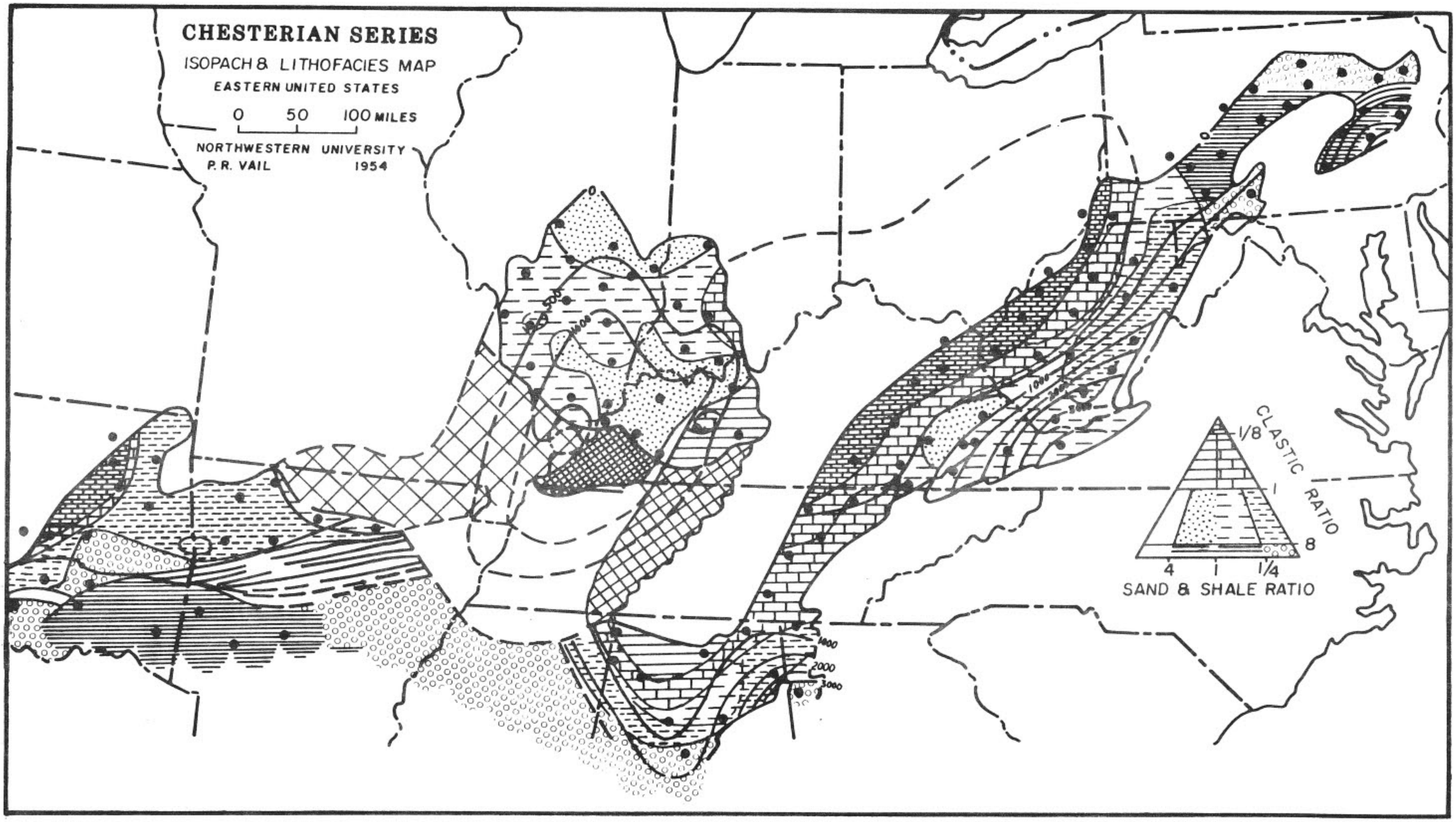

Figure 3A. Isopach and lithofacies map of the Chesterian Series (Sloss, Dapples, and Krumbein, 1960), partly restored by the author.

The other half of the basin can be restored by completing the isopachous contours and extending the facies to connect with those to the southeast and southwest (Fig. 3a). Once this is done, knowledge that deltas in open basins have a a submarine fan counterpart raises these questions; Was the Illinois basin open to the south-southwest, and if so, where was the fan system associated with it? The potential discussed earlier dictated pursuit of these answers.

At the May, 1980 AAPG Meeting in Denver, Phillip Heckel relayed virtual proof the basin was open to the southwest, and we were off to the races to answer the second question.

Hildebrand and others (1977) had done extensive gravity, aeromagnetic, and seismic work in the area in question (northeast Arkansas) to evaluate seismicity and earthquake potential of what was termed the "New Madrid earthquake zone." A large, well-defined rifted area emerged, enabling at least a partial answer to the second question. Subsequently, the area of aeromagnetic investigation was enlarged by the Arkansas Geological Commission (Fig. 4). John Bible in Houston was consulted to make a preliminary tectonic map and top magnetic basement map (Fig. 5). John found not only the mouth of the rift, but what he surmised was the shelf edge and a major graben system, roughly perpendicular to the rift axis, which was interpreted to be at least part of the continental slope. Because of the proximity to and notoriety of Reelfoot Lake in northwest Tennessee, this rift was dubbed the Reelfoot rift.

Figure 6 depicts the interpreted reconstruction of the Chester paleogeology; restoration of the southern half of the Illinois basin biased to the configuration of the rift, emplacement of shelf facies during Chester time (Pitkin Limestone, Batesville Sandstone, Fayetteville Shale, Pennington Shale. Parkwood Formation, Floyd Shale), and slope and geosynclinal facies that are stratigraphic equivalents to these (Stanley Shale and Chester turbidite sands.)

Isopachous values for the Chester in northwest Oklahoma, Arkansas (non-eroded areas), Mississippi, and Alabama, are from published data and/or subsurface information. The values from what is now the Ouachita Mountains are from outcrops. Quite numerous articles from various authors, as well as lengthy personal conversations with C. G. Stone and W. M. Caplan of the Arkansas Geological Commission over a period of two years went into this reconstruction. To my knowledge, this is the first localizing of the mouth of the rift and the adjacent slope deposits to the Chester deltas.

RIFT HISTORY

Although the primary interest in the Reelfoot rift was concentrated in Mississippian age strata, these investigations uncovered some hints (later confirmed in part by seismic work) as to the history of the rift. The rift apparently became active during late Precambrian-Early Cambrian time in response to continental (?) orogeny that not only induced rifting, but generated large amounts of clastics as a result of concomitant uplifting. During Late Cambrian to Early (?) Devonian, widespread carbonates indicate a time of quiescence, hence little orogenic movement and probably little topographic expression of the rift. During Early Mississippian (possibly Late Devonian) deep-water shales and cherts reflected the beginnings of orogenic movement and probable early, though slight, movement of the rift. By Late Mississippian, neighboring basins were receiving siliciclastics, reflecting uplift and crustal adjustment (rifting). It was during this period that large amounts of shelf clastics were being funneled down the Reelfoot rift into the Ouachita geosyncline; the geosyncline also received clastics from a high-

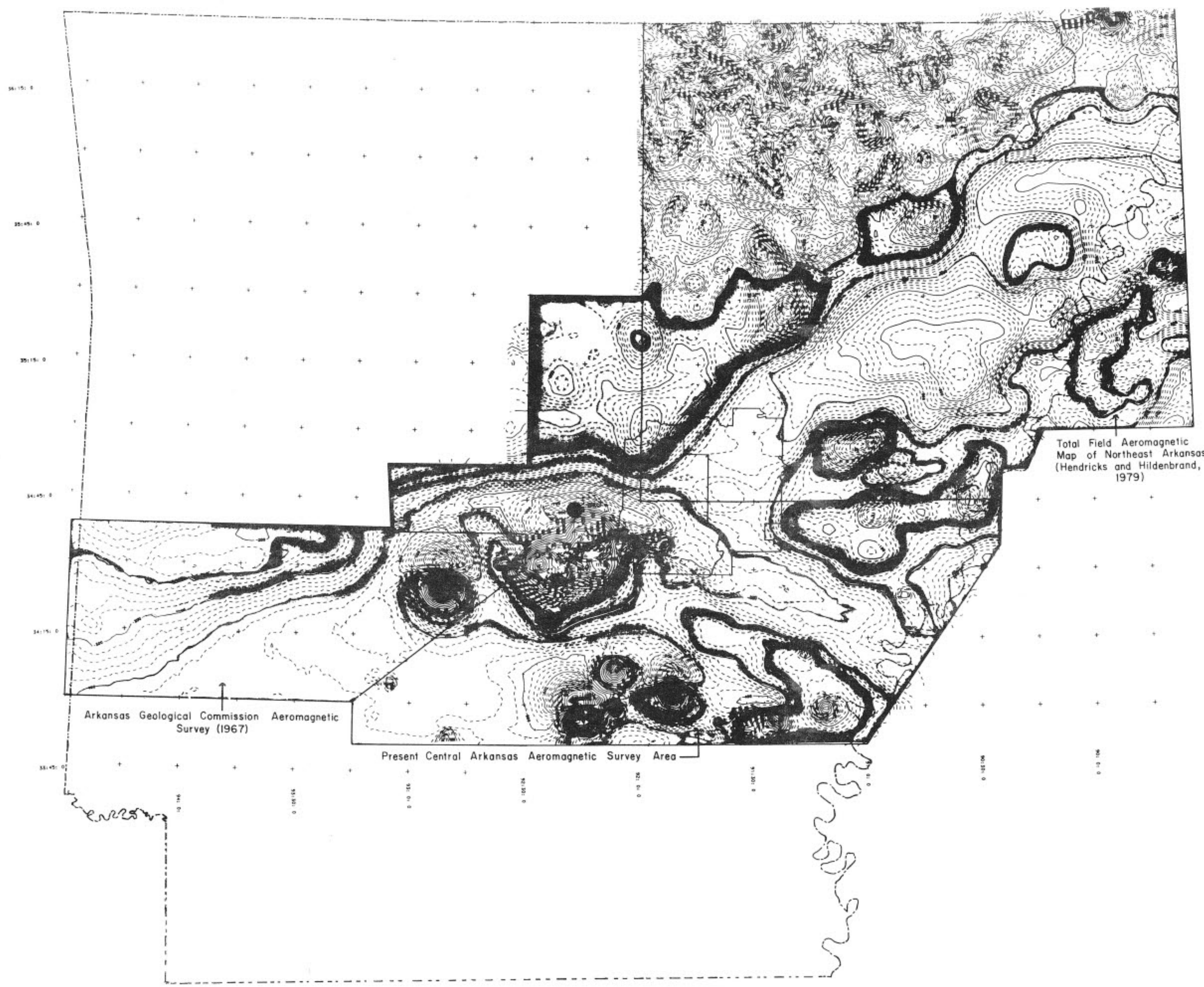

Figure 4. Aeromagnetic map of part of Arkansas compiled by the Arkansas Geological Commission.

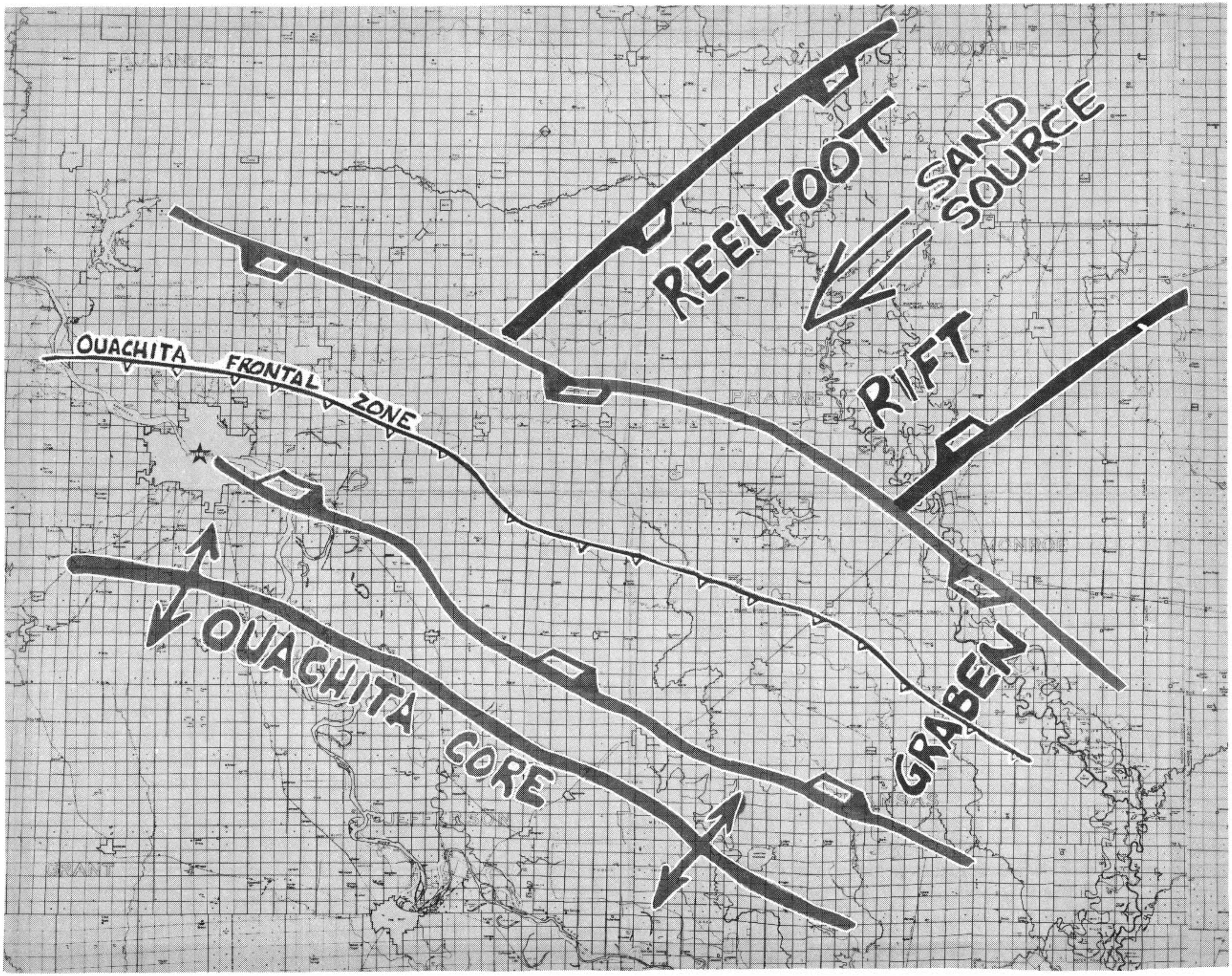

Figure 5. Map showing relationship of major tectonic features. Modified from John Bible (1983).

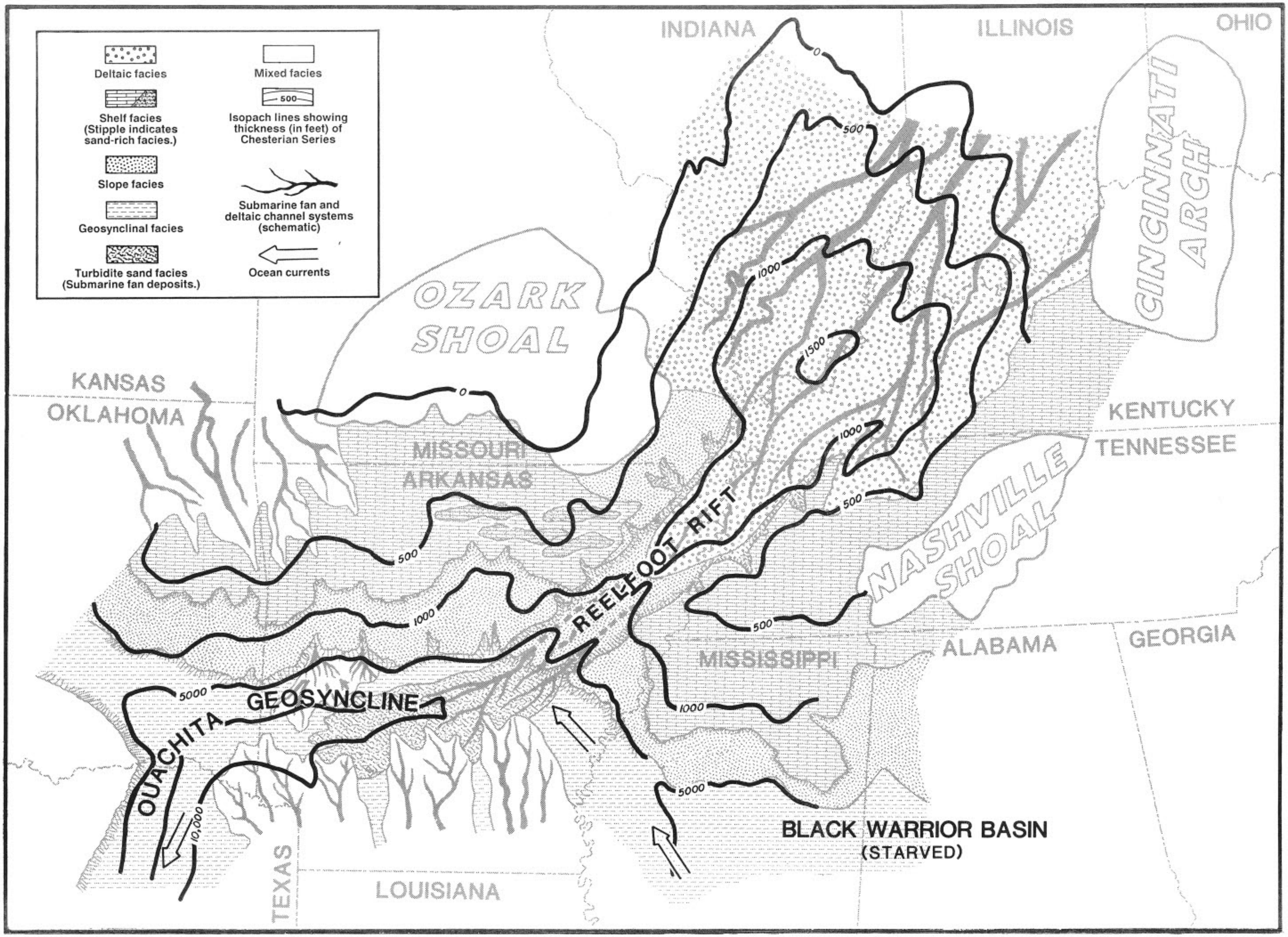

Figure 6. Interpreted reconstruction of Chester paleogeography. In part from Berry (1984).

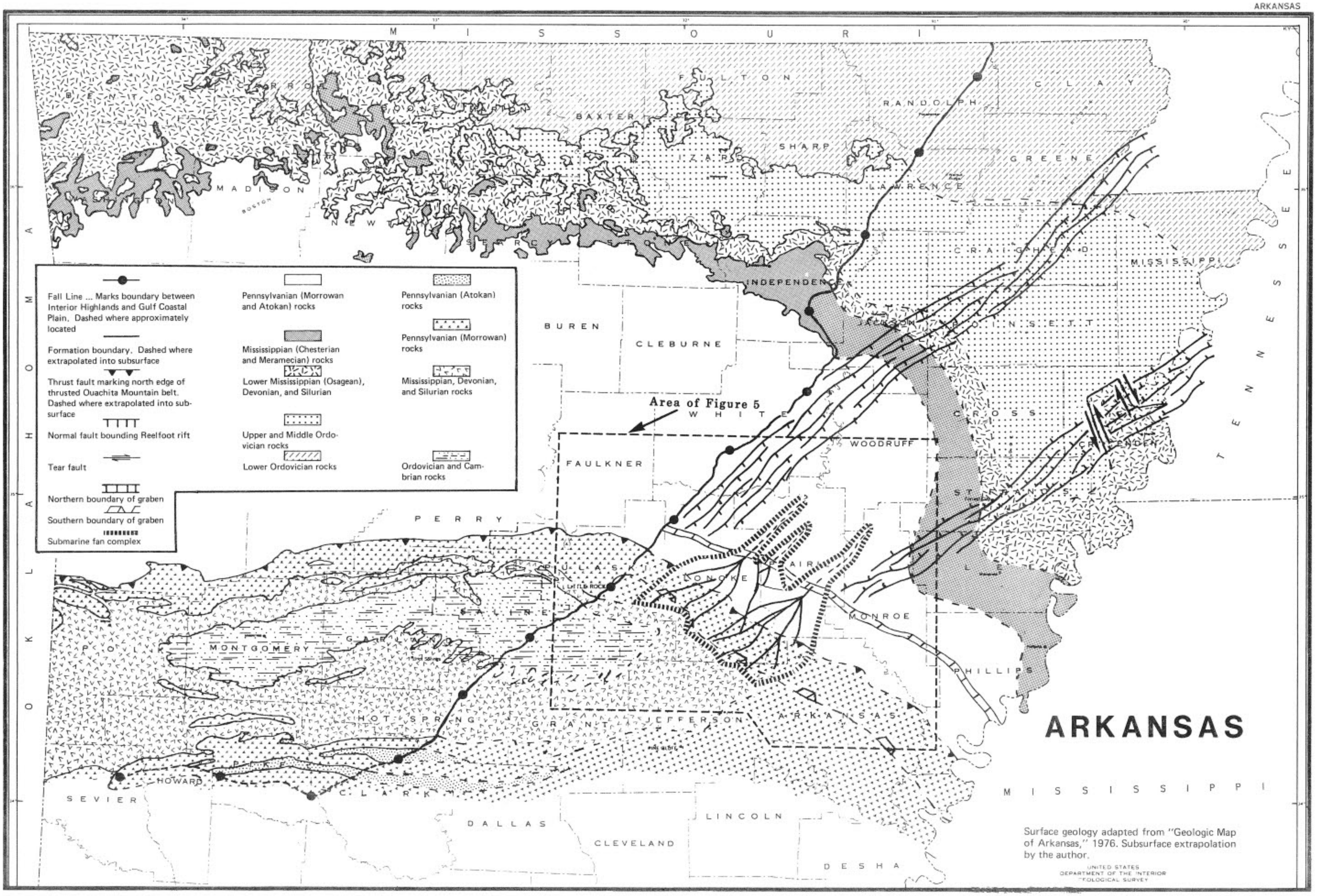

Figure 7. Interpreted subcrop map of Arkansas compiled by extrapolation of surface trends, well data, and limited geophysical data.

land to the south (colliding continent-South America?) and west.

By the end of the Mississippian Period, continental collision had begun. The Ozark, Cincinnati, Nashville and other shoal areas began to rise in response to collision, and were exposed to erosion. As this progressed, the Pascola arch began to rise between the Ozark and Nashville uplifts, exposing previously desposited Mississippian deltaic deposits. These second-or third-order clastics comprised part of the Jackfork formation, and were transported down the Reelfoot rift into what was left of a disappearing Ouachita geosyncline and into a deep emerging foreland basin parallel to and north of the Ouachita geosynclinal axis. This foreland basin received sediment throughout most of the Pennsylvanian Period.

PRESENT DAY GEOLOGY

Once this interpretation reached the final stages of refinement (Fig. 5), it became apparent that no sooner are two questions answered, than two more arise. Considering the proximity of the interpreted submarine fans to the Ouachita Mountains, are there any sizeable areas undisturbed? And if so, are there hydrocarbons and suitable traps within drillable depths?

In pursuing these questions, an interpreted subcrop map (Fig. 7) of Arkansas under the Mississippi delta alluvium was compiled from extrapolation of surface trends, subsurface well data, and limited geophysical data. It can be seen that an area 30 miles by 40 miles remained undisturbed by thrusting. One half remained under the frontal zone, one half outside. If tectonic and stratigraphic relationships present in other rift/slope systems hold true for the Reelfoot, then this area should contain the proximal fan sediments, those with highest sand percentages. Traps should be primarily stratigraphic, as sands deposited at the break in the continental slope are not present updip on the shelf within the rift. This is because the same currents which swept the winnowed shelf sands down the rift, swept it clean as the source was shut off. Upwards of 6000 feet of clastic section, 10% – 20% of it sand, is anticipated in the Mississippian Chester section alone.

EPILOGUE

Throughout 1983, a fairly comprehensive seismic program was conducted. This confirmed the aeromagnetic interpretation with extremely close agreement. The frontal zone, shelf edge, slope, and large graben perpendicular to the rift axis were recognized, as well as several very large nonthrusted structures.

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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	1,900'
Blakely Sandstone - shale, sandstone, and erratic boulders	450'
Mazam 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'

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.		ℙby	Missing		
			Savanna Fm.		ℙsv			
			McAlester Fm.		ℙma			
			Hartshorne Sandstone		ℙhs			
		ATOKA	Atoka Fm.		ℙa	Atoka Fm.		ℙa
		MORROW	Bloyd Shale	Kessler Ls. Mbr.	ℙbh: ℙpk	Johns Valley Shale		ℙjv
				Woolsey Mbr.	ℙpw			
				Brentwood Ls. Mbr.	ℙpb			
			Hale Fm.	Prairie Grove Mbr.	ℙhp	Jackfork Fm.		ℙj
				Cane Hill Mbr.	ℙhc			
	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			
			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
			Lafferty Limestone		Slsb	Blaylock Sandstone		Smb
			St. Clair Limestone					
		LOWER	Brassfield Limestone					
ORDOVICIAN		UPPER	Cason Shale			Polk Creek Shale		Opc
			Fernvale Limestone		Of			
		MIDDLE	Kimmswick Limestone		Ocj	Bigfork Chert		Obf
			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		Oc
			Gasconade-VanBuren Fm.	Gunter Mbr.				
CAMBRIAN		UPPER	Eminence Dolomite					
			Potosi Dolomite					
			Derby-Doerun-Davis Fm.					
			Bonneterre Dolomite			Basal Collier and Older rocks not exposed		
			Lamotte Sandstone					
PRE-C			Igneous Rocks					