STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

Norman F. Williams, State Geologist

MISCELLANEOUS PUBLICATION 18

CONTRIBUTIONS

to the

GEOLOGY of ARKANSAS

I

Edited By

John David McFarland, III

Little Rock, Arkansas
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S T A T E O F A R K A N S A S
Frank White, Governor

Arkansas Department of Commerce
Shirley Thomas, Director

Arkansas Geological Commission
Norman F. Williams, State Geologist

PREFACE

This publication contains various papers and abstracts concerning the geology of Arkansas. The papers were collected by a "call for papers" issued in February, 1981 and represent the diversity of geological studies being conducted in Arkansas. The abstracts are from thesis work conducted by various students at the universities indicated with each abstract and are printed here to make the reader aware of these, often unpublished, research efforts.

The preparation of this volume was made possible by the work of several people. W. V. Bush, B. R. Haley, J. M. Howard, C. G. Stone, and the rest of the staff of the Arkansas Geological Commission gave freely of their time in proof reading and editorial suggestions. Without them the preparation of this publication would not have proceeded as it did. A special thanks goes to: Loretta Chase who typed and composed the manuscripts; and, L. P. Kelone and April Brewer who assisted in the drafting of various figures and cover design.

John David McFarland, III
Editor

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John Gray .... El Dorado

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A B S T R A C T S (cont.)

THE PRAIRIE CREEK KIMBERLITE, ARKANSAS

by

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ABSTRACT

The Prairie Creek intrusion of middle Cretaceous age is characterized by three rock types: micaceous peridotite, kimberlite breccia, and associated tuff. The intrusion is oval shaped covering about 0.3 km^2. The peridotite crops out in the northwestern half of the intrusive and is nearly 600 m (~1970 ft) long and 240 m (~790 ft) wide. Kimberlite breccia covers the eastern 40% of the intrusive and is about 480 m (~1575 ft) long and 240 m (~790 ft) wide. The tuff occurs in scattered patches.

The absence of magnesian ilmenite, enstatite, chrome diopside, and rarity of garnet in the kimberlite breccia suggests that it is not a true kimberlite (*sensu strictu*), however, the breccia is highly altered and the observed mineralogy is not believed to be representative of the original composition.

The genetic relationship between peridotite and breccia is not fully understood, but the chemical similarity of the two rock types suggests a differentiation trend from micaceous peridotite to kimberlite breccia; however, geophysical evaluations suggest the sequence of intrusion is breccia, peridotite, and then tuff. The kimberlite breccia is believed to have undergone several separate intrusions or pulses. Field exposures are very weathered and do not aid in interpretation.

Magnetic data for over 1000 stations clearly distinguish the boundaries of the peridotite. However, the contacts between the kimberlite breccia, tuff, and country rock are indistinguishable. Qualitative interpretation of profiles suggests that the peridotite is a dike-like, vertical intrusion of variable thickness dipping slightly to the south. The shape of the kimberlite is believed to be similar. Both rock units form funnel shaped bodies that rapidly narrow at depth.

INTRODUCTION

Very little pre-1977 literature is available on the Prairie Creek kimberlite. Historical data for the early 1900s are summarized in Miser and Ross (1923b) and Miser and Purdue (1929). U. S. Bureau of Mines Report 4549 summarized the mine potential for wartime production of diamonds (Thoenen et al., 1949) and includes an excellent historical summary of pre-1943 papers. Gregory (1969) completed a geochemical study of the Prairie Creek kimberlite and outlier dikes. More recently, Langford (1973), Giardini and Melton (1975a, b), and Melton and Giardini (1975) have published articles on Prairie Creek diamonds and their inclusions.

The Prairie Creek intrusion was intensely studied during 1975-1977 by Bolivar (1977) and Lewis (1977). These works include detailed geological, chemical, geophysical, and Rb-Sr isotopic studies. Also in 1977, the American Geophysical Union sponsored the Second International Kimberlite Conference. Several papers presented at this meeting involved the Prairie Creek kimberlite--Bolivar and Brookins (1979), Brookins et al. (1979), Lewis and Meyer (1977), Steele and Wagner (1979), and Meyer et al. (1977). Bolivar et al. (1976) and Lewis (1977) discuss the geophysical data in detail. This report is mainly to describe the geology of the Prairie Creek kimberlite and associated rocks.

LOCATION AND GENERAL SETTING

Four bodies of ultramafic rock found near Murfreesboro in Pike County, Arkansas, are now recognized as kimberlites (Meyer,

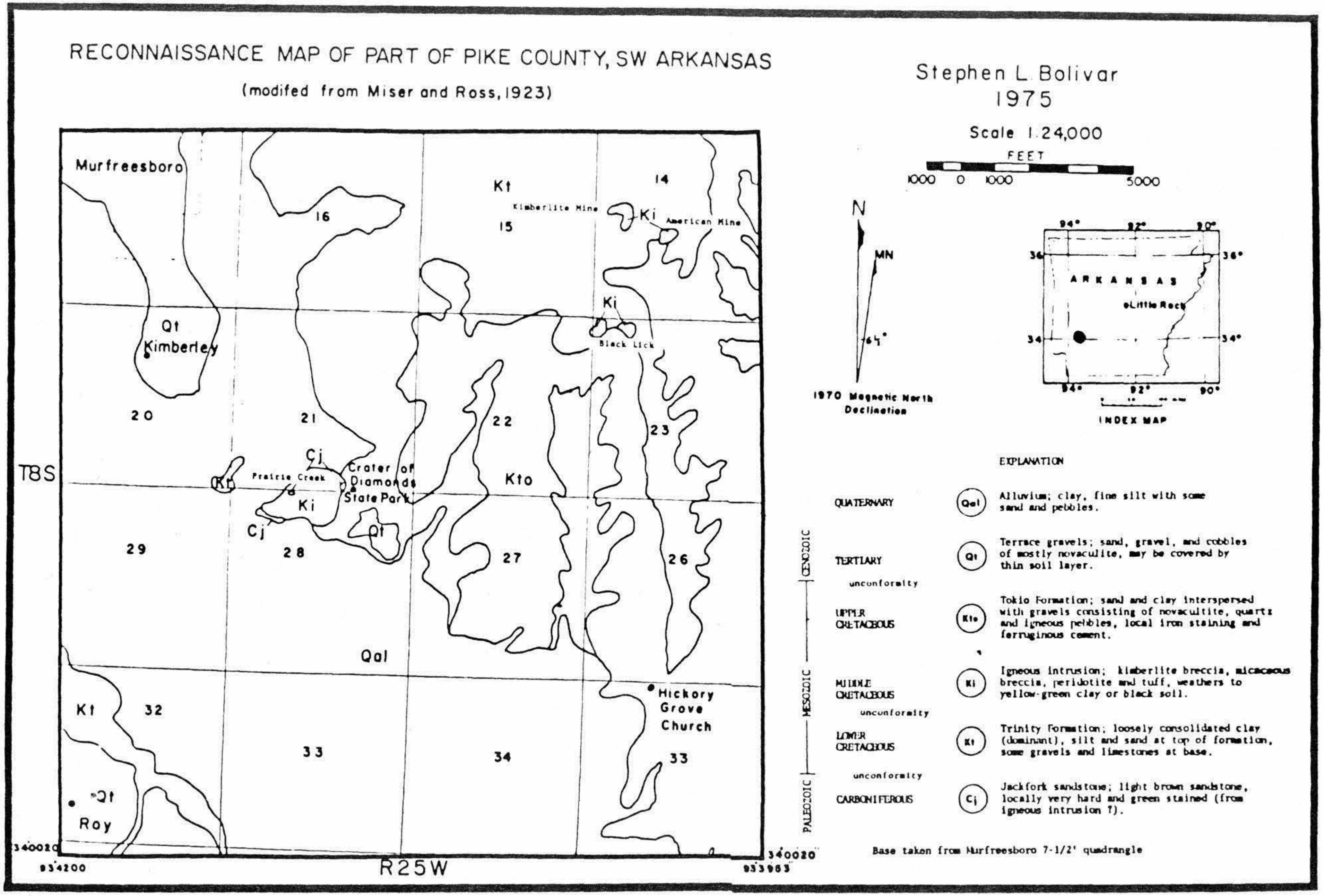

RECONNAISSANCE MAP OF PART OF PIKE COUNTY, SW ARKANSAS
(modifed from Miser and Ross, 1923)
Stephen L. Bolivar
1975
Scale 1:24,000
FEET
1000 0 1000 5000
N
MN
6½°
1970 Magnetic North Declination
94° 92° 90°
36° 34°
ARKANSAS
Little Rock
INDEX MAP
Murfreesboro
Kimberley
Kimberlite Mine
American Mine
Black Lick
Prairie Creek
Crater of Diamonds State Park
Hickory Grove Church
Roy
Kt Ki Kto Qt Qal Cj
14 15 16 20 21 22 23 26 27 28 29 32 33 34
T8S
R25W
340020
934200
933963
EXPLANATION
CENOZOIC
MESOZOIC
PALEOZOIC
QUATERNARY
Qal Alluvium; clay, fine silt with some sand and pebbles.
TERTIARY
Qt Terrace gravels; sand, gravel, and cobbles of mostly novaculite, may be covered by thin soil layer.
unconformity
UPPER CRETACEOUS
Kto Tokio Formation; sand and clay interspersed with gravels consisting of novaculite, quartz and igneous pebbles, local iron staining and ferruginous cement.
MIDDLE CRETACEOUS
Ki Igneous intrusion; kimberlite breccia, micaceous breccia, peridotite and tuff, weathers to yellow-green clay or black soil.
unconformity
LOWER CRETACEOUS
Kt Trinity Formation; loosely consolidated clay (dominant), silt and sand at top of formation, some gravels and limestones at base.
unconformity
CARBONIFEROUS
Cj Jackfork sandstone; light brown sandstone, locally very hard and green stained (from igneous intrusion ?).
Base taken from Murfreesboro 7-1/2' quadrangle

FIGURE 1

1976). The largest known kimberlite is at the Prairie Creek locality, and covers 0.3 km^2 (~.1 mi^2) (Fig. 1). The other intrusions are at the American mine, the Kimberlite mine, and the Black Lick prospect. These last three localities are kimberlite dikes of extremely small size (less than 9 m^2 or 97 ft^2) and poor surface expression.

Kimberlite has also been reported a few miles east of Prairie Creek (Miser and Ross, 1923b). The present owner of the land reported a peridotite-like rock encountered in a water well (W. Fugget, personal communication, 1975), but subsequent field work did not confirm this report. Kimberlite has been reported about 5 km (3 mi) south of Corinth (Miser and Ross, 1923b), but this has not been confirmed by recent work (B. Clardy, Arkansas Geological Commission, personal communication, 1975). Peridotite core has also been reported in wells from Scott County, about 80 km (50 mi) north of Murfreesboro (Miser and Ross, 1923a), Cleveland County (Moody, 1949), and Ashley County (Caplan, 1954). There is doubt, however, that any of these areas contain kimberlite (B. Clardy, Arkansas Geological Commission, personal communication, 1975). Only the Prairie Creek intrusion will be discussed in this report.

The Prairie Creek intrusion is contained entirely within the "Crater of Diamonds," an Arkansas State Park. The land is covered with thick forests of oak, pine, and scrub oak brush. Exposures are minimal except for the eastern and southern edges of the park, which are plowed periodically for diamond searchers. The northern and western parts of the park are dominated by East Hill, Middle Hill, and West Hill. A small knoll located on the southwestern edge of the plowed area and famous as the locality of several diamonds, is called Canary Hill. Maximum elevation is 140 m (~460 ft) above sea level; the maximum relief is about 30 m (~100 ft).

The drainage is to the south and southwest into the Little Missouri River that borders the southern edge of the State Park. A tributary, Prairie Creek, parallels the western boundary. The climate is mild year round, although frequent rainshowers turn the plowed area into a mudmire and the southern area into a swamp.

There are washing plant ruins, abandoned mining equipment, trenches and pits, and remnants of earlier mining attempts scattered throughout the park.

HISTORY

Although the Prairie Creek intrusion was discovered in 1842, it was not until August 1, 1906, that John Huddleston, then owner of the land, discovered three small diamonds while plowing a field. This area soon became the only commercial diamond mine in North America. Subsequent searches in the vicinity of Murfreesboro resulted in the discovery of the American, Kimberlite, and Black Lick kimberlites (all small dikes) about 3.5 km (~2.2 mi) north of Prairie Creek. Diamonds have been reported from all except the last area.

The history of mining at the Prairie Creek kimberlite is varied and interesting. Initially, four companies and two private owners controlled the land. Until the early 1950s, numerous attempts were made to mine the area. Several personalities have been linked to mine development, but all commercial attempts were shrouded in mystery and accompanied by sabotage, court litigations, and poor planning, resulting in failure (S. and M. McCarthy, personal communication, 1975). In the early 1950s, H. A. Millar, son of one of the previous mine operators, opened part of the area as a tourist attraction. On March 14, 1972, the Arkansas Department of Parks and Tourism purchased slightly over 3.6 km^2 (~ 1.4 mi^2) of land that included 0.3 km^2 (~ .1 mi^2) of diamond-bearing kimberlite. The area is known today as Crater of Diamonds State Park, and tourists can look for diamonds for a nominal fee. B. Janse (personal communication, 1976) has estimated that the Prairie Creek kimberlite contains 300,000 carats of diamonds, but that the area is still subeconomic due to the large tonnage of gangue that would have to be treated for diamond recovery.

The exact number of diamonds found to date is difficult to determine as many of the early mining ventures did not publish their finds. Probably over 100,000 diamonds have been found, about 10% are gem quality. About 1 out of 300 tourists is fortunate enough to find a diamond; the average size is 0.2 carat (J. Cannon, Park Supervisor, personal communication, 1975). Some of the more famous stones are listed in Table 1.

GEOLOGY

The Prairie Creek intrusion lies on the northern edge of the Gulf Coastal Plain, just south of the Ouachita Mountain region. Except for the four kimberlite intrusions previously mentioned, all other rocks are sedimentary. The rocks in the Ouachita Mountains are primarily shales, sandstones, novaculites, and cherts, which have been intensely folded. These formations are Ordovician to Carboniferous in age and are at least 6100 m (20,000 ft) thick (Morris, 1974a, 1974b). They dip under Cretaceous rocks to the south. The Ouachita Mountains were formed during the Pennsylvanian by folding and thrusting, which destroyed the Ouachita geosyncline. This orogeny was the result of lateral compression from the south, causing extensive overthrusts to the north. No crystalline basement rock is observed (Caplan, 1954, Morris, 1974a).

Northeast of the study area is the Mississippi Embayment in which poorly consolidated Cretaceous and younger formations dip southeast. The embayment is believed to have formed during the early Cretaceous, initiated by downwarping probably resulting from post deformational structural readjustments to the Appalachian orogeny (Wickham et al., 1976).

SEDIMENTARY ROCKS

The sedimentary rocks beneath the Gulf Coastal Plain (and the study area) are Carboniferous (?), Lower Cretaceous (Trinity Formation), Upper Cretaceous (Tokio Formation), and Quaternary (extensive terrace and alluvial deposits) in age. These rocks generally dip gently to the south and little surface structure is observed (Fig. 1).

Carboniferous (?) sandstone occurs in isolated patches around the intrusion on the east and south borders, and in a 30-m x 15-m (~100 ft x 50 ft) block on top of East Hill. This sandstone is generally massive and light brown, although at East Hill, the sandstone is hard and similar to quartzite. This block may have been rafted to its present position by the kimberlite emplacement. The largest body of Carboniferous (?) sandstone is south of West Hill. The unit dips toward the kimberlite and is characterized by localized green staining, which appears to be chlorite alteration derived from the kimberlite. The sandstone is probably the Jackfork Formation (B. Clardy, Arkansas Geological Commission, personal communication, 1975).

The dominant country rock in the immediate vicinity of the Prairie Creek intrusion is the Trinity Formation, which consists of loosely consolidated clay (dominant), silt, sand, gravel, and fossiliferous limestone. The clay, silt, and limestone occur near the top of the formation whereas gravels and sands characterize the base. The Trinity Formation in the study area is about 90 m (~295 ft) thick (Caplan, 1954). This formation dips gently to the south and rests unconformably on steeply dipping Carboniferous rocks (Miser and Ross, 1923b).

The Tokio Formation is composed largely of sand, gravel, and clay. Gravels are interspersed throughout the formation and are composed of novaculite, quartz pebbles, and rare peridotite pebbles (Miser and Ross, 1923b). Locally the clay may be iron stained (e.g., near the small knob just east of the intrusion). The exact thickness of the formation is unknown, but believed to be between 30 m and 90 m (100 ft and 295 ft).

The kimberlite intrusion is surrounded by extensive Quaternary alluvium and terrace deposits. The terrace deposits contain poorly

TABLE I

FAMOUS DIAMONDS OF THE PRAIRIE CREEK KIMBERLITE

Stone	Date Found	Weight in Carats
Uncle Sam	1924	40.23; cut to emerald shape (14.42 carats).
Gary Moore Diamond	early 1950s	6.43; found by man who saw the manager of the "crater" on Moore's television show. Flawless canary yellow color.
Star of Arkansas	1956	15.31; cut to marquise shape (8.27 carats); found by Dallas housewife.
Star of Murfreesboro	1964	34.25 (worth $45,000 uncut).
Amarillo Starlight	1975	16.37 (worth $25-100,000). Largest gem ever found by a visitor.

sorted, well rounded novaculite, quartz, and sandstone cobbles that were probably derived from the Ouachita Mountains. Thickness varies from a few meters to 15 meters. Most streams and stream valleys are flanked by terrace deposits. The alluvium consists of a fine clay and silt covered by surface loam. Most of the broad valleys are filled with alluvium that varies from 3 to 8 m (~10 ft to 26 ft) thick.

KIMBERLITE AND ASSOCIATED ROCKS

The igneous intrusion covering 0.3 km^2 (~.1 mi^2) is complex. Miser and Ross (1923b) recognize three rock types: earliest hypabyssal peridotite, volcanic breccia, and tuff and fine-grained breccia. The depth of the intrusion is not known, but a drilling report by Thoenen et al. (1949) shows weathered kimberlite to a depth of at least 70 m (~230 ft).

Assisted by detailed geochemical and geophysical studies, the intrusion was remapped in detail. Exposed rock is extremely weathered and contacts between the country rock and intrusion are not observed; however, geophysical data (predominantly magnetics) proved invaluable in determining outer boundaries of the intrusion.

The author also recognizes three rock types: a kimberlite breccia, a micaceous peridotite, and an associated tuff. All three units are extremely variable and consequently were divided into subgroups (Table II).

The map of Miser and Ross has been superimposed on the geologic map of this study (Fig. 2). The results are generally compatible. However, the boundaries of the micaceous peridotite, as outlined by geophysical data, are probably more accurately defined in this study. In addition, several small bodies of micaceous periodotite were found to intrude the kimberlite breccia in the southwest corner of the map area. Much of the kimberlite breccia is covered by forest growth and the contacts of Miser and Ross may be more accurate for this unit. The tuff unit of this study is much less extensive than mapped previously; this is attributed primarily to man-made excavations in the last five decades.

MICACEOUS PERIDOTITE

The micaceous peridotite crops out in

FIGURE 2

GEOLOGIC MAP OF THE PRAIRIE CREEK INTRUSIVE

Stephen L. Bolivar - 1975

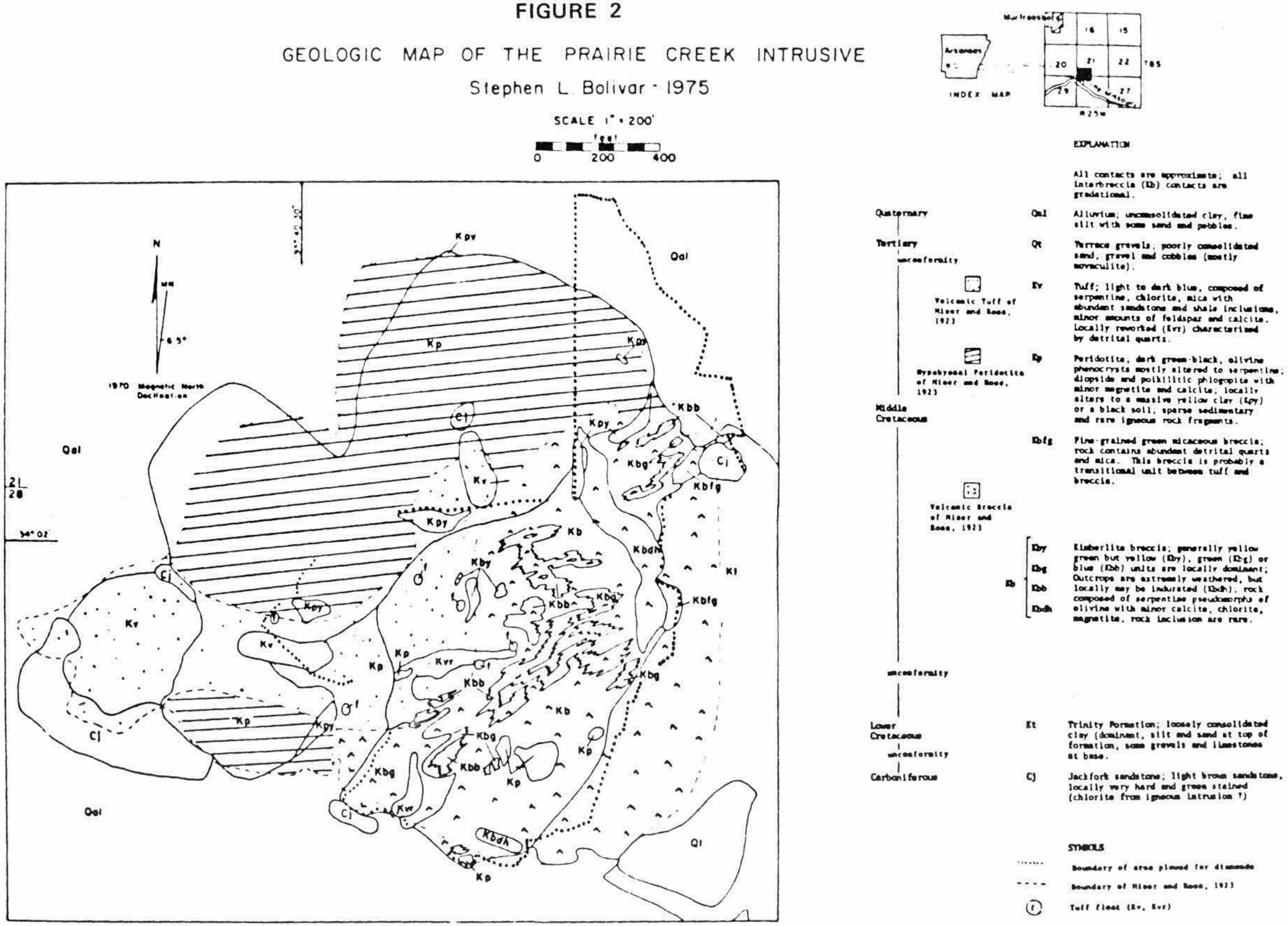


TABLE II

MAJOR CHARACTERISTICS OF THE PRAIRIE CREEK ROCK UNITS

Rock Unit	Subgroups	Texture	Color	Xenoliths
Tuff	Tuff	Coarse grained, brecciated	Shades of blue, gray, and white. Yellow and brown increase with weathering	Abundant sandstone, shale, coal, chert, rare breccia, and peridotite fragments
	Reworked tuff	sandy, a.a.		
Micaceous peridotite	Micaceous peridotite	Porphyritic massive, earthy	Yellow	Unidentified dark yellow fragments
	Massive yellow clay			
Kimberlite breccia	Fine-grained micaceous	Micaceous breccia	Green, weathers to yellow-green	Sparse sandstones and shales
	Massive yellow clay	Earthy	Yellow	
	Yellow-green breccia	Coarse-grained breccia	Yellow, weathers to brownish yellow	
	Green breccia	a.a.	Green	
	Blue breccia	a.a.	Blue	
	D&H breccia	Very coarse breccia	Yellow-black	

a.a. = as above

the northwestern half of the study area comprising Middle and East Hills and occurs as knob-like boulders on the sides of these hills. It covers about half of the exposed intrusion and occurs in an oval-like pattern. The oval is elongated to 600 m (~1970 ft) in a northeast-southwest direction and is about 240 m (~790 ft) wide. Several small exposures were also noted intruding the breccia at the southeastern edge of the intrusion. Some of these "exposures" of peridotite are mine dumps (e.g., the hill south of the shack east of Fuggits Bank), but some may be actual intrusions as suggested by geophysical data.

The peridotite is a hard, black to dull brown (or dark green) porphyritic rock containing olivine phenocrysts. The rock weathers to a brownish-green with olivine phenocrysts occurring as altered black grains. In most weathered specimens the olivine weathers out leaving a jagged or pitted appearance; phlogopite may also weather out giving a similar appearance. Ultimately the peridotite decomposes through a massive yellow clay to a black gumbo soil (Gregory, 1969). The yellow clay is difficult to distinguish from a similar weathering product of the kimberlite breccia. Secondary coatings of carbonate and kerolite are abundant, and some barite and serpentine veins can be found. A few small diamonds are reported from the weathered portions of this rock (Miser and Ross, 1923b).

In thin section the peridotite displays a porphyritic texture of subhedral olivine phenocrusts. The groundmass consists of phlogopite, serpentine, and diopside, with minor amounts of perovskite, pyrite, amphibole, chrome spinels, and magnetite (Fig. 3). An "average" modal composition is listed.

Composition	Percent
olivine	14
serpentine after olivine	36
phlogopite	40
diopside	5
perovskite	1
amphibole	1
pyrite	1
spinels (magnetite and chromite)	2

The olivine phenocrysts (Fo_{92}) occur in various stages of serpentinization. The serpentine is generally yellow-green and contains small inclusions of magnetite. The phlogopite in the groundmass may occur as large books up to 1-mm diameter that poikilitically enclose opaques, olivine, and small acicular needles of diopside. Up to 40% of the phlogopite may be altered to chlorite. The diopside (called augite by earlier workers) ranges from 0.05 to 0.15-mm length. Many of the spinels and some of the olivines are rimmed with magnetite. Rare, potassic richterite has been reported (Lewis et al., 1976). Chemical compositions for several of the peridotite minerals and representative electron microprobe analyses and structural formulae can be found in Bolivar (1977) and Lewis (1977).

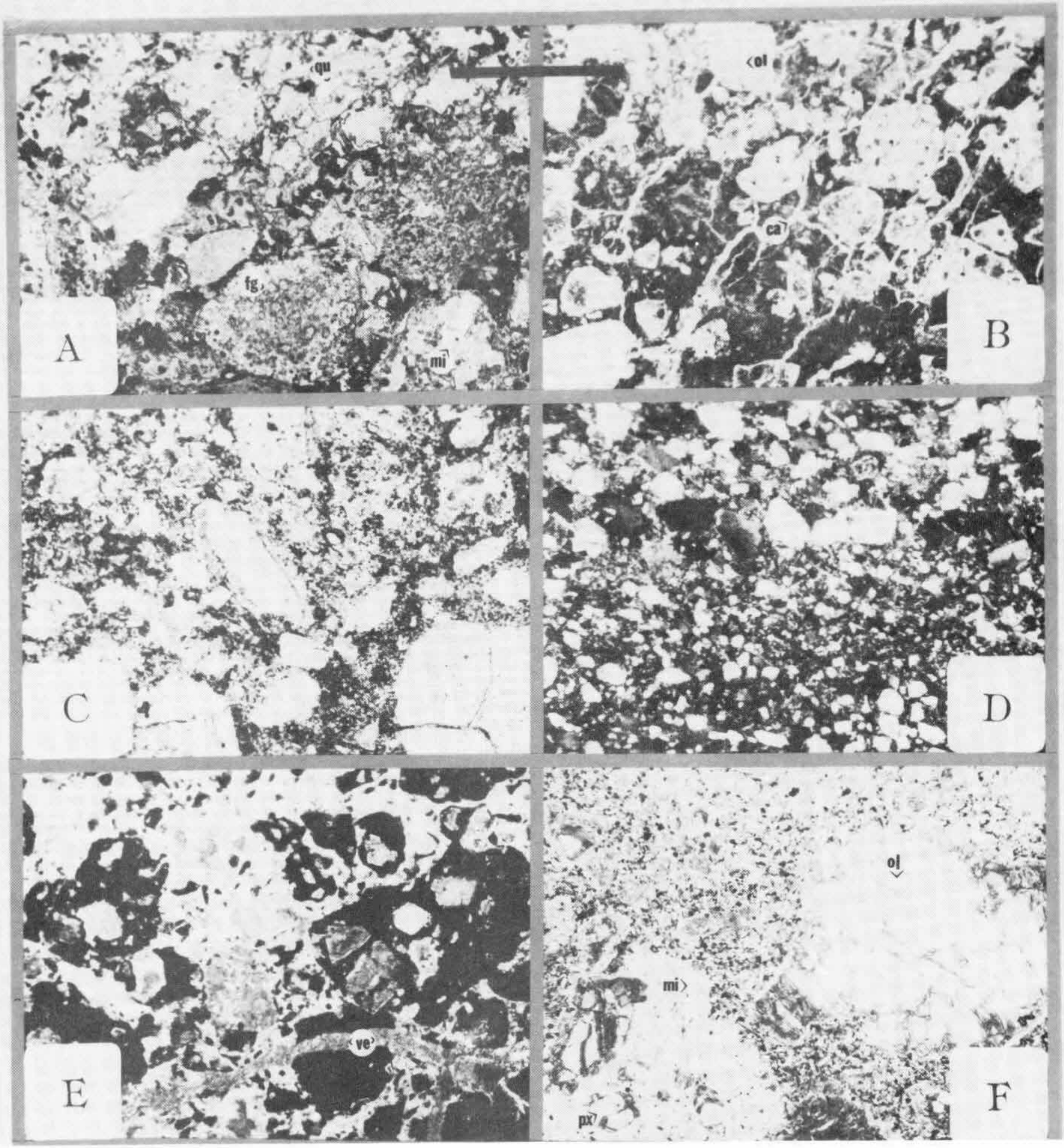


FIGURE 3. Photomicrographs of the Prairie Creek intrusion. All photos taken at 39X; bar is 1 mm long. **a.** Tuff; sandstone fragment (fg), quartz (qu), biotite (mi) in a matrix of chlorite, serpentine, and clay, plane polarized light (PPL). **b.** Fine-grained green micaceous breccia, containing serpentinized olivine and cut by several calcite stringers. Detrital quartz and feldspar may be locally abundant (PPL). **c.** Yellow-green kimberlite breccia; typical weathered sample showing clay and serpentine-rich groundmass with serpentinized breccia fragments (PPL). **d.** Reworked tuff; containing predominantly quartz fragments in a clay-chlorite matrix. Note graded bedding, crossed nichols (XN). **e.** D&H kimberlite breccia; showing serpentinized breccia fragments cut by secondary calcite stringers (ve) (XN). **f.** Micaceous peridotite; with partly serpentinized olivine (ol) and phlogopite (mi) poikiolitically enclosing diopside (px) and olivine. Groundmass contains serpentine, perovskite, and opaques (PPL).

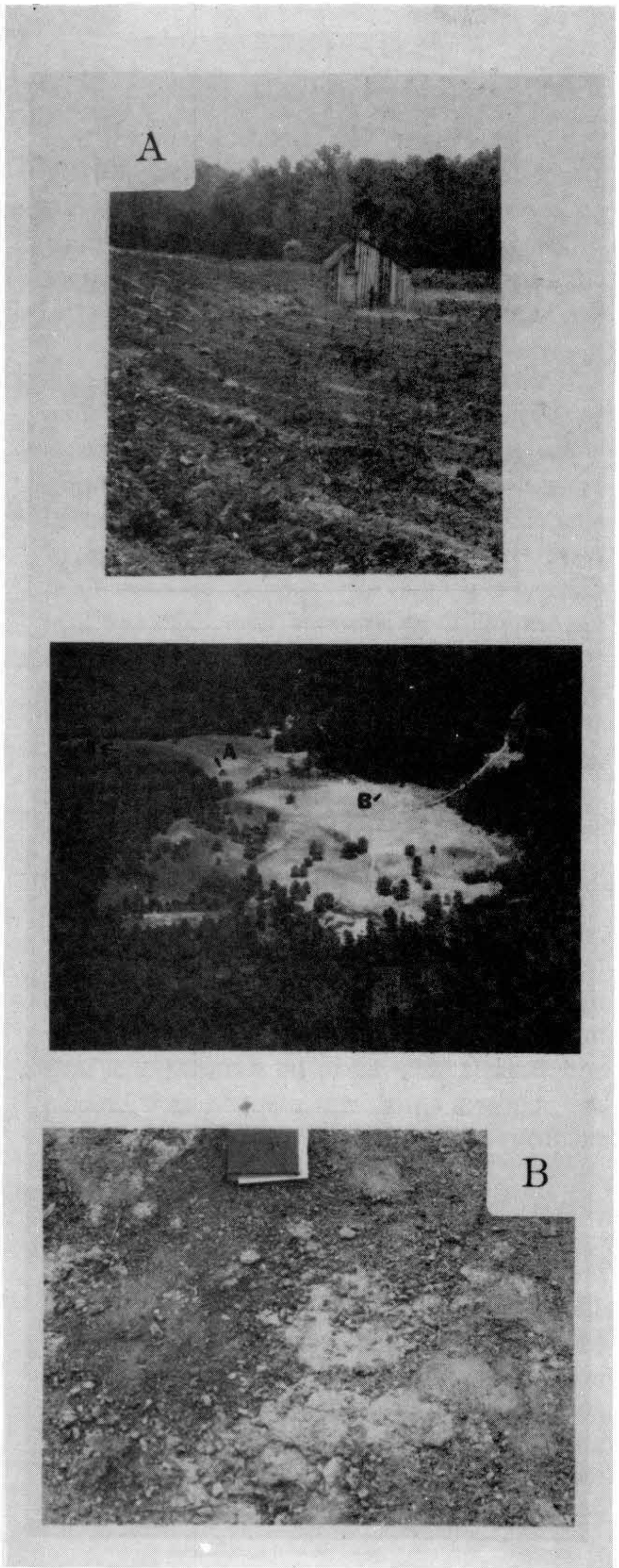


FIGURE 4. Photographs of the Prairie Creek kimberlite breccia. **a.** Photograph looking toward abandoned mine shaft, scanning over typical plowed kimberlite breccia, just east of East Hill. **b.** Closeup of yellow-green kimberlite breccia, showing the extremely weathered nature of breccia; field notebook is 15 cm long. Middle photograph is an aerial view of study area, showing respective locations of photos a and b.

KIMBERLITE BRECCIA

The kimberlite breccia is the second most abundant igneous rock in the study area, constituting about 40% of the total intrusive. The shape of this unit is also oval, over 480 m (~ 1575 ft) long in a northeast-southwest direction, and about 240 m (~790 ft) wide.

The rock is extremely variable in appearance and is so extensively weathered and altered that the true mineralogy is difficult to assess. In general, the kimberlite breccia is yellow-green, extensively serpentinized, and porphyritic. The breccia fragments are extremely variable in size and texture, consisting predominantly of porphyritic kimberlite. A brown mica is the only recognizable megascopic mineral beside serpentine. The breccia weathers through blue, green, and yellow decomposition products to a black gumbo soil (Gregory, 1969). Veins of quartz, barite, fluorite, and amethyst are found cutting the breccia. The breccia units contain the most diamonds.

The breccia has been divided into five subgroups (Table II): a relatively indurated breccia (designated D&H); a blue-green breccia that occurs in scattered patches; a green breccia, very difficult to distinguish from yellow and blue types; a yellow-green breccia that represents the majority of exposed breccia; and a fine-grained green micaceous breccia that appears to be transitional between the kimberlite breccia and the tuff. Extremely weathered breccia grades into a massive yellow, clay-rich soil. This unit is visually indistinguishable from a similar massive yellow clay soil of the peridotite. However, these two clays do differ slightly in their chemistry.

Kimberlite breccia is exposed predominantly in the eastern half of the study area (Fig. 2). Most of it is covered by a weathered yellow-green soil (Fig. 4a), although a few isolated patches of bedrock occur (Fig. 4b). Most of this area was mapped as yellow-green breccia with isolated patches of blue breccia. The blue color appears to be a weathering phenomenon as darker blue colors are found in "fresher" samples. But the blue breccia has also been found grading laterally into yellow and green subgroups. The green breccia occurs locally in isolated patches and appears to grade into the massive yellow clay unit. In a zone almost 300 m (~985 ft) long and 3 to 30 m (10 to 100 ft) wide, relatively indurated breccia (D&H) is found. This unit is a dark brown and in places is fairly hard. It also grades into the yellow-green breccia. The most distinctive breccia subgroup is a fine-grained green micaceous breccia found in small patches northwest of the park restaurant at Fuggits Bank and at Canary Hill. This unit contains some detrital quartz and appears to be transitional between the kimberlite breccia (all six subgroups) and tuff.

It would be necessary to employ an extensive trenching program to define contacts accurately because weathered kimberlite breccia is reported to depths of 70 m (~230 ft) (Thoenen et al., 1949). This study suggests that these color differences are partly the result of weathering and chemical variations; they might also be due to multiple intrusions (i.e., pulses) within a short period of time.

In thin section all breccia subgroups are extensively altered and weathered. The olivine phenocrysts are almost completely serpentinized. The groundmass consists predominantly of serpentinized olivine and phlogopite, with minor amounts of magnesium-rich chrome spinels, perovskite, secondary biotite, chlorite, pyrolusite (locally abundant), and secondary calcite (Fig. 3). Magnesian ilmenite, enstatite, garnet, and chrome-diopsides are extremely rare. Using panning techniques, spinel, and garnet separates were obtained. The garnets are represented by two suites, one kimberlitic (high Cr_2O_3) and one from another source (low Cr_2O_3). Ranges of chemical compositions for panned garnet and chrome spinel, representative electron microprobe analyses, and structural formulae are given in Bolivar (1977) and Lewis (1977).

The apparent lack of magnesian ilmenite, enstatite, and chrome diopside, and the rarity of garnet suggest that this rock is not a true kimberlite in *sensu strictu* (Mitchell, 1970); however, the observed mineralogy is not believed to be representative of the original composition because of the extreme secondary alteration and weathering of the breccia.

TUFF

The third major rock unit is an extremely variable tuffaceous rock. This unit occurs in scattered patches throughout the study area, but the major exposure is confined to West Hill. In some areas, such as east of Canary Hill, the tuff appears to have been reworked as it contains over 50% detrital quartz. The tuff was mapped as a continuous unit from West Hill to the base of East Hill by Miser and Ross (1923b). Apparently this unit was extremely thin between these two hills for only one major locality of tuff, that comprising West Hill, was found. Isolated patches of tuff do occur at the foot of East Hill, in the center of the kimberlite breccia, and in a plowed field just east of West Hill (Fig. 2). Float was found scattered between East and West Hills. The fine-grained green micaceous breccia mapped as a tuff by Miser and Ross is believed to be a transitional unit and, consequently, was mapped as a breccia subgroup.

Tuffaceous units associated with kimberlites are not uncommon and have been previously reported (Dawson and Hawthorne, 1970; Dawson, 1971). The tuff probably formed by fragmentation of peridotite and breccia after the initial intrusion, with tuffaceous material from the intrusion washing back into the vent, forming sedimentary features such as flow textures and graded bedding, which are observed on samples from West Hill (Fig. 3d).

The tuff is extremely variable, ranging in color from blue-gray in fresh specimens to light buff-gray in weathered samples. Fresh samples are characteristically hard, but may occur as a clay-like rock in extremely weathered specimens. The tuffs contain a reddish mica (mostly biotite, usually less than 1-mm diameter) and abundant sedimentary rock fragments in a white-blue-yellow (clay-chlorite-serpentine) matrix of secondary minerals.

In thin section the tuff contains quartz, some potassic feldspar, biotite, and kimberlite breccia fragments in a groundmass of secondary minerals including chlorite (and other clay minerals), serpentine, and carbonates (Fig. 3a and 3d).

INCLUSIONS

All three rock types contain xenoliths of sandstone and shale, but the tuff contains the majority of inclusions, including rare xenoliths of kimberlite breccia and peridotite.

All peridotite samples contain some xenoliths, but the knobby hill just north of the old mine shaft apparently contains a relative abundance of inclusions. Most of these are mudstone and sandstone that have been extensively altered, baked, and serpentinized. A few shales and limestones, extensively altered to serpentine and chlorite, were also found. Igneous inclusions containing serpentine, secondary amphibole, and pyroxene have been reported (Gregory, 1969), but only one similar fragment was found in this study.

The kimberlite breccia contains numerous shale fragments and sandstones. One dunite (?) fragment was found, but it was so severely serpentinized that its true mineralogy could not be fully determined. In general, the breccia contains fewer rock fragments than the tuff and periodite.

The tuff contains abundant sedimentary inclusions, ranging from microscopic to several tens of centimenters in diameter. The majority of rock fragments are shales and sandstones that display minor reaction rims. Some fragments of coal were also noted; no igneous rock fragments were found except for rare fragments of the kimberlite breccia and micaceous peridotite.

AGE OF INTRUSIVE

The Prairie Creek intrusion intrudes Lower Cretaceous sediments (Trinity Formation). Peridotite pebbles have been reported at the base of the Upper Cretaceous (Tokio Formation) by Miser and Purdue (1929). Miser and Ross (1923b) bracket the age between Lower Cretaceous (Trinity Formation) and Upper Cretaceous (Tokio Formation) with a probable age of 130 Myr B. P. Bolivar (1977) reports two preliminary age dates for montmorillonite (with minor chlorite and kaolinite) clay samples, one of 108 Myr B. P. and one of 235 Myr B. P. The variability of the analyses is due to the presence of secondary calcite that was not completely removed during a leaching step. Until these analyses are confirmed, mid-Cretaceous appears to be the most reasonable estimate for the age of intrusion.

CHEMISTRY

Whole rock analyses (Bolivar, 1977), mineral separates (Lewis, 1977), uranium geochemistry (Brookins et al., 1979), and Rb-Sr systematics (Bolivar, 1977 and Bolivar and Brookins, 1979) will be briefly discussed. Whole rock analyses and CIPW norms are listed in Table III.

Kimberlite breccia, micaceous peridotite, and tuff are distinguished from each other by their SiO_2 contents (percent): 44, 40, and 55, respectively. Rock types can also be distinguished by their total Sr, Rb, and U contents (Table IV). All rock types show considerable variations in the major oxides, but the peridotite contains greater FeO, CaO, TiO_2, and MgO than the breccia and the tuff contains greater CaO, K_2O, Na_2O, and Al_2O_3 than the breccia.

The kimberlite breccia is hypersthene normative, the micaceous peridotite is olivine normative and the tuff is quartz normative. The breccia is classified as lamprophyric.

The relationship between the micaceous peridotite and kimberlite breccia is not fully understood, although their similar whole rock chemistry implies a genetic relationship. Micaceous peridotite does outcrop within the kimberlite breccia, but the age relationships are still unclear. Harker variation diagrams

TABLE III
Chemical Analyses and CIPW Norms for Selected Prairie Creek Rocks

A. Tuff	1	2	3	4
SiO_2	60.24	62.73	54.52	44.77
Al_2O_3	5.40	6.01	4.85	4.34
Fe_2O_3	3.24	2.44	3.70	4.29
FeO	1.64	1.82	1.88	1.59
MgO	7.10	6.35	8.95	15.40
CaO	5.48	3.54	6.33	6.59
Na_2O	1.52	1.52	1.96	0.74
K_2O	5.82	7.50	5.84	5.50
H_2O^+	0.39	1.47	0.28	1.96
H_2O^-	0.56	0.88	1.06	1.39
TiO_2	1.81	1.30	2.32	2.16
P_2O_5	2.15	2.30	3.50	1.21
MnO	0.13	0.11	0.13	0.16
CO_2	4.46	2.22	5.00	9.90
SrO	0.07	0.05	0.13	0.10
S	0.16			
Total	100.17	100.24	100.45	100.10
Q	21.90	24.84	15.04	0
Or	31.54	34.73	28.34	26.71
Ab	0	0	0	0
An	0	0	0	0
Lc	0	0	0	0
Ne	0	0	0	0
Kp	0	0	0	0
Si	11.33	2.26	7.36	21.94
Hy	15.38	18.58	22.77	25.44
Ol	0	0	0	8.65
Ac	9.70	7.20	11.04	5.99
Mt	0	0	0	0
Il	2.65	1.92	3.34	3.06
Hm	0	0	0	1.87
Ap	4.83	5.09	7.83	2.85
$CaTiSiO_4$	0.09	0	0.19	0.50
Pr	.15	0	0	0
Ru	0	0	0	0
Ks	1.58	3.65	2.58	2.98
Ns	0.76	1.63	1.51	0
Cs	0	0	0	0
Mg/Mg+Fe	.74	.74	.75	.83
Total Fe as FeO	4.56	4.02	5.21	5.45

1. P.C. 3-33 Tuff
2. P.C. 2-W4 (BBB) Tuff
3. P.C. 4-19 Tuff
4. P.C. 4-#5 Tuff

B. Breccia	1	2	3	4	5	6
SiO_2	44.32	44.30	46.50	43.45	43.59	44.04
Al_2O_3	3.80	3.65	4.20	3.67	4.10	4.52
Fe_2O_3	5.95	5.26	5.82	7.18	7.43	6.10
FeO	1.15	1.04	1.18	0.81	0.57	0.82
MgO	20.00	22.40	19.20	21.70	20.85	16.90
CaO	4.15	3.60	3.70	2.95	2.76	5.24
Na_2O	0.50	0.16	0.23	0.13	0.20	0.14
K_2O	3.07	1.66	2.75	1.48	1.77	1.02
H_2O^+	0.30	3.36	0.58	2.76	0.74	1.70
H_2O^-	3.62	6.25	5.44	6.49	5.02	4.70
TiO_2	2.22	2.20	2.12	2.38	2.44	1.70
P_2O_5	1.85	1.45	0.95	1.15	1.06	2.94
MnO	0.11	0.05	0.12	0.11	0.08	0.20
CO_2	8.85	4.22	7.27	5.15	9.01	10.02
SrO	0.07	0.09	0.06	0.09	0.09	.08
Total	99.96	99.69	100.12	99.50	99.21	100.12
Q	0	0.87	2.99	2.12	2.10	12.21
Or	20.24	11.02	18.29	10.0	12.01	7.15
Ab	2.91	1.61	2.33	1.33	2.06	1.49
An	0	4.88	2.60	5.79	5.81	8.31
Lc	0	0	0	0	0	0
Ne	0	0	0	0	0	0
Kp	0	0	0	0	0	0
Di	5.22	0.77	6.90	0	0	0
Hy	52.33	69.11	56.23	68.51	66.10	55.35
Ol	5.01	0	0	0	0	0
Ac	1.68	0	0	0	0	0
Mt	0	0	0	0	0	0
Il	2.18	1.90	2.27	1.63	1.16	1.88
Hm	4.21	4.12	4.57	5.72	5.95	5.04
Ap	4.32	3.41	2.24	2.75	2.55	7.29
$CaTiSiO_4$	1.91	2.32	1.58	1.58	1.34	0
Pr	0	0	0	0	0	0
Ru	0	0	0	0.55	0.93	0.47
Ks	0	0	0	0	0	0
Ns	0	0	0	0	0	0
Cs	0	0	0	0	0	0
Mg/Mg+Fe	.85	.87	.84	.84	.84	.83
Total Fe as FeO	6.50	5.77	6.42	7.27	7.26	6.31

1. P.C. 3-9 Blue Kimberlite breccia
2. P.C. 3-18 Blue Kimberlite breccia
3. P.C. 3-8 Yellow green Kimberlite breccia
4. P.C. Ark C Yellow green Kimberlite breccia
5. P.C. 3-7 Yellow green Kimberlite breccia
6. P.C. 3-1 Yellow green Kimberlite breccia

C. Miscellaneous Rocks

	1	2	3	4	5	6	7	8
SiO_2	38.34	40.33	39.26	38.78	42.90	41.48	38.04	37.09
Al_2O_3	5.10	4.00	3.97	3.38	3.75	3.72	3.84	3.69
Fe_2O_3	7.37	5.31	6.48	7.03	3.48	7.47	5.01	4.61
FeO	5.40	2.65	1.81	1.34	4.25	0.88	4.52	8.36
MgO	18.70	26.00	24.55	28.00	27.50	22.25	27.80	26.50
CaO	3.19	4.61	5.32	5.04	4.20	3.63	4.68	5.10
Na_2O	0.24	0.48	0.36	0.22	0.28	0.84	0.23	0.19
K_2O	1.42	2.80	2.41	2.13	4.00	1.80	3.40	2.30
H_2O^+	2.25	0.40	1.02	0.43	0.54	0.12	0.33	3.18
H_2O^-	4.95	0.48	2.59	1.59	0.48	3.01	1.45	1.52
TiO_2	3.80	2.47	2.68	2.61	2.48	2.92	2.10	2.50
P_2O_5	0.85	0.40	.21	0.38	1.01	1.22	0.40	0.28
MnO	0.15	0.12	.12	0.13	.12	0.10	0.14	0.16
CO_2	8.16	9.32	8.86	9.38	5.00	9.94	7.43	4.33
SrO	.14	0.09	.12	0.12	.11	0.13	0.11	0.11
S	.09	0.09			.09			
Total	100.15	99.55	99.75	100.56	100.19	99.51	99.48	99.92
Q	0	0	0	0	0	0	0	0
Or	9.87	17.55	15.57	13.33	20.56	11.89	4.32	6.77
Ab	2.54	4.57	3.53	2.09	0	8.43	0	0
An	10.17	0.52	2.30	2.06	0	1.19	0	2.55
Lc	0	0	0	0	0	0	13.32	6.04
Ne	0	0	0	0	0	0	0.55	1.08
Kp	0	0	0	0	0	0	0	0
Di	1.89	16.98	18.71	14.84	11.68	2.64	17.45	17.99
Hy	57.50	2.96	5.72	4.86	9.96	42.79	0	0
Ol	1.72	48.51	44.27	52.21	46.26	18.41	54.35	56.20
Ac	0	0	0	0	2.02	0	1.00	0
Mt	5.56	1.11	0	0	2.90	0	5.09	5.08
Il	6.23	3.65	3.27	2.42	3.47	1.70	3.05	3.67
Hm	2.34	3.19	4.94	5.19	0	5.82	0	0
Ap	2.09	0.89	0.48	0.84	2.12	2.85	0.87	0.62
$CaTiSiO_4$	0	0	1.22	2.16	0	4.27	0	0
Pr	.09	0.08	0	0	.08	0	0	0
Ru	0	0	0	0	0	0	0	0
Ks	0	0	0	0	0	0	0	0
Ns	0	0	0	0	0	0	0	0
Cs	0	0	0	0	0	0	0	0
Mg/Mg+Fe	.74	.86	.85	.87	.87	.84	.85	.79
Total Fe as FeO	12.03	7.43	7.64	7.67	7.38	7.60	9.03	12.51

1. P.C. R Massive yellow clay soil
2. P.C. 3-25 Micaceous Peridotite
3. P.C. B-11 Micaceous Peridotite
4. P.C. 4-16 Micaceous Peridotite
5. P.C. 3-23 Micaceous Peridotite
6. P.C. 3-20 D+H kimberlite breccia
7. P.C. 4-12 Micaceous Peridotite
8. P.C. 4-18 Micaceous Peridotite

TABLE IV

ISOTOPIC DATA FOR MAJOR PRAIRIE CREEK ROCK UNITS
(from Bolivar, 1977 and Brookins et al., 1979)

	Sr^{87}/Sr^{86}	Total Sr (ppm)	Total Rb (ppm)	Average Total U (ppm)
Micaceous peridotite	0.7089	1015-1241	155-204	2.35
Kimberlite breccia	0.7092	515-1253	95-196	
green-micaceous breccia	0.7110			2.76
blue breccia	0.7106			1.87
yellow-green breccia	0.7093			1.61
D&H breccia	0.7084			1.79
Tuff	0.7095	527-1414	113-144	4.05

(Bolivar, 1977) and Sr^{87}/Sr^{86} ratios suggest that the kimberlite breccia may be a differentiated product of the micaceous peridotite. Geophysical interpretations (Lewis, 1977) suggest the kimberlite breccia intruded before the micaceous peridotite. This is in conflict with the interpretations of previous workers (Miser and Ross, 1923b). The sequence of intrusion is, therefore, believed to be kimberlite breccia then micaceous peridotite. The tuff unit was deposited near the end of the eruption sequence. The tuff unit is primarily igneous in origin, but many of the erosional remnants are believed to be reworked tuffaceous materials.

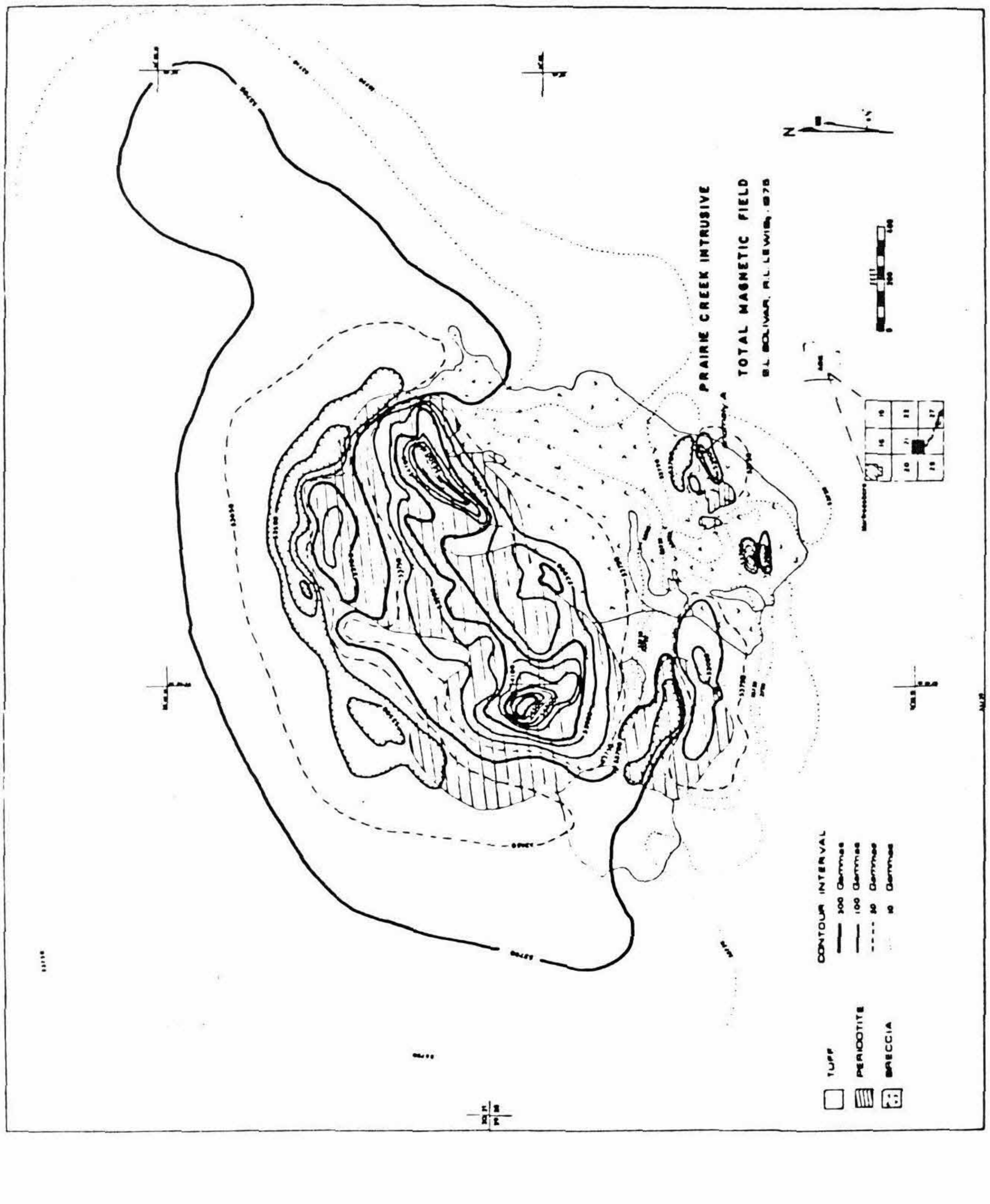
Based on chemical analyses, the kimberlite breccia is believed to have undergone several separate intrusions or pulses. The initial intrusion is the D&H breccia, followed by the yellow-green and green varieties, followed in turn by the blue breccia. Last, the transitional fine-grained green micaceous breccia was deposited. This interpretation is supported by the geophysical data of Lewis (1977).

GEOPHYSICAL STUDY

Because of limited field exposure and the extremely weathered nature of the kimberlite, magnetic and gravity surveys were undertaken. A total of 120 permanent stations were surveyed for location and elevation at 30 to 150 m (~100 to 490 ft) spacings. Temporary stations were then set up at 15 to 30 m (~ 50 to 100 ft) intervals. Magnetic measurements were taken at all stations, gravity was taken at permanent stations only. All magnetic observations were made with a total field intensity magnetometer (±1 gamma). Diurnal corrections were made hourly.

Gravity measurements were made with a portable gravimeter (±0.01 mgal). Instrumental, tidal, free air, and Bouguer corrections were made, terrain corrections were not.

A regional Bouguer gravity map and regional total field intensity magnetic map (each covering about 10 kl^2 or 3.9 mi^2) did not indicate any regional anomalies associated with the Prairie Creek intrusion (Bolivar, 1977). The total gravity anomaly



PRAIRIE CREEK INTRUSIVE
TOTAL MAGNETIC FIELD
B.L. BOLIVAR, R.L. LEWIS
N
CONTOUR INTERVAL
500 Gammas
100 Gammas
50 Gammas
10 Gammas
TUFF
PERIDOTITE
BRECCIA

FIGURE 5

over the Prairie Creek intrusion was only 0.5 mgal, suggesting the intrusion is very shallow. The gravity data will not be further discussed in this paper (see Lewis, 1977).

The detailed total magnetic intensity map (Fig. 5) is dominated by several highs in the northwestern half that reach a maximum of 900 + gammas. Magnetic profiles were examined and showed that magnetic highs occur only over the micaceous peridotite.

Magnetic anomalies are generally caused by differences in magnetic susceptibility which, in general, reflect the magnetite content of the rock. Igneous rocks are commonly more magnetic than sedimentary rocks. Magnetic intensity is an inverse square function; therefore, the distance of any magnetic body from a magnetometer affects the size of the anomaly. Consequently, the intrusion of basic igneous rock into sedimentary rock would be expected to produce an anomaly.

Qualitative interpretation of magnetic and gravity data suggest the micaceous peridotite is a dike-like almost vertical, intrusion of slightly variable thickness, dipping slightly to the south. Small intrusions of peridotite in the southeast are believed to represent small apophyses of the large peridotite intrusion. Magnetic and gravity readings for one anomaly (anomaly A on Fig. 5) were taken at 3 m (~10 ft) intervals for 30 m (~100 ft) traverses for north-south, east-west, northeast-southwest, northwest-southeast legs, respectively. The gravity data reveal no anomaly, but the magnetic data confirm the above interpretation.

Boundaries of the peridotite define (Fig. 2) an elongated oval shape. By comparison, the kimberlite breccia is not clearly distinguishable by magnetic data, but field relationships suggest a similar oval shape, southeast of the peridotite, about 480 m (~ 1575 ft) long (northeast-southwest) and 240 m (~790 ft) wide. Both the peridotite and kimberlite thin rapidly at depth, resembling a tapered funnel. The tuff is indistinguishable from the breccia and country rock and has been mapped by field occurrence only. The relative magnetite content of the breccia, tuff, and country rock (alluvium and Cretaceous conglomerates, sandstones, and clays) apparently is very similar explaining why these rocks were indistinguishable using magnetic data. Using the above data and field relationships, a hypothetical schematic cross section of the Prairie Creek intrusion has been constructed (Fig. 6).

Several traverses were conducted over the three small kimberlite dikes northeast of the study area. Only very small localized anomalies of less than 200+ gammas were found. It appears that only if a micaceous peridotite is present, will gravity and especially magnetic geophysical investigations be fruitful.

SUMMARY

The igneous intrusion, covering 0.3 km^2 (~ .1 mi^2) at Prairie Creek, Arkansas, is characterized by three rock types--a micaceous peridotite, a kimberlite breccia, and an associated tuff. The sequence of intrusion (mid-Cretaceous), based on geophysical interpretations, is believed to be kimberlite breccia, closely followed by micaceous peridotite. A tuff was deposited after these intrusive events. This sequence is in disagreement with interpretations of earlier workers. The kimberlite breccia covers the eastern part of the study area, comprising aerially about 40% of the total intrusive. The shape of the breccia is oval-like, over 480 m (~1575 ft) long in a northeast-southwest direction and about 240 m (~790 ft) wide. The kimberlite is an extremely variable porphyritic breccia that weathers through blue-green-yellow decomposition products to a black gumbo soil. Veins of quartz (some amethyst), fluorite, and barite are found cutting the breccia. The breccia is so extremely weathered and serpentinized (to at least 70 m or 230 ft) that its true mineralogy is unknown. The breccia was divided into six subunits: a yellow-green unit that represents the majority of the breccia exposed; a blue-green unit that occurs

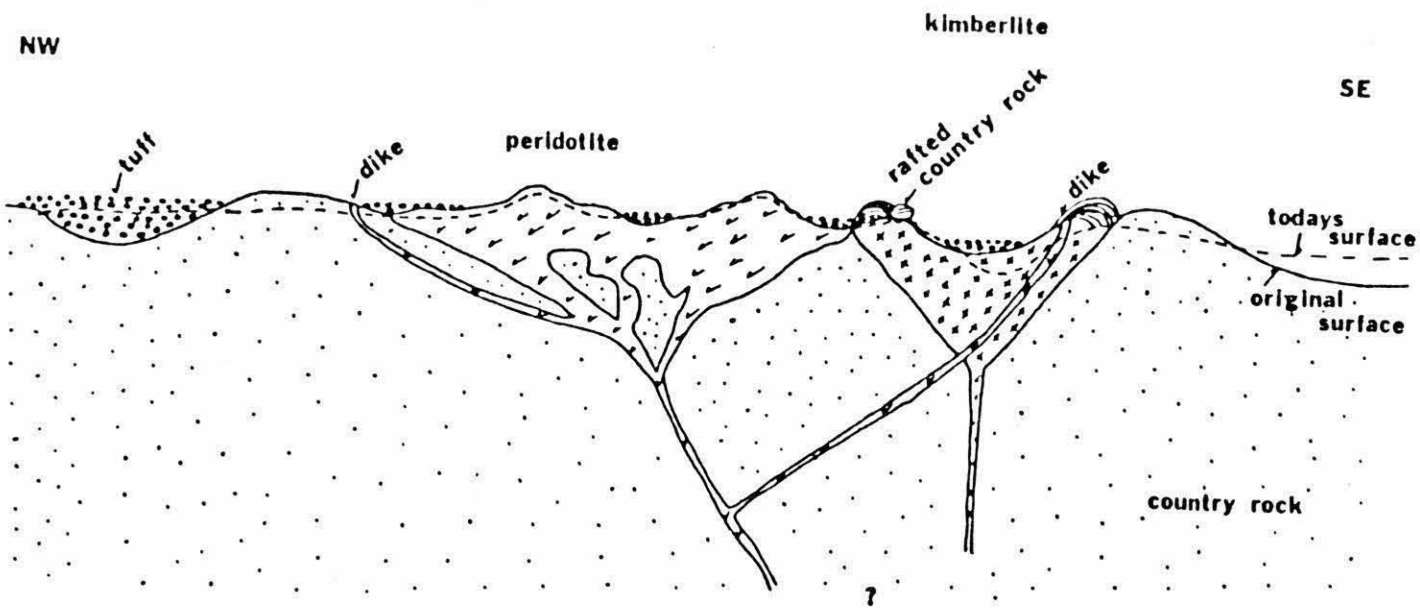


FIGURE 6. Hypothetical cross section of the Prairie Creek intrusion.

in scattered patches; a green unit, very difficult to distinguish from yellow and blue varieties; a relatively indurated breccia, designated D&H; a massive yellow clay soil, which is an obvious decomposition product of breccia; and a fine-grained, green micaceous breccia, which appears to be a transitional unit between breccias and tuff. The blue unit may represent "fresher" material that ultimately weathers to a yellow breccia, although blue units (as do other units) grade laterally into other units, respectively. This suggests, in addition to chemical variations, the possibility of multiple intrusions (pulses) over a short period of time. In thin section the breccia is characterized by serpentinized olivine phenocrysts in a groundmass of serpentinized olivine and phlogopite with minor amounts of spinel, perovskite, secondary biotite, chlorite, and secondary calcite. There is an apparent lack of magnesian ilmenite, enstatite, chrome diopside, and the rarity of garnet, however, the observed mineralogy is not believed to be representative of the original composition because of the extreme secondary alteration of the breccia.

The micaceous peridotite crops out in the northwestern half of the study area comprising Middle and East Hills. This unit occurs in an oval-like pattern, about 600 m ($\sim$1970 ft) long in a northeast-southwest direction, about 240 m ($\sim$790 ft) wide, comprising about half of the total intrusive. Small intrusions of peridotite were noted (from geophysical studies) intruding the breccia in the southwest part of the study area. The peridotite is a hard, black to dull brown porphyritic rock containing olivine phenocrysts that occur as altered black grains. This rock ultimately weathers through a massive yellow clay (similar to the breccia yellow clay) to a black gumbo soil. Secondary coatings of carbonate, kerolite, barite, and serpentine veins can be found. In thin section the peridotite has a porphyritic texture with phenocrysts of subhedral, partially serpentinized olivine (Fo 92) in a groundmass of phlogopite, serpentine, and diopside with minor amounts of perovskite, pyrite, amphibole, and magnetite. Phlogopite, which alters to chlorite, may reach maximum dimension of 1 mm and may poikilitically enclose opaques, olivine, and small acicular needles of diopside. Spinels are rimmed by magnetite.

The tuff unit, an extremely variable blue-gray unit, occurs in scattered patches throughout the study area, but the major exposure is confined to West Hill. The tuff probably formed by fragmentation of peridotite or breccia or both after the initial intrusion, with tuffaceous material from the intrusion washing back into the crater, forming sedimentary features such as flow textures and graded bedding. In thin section the tuff contains quartz, potassic feldspar, and biotite in a groundmass of chlorite, serpentine, and clay material. Reworked tuff contains up to 50% quartz.

All three rock types contain inclusions of sandstone and shale, but the tuff contains the majority, including rare xenoliths of micaceous peridotite and kimberlite breccia. Analyses of geophysical data suggest a shallow, almost vertical intrusion of slightly variable thickness that dips slightly to the south.

Tuff, kimberlite breccia, and micaceous peridotite are distinct from each other by their SiO_2 contents (wt. percent): 55, 44, and 40, respectively. Total Sr, Rb, U, and Sr^{87}/Sr^{86} ratios are also distinct for each rock unit. All rock types show considerable variations in the major oxides, but the peridotite contains greater FeO, CaO, TiO_2, MgO than the breccia and the tuff contains greater CaO, K_2O, Na_2O, and Al_2O_3 than the breccia. The genetic relationship between the peridotite and breccia is not completely understood, but the chemical similarity of the two rock types is apparent even though the breccia is extensively altered. The micaceous peridotite is olivine normative, the kimberlite breccia is hypersthene normative, and the tuff is quartz normative.

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DIERKS BARITE DISTRICT GEOLOGICAL OBSERVATIONS

by
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Berton J. Scull presents an excellent description of the Dierks Barite District in the Arkansas Geological Commission's Information Circular 18 entitled "Origin and Occurrence of Barite in Arkansas," 1958. During examination of outcrops of Lower Cretaceous Age in Pike, Howard, and Sevier Counties, Arkansas, observations were made of geological features not described by Mr. Scull. These features are described below using the names Mr. Scull used for the deposits.

NORTHWESTERN 16 DEPOSIT

The Northwestern 16 Deposit is located in the NW¼, Sec. 16, and SE¼, Sec. 8, T. 8 S., R. 29 W. A gravel road trends in a northwest-southeast direction across the Northwestern 16 Deposit. In the road ditch on the south side of the road (map reference #1), many shear joints occur in the loosely consolidated sand. Most of the joints observed strike approximately north 80° west and dip from vertical to 30° to the south. Lenses and thin beds (up to 16 inches thick) of barite impregnated sand occur in the area of these joints. Underlying the sand is a bed of silty clay. Crystalline barite fills the joints in this bed of clay and forms intersecting veins of barite from 0.1 inch to 0.5 inch thick.

LUCKY THIRTEEN DEPOSIT

In addition to the area outlined by Scull (1958) for the Lucky 13 Deposit, barite was observed in the Trinity Group in the NE¼, Sec. 24, T. 7 S., R. 28 W., and at several places along the Muddy Fork road in Sec. 19, T. 7 S., R. 27 W.

A small amount of barite was found as a cement in the Pike Gravel in the NE¼, Sec. 17, T. 7 S., R. 27 W.

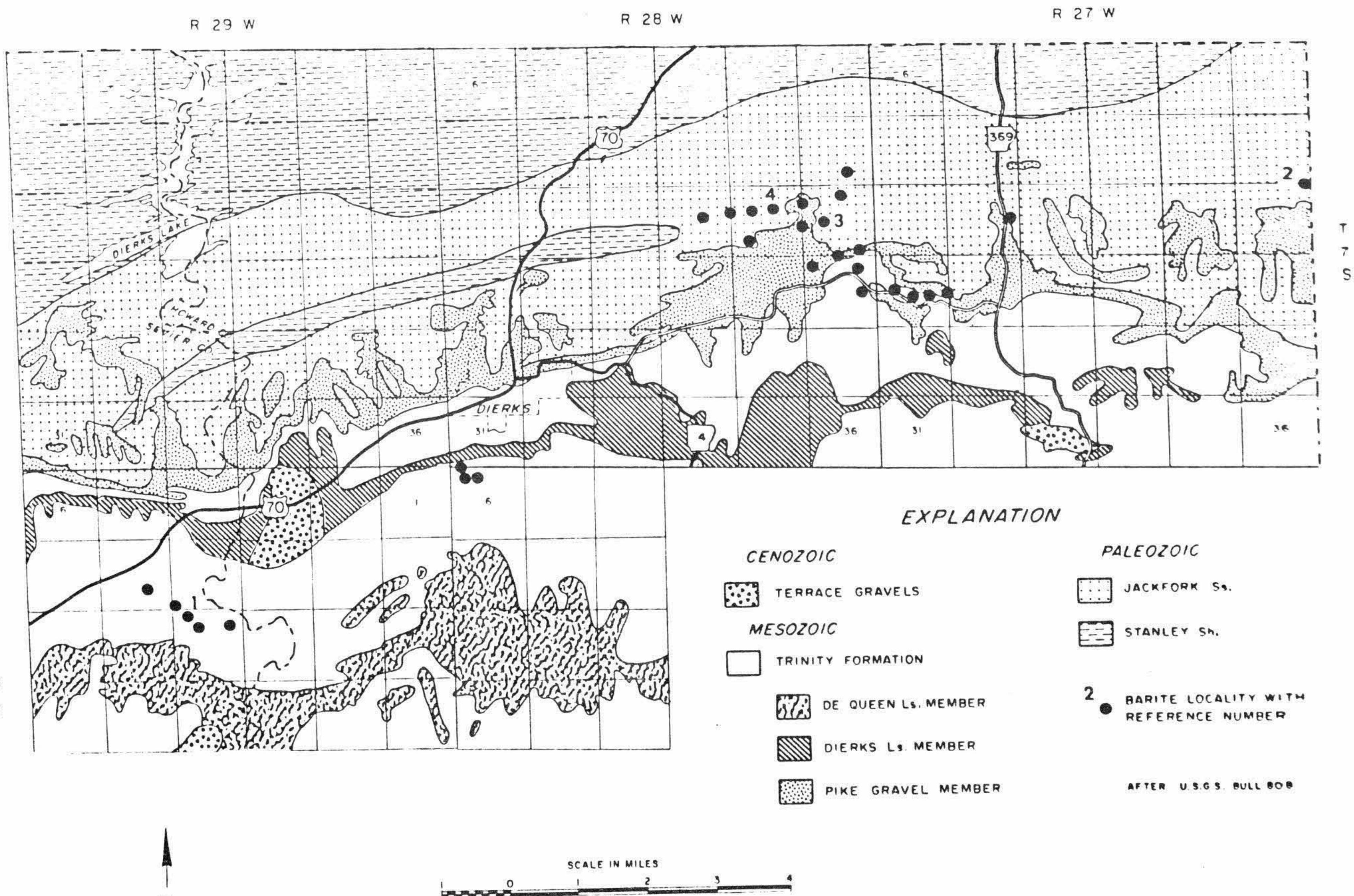
BARITE VEINS IN PALEOZOIC ROCKS

Reed and Wells (1938) reported barite in the Pyle Prospect located in the SE¼, Sec. 12 and the NE¼, Sec. 13, T. 7 S., R. 27 W. (map reference # 2). They stated:

> "The sandstone is fractured and contains dickite, barite, and some cinnabar. Small cinnabar crystals were observed in larger crystals of barite."

In the SW¼, Sec. 13, T. 7 S., R. 28 W. veins of quartz, barite and dickite occur in Paleozoic Age sandstone (map reference #3). In places the sandstone is brecciated and the barite occurs as a cement in the breccia. The quartz is slightly smoky and contains numerous fluid, gas, mineral, and rock inclusions. The sandstone strikes north 60° east and dips 50° north. Veins containing barite vary in strike and dip; however, one prominent strike direction is north-south with a corresponding dip of 30° east. These veins are generally less than 0.5 inch thick. The thickest veins contain quartz crystals up to 1.5 inches in diameter.

Similar thin veins containing barite, quartz, and dickite occur in the northern part of Sections 13, 14, and 15, and in the southern part of Sec. 12, T. 7 S., R. 28 W. Samples were collected from these localities and have been briefly examined in the laboratory. One sample of particular note came from the NW¼, Sec. 14, T. 7 S., R. 28 W. (map reference # 4). The sample is a 0.5 inch by one inch by three inches piece of sandstone with barite and quartz adhering to one surface. The barite is clear and up to 0.125 inch thick. The quartz occurs as milky crystals up to 0.25 inch in diameter with microscopic cavities. Silver colored stibnite



DIERKS BARITE DISTRICT

ARKANSAS GEOLOGICAL COMMISSION

occurs with a brilliant canary yellow coating of stibiconite on one surface in one of the cavities in the quartz.

SUMMARY

In the Dierks Barite District, barite occurs as veins and breccia cement in Paleozoic rock with associated stibnite, cinnabar, stibiconite, quartz, and dickite.

In the Trinity Group of Lower Cretaceous Age barite occurs as a cement in the Pike Gravel, in the sand between the Pike Gravel and Dierks Limestone and in the sand and clay between the Dierks Limestone and the DeQueen Limestone. Scull (1958) noted discordant veins of barite in the Pike Gravel and lower Trinity sand. The author observed veins of crystalline barite in the clay at the Northwestern 16 Deposit.

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PROBLEMS CONCERNING THE GEOCHEMISTRY AND GENESIS OF STRATIFORM BARITE – PYRITE ORE DEPOSITS IN ARKANSAS

by

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ABSTRACT

Stratiform barite-pyrite ore deposits continue to be an important economic source of barite in Arkansas. Studies by Hanor and Baria (1977) suggest that many of these deposits formed in areas where sedimentary formation brines containing dissolved barium ponded in depressions on the sea floor. Much of the barium sulfate now present in the deposits probably precipitated out at the brine-seawater interface furing thermal convection of a warm brine. Carbonate and sulfides, on the other hand, may have precipitated during stagnant, anoxic conditions, when the brine had cooled and downward advective transport of oxygen to the seafloor had ceased. Episodic refilling of the brine pool may have given rise to the rhythmic layering characteristic of many of these deposits.

Observed stratigraphic variations in the Sr/Ba Ratio of the barite may reflect fractionation of Sr and Ba during precipitation of $(Ba,Sr)SO_4$ from a system closed with respect to Ba.

Further detailed geochemical study of representative deposits will permit testing of the above hypotheses and will lead to more specific constraints on the sources of ore components, mechanisms of precipitation and mass transport, and controls on the localization of these stratiform ore deposits.

INTRODUCTION

Stratiform sulfide deposits associated with marine sediments and with marine--volcanic sequences constitute an important source of the world's barite, copper, lead, and zinc. The origin of many of these deposits is obscure, but remains an important goal of fundamental research in the exploration for non-renewable resources (Rose, et al., 1976).

An important member of the broad and complex spectrum of stratiform ore deposits is the bedded barite--pyrite deposit. In these deposits, barite occurs as disseminated fine crystals and/or as nodular concretions in marine shales and siltstones. Pyrite occurs as disseminated framboids and cubes. Other sulfides are usually absent. As a group, the deposits are of great importance. The Chamberlain Creek deposit near Magnet Cove, Arkansas, for example, was for many years the largest producer of barite in the world. Other deposits are now being mined in this district. A large group of bedded barite--pyrite deposits, some of which are also important ore producers, occur in a belt extending from Nevada to Alaska (Dunham and Hanor, 1967; Dawson, 1975).

The low degree of post-ore thermal metamorphism and structural deformation make the Arkansas stratiform barite-pyrite deposits ideal examples for study of processes of ore deposition. Active mining and exposure of new ore deposits continues in this district, and research into the genesis and controls on the distribution of these deposits could have immediate, practical application in the prospecting for new deposits here and elsewhere in North America.

The purpose of this paper is to discuss briefly some of the problems concerning the geochemistry and genesis of stratiform barite-pyrite deposits in Arkansas. The paper is not intended as a rigorous review of the published work on stratiform barite deposits in general or on the Arkansas deposits in particular. Rather, it will concentrate on a few of the geochemical implications of the sedimentary model of ore deposition proposed by Hanor and Baria (1977).

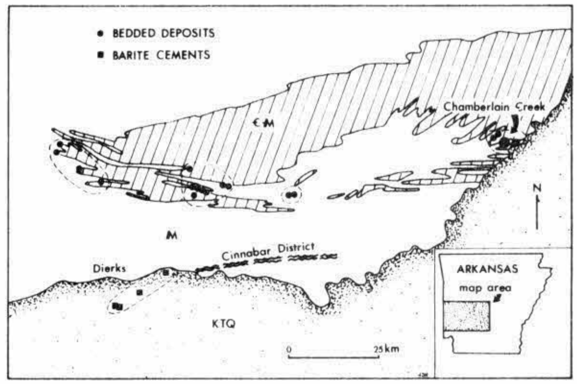

FIGURE 1. Map of the Ouachita region of central Arkansas, showing the location of bedded barite-pyrite deposits (solid circles). Most of the bedded deposits occur near the base of the Stanley Formation, indicated on this map by the boundary between Lower and Middle Paleozoic sediments (O-M) and Upper Paleozoic sediments (M). Barite-cemented sandstones and gravels (solid squares) occur in younger Gulf Coastal Plain sediments (KTQ) to the south.

STRATIFORM BARITE–PYRITE DEPOSITS OF ARKANSAS

DESCRIPTION

The Arkansas stratiform deposits occur as conformable lenses of disseminated barite and pyrite in Mississippian shales and siltstones of the Stanley Group (Fig. 1). Individual deposits range from 1 to 30 m (~3 to 100 ft) in stratigraphic thickness and from 40 to 7500 m (~130 to 24,600 ft) in outcrop length. The deposits contain up to 85 weight % barite and up to 10 weight % pyrite. The largest known deposit in the district was the Chamberlain Creek deposit, which produced over 400,000 tons of ore per year at its peak.

ORIGIN

Park and Branner (1932) proposed a late hydrothermal replacement origin for the Chamberlain Creek ore deposit because of the spatial proximity of the deposit to the Magnet Cove igneous intrusive of the Cretaceous Age. Scull (1958) suggested that all of the deposits in the Ouachitas were late hydrothermal replacements. Beginning with the work of Zimmerman and Amstutz (1961), however, an ever-increasing body of petrographic, sedimentological, and geochemical information has demonstrated that most but not necessarily all of the barite was deposited in Mississippian time, penecontemporaneously with the host clays and silts (Zimmerman and Amstutz, 1961, 1964a, 1964b; Zimmerman, 1965, 1976, Brobst and Ward, 1965; 1973; Miller et al., 1977; Hanor, 1966; Hanor and Baria, 1977). Still, the sources of ore components and mechanisms of precipitation have remained obscure. It has been suggested for example, that deposits of this type are analogous to the Recent barite-rich sediments of the Pacific (Shawe, et al., 1969), but regional accumulation rates for Recent pelagic barite are orders of magnitude too low to account for the concentration of barite observed in the Arkansas deposits (Hanor, 1972).

Hanor and Baria (1977) have proposed the following general explanation for the origin of the deposits. In Middle Mississippian time, compressive regional deformation and a change in tectonic regime along the Ouachita continental margin (Thomas, 1976) resulted in an increased influx of clastic materials into the Ouachita geosyncline and the development of submarine depressions on the sea floor near the base of the continental slope. The areal distribution of sedimentary facies in the underlying Arkansas Novaculite suggests that these shallow, submarine basins may have been in existence as early as the Devonian (D. R. Lowe, pers. comm.). Faulting provided conduits for formation brines in underlying sediments to migrate upward and to pond in the submarine depressions.

It is known that sedimentary formation waters are usually depleted in sulfate and highly enriched in barium relative to sea water (White, et al., 1963; Hanor, 1979). We have postulated that barite precipitated at the interface between the barium rich brines and the overlying sulfate-rich seawater (Fig. 2). This fine-grained barite sank to accumulate as massive beds. A similar mechanism has been proposed by Mitchell (1980) for the origin of the stratiform barite deposits of Nevada. The single published δS^{34} measurement done on the Arkansas barite (Church, 1970) yields a value of δS^{34} (troilite) = 18.3 o/oo, which corresponds to the proposed sulfur isotopic composition of Middle Mississippian sea water (Thode and Monster, 1965; Holser and Kaplan, 1966), and is thus consistent with our proposed mechanism of precipitation. Additional barium may have been transported downward by adsorption on clays or organic matter, later to be precipitated out as nodules during early diagenesis. As the supply of subsurface brine was exhausted, barite deposition ceased.

The Hanor-Baria model requires no exotic source for barium or for sulfur and explains in general terms both the timing of ore deposition and the localization of barite in areally restricted deposits.

GEOCHEMICAL CONSEQUENCES OF THE BRINE POOL MODEL

The conceptual model that Baria and I proposed for the origin of the Arkansas stratiform barite-pyrite deposits has a variety of important geochemical consequences, the effects of which should be preserved in the ore deposits. A detailed and rigorous study of the geochemistry of the deposits should provide a means of testing our hypothesis and of quantifying our concepts of the controls on the distribution of these ores.

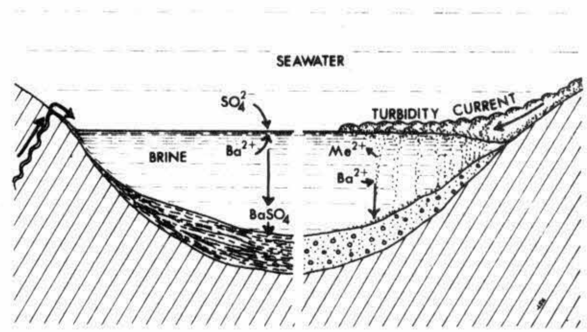

FIGURE 2. Idealized sedimentological model for the origin of bedded barite deposits. On the left, subsurface formation brines discharge onto the sea floor and pool in submarine depressions. Barite precipitates at the interface between seawater and the brine and sinks to accumulate as massive beds. On the right, turbidity currents surge across the brine interface. Clays and organic matter settling through the brine absorb barium, transporting it to sediment below. This barium may later be stripped off the clays and organic matter to form concretionary barite beds. From Hanor and Baria (1977).

I will explain some of the geochemical effects briefly.

RHYTHMIC LAYERING OF BARITE AND PYRITE

Zimmerman (1965, 1976, and references cited therein) was among the first to describe and speculate on the origin of the pronounced rhythmic alternation of barite-rich, carbonate-rich, and pyrite-rich layers which characterize portions of the Arkansas stratiform barite deposits. Two general processes figure strongly in Zimmerman's interpretation of the origin of this layering: 1) changes in rate of deposition of clastics and barite; and 2) variations in redox conditions at the ocean bottom. Zimmerman's general interpretations I believe to be valid and can be accounted for in the following way. As proposed by Hanor and Baria (1977), most of the submarine precipitation of barite in the Ouachitas occurred at an interface between a ponded brine and overlying seawater. A sedimentary brine which has migrated rapidly from depth in the crust should be warmer than bottom seawater. Following the contemporary example provided by the modern Red Sea Brines, warm brine ponded in a submarine depression will convect as cooling

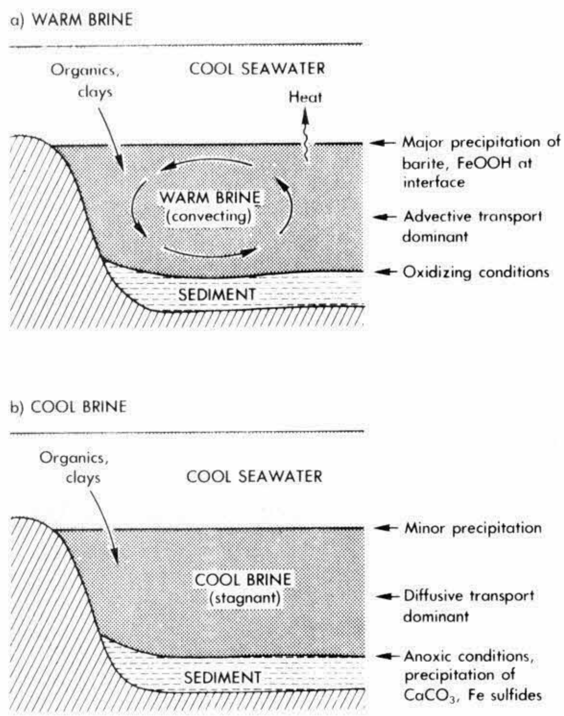

FIGURE 3. Effect of brine convection on the precipitation of barite and iron sulfides. a). Loss of heat from a warm brine causes convective overturn and rapid upward transport of dissolved barium and iron to the brine-seawater interface where precipitation of barium and iron oxyhydroxides occurs. Dissolved oxygen may be carried to the seafloor. b) When the brine has cooled, upward mass transport of barium is by diffusion, and precipitation at the interface slows. Bottom conditions become more strongly reducing, favoring the precipitation of iron sulfides and carbonate. Epizodic refilling of the brine pool may give rise to rhythmic layering.

occurs at the brine-seawater interface (Figure 3a). Vertical loss of heat from the brine, however, takes place faster than loss of dissolved salts by diffusion or entrainment (Turner, 1969), and when the brine eventually cools to ambient seafloor temperatures, it will cease to convect (Figure 3b). The brine will be cooler, less salty, and likely less dense than it was when it was originally injected onto the ocean floor.

The rate of precipitation of barite at the brine-seawater interface should be dependent to a significant degree on the concentration of dissolved barium in the brine immediately below the interface. Convection is an efficient means of supplying barium to this interface and maintaining high rates of precipitation (Figure 3a). If the brine pool has cooled and convection has stopped, upward transport of barium would be by molecular diffusion only and the rate of barite precipitation by mixing with seawater would significantly decline (Figure 3b). The rate of precipitation would also decrease as the brine becomes depleted in barium. Thus, the rate of barium precipitation would be high after initial filling of the brine pool, then decline. If clastic sedimentation continued at a constant rate, shale/barite ratios would increase. I believe that the quantity of barite that could be precipitated by cooling a saturated brine is probably secondary (Blount, 1977), but this is an aspect which should be evaluated further.

During the convective phase of the brine pool, dissolved oxygen derived from bottom seawater might be advected downward to the bottom of the pool (Figure 3a). Iron sulfide could be oxidized and replaced by barite, a petrographic feature which has been described. During the stagnant phase, however, there could be no advection of oxygen, and the downward rain of organic matter, which is known to have occurred (Miller, et al., 1977), would result in reducing conditions (Figure 3b). This in turn would favor the precipitation of iron sulfides as a result of reduction of sulfate to sulfide and ferric iron to ferrous iron. Precipitation of calcite could occur as a result of the increase in carbonate alkalinity accompanying sulfate reduction (Berner, 1981).

Mass balance calculations (Hanor, in prep.) show that the amount of barite present at Chamberlain Creek could not have been supplied by a single filling of a submarine brine pool. Episodic refillings had to have been necessary. I believe, therefore, that the rhythmic layering characteristic of many stratiform barite deposits probably represents the episodic refilling and cooling of brine pools on the ocean floor.

BARIUM—STRONTIUM FRACTIONATION

Strontium co-precipitates with barium in barite, and most natural barites contain between 1 and 22 mole % $SrSO_4$ in solid solution (Hanor, 1968). Barium is preferentially fractionated into the solid phase, however, and as precipitation continues, both the aqueous solution and the solids that precipitate from it become progressively enriched in strontium. The partitioning is both temperature and rate dependent (Starke, 1962).

During a single filling of a brine pool, the first barite to be precipitated at the brine-seawater interface and to accumulate would be Sr-poor. This would be followed by a succession of progressively Sr-rich barites as fractionation occurred. With a new influx of brine, however, a reversal in Sr content would occur, and the process of fractionation would begin again.

If the precipitation at the brine-seawater interface is the dominant mechanism for barite formation, it is possible that variation in Sr can be used to estimate the fraction of barium precipitated out of the brine during each episode of fill and the quantity of old brine which might be retained during refilling.

If barite were precipitated solely by cooling a saturated brine, the Sr values could possibly decrease upward during precipitation from a single fill of the brine pool. Cooling is likely a secondary effect, however.

Stratigraphic fluctuations of over 1 mole % $SrSO_4$ in the Arkansas barite have indeed been noted by Zimmerman (1965, 1976) and by Hanor (1966), but the degree of stratigraphic control is not adequate at present to evaluate what process or processes caused these variations.

CONCLUSIONS

Many of the observed textural geochemical features of the Arkansas barite-pyrite deposits can be explained by the hypothesis that ore deposition took place from brines ponded in closed depressions on the middle Mississippian sea floor. Convection of a warm, newly injected brine favored massive precipitation of barite at the brine-seawater interface. As the brine cooled, circulation stagnated. Barite precipitation slowed, and bottom conditions became more strongly reducing, favoring the precipitation of pyrite. Episodic refilling of the brine pool resulted in the rhythmic layering of barite-rich and pyrite-rich sediments.

Additional systemmatic study of the strontium zoning and stable isotope geochemistry of the deposits is needed to help refine the above hypotheses and provide a better understanding of sources of ore components, mechanisms of precipitation, and controls on ore localization.

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SMOKY QUARTZ IN RESIDUAL BAUXITE, SALINE COUNTY, ARKANSAS

by

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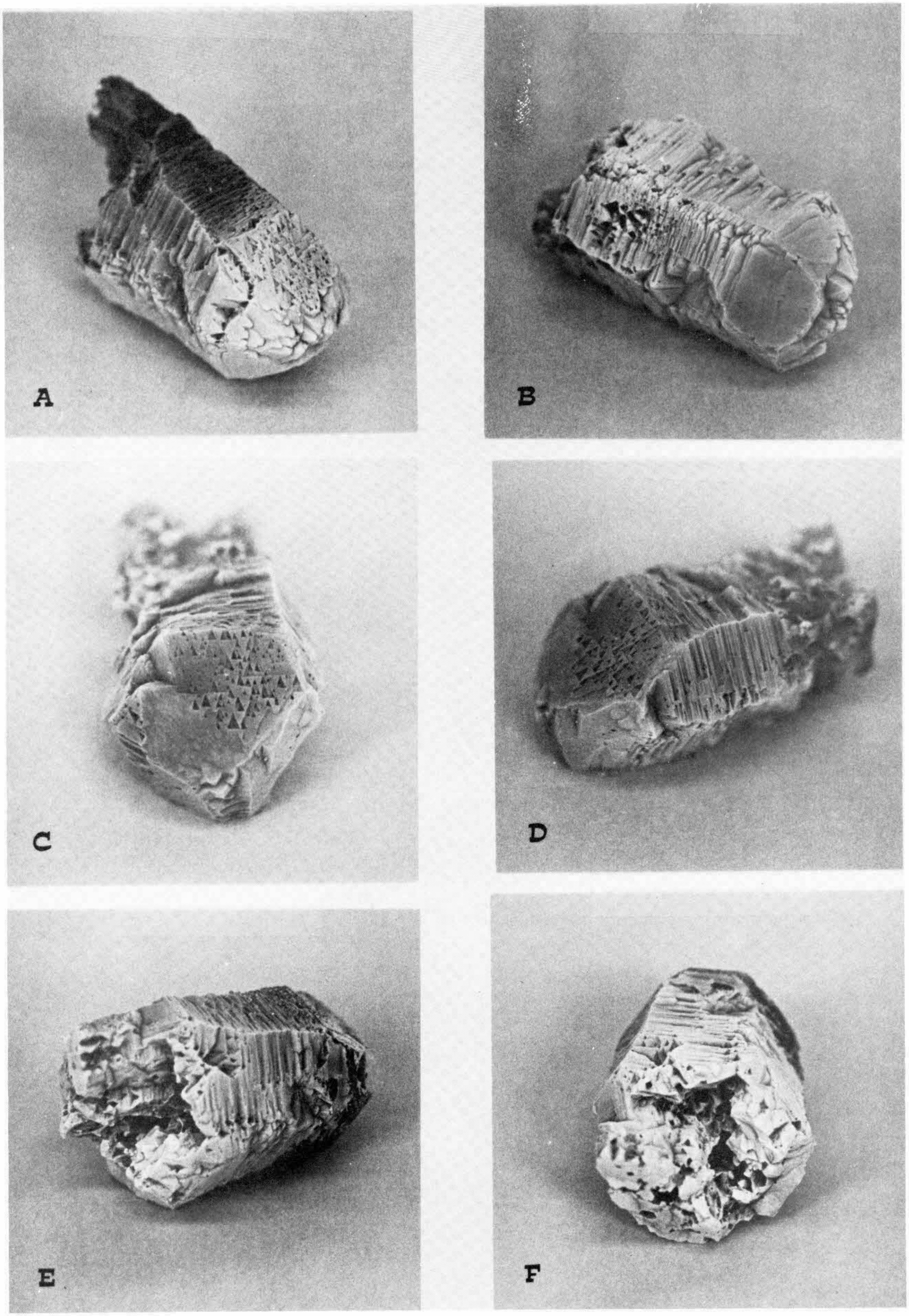
J. Francis Williams, in his classic work *The Igneous Rocks of Arkansas* (1891), mentions only one occurrence of quartz associated with the igneous (dominantly syenite) rocks of Saline County, Arkansas. Williams's description of dike number 252 (located in SE¼ sec. 16, T. 2 S., R. 14 W.) notes small anhedral masses of quartz associated with euhedral microperthitic orthoclase and small scattered laboradorite-range plagioclase crystals. During recent field investigations in the bauxite mines of Saline County, Arkansas Geological Commission staff geologist Ben Clardy recovered several specimens of dark smoky quartz from the Aluminum Company of America's section 21 mine. This location (SE¼ NW¼ section 21, T. 2 S., R. 14 W., near the center of the section) is less than one mile from Williams' dike number 252. Further field investigations by Clardy and the author led to the discovery of a second site approximately 30 feet east of the original location. Approximately 15 pounds of quartz was collected from the two sites. Both quartz zones were clayey and appear to be vertically dipping, highly weathered veins or dikes. The original discovery site measured 6 by 15 inches and produced less than one pound of quartz. The second site had quartz littering a surface area about 5 by 8 feet. Excavation revealed an irregular zone approximately 1 by 4 feet containing quartz.

The bulk of the quartz is light smoky, but varies from slightly smoky to black morion. Surface luster is vitreous and surface texture is extremely rough and irregular, suggesting little or no transportation. Unless fractured, the quartz has highly irregular striated faces. Some of these faces appear to be crystal faces and others appear to be the impression of striated feldspar faces which the quartz had contact with; the feldspar subsequently having weathered to clay. Internally, most of the quartz is transparent and unzoned and contains many planes and trails of bubbles. A number of specimens are highly shattered and/or broken which appears to be due to the freezing of the fluid filled cavities.

Although Williams did not mention inclusions in the quartz of dike number 252, it is associated with aegerine and plagioclase. The smoky quartz from the section 21 mine contains several types of inclusions. No positive identification of the inclusions have been made; however, visual descriptions are given:

1. green elongate euhedra - acmite (?)
2. irregular red spot - cinnabar (?)
3. translucent gray cubes - halite (?)
4. white fuzzy masses - (?)

Three noteworthy crystals were found and exhibit several common characteristics (Figure 1). Sharp clean terminations are missing. Although the pyramid faces (r) predominate the terminations, the tips of the crystals are bounded by a series of stacked z faces. The pyramid faces (r) have triangular pits developed on their surfaces; the triangle apices pointing in the direction of the term-


A
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ination. Prism faces are predominantly deeply striated consisting of successive stacking of r and m faces or z and m faces. Pyramid to prism boundaries are rounded. No internal zoning is present in the crystals and they appear to be faceting quality morion. Despite the similarities, there are several differences in these crystals. The bases of two crystals have cavities which appear to have contained pyroxene and/or feldspar on which the quartz originally formed. The third crystal has a conchoidal break on the attachment end. Two crystals contain needle type inclusions, now altered, which probably were pyroxene.

Two samples were analyzed by G. F. Bell (chemist, Arkansas Geological Commission) for a selected suite of metals. Sample number 1 was smoky quartz which had been boiled in a dispersing agent to remove the clay matrix and its contained residual minerals. Sample number 2 was the raw clay matrix with smoky quartz present (Table 1).

Except for Ti, the values presented in Table 1 fall in the normal ranges of these elements for quartz. The initial Ti value of the cleaned smoky quartz (sample 1) is greater than the Ti value for smoky quartz given by Frondel (1962, p. 143-147) by more than 100X. Frondel attributes high TiO_2 values of blue quartz to needle-like inclusions of rutile (p. 190). The sample 1 value for Ti is 10X greater than Frondel's value for blue quartz (Frondel's Table 27). A second sample of smoky quartz (the *value, Table 1) was acidized to remove all external impurities and

FIGURE 1. – Smoky quartz from Section 21 Mine. Magnification 2X. The crystals have been coated with MgO to enhance the surface texture.
A&B – same crystal. Note triangular pits on pyramid faces, deeply striated prism faces, and unusual termination.
C through F – same crystal. Note same features as A&B. Photographs E and F exhibit partial termination and embayed areas of attachment on ends of crystal.

Table 1 - Chemical Analyses

Element	Sample 1 (%)	Sample 2 (%)
Au	Nil	Nil
Ag	Nil	Nil
Pb	Nil	0.004
Zn	0.001	0.013
Cu	0.002	0.006
Co	Nil	0.011
Ni	0.002	0.010
Ti	0.110 *0.022	0.750
V	0.014	0.083
Mo	0.014	0.019
Sb	0.002	0.003
Hg	Nil	Nil
Li	Nil	0.018

analyzed for Ti. This value (0.022% Ti or 0.036% TiO_2) is high by 10X "normal" smoky quartz and in the range of blue quartz. Thin sections have not yet been made to determine if rutile is present in the smoky quartz of the section 21 mine. The presence of Sb without detectable Hg is interesting because both elements are expected to behave similarly geochemically; by being concentrated in late stage hydrothermal fluids.

Bauxite which retains the original igneous rock texture is the host rock for both lens of quartz. Several possible explanations exist for this occurrence. Quartz-bearing miarolitic cavities are known from the Bigrock syenite quarry in Pulaski County, Arkansas. The quartz from such cavities is euhedral, unzoned, and encases earlier formed minerals. However, the quartz is extremely scarce; two single crystals, each in separate cavities, being the total observed by the author in several years of collecting. Quartz veins may have been emplaced in the syenite prior to laterization of the rock to form bauxite. The appearance of the smoky quartz in the section 21 mine differs greatly from smoky quartz known to be Cretaceous age or younger from Magnet Cove, Hot Spring County, Arkansas approximately 22 miles to the southwest. The quartz deposit appears to represent quartz-bearing syenite dikes which were emplaced in host syenite. Laterization of the host and dikes resulted in the alteration of silicate minerals unless they were totally encased by quartz. The physical appearance of the quartz, particularly the highly irregular but crystalline-appearing surfaces, supports this theory.

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EXPLORATION FOR FRACTURED PETROLEUM RESERVOIRS, NORTHERN FLANK OF ARKOMA BASIN, ARKANSAS

by

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BACKGROUND

During the past two decades the petroleum industry has shown increasing interest in fractured reservoirs because many of the world's oil and gas fields have reservoirs in which porosity and, perhaps more important, permeability are fracture controlled. Knowledge of fracture control in a reservoir not only aids the primary recovery of hydrocarbons but also guides the design of well stimulation and enhanced recovery programs. Because fractures are commonly propagated upward and reflected at the earth's surface as subtle linears, detection of these surface features is extremely important in many phases of petroleum exploration and development.

To document the utility of microwave analysis for petroleum exploration, the Arkansas part of the Arkoma basin was selected as a prime test site. The research plan included comparison of aircraft microwave imagery, and Landsat imagery in an area where significant subsurface borehole geophysical data were available. The test site provides contrasting rock types and structures in an area where surface cover includes cropland and deciduous, coniferous, and mixed forest types. There is little discernible relationship between structure and gas production in the area, and stratigraphic entrapment appears to be the primary factor influencing the presence of gas.

The test site is in northwestern Arkansas, generally within a rectangle bounded by latitudes 35°45'N and 35°07'N and longitudes 94°30'W and 92°45'W, encompassing approximately 11,000 sq km (4250 sq mi) (Fig. 1). It includes all the major gas fields in the Arkansas part of the Arkoma basin. The Arkoma basin is an arculate structural trough 400 km (250 mi) long extending east-west across central Arkansas and northeast-southwest in eastern Oklahoma. The basin is typified by imbricate thrust faults in the south and normal faults, monoclines, and east-west trending anticlines and synclines in the north.

LINEAR REMOTE SENSOR ANALYSIS

DIGITIZATION OF LINEARS

The end points of each linear from primary remote sensor data sets were digitized on a latitude (X)--longitude (Y) coordinate system. Digitization was accomplished by means of a Tektronix model 4954 digitizing tablet which has a 40-inch by 30-inch sensitive surface area and provides resolution of 0.01 inch. The tablet was attached to a Tektronic 4015 graphics terminal which, in turn, was linked to an IBM 370-155 host computer. Data stored on magnetic tapes were used to produce linear and well location plots on a Zeta 3653 plotter.

RADAR (SAR) AND LANDSAT PROCESSING AND ENHANCEMENT

In support of this research effort, the Jet Propulsion Laboratory provided Synthetic Aperture Radar (SAR) imagery of the test site obtained during May of 1977 and April of 1978. Because of funding limitations, only

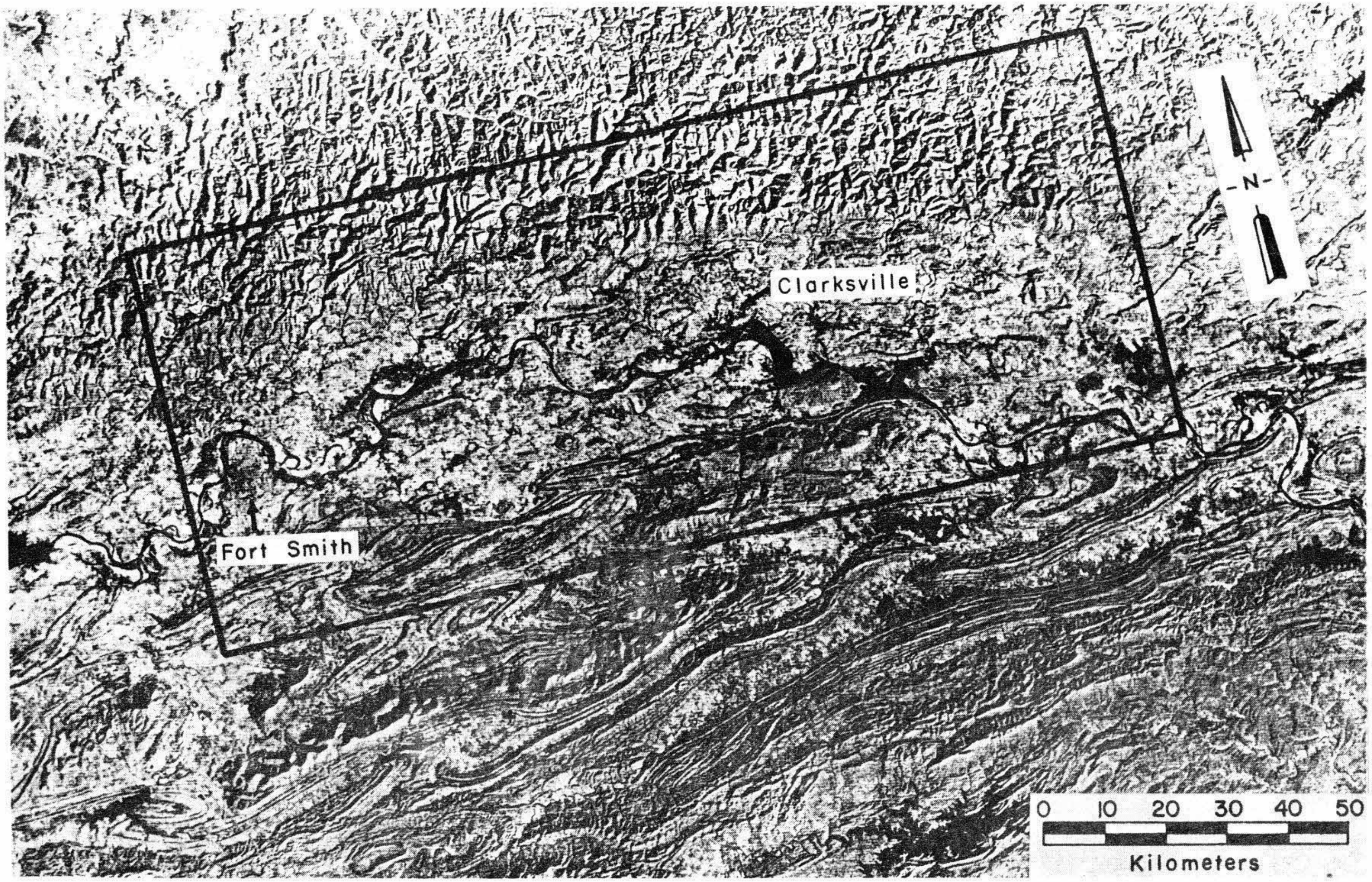

Figure 1. Landsat mosaic of winter images (solar elevation 21°) of the Arkoma basin with the study area indicated.

the 1978 data set was digitally processed. This L-band (23 cm wavelength) imagery was obtained in a series of north-south flight lines with approximately 8 km (5 mi) swath widths and providing dual-polarization coverage. Two different Landsat scenes (winter and summer) were selected to provide maximum changes in solar illumination (elevation) and terrain cover. Both radar and Landsat imagery was subjected to various computer enhancement and analysis procedures performed at the Image Processing Laboratory of the Jet Propulsion Laboratory. Processing and enhancement techniques used on the SAR imagery included digitization, removal of gain variation, conversion from slant range to ground range, mosaic generation, Gaussian brightness transformation, uniform distribution stretch, spatial filtering, and registration to the Landsat image. Landsat image processing and enhancement techniques used on all four bands (scenes) included geometric corrections, Gaussian and uniform distribution of brightness, and spatial filtering. Color IR and enhanced color composites were made for each summer and winder Landsat scene. To ensure that spectral variations in all bands were equally displayed, the images were first subjected to the Gaussian brightness transformation.

LINEAR DETECTION

Three experienced interpreters were selected for inferring linears from various remote sensor data sets. Histograms for each different image scene or combination were compared between data sets and operators.

SIGNIFICANCE OF LINEARS

Production or gas yield data (initial calculated open flow) combined with well locations and linears from various remote sensor data sets were called up simultaneously from the Zeta 3653 plotter. The superimposed plots provide an overall comparison of poor, average, and good gas well yields with respect to linear position, clustering, and density. Regardless of the remote sensor data set used, it was apparent that the test site could be subdivided into two contrasting regions: the southern two-thirds of the test site which is characterized by an overall lack of linears in an area where producing wells are most numerous, and the northern third of the test site which has a relative abundance of linears but where gas wells are less numerous.

SOUTHERN REGION

Within the southern region or Arkoma basin proper, where wells are numerous and linears sparse, all attempts (linear regression analysis) to establish a relationship between well productivity and linear proximity proved futile. In addition, no significant trend or correlation could be established between linear density and gas production.

NORTHERN REGION

In parts of the northern region well control and linear density contrast are sufficient for use in examining the relationship between well yield and linear trends. To facilitate computer analysis, the northern one third of the test site was subdivided into half-quad (7.5′ quad maps) areas (Fig. 2). In addition, the various gas-bearing zones within the stratigraphic column were consolidated into manageable groups based on their stratigraphic position and reservoir or lithologic similarities.

Within the northern region, a relatively large number of producing gas wells are clustered in the vicinity of half-quads 34 and 22 (Fig. 2). Whereas half-quad 34 (immediate vicinity of Rock Creek gas field) is characterized by few linears, half-quad 22 (Batson gas field) has a relatively large number of linears, especially in a north-south orientation. In an attempt to define the relationship between linears, subsurface structure, and gas production in these two contrasting areas, subsurface structure maps were constructed from mechanical well logs (induction electric, formation density, and gamma ray/neutron).

The Boone Formation (up to 60-70 percent chert) yields gas in the Batson field which is situated on a structural high coincident with high linear density. However, in the Rock Creek field, the Boone Formation is on a structural high in an area of low linear

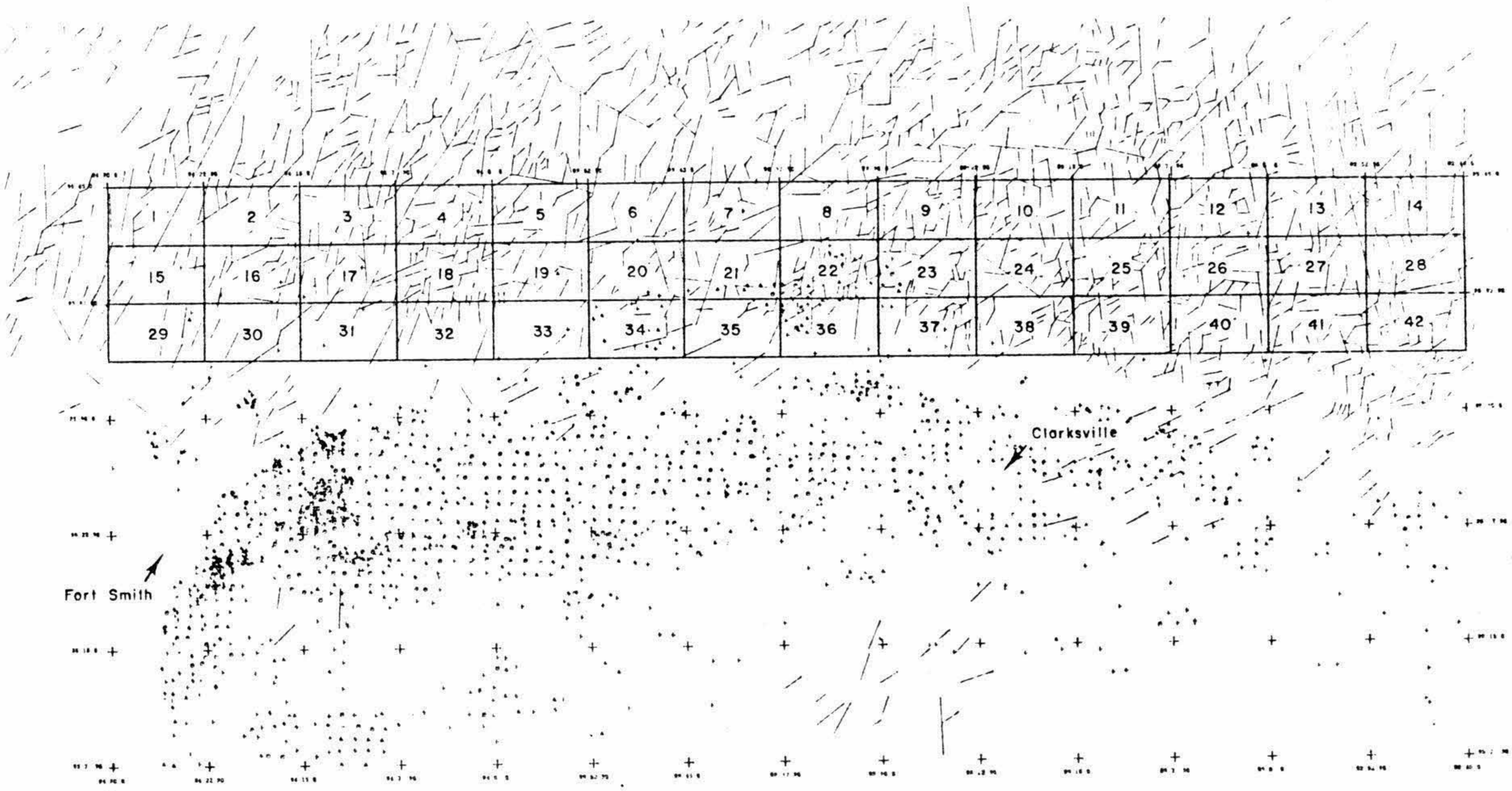

Figure 2. Linears detected from Landsat winter scene band 7 and plot of gas wells.

density and is essentially nonproductive. A study of mechanical logs from both fields indicates that the Boone interval is generally lithologically consistent throughout. Because of the structural position of the Batson field, relatively tight fractures may have been changed to open fractures. The Batson field is situated on the hinge line of a regional monocline which is also coincident with a local anticlinal closure having relatively high linear density. The Rock Creek field, although also on a local anticlinal closure, and in proximity to the hinge line of the monocline, is located in an area of low linear density, and has minimal evidence of fracture production. Contrasting these two areas provides empirical support for an interrelationship between remote sensor-derived linears and fracture production.

The Pearson correlation coefficient indicates a positive correlation between the number of linears in a given area (linear density) and production from the Boone Formation; however, there is no significant correlation between production and the distance to the nearest linear. These findings have direct application to exploration and development of the Boone Formation in the northern Arkoma Basin. More important, the findings agree with those of Gorham et al., (1979) that exploration efforts for traps with fractured reservoirs should focus on areas of maximum curvature of folds, especially monoclines.

SUMMARY OF DATA ANALYSIS

Of Landsat bands, band 7 provides for the detection of the greatest number of topographic linears. However, the variation among the three operators is least with band 6. The winter Landsat scene consistently provides for the detection of more linears than the summer Landsat scene because of the lower solar elevation during the winter. The uniform distribution stretch enables interpreters to detect more linears than the Gaussian stretch. The Gaussian stretch enhancement decreases contrast in the middle-gray range, thereby suppressing linear expression. In summary, the best Landsat combination is the winter scene, band 7, uniform distribution stretch.

Of the SAR data products, the VH SAR radar mosaic provided for detection of the most linears; however, none of the SAR enhancement products is significantly better than the others. A black and white band 7 winter Landsat scene merged with radar mosaic (VH), having a look-direction orthogonal to the Landsat solar azimuth, is suggested as a complementary image merge. Both of these data sets alone allowed for the detection of most linears.

The southern region of the Arkansas Arkoma basin proper is characterized by high well density but few linears. Little relationship is discernible between surface structure and gas production, and no correlation is found between gas productivity and linear proximity or linear density as determined from remote sensor data. Stratigraphic gas entrapment is most probably related to depositional environment, and is the main factor influencing porosity and permeability in the predominantly sandstone reservoirs.

In the northern Arkoma basin a positive correlation is found between the number of linears in a given area and production from cherty carbonate strata. Most such production is from the Boone Formation. The high chert content of the Boone Formation makes it particularly susceptible to fracturing and the development of fracture permeability. No correlation is evident between linear density and any of the other gas-bearing units. These other gas-bearing units are predominantly sandstone, and are somewhat similar lithologically to the sandstone reservoirs in the southern Arkoma basin.

Linear density analysis should not be the single basis for petroleum exploration on the northern flank of the Arkoma basin. Regional and local structural position and surface joint orientation are equally important data sets to be evaluated in an exploration program. However, the probability of economic savings in the exploration for fractured reservoirs (similar to the Boone Formation) in other parts of the world can be considerable if linear density maps derived from radar/ Landsat merges, are used to target prospects for further geological and geophysical investigations.

ACKNOWLEDGEMENT

This paper provides a summary of a detailed final report submitted to the Jet Propulsion Lab, Pasadena, CA (MacDonald et al., 1980). Funding was provided through NASA/JPL Contract No. 955048.

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A SMALL BITUMEN DEPOSIT NEAR PONCA, ARKANSAS

by
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Near the old lead-zinc mining town of Ponca, in northern Newton County, Arkansas, recent road construction has uncovered a small deposit of bitumen near the top of the Everton Formation (E½, NW¼. Sec. 36, T. 16 N., R. 23 W.). At this location 18 feet of middle Ordovician Everton crops out overlain by 19 feet of upper Ordovician Fernvale Limestone, 2.5 feet of basal Mississippian conglomerate, and 20 plus feet of Mississippian age St. Joe Limestone. The Everton here is a fine grained limy dolostone grading upward to a very fine grained limestone. Allochemical and terrigenous constitutents include some fossil debris and scattered, well rounded, frosted, quartz sand. The upper contact is unconformable and marked by thin, cherty beds. The Fernvale is a calcirudite, crinoidal, lime grainstone. The unconformity separating the Fernvale from the superjacent Mississippian unit is generally even but occasionally entrenched as much as 3 feet. The bitumen is found as small mass deposits and fracture films in the Everton and as fracture films in the Fernvale.

The mass bitumen deposits were all found in the Everton Formation. It occurs interstitial to spar calcite filling "cavities" that are sometimes partially lined with travertine. A bitumen film is present between the spar and wall rock or travertine but not between the travertine and wall rock. The largest mass observed was an irregular lens approximately 8 x 3 x 2 inches. Most mass deposits involved less than a cubic inch of material. Films of bitumen line some fractures in the rock and extend across the Everton-Fernvale unconformity in some cases. No mass deposits were found in the Fernvale and the fracture films appear to die out near the top of the unit. No bitumen was detected

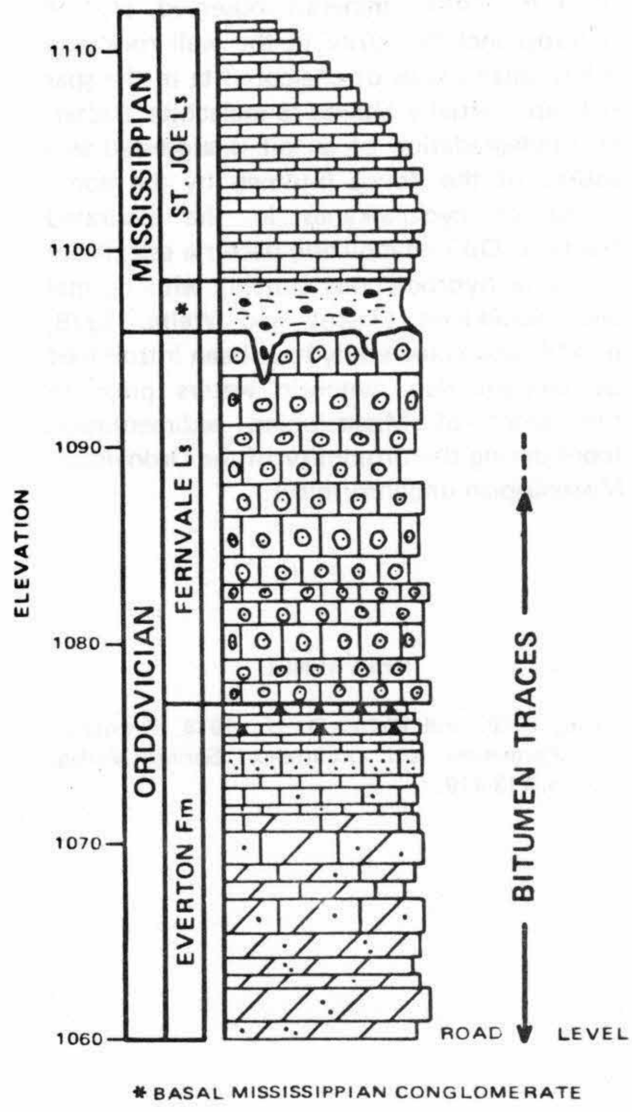

Figure A – Graphic Columnar Section for E½, NW¼, Sec. 36, T. 16 N., R. 23 W.

in the Mississippian units. Investigations of lateral equivalents in the general area have not revealed any other bitumen traces.

Analysis of the bitumen by the USGS, through the help of Boyd Haley and Joseph R. Hatch, showed it to be 41.1% saturated hydrocarbons with a dominance of cyclo-alkanes over normal and iso-alkanes (Fig. 1), 24.2% aromatic hydrocarbons, and 31.7% organic compounds containing nitrogen, sulfur, and oxygen. The bitumen has a subconchoidal fracture and a specific gravity of 1.25. Other minerals observed on the outcrop include pyrite in the wall rock and a few small grains of chalcopyrite in the spar that are partially altered to malachite. Bacterial biodegradation of an oil is suggested as a source of the Ponca bitumen by the dominance of cyclo-alkanes in the saturated fraction. Oil metabolizing bacteria selectively consume hydrocarbons starting with normal and iso-alkanes (Tissot and Welte, 1978, p. 414) and could easily have been introduced by oxygen rich meteoric waters prior to the onset of Mississippian sedimentation (considering the proximity of the Ordovician-Mississippian unconformity).

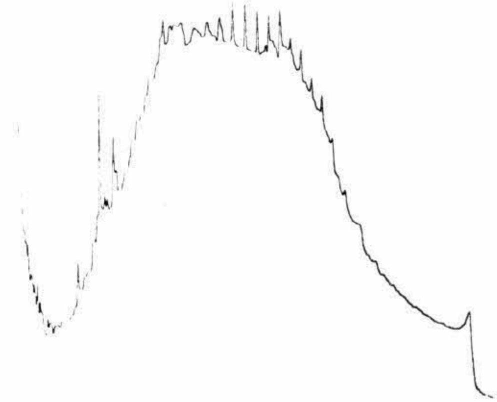

FIGURE 1 — Gas chromogram of the Ponca (Everton Formation) bitumen. The large "hump" represents the cyclo-alkanes; the spikes represent normal and iso-alkanes (courtesy of J. R. Hatch, USGS, Denver).

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A CASE HISTORY OF A MAJOR LANDSLIDE ON CROWLEY'S RIDGE, VILLAGE CREEK STATE PARK, ARKANSAS

by
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ABSTRACT

Crowley's Ridge in the vicinity of Village Creek State Park in eastern Arkansas is an erosional remnant of unconsolidated Pleistocene age sands and gravels underlain by Tertiary age clays, capped by loess, and characterized by numerous landslides. Most landslides noted in recent times have been small slumps or slides displacing a few tens of yards of material. The Village Creek State Park landslide is rather unique in that it is much larger than the "normal" slide. The slide developed on the east side of a wooded hill forming the south abutment of Lake Austell Dam. The slide appears to be the result of near horizontal movement of a large, essentially single block producing pressure ridges in the direction of movement and developing a graben behind. The area disturbed is about 600 feet long by 250 feet wide. Model constructs using topographic profiles and graben block dimensions and displacements indicate a 15 to 20 foot near horizontal displacement of the main block and depth-to-slide-surface of less than 10 feet beneath the original valley floor. The main part of the graben is 50 to 90 feet wide with a maximum vertical displacement of 35 feet on the uphill side and 15 feet on the downhill side. Pressure ridges developed at the toe of the hill temporarily impounded a small stream. The slide did not occur as a single event but rather as a series of movements, most of which occurred during the first 45 days but extended over a period of months. Each significant movement occurred a few days after a heavy rain. The instability of this slope is apparently self generated. The impounded stream, forced to seek a new course, cut its new channel into the toe of the hill. A series of abandoned stream channels indicates each slide previously developed on this hillside has diverted the stream into the toe of the hill.

INTRODUCTION

R. Ellsworth Call in the Geology of Crowley's Ridge (1891) makes note of "numerous landslides which have characterized the region" (1891, p. 40) and warns of the difficulties the stratigrapher has because of this process. Most landslides noted in more recent times have been small slumps or slides displacing a few tens of yards of unconsolidated Pleistocene and Tertiary age sediments. The landslide described in this report is rather unique in that it is much larger than the normal slide. This slide is classified as a multiple pulse block glide (Simonett, 1968, p. 640) with pressure ridges developed along the advancing front and a graben (with associated slump blocks) developed between the retreating front and the crown of the slide. The area of the slide is in Village Creek State Park, Cross County, Arkansas, on the east side of a wooded hill forming the south abutment of Lake Austell Dam (SW¼, Sec. 7, T. 6 N., R. 4 E)(Fig. 1). The statements set forth in this report are the result of repeated geological reconnaissance of the area by the authors augmented by conversations and reports from Arkansas State Parks personnel and personnel of the Tennessee Earthquake Information Center. Base maps and cross-sections were developed from tape and compass surveys of the area by the authors and from existing topographic information.

DESCRIPTION

The area disturbed by the landslide is about 550 feet long by 250-300 feet wide. The slide can be divided into three general

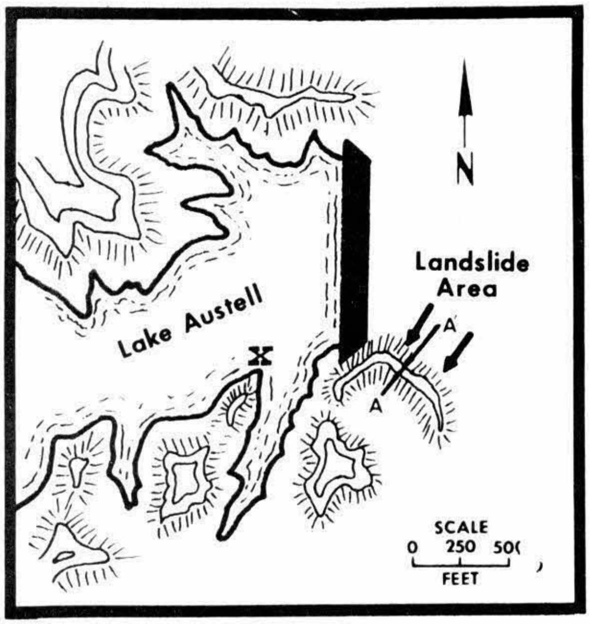


FIGURE 1 – Location map for Village Creek State Park landslide. A–A' is line of Figure 4 topographic profile. X marks the location of the borrow pit from which clay was taken for the dam core and bank blanket.

areas: a pressure ridge zone, a glide block, and a graben (Fig. 2). The area of pressure ridges is presently at the toe of the hill and extends for a short distance out onto the valley floor. In this area many indications of uplifted ridges of various lengths subparallel to the long axis of the block glide are evident. Where the surface was compressed, shallow roots of the trees were folded and forced out of the ground and in some cases broken. Numerous holes and short cracks initially seen throughout this area seemed to be the result of these buckling roots. Cracks in the ground surface seemingly unrelated to tree roots were seen only at places where the forest floor litter was thin or nonexistent. Most of these cracks trended subparallel to the long axis of the slide. Plants on the crests and troughs of the pressure ridges showed little indication of the dramatic activity they had undergone; whereas trees on the flanks of these ridges were tilted and in a few cases had fallen.

A small creek passed close to the toe of the hill before the landslide took place. The pressure ridges changed the local topography enough to partially impound the stream, flooding patchy areas. The stream bed itself is the site of the most obvious pressure ridges. The creek bed in some places had been uplifted so that it was the same level as the bank tops. (Subsequent erosion has partially retrenched the stream). Semipolygonal cracks were present where mud covered the surface of the crests of the pressure ridges. Continued observations of the site revealed the development of fresh tension cracks for several weeks indicating continued movement (uplift). Repetitive surveys by the Arkansas State Parks survey crew over a period of 10 months showed a fairly uniform decreasing rate of growth (see Fig. 3). Buried logs were partially raised and left protruding from the ground with strings of roots and vines seemingly trying to tie them down. During our initial investigations incipient low scarps (18" - 30") were observed in the creek bed. Although most of the material we examined along the scarps was sand and gravel in flat-lying beds of Pleistocene age, near the center of the uplifted portion of the creek bed we found two varieties of clay, apparently extruded; a dark gray clay with fragments of lignite, and a mottled light tan to orange silty clay considered to be in the upper Claiborne Group of Eocene (early Tertiary) age. At the time of our initial examination both clays were soft and plastic.

One hundred and fifty feet or so up the slope from the zone of pressure ridges a graben feature is developed. The graben is about 400 feet long and 50 to 90 feet wide. It shows a maximum vertical displacement of 12 to 18 feet on the downhill side and about 25 to 35 feet on the uphill side. Tension cracks with minor displacement extend from each end of the graben resulting in a total main scarp length of 500 - 550 feet. One major block, partially split by a transverse crack has collapsed into the graben along with numerous secondary blocks (Figs. 2 and 4). The main block formerly was the crest and part of the slope of the hill. Trees that were

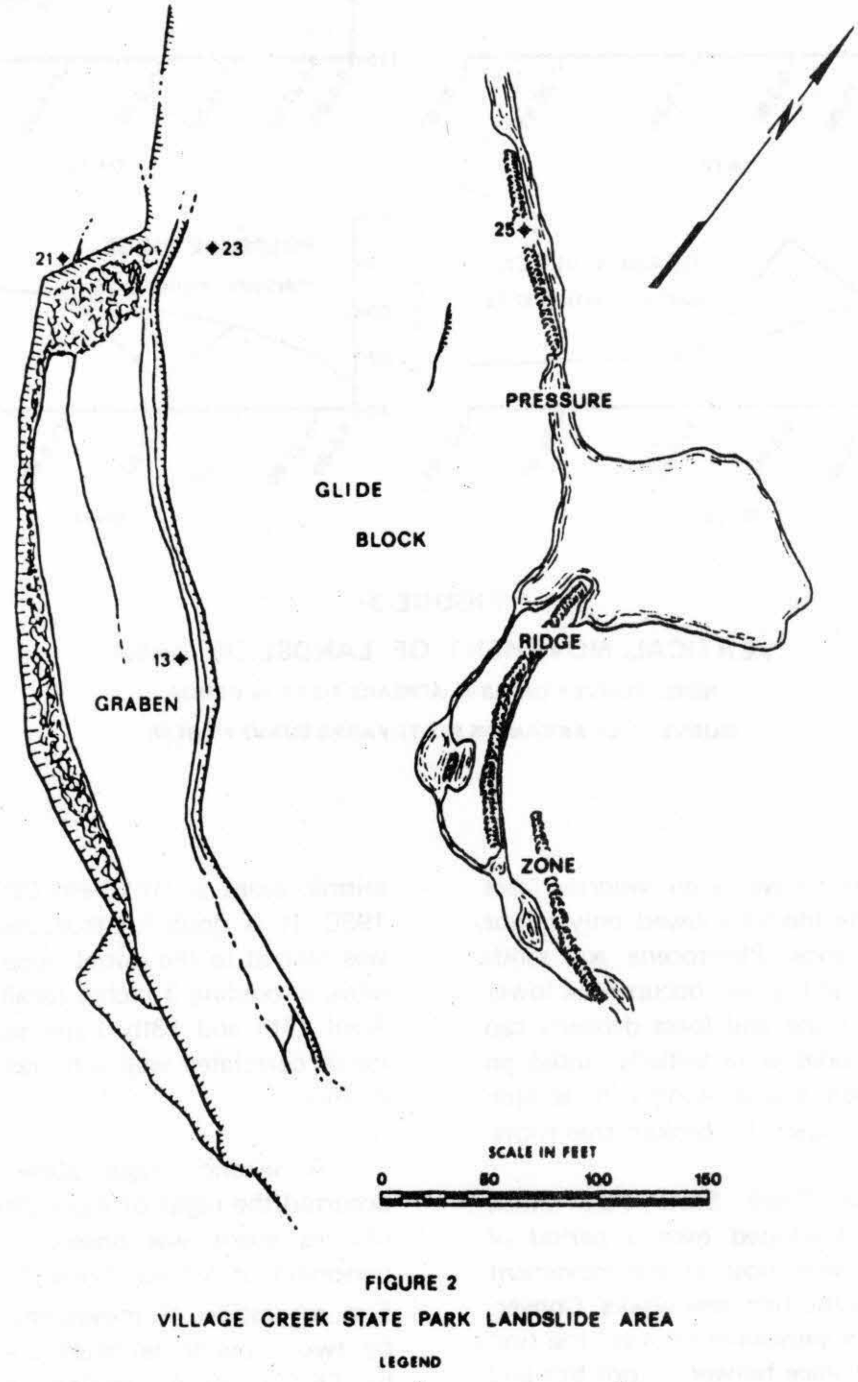
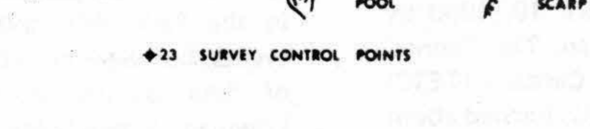


FIGURE 2

VILLAGE CREEK STATE PARK LANDSLIDE AREA



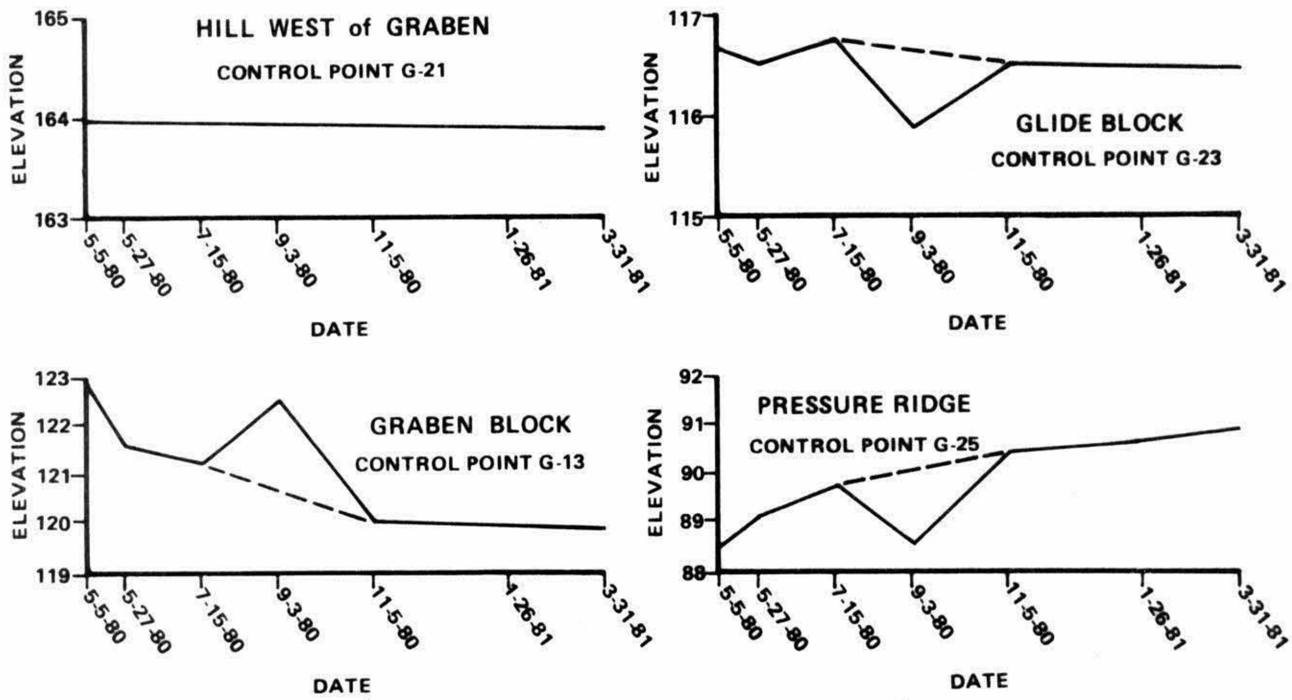


FIGURE 3

VERTICAL MOVEMENT OF LANDSLIDE AREA

NOTE: SURVEY ON 9-3-80 APPEARS TO BE IN ERROR

(SURVEYS BY ARKANSAS STATE PARKS SURVEY CREW)

astraddle the faults have fallen; whereas trees that were on the blocks showed only minor signs of disturbance. Pleistocene age sands with some clay and gravel occupy the lower portions of the slope and loess deposits cap the hill. Slickensides were initially noted on some of the fault scarps along with scratch and drag marks caused by broken tree roots.

The Village Creek State Park block glide landslide developed over a period of several months with most of the movement occurring during the first few weeks. Conversations with Park personnel indicate the first movement took place between April 5th and 18th, 1980. The graben and pressure ridges were first discovered on April 19, 1980 by Park Naturalist Larry Lowman. The Tennessee Earthquake Information Center's (TEIC) Wittsburg Lake Station (WLA), located about 2 miles north of the slide area, recorded a local (recorded only at this one station) seismic event at 10:10 PM CDT on April 11, 1980. It is doubtful that this seismic event was related to the initial slope failure. Heavy rains, exceeding 3 inches locally, fell between April 11th and 13th. Later significant movements correlated well with moderate to heavy rainfall.

A second major pulse of movement occurred the night of April 28-29, 1980. Part of this event was observed first hand by personnel of Village Creek State Park. The first suggestion of movement was indicated by two coincidental seismic events detected by TEIC's WLA station around 9:00 PM local time. Park personnel living nearby, within the Park, felt nothing of these seismic events, but were called by TEIC and notified of their occurrence. Park Naturalist Larry Lowman entered the site about 9:45 PM and reported the following (Lowman, 1980, p. 12-13):

"To my astonishment, there was no water flowing in the channel where water had flowed the day before; a few small fish flopped helplessly on the gravel. The bed of the creek was rising again, and a portion of an adjacent bank was tilting upward as well. As the trees which grew on the bank were tilted ever more precariously, their branches tangled or interlocked and thrashed or snapped overhead. Roots beneath the surface groaned or occasionally parted with a muffled pop. But surpassing everything else, was the eerie sound that emanated from beneath the upwelling mud, sand, and gravel of the creek: a bubbling, boiling sound. This was initially (around 10:00 PM) rather sporadic; as time passed, it reached a very vigorous peak (around 11:30 PM) and quickly subsided thereafter.

"Along with the bubbling, boiling sound, there was a gritty, grinding sound as the sand and gravel moved. Together, the bubbling and the grinding action produced slightly perceptible vibrations, but there were no shakes or tremors. The uplifting motion was not detectable at any given moment, but could be measured at intervals as the soil rose near adjacent trees on the opposite bank which was not rising. At one point, the gravel material in the creekbed apparently rose about 4 to 5 inches in roughly a half hour.

"Over at the graben, cracks had widened, indicating lateral displacement. Some additional sinking was occurring in all parts, as indicated by additional movement of trees already toppled or dislocated. At the northern end of the graben, considerable additional sinking took place (6 to 8 feet) and the graben extended northward an additional 50 feet or so, toppling several trees previously undisturbed . . . . large hunks of loess were caving off the face of the escarpment with ponderous thuds. The various evidences of sinking near the north end of the graben, and the rising and bubbling in the creekbed seemed to very gradually increase over the next hour (reaching a peak about 11:45 PM). An entirely new area of uplift occurred near the creek, extending northward from the original uplift more than 50 feet. It followed the creekbed very closely . . ."

Although Mr. Lowman interpreted the bubbling sound as the result of escaping gases, he heard "no whistling or rushing of large amounts of gas," nor did he report any distinctive odor. Our investigations did not reveal any indications of significant gas expulsion.

TEIC staff members arrived on the site around midnight, set up two portable seismometers, and explored the area, but activity had subsided and nothing significant was recorded.

The two earlier events recorded at TEIC WLA Station were preliminarily interpreted as shallow (less than 3280 feet deep), earthquake-like, and involving a source area several hundred yards across (Zollweg, 1980) (Bob, 1981), but it does not seem likely that strain energy could be stored in unconsolidated sediments to the point of catastrophic release. Later analysis resulted in the events being interpreted as possibly caused by air blasts questionably related to the block glide (Arch Johnson, TEIC, personal communication). Attempts by the TEIC staff to monitor subsequent events by portable seismometers located on the hill above the slide were somewhat thwarted by equipment malfunction.

Creep and settling occurred over the next several weeks, temporarily increasing after significant rainfall. For example, three months after the April glide a 6-inch plus rainfall resulted in a 12-15 inch subsidence in the graben and minor uplift along the pressure ridge zone (Lowman, 1980, p. 49).

On the valley side of the pressure ridge zone and extending out into the valley some 150 feet a series of abandoned stream channels were observed. From the degree of channel degradation and estimated ages of trees and other plants growing in the abandoned channels a rough chronology of the stream's adjustments could be made. The older appearing channels were in general most distant from the toe of the hill. The effect of the pressure ridges was to impound the present stream, forcing it to seek new channels. Although the stream reestablished its original channel in part, overflow is now diverted into the toe of the hill. The consequences of this action would reasonably seem to result in the erosion of the toe of the hill thereby reducing the static stability of the slope. The evidence of the abandoned channel chronology indicates this process has been active for some time: erosion of the slope toe, landslide, reestablishment of the stream channel into the toe of the slope, and subsequent erosion of new slope toe, slope destabilization and landslide. A low linear ridge trending subparallel to the hillside and pressure ridges was found on the essentially flat valley floor beyond the pressure ridge zone and abandoned stream channels. This linear ridge has the external appearance of an old pressure ridge further supporting the above process. None of the recent developments described herein affected this ridge.

The proximity of Lake Austell to the Slide area (Fig. 1) may be cause for concern. No evidence of stress has been observed behind the slide, where the dam abuts the hillside, or in the emergency spillway located just behind the hill. Six piezometer and standpipe test wells were drilled on the Dam by Arkansas State Parks to monitor the Dam's integrity. Lake Austell is a new lake filled for the first time in 1979. Clay mined from a pit in the center of the Lake was used as a dam core and to blanket the banks of the lake around the south end of the dam and spillway area. Much of this clay appears to have been eroded away at present lake levels (full). Undoubtedly some water from the lake is migrating into these sediments. The water levels in the lake being higher than "normal" groundwater produces an anomalous hydrostatic head thereby increasing the pore pressure in the local sediments. Such a situation can contribute to a lowering of the shear strength and sliding friction of various strata. Add to this the additional weight and lubrication of rain soaked sediments and one can expect a pronounced loss of strength. Without core drilling or some sensitive geophysical device the exact stratum or zone of failure is a matter of speculation. But, model constructs (Fig. 4) using topographic profiles and graben block dimensions and displacements indicate that the observed features are likely caused by a 15 to 20 foot horizontal displacement of the glide block and a depth-to-slide surface of less than 10 feet beneath the original valley floor. (The model constructs were developed for the slide as it appeared shortly after the late April, 1980 movement). The failure mechanism could be in part liquefaction of a sand layer(s) but field investigations indicate mostly the shear of a sensitive silty clay.

It is impossible to say with certainty whether the lake is in danger of dam failure due to continued slumping and sliding, but it is our opinion that this landslide did not affect the integrity of the dam. Future slides are equally difficult to predict, but observations seem to indicate that the glide block may be displaced a few more feet horizontally, and that the portion of the hill behind the slide may continue to slump into the graben. Eventually the limb of the hill on which the slide occurred should become subdued, losing some 20 feet or so from its crest but forming a new and more stable slope. Whether or not this will progress to the extent of endangering the stability of the dam only time will tell; but as things look now, no danger is foreseen in the immediate future. Other landslide scars were observed on the hill in the same

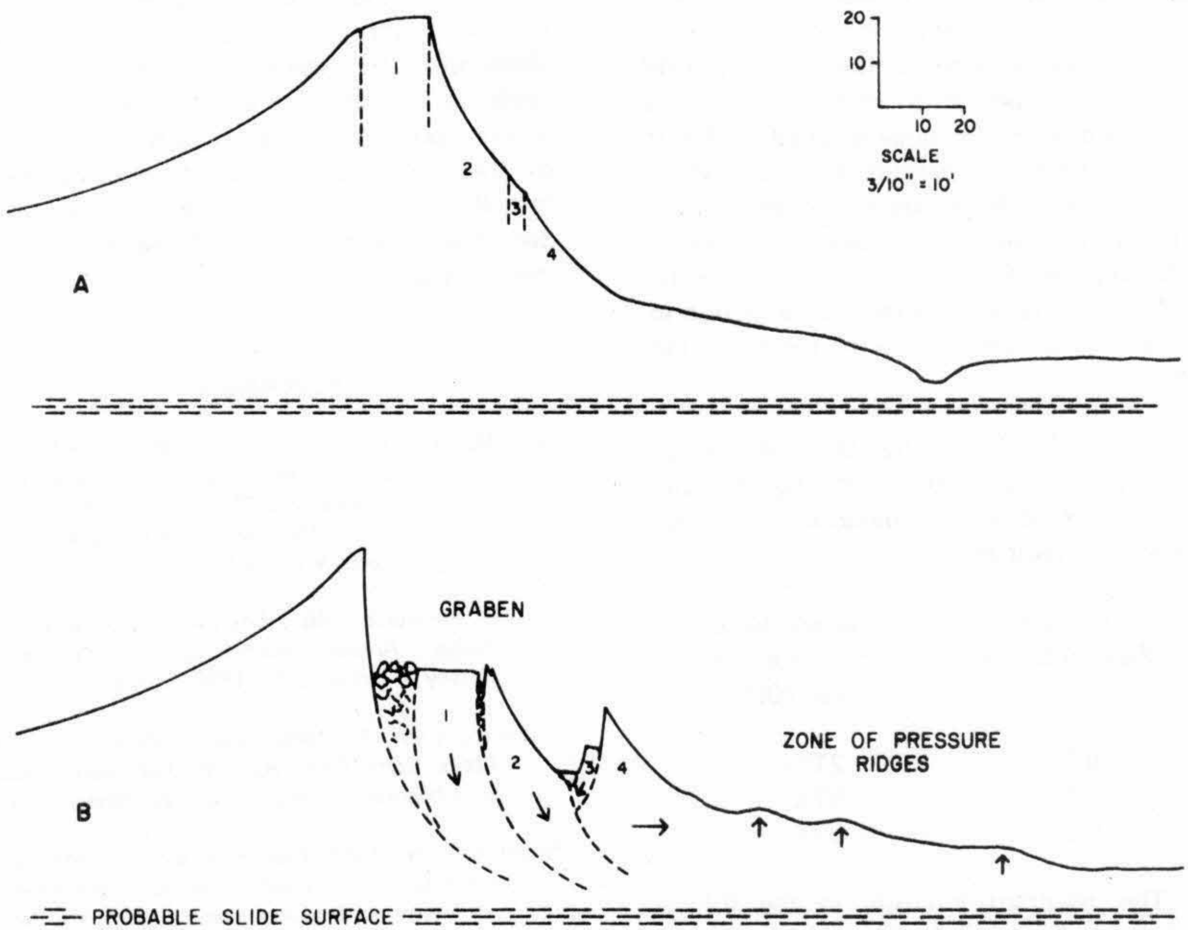


FIGURE 4

A. This topographic profile of the landslide area is taken from Figure 1 (A–A') and indicates what the hill looked like before the landslide. The dashed lines show the boundaries of the major blocks involved in the slide.

B. This idealized cross-section is a construction from the same profile as "A" modified per the authors' field observations. The horizontal displacement of block 4 as shown here is about 17 feet. The depth to slide surface was based on the cross-sectional areas of these two models. Arrows indicate direction of movement for each block.

general area as this slide, but were much smaller. Judging from the trees growing on these older slides, slides occur naturally at least decades apart. If the lake is a contributing factor to the present landslide (the factor that must be considered) then the landslide rate can be expected to increase until such time as a more stable slope is established. But if the landslide is incidental to the lake which some of the evidence suggests, then there is no reason to expect an increase in the rate of landsliding. In fact, if this is an incidental occurrence, one might expect a reduction in the rate of landsliding due to the reduction of the hill.

A recent report by Otto W. Nuttli (1981, p. 1-2) gives the following probabilities for damaging earthquakes in the nearby New Madrid fault zone.

Surface-wave Magnitude (Ms)	Probability of Occurrence before year 2000
8.5	21%
7.5	51%
6.5	63%

The resultant intensity in the Village Creek State Park area from any of the above listed earthquakes might result in massive failure of the hillside and breechment of the lake, especially if the event were preceeded by heavy rains. When full, Lake Austell holds about 1100 acre feet of water. The Willow Creek valley downsteeam from Lake Austell covers about 300 acres. Hill failure could flood major portions of the valley and represents a danger to the few homesites located within it.

The borrow pit for the clay used for the dam core and bank blanket was developed into the toe of the ridge marked by an X on Fig. 1. Although the pit was bermed on the ridge side, the removal of the natural slope along with the demonstrated propensity for landslides in the immediate area indicates another potential danger. If a sizable portion of the ridge were to catastrophically glide into the lake, water could be swept over the dam resulting in erosion of the dam, abutments, or both.

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VASHEGYITE FROM NEVADA AND "PALFEVITE" (= RICHMONDITE) FROM NEVADA AND FROM ARKANSAS (= KINGITE)

by

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ABSTRACT

Vashegyite $Al_4(PO_4)_3(OH)_3 \cdot 13H_2O$(?) from Eureka, Nevada, appears to be closely similar to the type mineral from Slovakia which has been shown by D. McConnell to be well crystallized. "Amorphous" hydrous aluminum phosphate, with more or less iron and vanadium, is also found in Nevada and the Union Carbide Vanadium Mine at Potash Sulfur Springs, Arkansas, and the term "palfevite" has been suggested by D. M. Hausen to designate this gel differentiating it from the mineral vashegyite. Vashegyite from Nevada and "palfevite" from Nevada and Arkansas are described, with chemical analyses, of vashegyite from Nevada, and of "palfevite" from Nevada and Arkansas; and with X-ray powder data for the Nevada vashegyite, and for "palfevite" from Nevada and Arkansas (no pattern). Following the view of A. Kato, amorphous "palfevite" from Nevada can be referred to as ferrian vanadian richmondite $(Al_{0.69}Fe_{0.31})$ $(P_{0.83}V_{0.17})O_4 \cdot 3.53H_2O$, even though, in default of crystallographic data, richmondite ($AlPO_4 \cdot 4H_2O$) itself is of uncertain standing as a mineral name. The similar amorphous Arkansas "palfevite", $Al_{6.00}(P_{1.87}V_{0.13})_2O_{19}.18H_2O$ however, can be referred to the accepted species kingite $Al_6P_4O_{19}.21H_2O$ which T. Kato found to vary from well crystallized (triclinic) to poorly crystalline and even amorphous phases.

Vashegyite $Al_4(PO_4)_3$ $(OH)_3 \cdot 13H_2O$(?) orth. (Fleischer, 1980) has been a problematic mineral since it was discovered and so named by Zimanyi in 1909. The H_2O content is indicated by Dana (1951) as nH_2O(?); no crystal symmetry is assigned; and Larsen-Berman (1934) lists vashegyite as "amorphous," as did Fleischer (1975). However, McConnell (1974) re-examined the type Vashegy material, and found it to give a good X-ray diffraction pattern, indexed to an orthorhombic unit cell, and Fleischer (1980) recognizes the species name accordingly, although still expressing uncertainty as to its composition.

McConnell's work is confirmed by the unpublished study by Hausen (1960) of vashegyite from near Eureka, Nevada, which chemically and structurally by X-ray diffraction is very similar if not identical to the Vashegy type vashegyite (Tables 1 and 2). However, in both Nevada and Arkansas, and probably also in Vashegy, there occurs hydrous aluminum (iron, vanadium) phosphate of variable composition, which may approximate that of vashegyite, but is "amorphous" both optically and to X-rays. This report, largely based on Hausen's data, compares the Nevada and Vashegy vashegyites, and also the "amorphous" mineral from Nevada and Arkansas which Hausen termed "palfevite," but which Akira Kato (personal communication) recognizes as ferrian vanadian richmondite and kingite respectively.

A. Kato (personal communication, October 30, 1980) has computed the two "palfevite" analyses, from Nevada and Arkansas, as respectively $(Al_{0.69}Fe_{0.31})$ $(P_{0.83}V_{0.17})O_4 \cdot 3.5H_2O$ (ferrian vanadian richmondite), and $Al_{3.00}(P_{1.87}V_{0.13})O_8$ $(OH)_3 \cdot 7.85H_2O$ (kingite, which has $9H_2O$).

Richmondite, not listed in Fleischer's 1980 Glossary, was considered to be among "several ill-defined substances, that may be identical with variscite-strengite or wavellite" (Palache, C., Berman, H. and Frondel, C., 1951, Dana's System V. II, p. 761), where it is briefly stated that in 1847 Kenngott described it as "gibbsite," with which it was found in a limonite deposit at Richmond, Berkshire County, Massachusetts. Hermann analyzed it the same year, finding Al_2O_3 26.66 %, P_2O_5 37.62 %, H_2O 35.72 %, total 100.00 percent, close to $AlPO_4 \cdot 4H_2O$. Thus richmondite, though of questioned validity as a species name, does have priority over Hausen's Nevada "palfevite," as A. Kato suggests. However, because of its being "amorphous to X-rays" (Table 2), a unit cell cannot be determined, and richmondite must still be considered as a mineral in limbo.

Kingite, to which A. Kato would refer the Arkansas "palfevite," is a well-defined species (T. Kato, 1970) with triclinic symmetry, first reported from South Australia by Norris, Rogers, and Shafter (1957). T. Kato, in a personal communication to A. Kato, noted however that the kingite may be poorly crystallized, even amorphous. Therefore A. Kato's suggestion that the Arkansas "palfevite" is the amorphous variety of kingite should be acceptable.

Figure 1 shows typical banded Arkansas "palfevite." An EDAX scan of eight such grains showed Al most abundant, next P, then Si, and vanadium present (in probably less amount) in all. One specimen showed a trace of Ca.

Some grains show a greenish fluorescence in U.V.; possibly, from opaline silica. Others show a rough coating of a brown isotropic unidentified phosphate with major Fe and P, minor Al and V, shown in Figure 2. This "palfevite" contains only Al and P, with minor V--no Fe. Four such grains with the coating removed, showed relative "peak heights" (EDAX) thus:

	Al	P	V
1	10	7	1
2	10	7	1
3	10	6.5	1.5
4	10	7	6

confirming the non-stoichiometry of the "palfevite" gel, and the composition obtained by chemical analysis (Table 1). Still other grains are coated with sanidine feldspar (Figure 3).

Hausen noted the color of the Arkansas "palfevite" from colorless (or whitish) to greenish blue; but in a letter to C. M. (Hausen, 1979) he quotes Mary Jaehnig that the Arkansas mineraloid "is mostly amber in color, mostly isotropic with average index of refraction between 1.462 and 1.464." But it is only when immersed in oil that the anomalous brown or yellow color appears; and is an optical effect, not a true color.

ACKNOWLEDGMENTS

We are grateful to Dr. Donald M. Hausen, for his unpublished data on the Nevada and Arkansas occurrences of the vanadian phosphates, and to Dr. Akira Kato for clarification of the relationship of the amorphous phosphates to richmondite and kingite respectively; and to Mr. Don R. Owens who first brought this problem of identification to our attention, and supplied the material we have studied.

Table 1. Chemical analyses of Vashegyite and "Palfevite"

	Vashegyite		"Palfevite" P, Al, Fe, V oxide Hydrate gel		
	$4Al_2O_3 \cdot 3P_2O_5 \cdot 30H_2O$ near Eureka, Nevada	$4Al_2O_3 \cdot 3P_2O_5 \cdot 29H_2O$(?) near Vashegy, Slovakia	near Eureka, Nevada	Potash Sulfur Springs, Arkansas Sample A	Potash Sulfur Springs, Arkansas Sample B
	%	%	%	%	%
P_2O_5	32.7	31.32	29.15	28.3	(23)
V_2O_5	tr. (0.8)	--	7.86	2.6	(14)
Al_2O_3	28.9	28.33	17.4	32.7	(7)
Fe_2O_3	0.73 (0.7)	1.19	12.33	--	(3)
CaO	-- (0.8)	--	--	--	(1.1)
BaO	-- (0.8)	--	--	--	(0.4)
SrO	-- (0.5)	--	--	--	(0.5)
MgO	-- (0.2)	--	--	--	(0.1)
CuO	-- (0.025)	--	--	--	(1.1)
TiO_2	-- (0.2)	--	--	--	(1.6)
H_2O+	31.0	38.97	$H_2O\pm$ [31.58	$H_2O\pm$ [36.0	
H_2O	7.18	0.57			
SiO_2	--	--	--	0.6	(9)
Remainder	--	0.57	--	--	
	100.51	100.38	98.32	100.2	
	J. P. Moore Union Carbide Nuclear, analyst	Dana VII, vol. II, 1951, p. 999	J. P. Moore Union Carbide Nuclear, analyst	J. Marinenko Union Carbide Nuclear, analyst	B. D. McCarty Union Carbide Nuclear, analyst

(figures in parentheses are spectrographic determinations. See end of table.)

Table 1 (continued)

Element	Vashegyite Nevada Spectrographic - %	Vashegyite Slovakia PPM	"Palfevite" Arkansas (sample B) Spectrographic - PPM
Ag		0.27	
As		< 150	
Au		< 10	
B	n.d.< 0.01	< 4.6	
Ba	0.7	550	
Be		81	50
Bi		< 15	
Cd		57	
Ce		76	
Co	0.02	< 1.0	
Cr	n.d.< 0.1	2.3	
Cu		< 1.5	
Dy		22	
Er		< 10	
Eu		< 1.5	
Ga		< 15	
Gd		< 15	
Ge		< 1.5	
Hf		< 15	
Ho		< 6.8	
In		< 6.8	
Ir		< 15	
La		25	
Li		< 68	
Lu		< 22	
Mn	n.d.< 0.01	200	300
Mo	n.d.< 0.1	< 2.2	
Nb		< 2.2	
Nd		57	100

Table 1 (continued)

Ni	n.d.< 0.1	< 1.5	
Os		< 22	
Pb		< 6.8	
Pd		< 1.5	
Pr		< 68	
Pt		< 6.8	
Re		< 10	
Rh		< 2.2	
Ru		< 3.2	
Sb		< 46	
Sc		1.1	
Sm		< 22	
Sn		< 1.5	
Sr	0.4	210	
Ta		< 460	
Tb		< 32	
Te			
Th		< 22	
Tl		7.3	
Tm		< 4.6	
U		< 320	
V	0.8	> 1000	
W		< 10	
Y		21	
Yb		< 10	
Zn		450	
Zr		36	100
	B. D. McCarty U. C. N., Analyst Hansen, 1960 p. 22	D. W. Golightly U. S. G. S., Analyst	B. D. McCarty U. C. N., Analyst Hansen, 1962 p. 5

n.d. - not detected

Notes on Analysis by J. Marinenko, U. S. G. S., on Arkansas "palfevite"

Silicon and phosphorus were determined spectrophotometrically by heteropoly blue procedure; aluminum by atomic absorption; total vanadium spectrophotometrically with hydrogen peroxide; total water, by loss on ignition to 900° C.

Table 2. -- X-ray powder patterns and indices of refraction of Vashegyite and of "Palfevite".

Vashegyite				"Palfevite"	
$4Al_2O_3 \cdot 3P_2O_5 \cdot 30H_2O$ Near Eureka, Nevada* Bisoni Property (from Hausen, 1960, p. 27)		$4Al_2O_3 \cdot 3P_2O_5 \cdot 29H_2O$(?) Vashegy, Slovakia, USSR $3AlPO_4 \cdot Al(OOH) \cdot 12H_2O$ XRPD 29–68		"P,Al,Fe,V oxide hydroxide gel" Near Eureka, Nevada	"P,Al,Fe,V oxide hydroxide gel" Potash Sulfur Springs, Arkansas
I	d	I	d		
vs	10.3	100	9.80	No pattern	No pattern
	9.4	100	9.20		
--	--	40	8.35		
--	--	40	7.71		
m	7.4	100	7.24		
m-s	6.9	60	6.80		
w	5.25	20	5.25		
w	4.35	60	4.40		
w	3.62	--	--		
w	3.45	40	3.46		
m	3.28	--	--		
w	3.04	60	3.15		
--	--	40	2.96		
s	2.88	100	2.90		
--	--	60	2.76		
w	2.67	60	2.68		
	2.52	80	2.51		
w	2.40	40	2.413		
w	2.17	--	--		
w	2.12	80	2.127		
w	1.99	40	1.982		
--	--	60	1.533		
--	--	60	1.471		
--	--	60	1.455		
--	--	40	1.371		
n		n		n	n
"1.49–1.49 fully hydrated to 1.53–1.54 partially dehydrated." (Hausen, 1960)		1.48 + 0.01		1.46 (Hausen, 1960)	1.46–1.48; 1.51–153 (Hausen, 1962)

*"In slightly dehydrated material, strongest spacing, 10.3 may range down to 9.4 and double at 6.9A, may increase considerably in intensity."

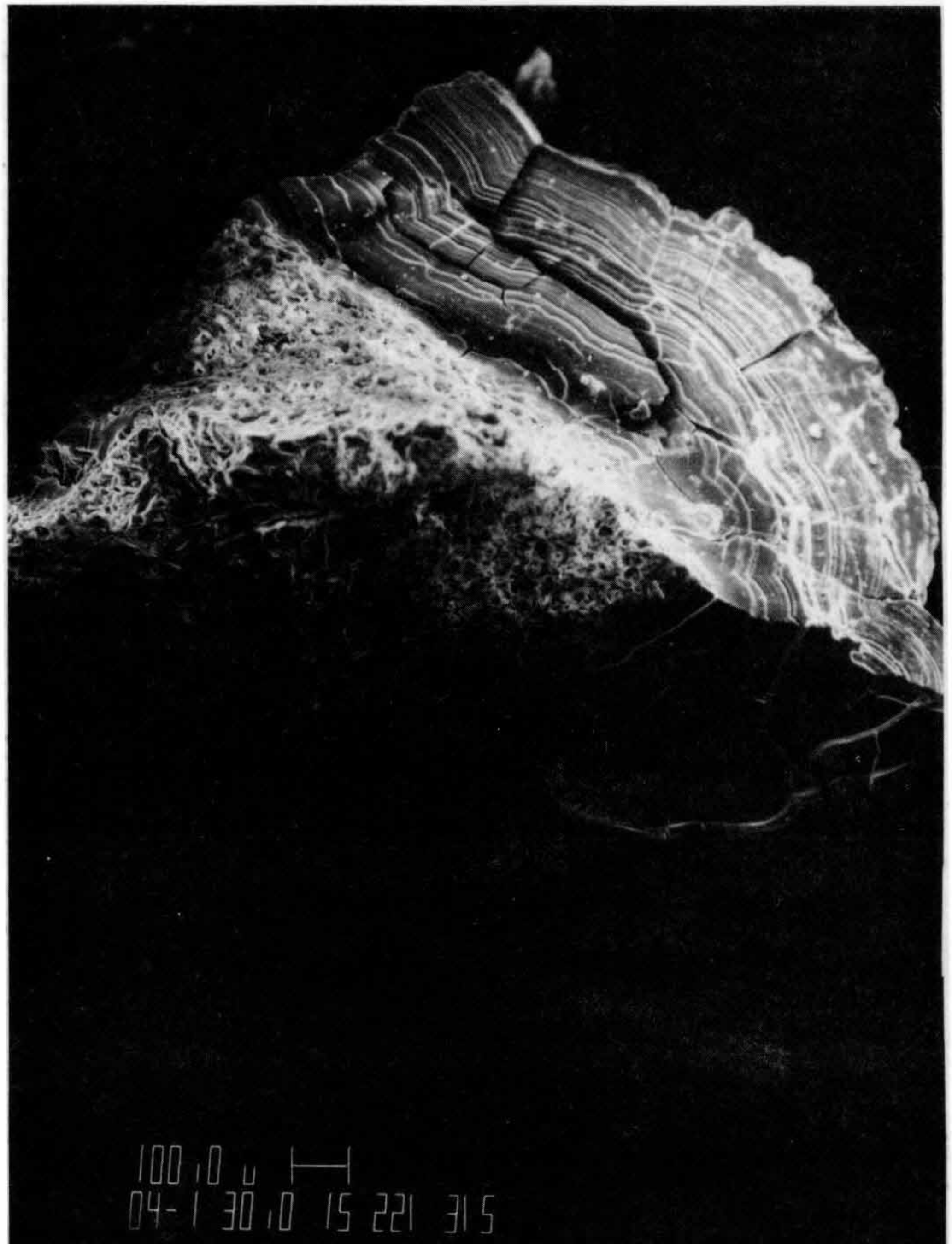

FIGURE 1

"Palfevite" (kingite) from Potash Sulfur Springs, Arkansas.

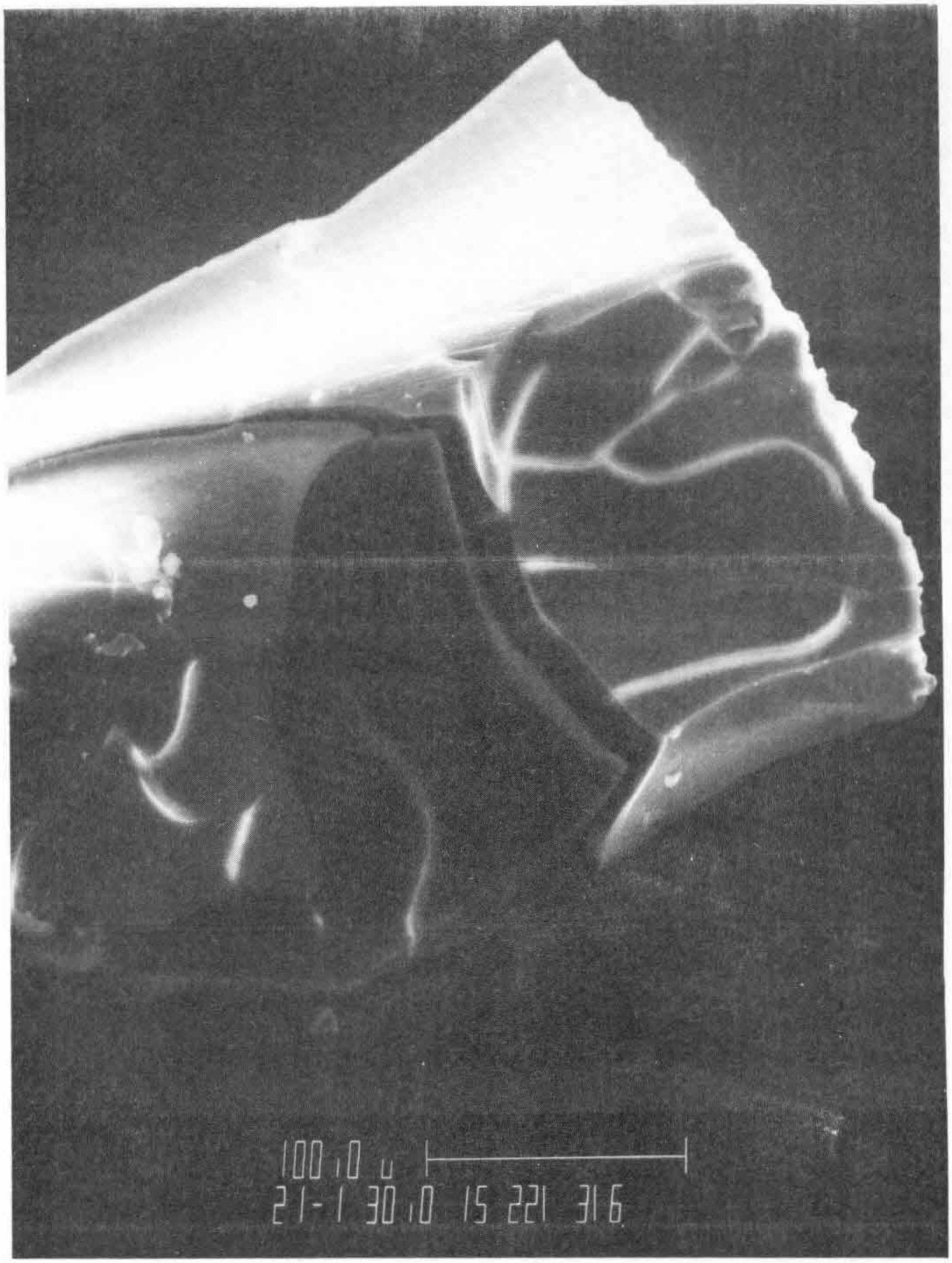

FIGURE 2

Arkansas "Palfevite" (kingite) shows mammillary brownish (white in picture) crust containing major Fe, P, and minor Al, V. Under the electron beam, the "palfevite" develops cracks as shown. This material, after removal of the iron-containing crust, was analyzed (Table 1).

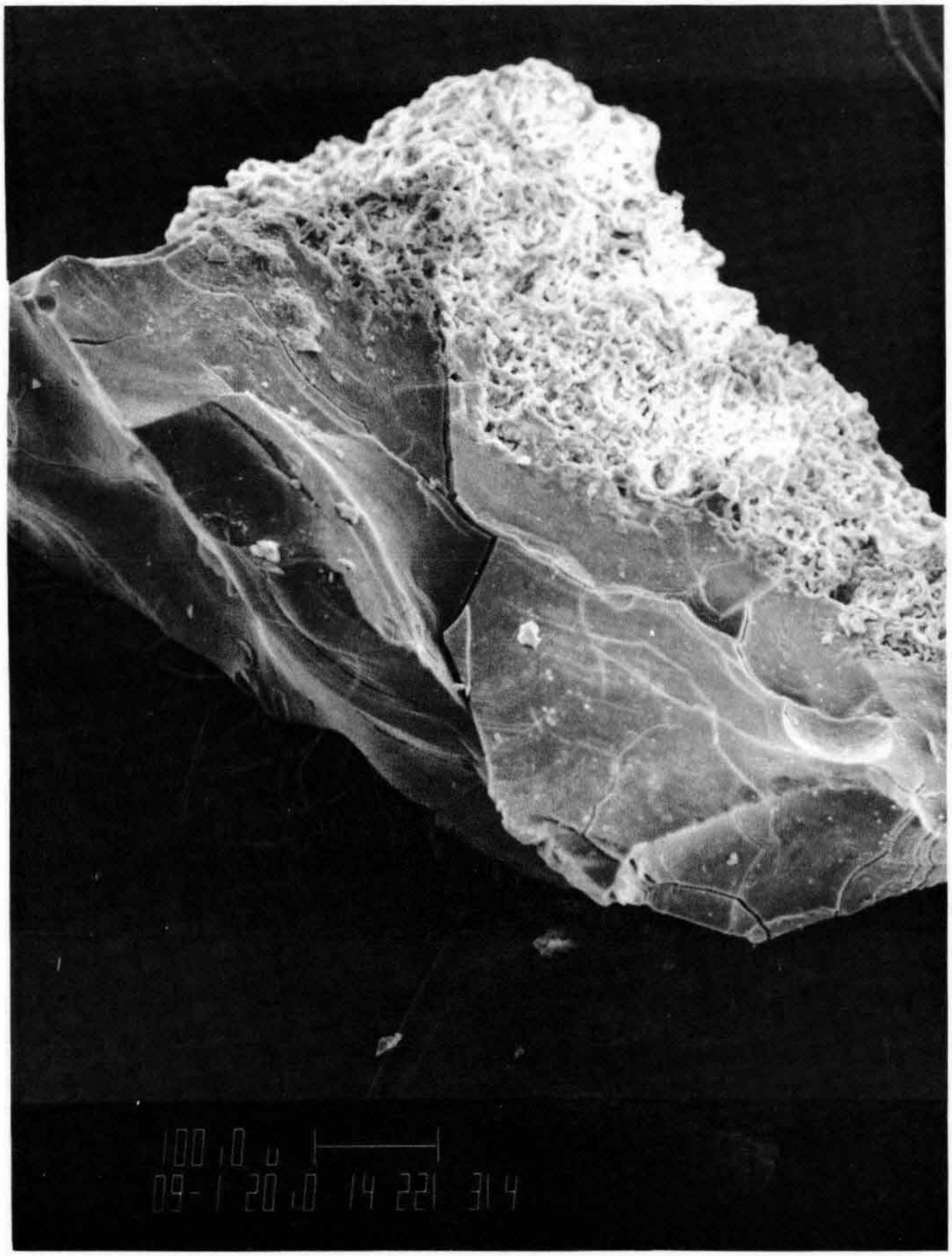

FIGURE 3

"Palfevite" (kingite) from Arkansas. The bright coating is sanidine feldspar. The "palfevite" shows only Al and P by EDAX; it is isotropic, n ~ 1.484, but large grains show a vague uniaxial positive interference figure (strain following shrinkage?).

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URANIUM CONTENT OF GROUND WATER FROM CENTRAL ARKANSAS

by

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ABSTRACT

Uranium and helium concentrations, along with the other parameter values (pH, Eh, specific conductivity, nitrate, ammonia, phosphate, and sulfate) have been determined for 335 ground water samples from central Arkansas. Ground water samples from the Ouachita Mountain region contain about 7 times the amount of uranium as samples from the Gulf Coastal Plain region, 0.26 ppb and < 0.04 ppb mean values, respectively. The Womble Shale Formation of the Ouachita Mountain region yields ground water samples with the highest uranium concentrations, 0.34 ppb mean value. The Jackson Group water samples with a mean value of 0.09 ppb have the highest uranium content of the Gulf Coastal Plain region formations. It is noteworthy that the values obtained for the Gulf Coastal Plain region samples are lower than for similar studies, especially for the Clairborne and Wilcox Groups which have mean values 3-5 times lower than samples from these same units in nearby areas.

The above observations and the lack of the correlation of uranium content with other parameter values suggest that the uranium content of the survey area ground water, apparently is dependent largely upon the original uranium content of the rock. However, samples collected near known uranium mineralization do not yield an unusually large percentage of samples with higher uranium content. The small, erratic nature of the uranium mineralization probably best explains this dilema. It is interesting to note that all four samples within 2 miles of the Benton Breccia (igneous) contain significantly higher uranium concentrations than other samples.

INTRODUCTION

Three hundred and thirty-five ground water samples were collected from a 1200 sq. mi. area (Fig. 1) of central Arkansas using a 3.5 sq. mi. grid as part of an orientation survey by the National Uranium Evaluation Program (SRL, 1979). The survey area is located between 92°15' and 93°05'W longitude and 34°12' and 34°37'N latitude and includes parts of Grant, Garland, Hot Spring and Saline Counties. Although samples were collected primarily from domestic wells, a few springs were sampled. Figure 1 shows the areal distribution of the samples. The data from this survey can be used to (1) determine the differences in ground water composition of various stratigraphic formations, (2) investigate the effect of uranium mineralized deposits on local ground water composition, (3) identify anomalous areas, and (4) determine the parameters which may be used as pathfinders for uranium in this area, and/or the parameters which affect the uranium content of the ground water.

The concentration of uranium in ground water can be affected by various parameters and by complexing ions, and also by original uranium content of nearby uranium bearing rocks. Normally with low pH values (more acidic) the mobility of uranium is increased, and as the pH becomes more alkaline its mobility is decreased. However, because

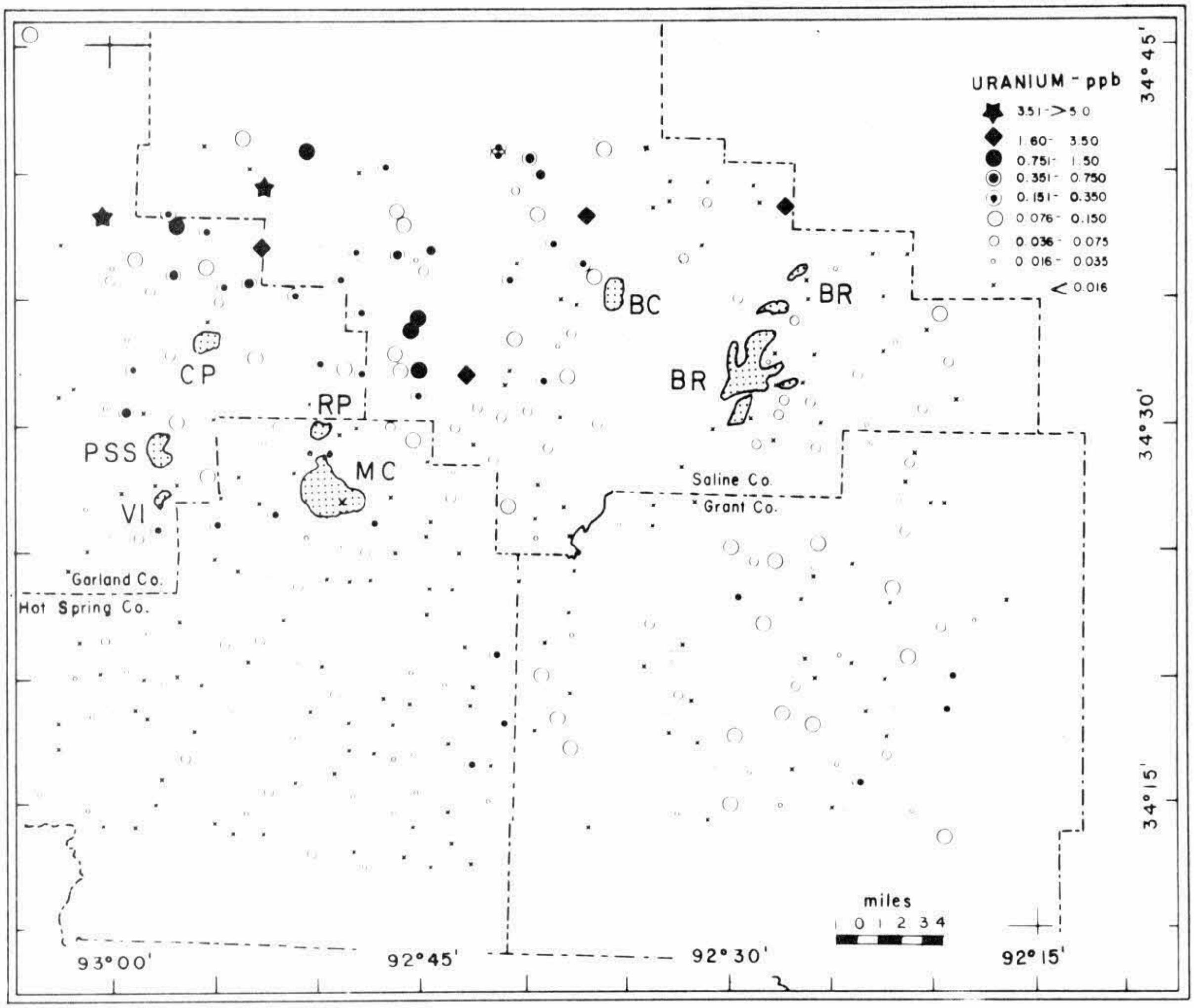


FIGURE 1

Location of survey area showing distribution of the ground water sites. Igneous bodies (BC = Benton breccia, BR = Bauxite region, MC = Magnet Cove, PSS = Potash Sulfur Springs, and VI = "V" Intrusive) and uranium prospects (Chandler Prospect and Runyan Prospect) are also shown.

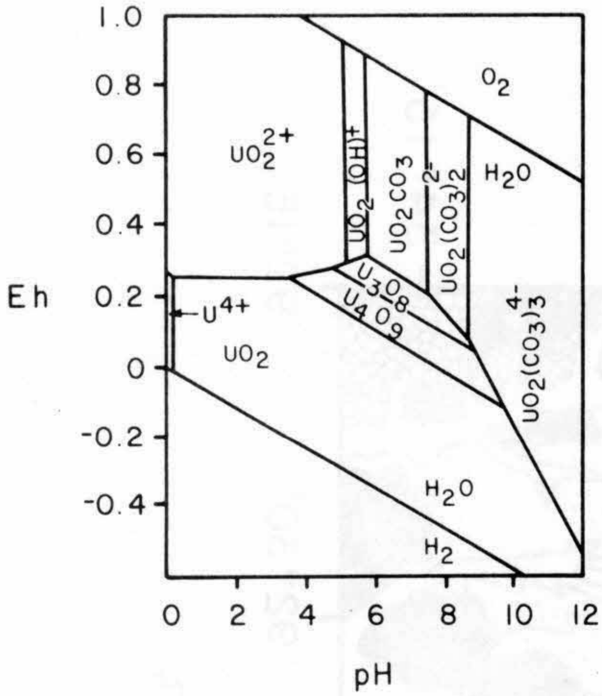


FIGURE 2 — Eh - pH diagram for the system U-O-H-CO_2 showing the mobility of the uranyl complexes, and the stability fields of three solid uranium oxides, at 25°C, U = 1 ppm, $P_{CO_2} = 10^{-3.5}$. After Langmuir (1978) and Levinson (1974).

uranium forms many complexes at higher pH values, it is more mobile than elements such as Zn and Cu because these elements do not form stable complexes soluble in alkaline water.

Figure 2 illustrates the stability fields for the soluble uranyl carbonates, uranyl hydroxide, the uranyl ion, and uranous oxides UO_2, U_3O_8, U_4O_9 (all of which are here considered to be uraninite). From Figure 2, it can be seen that in this system it is not possible to precipitate uranium from natural waters of the chemical weathering environment solely by a change of pH (because uranyl complexes are stable over the entire range of pH). Only by means of an environmental change in which Eh becomes more reducing will uranium precipitate.

Other mechanisms by which mobility is reduced are:

1) Adsorption: Adsorption of uranyl complexes by organic matter and other materials, e.g., clays and iron oxides. Evidence appears to be emerging that following the initial adsorption of the uranyl complexes, there may be subsequent reduction and precipitation by mobile reductants, such as methane and hyrogen sulfide.

2) Formation of insoluble compounds: Uranyl ion (in an oxidizing environment) can be precipitated from solution when it combines with vanadate, phosphate, arsenate, silicate, carbonate or sulfate anions in association with Ca, Mg, K, Ba, Pb, Cu and several other elements. Formation of minerals such as carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ and soddyite $(UO_2)_5Si_2O_9 \cdot 6H_2O$ results.

Uranyl ions may also be precipitated from solution after the dissociation of uranyl carbonate complexes at elevated temperatures (Levinson, 1974).

Thus with respect to uranyl complexes the following generalizations can be made.

1) Carbonate complexes are very important in slightly acid to alkaline pH in absence of phosphate, but their stability gradually decreases with increasing temperature because the solubility of CO_2 (and other volatiles) decreases with increasing temperature resulting in less CO_2 to complex with uranium.

2) In the presence of phosphate, even as little as 0.1 ppm PO_4, low temperature phosphate complexes dominate the slight acid to slightly acid to slightly akaline pH range. This phosphate will tend to extract uranium from rocks, stream sediment and other media.

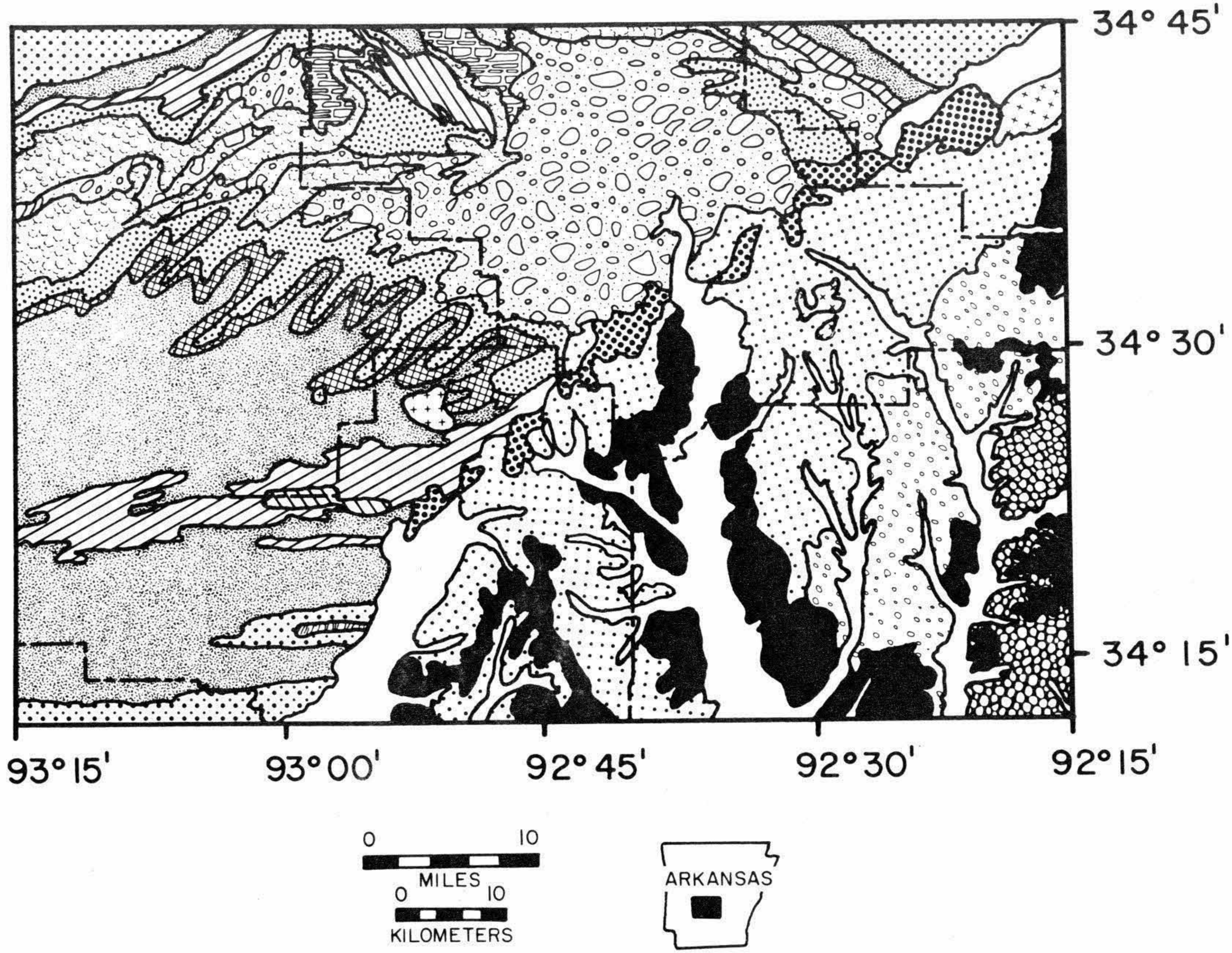
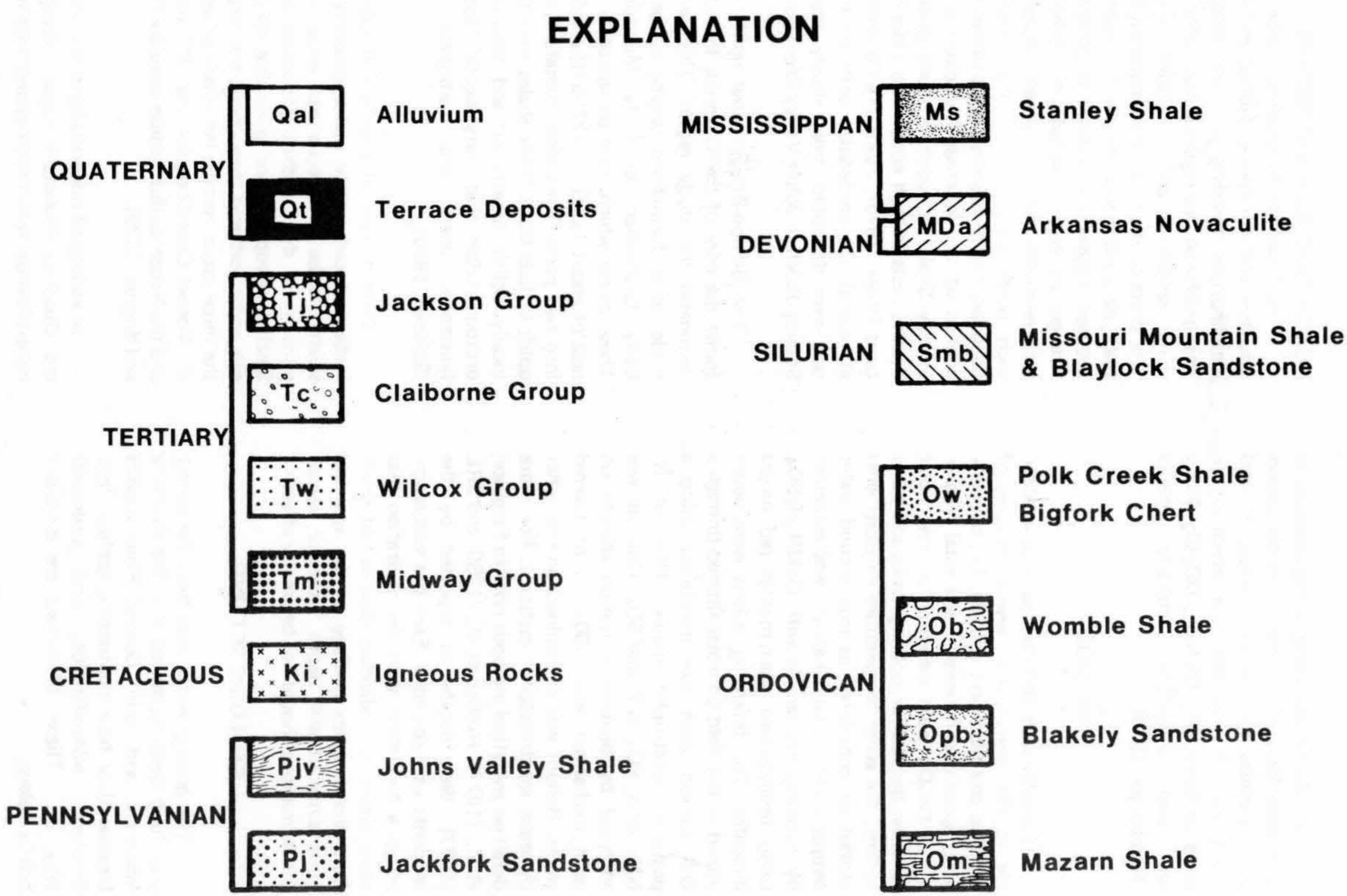


FIGURE 3 a – Geologic map of the study area.

FIGURE 3 b – Explanation of Figure 3 a geologic map.



3) Additional complexing agents such as sulfate (SO_4^{-2}) which forms complexes with uranium such as $UO_2(SO_4)_2^{-2}$, and $UO_2(SO_4)_3^{-4}$ and ammonia which complexes to form $UO_2\ Cl_2NH_3$, $UO_2Cl_2\ 4NH_3$ are also important mobility media (Romberger, 1979).

METHODS

Samples were collected as close as possible to the source after several minutes of flushing any plumbing and pH, Eh, temperature, specific conductivity and total alkalinity as $CaCO_3$ were measured on raw water samples. Because of holding tanks and other factors, the water temperature measurements cannot be considered as true ground water temperatures. Total alkalinity was measured by titrating the sample with 0.02N H_2SO_4 using bromocresol green-methyl red mixed indicator. The following anions were determined in the field on water filtered through a 0.8 micron pore size membrane using a portable spectrophotometer: NO_3 as N, NH_3 as N, PO_4 as P, and SO_4. Uranium was analyzed by neutron activation analysis on resin exchanged with 1000 ml of filtered water. Helium was determined on raw water by mass spectrographic methods. For more detail on analytical methods refer to Ferguson et al., (1977), Hoshell et al., (1980) and SRL (1977). Well depths as reported by the residents were recorded. Each site was assigned to a formation with the realization that some errors for individual sites would result from the complex geology of the area and uncertainty of well depth. However, means for formations should not be greatly affected.

GEOLOGIC SETTING

The ground water data from the survey area have been separated into the Ouachita Mountain and Gulf Coastal Plain regions because they have contrasting geology (e.g. lithology, mineralization, and structure) (Fig. 3). These differences are discussed briefly below.

OUACHITA MOUNTAINS REGION

The Ouachita Mountains region is an intensely and complexly faulted and folded anticlinorium trending east and west. The stratigraphy of this region is mainly Paleozoic shale, sandstone and novaculite (Fig. 4). The strata of the Ouachita Mountains form a thick, deep water succession with a number of geologic formations. Viewed in general, the stratigraphic column includes two lithofacies, each relatively uniform in overall aspects but each quite distinct from the other. The boundary for this subdivision is drawn at the contact of the Araknsas Novaculite and the Stanley Shale, although in many places the Stanley rests in fault contact on older formations (Viele, 1973). Stone (1973) notes that in general, the pre-Stanley units are thinner and were deposited more slowly than the Stanley-Jackfork-Johns Valley Sequence.

The Benton-Broken Bow uplift which forms the core of the Ouachita folded belt, dominates the study region. This uplift is made up of formations ranging in age from Early Ordovician to Early Mississippian. These strata which have an aggregate thickness of about 1,000 m (~3280 ft) are divided into two parts. The oldest formations of the uplift include black fissile shales, micritic and locally oolitic limestones, and structureless orthoquartzites that carry exotic blocks of limestone, chert and carbonate strata (Shideler, 1970).

Various types of syenite and associated mafic and carbonatite rocks, generally considered to be Cretaceous age, occur in this portion of the Ouachita Mountain region. Small lamprophyre and phonolite dikes and sills occur scattered throughout the area, and the three major syenitic intrusions present are the Magnet Cove Complex, the "V" Intrusive and the Potash Sulfur Springs complex (Steele and Wagner, 1979).

A variety of mineralization is present in the Ouachita Mountain region. Manganese mineralization with its associated trace metals

Age	Formation	Thickness (meters)	Lithic Description
PENNSYLVANIAN	Atoka	457–5790	Shale, light gray, silty, micaceous with interbedded fine– to coarse–grained sandstone.
	Johns Valley	61–305	Shale, light gray to tan, dark gray near base with thin beds of sandstone and limestone.
	Jackfork	350–2134	Sandstone, light gray medium-to coarse–grained, massive, with intercalated green, fissile shale.
MISSIS-SIPPIAN	Stanley	741–863+	Shale, dark-gray,fissile, with interbeds of siltstone and sandstone (Hot Springs Sandstone at base). Five tuff sequences present.
DEVO-NIAN	Arkansas Novaculite	70–290	Chert, novaculite and interbedded shale near the top and base.
SILURIAN	Missouri Mountain	0–91	Shale, green to black, siliceous, sandy in part with thin beds of chert and quartoze sandstone.
	Blaylock	0–457	Sandstone, dark gray to green, thin bedded, fine grained with interbedded siltstone and shale.
ORDOVICIAN	Polk Creek	0–53	Shale, soft, brown, platy in most of the formations; hard and siliceous near base.
	Bigfork	183–244	Chert, gray to black, thin-bedded, extensively fractured, interbeds of black shale.
	Womble	73–305	Shale, black to green with thin interbeds of quartoze sandstone and limestone
	Blakely	0–152	Sandstone, gray, siliceous, with darker calcareous layers. Minor green clay-shale.
	Mazarn	305+	Shale, black to green, banded, fissle with thin layers of sandstone and limestone.

FIGURE 4 – Stratigraphic column for the Ouachita Mountain region of the study area. After Vogelpohl, 1977.

is present throughout the western part of the survey area. Titanium and vanadium mineralization is associated with the Magnet Cove are and Potash Sulfur Springs complexes. Also present in the Magnet Cove area are replacement-type barite deposits. Lead-zinc and copper deposits are rare and scattered. Conglomerates occurring in the upper part of the Womble Shale through a stratigraphic interval of about 91 m (~300 ft) have a P_2O_5 content up to 5% (Stroud, 1969). Uranium mineralization is associated with both the igneous rock and black shales and will be discussed under a separate heading.

GULF COASTAL PLAIN REGION

The Gulf Coastal Plain sediments consist primarily of sand, clay, marl, shale and limestone ranging in age from Mesozoic to Recent (Fig. 5). These sediments rest on a pre-Cretaceous erosional surface of folded and faulted Paleozoic rocks.

The final stage in the building of the Ouachita Mountains is believed to have been the vertical uplift of the frontal part of the Mountains and subsidence of the hinterland. As a result of the final stage in the formation of the Ouachita Mountain region, a basin was developed to the south which received sediments from the elevated Ouachita Mountains in later Permian time (Spooner, 1935). In this basin accumulated a section of upper Cretaceous and Cenozoic deposits in which nonmarine beds form a larger percentage of the whole than in comparable sequences in the coastwise outcrop belt. Only the most widespread transgressions of the sea over the Coastal Plain are marked by marine deposits in this area. After successive marine invasions of the embayment in late Cretaceous and Paleocene times, thick nonmarine deposits of the Wilcox and Claiborne Groups were laid down. Final inundation of the Mississippian Embayment occurred during part of the Jacksonian Age. Shortly after marine Jacksonian sediments were deposited, the basin cased to exist as a depositional center. Quaternary fluviatile activity produced alluvium and other deposits which mask older sediments over large parts of the embayment.

The dominant movements recorded in the Coastal Plain sediments are negative movements reflected in the downwarping of the sedimentary areas, and resulting in a general Gulf-ward inclination of the strata. Minor structural features are believed to be the indirect result of regional warping which suggests differential movements in the basement rocks. Where the movement is of sufficient magnitude, failure occurs in the Gulf Coastal Plain strata and normal folds are developed. Faults in the region are not related to development of local folds, but are thought to be related to the flexure of the basement rocks (Spooner, 1935).

Igneous activity in this region is represented by nepheline syenite at the Bauxite area in Saline County and the Benton Complex. The Benton Complex includes porphyritic trachyte dikes, lamprophyre dikes and an explosion breccia. These igneous rocks are also considered to be of Cretaceous age (Steele and Wagner, 1979). There is no major mineralization in the Gulf Coastal Plain region other than bauxite which is associated with the nepheline syenite. However, lignite deposits of economic importance occur in the Tertiary age sedimentary rock.

URANIUM MINERALIZATION

Most of the rock types present in the survey area are known to contain significant amounts of uranium at other locations around the world; however, there have been few analyses of the rocks in the survey area. The black shales of the area have uranium concentrations ranging from < 10 ppm to 40 ppm with a median value of 10 ppm (Landis, 1962). Lignite of the general area contains 2-4 ppm uranium on an "as received" basis (Rackley, 1972). Fryklund et al., (1954) report uranium values at Potash Sulfur Springs ranging from 0.002 to 0.15 percent. The uranium-bearing mineral has been identified as pyrochlore and soil samples assaying up to 0.4% uranium have been collected by Atomic Energy Commission geologists at Potash Sulfur Springs. However, the uranium mineralization apparently disappears at a

Age	Epoch	Group	Thickness (meters)	Lithic Description
QUATERNARY	Holocene	Alluvium	----	Alluvial deposits of present streams.
	Pleistocene	Terrace Deposits	----	Alluvial deposits on one or more terrace levels.
TERTIARY	Eocene	Jackson	----	Sands, white to gray, massive and thin-bedded; vary in texture from fine to coarse, and in places contain glauconite and lignite. Clays, gray, dark-gray, blue and green, massive and laminated. Marls, consist of calcareous and glauconitic clay and thin calcareous and glauconitic sands.
		Claiborne	274-458	Sands, light to dark gray when unweathered and alter to white, brown, and red when weathered. Silts, medium to dark gray, and clayey. Clays, light to dark gray, blue gray, and usually very silty or sandy.
		Wilcox	152-183	Sands, light gray when unweathered and alter to white, light brown, and red when weathered. Clays, light shades of gray or brown, contain varying amounts of fine sand. Lignite occurs as beds within this predominantly sand and clay sequence.
	Paleocene	Midway	137-183	Clays, gray, noncalcareous and shaly clays containing an abundance of siderite concretions. White to gray ash, and layers of chalk and limestone interbedded in the clay and shale.

FIGURE 5 – Stratigraphic column for the Gulf Coastal Plain region of the study area.

depth of seven feet (Stone and Sterling, 1964). Also reported at Potash Sulfur Springs is a nepheline syenite deposit, containing small amounts of pyrochlore, which had a 3% equivalent uranium (Erickson and Blade, 1963).

Two uranium prospects occur in the Arkansas Novaculite -- (1) the Chandler Prospect located in Garland County containing uraniferous (0.35% U_3O_8) material in a thin crust on the surface and in small fractures, and (2) the Runyan Prospect located in Hot Spring County contains radioactive material occurring in veins (Stroud et al., 1969). Figure 1 shows the distribution of the sample sites with respect to the major igneous intrusions and the two uranium deposits in the survey area.

WATER CHEMISTRY

The influence of other parameters on uranium concentration was investigated by correlation tests between uranium and individual parameters and combinations of parameters. There were no strong correlations (the highest correlation coefficient observed for either the Ouachita Mountain or Gulf Coastal Plain regions was 0.4). Considering the possible effect of Eh, pH and complexes, this observation is somewhat surprising. Thus, the data suggest the uranium content of the ground water is probably largely dependent simply on the original uranium content of the rock. Also the data may reflect the small size and low concentrations of uranium mineralization in the area.

As can be seen in Tables 1 and 2, the Jackson Group has the greatest concentration of uranium in ground water of the Gulf Coastal Plain formations based on the Duncan statistical test. The Jackson Group also has higher conductivity, total alkalinity and PO_4 values than the other formations. All of the other parameter means are indistinguishable among the Gulf Coastal Plain ground water samples.

In the Ouachita Mountain region, ground water from the Womble Shale has the largest values for uranium, specific conductivity, total alkalinity, NO_3 and NH_3; but has the smallest values for Eh and PO_4. The other parameter means are indistinguishable among the formations.

Comparing the two regions using the t-test and an alpha value of 0.05, indicates that the Ouachita Mountain region has higher uranium content for ground water, as well as the higher values for pH, specific conductivity, total alkalinity, SO_4 and He. The Gulf Coastal Plain region has higher NO_2 and Eh values, and there is no significant differences between the regions for NH_3 and PO_4.

COMPARISON OF FORMATIONS

Figure 6 compares mean uranium ground water values and ranges for the Ouachita Mountain region formations. The ground water samples with the highest values of uranium are from the Blakely sandstone (6.85 ppb), Polk Creek Shale-Bigfork Chert Formations (7.68 ppb) and the Missouri Mountain Shale (1.44 ppb); however, these formations are represented by only 1 to 12 samples (Fig. 6). The Duncan multiple range test was used to test for similarity of the uranium concentration of ground water from the Ouachita Mountain formations represented by at least 10 samples. Statistically the Womble Shale (mean 0.34 ppb) and the Polk Creek Shale-Bigfork Chert Formations (mean 0.67 ppb) are indistinguishable from one another and have the highest uranium concentrations for ground water. The Stanley Shale is the only other Ouachita Mountain formation with more than 10 samples and statistically its ground water content of uranium (mean 0.04 ppb) is not similar to the above formations. It is interesting to note that of the formations represented by more than 12 samples, the Womble Shale has the greatest number of the high range uranium ground water values ($>$ 80% and 95% cumulative frequency - 0.14 and 1.00 ppb respectively).

Table 1. Parameter values, standard deviation and number of samples analyzed in parentheses for the Ouachita Mountain Region. Note that each sample was not always analyzed for every parameter. Igneous rock values are not included in data for all formations.

Formation No. of analyses)	Temp ^{o}C	pH Units	Eh volts	Sp. Cond. μmhos per cm $25^{o}C$	Total Alkalinity mg/l as $CaCO_3$	NO_3 as N ppm	NH_3 as N ppm	PO_4 as P ppm	SO_4 ppm	U ppb	He ppm	Depth feet
Mazarn (1)												
mean	22.0	8	+140	310	175	0.00	0.00	0.94	0.0	0.22	-	110
std. dev.	-	-	-	-	-	-	-	-	-	-	-	-
Blakely (1)												
mean	25.0	7.5	+220	370	190	0.12	0.00	0.18	24.8	6.85	-	130
std. dev.	-	-	-	-	-	-	-	-	-	-	-	-
Womble (51-62)												
mean	14.0	8.1	+141	284	155	0.45	0.24	0.27	37.9	0.35	7.6	84
std. dev.	3.8	0.6	104	162	102	0.34	0.18	0.34	36.0	0.51	10.2	72
Bigfork-Polk Creek (7-12)												
mean	16.5	7.7	+215	107	42	0.28	0.02	0.36	21.2	0.67	5.4	123
std. dev.	7.8	1.3	164	204	98	0.37	0.06	0.26	32.8	2.21	0.3	170
Missouri Mountain (2)												
mean	13.5	6.9	+240	103	0.8	0.43	0.11	0.22	45.7	0.75	5.3	75
std. dev.	3.5	0.1	170	95	1.1	0.52	0.12	0.11	64.6	0.98	1.1	-
Blaylock (1)												
mean	8.0	8.2	+150	180	62	0.44	0.00	0.05	22.9	0.21	5.5	150
std. dev.	-	-	-	-	-	-	-	-	-	-	-	-
Arkansas Novaculite (3-6)												
mean	9.0	8.0	+262	109	43	0.39	0.02	0.32	28.7	<0.04	5.3	52
std. dev.	2.5	0.5	176	85	40	0.37	0.03	0.11	29.7	<0.04	0.8	42

Table 1 cont'd

Formation (No. of analyses)	Temp. ^oC	pH Units	Eh volts	Sp. Cond. µmhos per cm 25^oC	Total Alkalinity mg/l as $CaCO_3$	NO_3 as N ppm	NH_3 as N ppm	PO_4 as P ppm	SO_4 ppm	U ppb	He ppm	Depth feet
Stanley (23-56)												
mean	13.1	8.0	+185	207	89	0.27	0.06	0.50	22.9	0.04	10.2	89
std. dev.	7.6	9,6	96	130	64	0.30	0.14	0.32	26.9	0.07	24.7	57
Jackfork (1-4)												
mean	12.5	7.2	+170	66	30	0.46	0.07	0.60	6.2	<0.04	6.0	102
std. dev.	1.9	0.7	64	29	13	-	-	-	-	<0.04	0.2	17
All Formations (92-150)												
mean	13.7	7.9	+173	223	109	0.38	0.16	0.35	31.7	0.26	8.7	87
std. dev.	6.0	0.7	172	158	93	0.33	0.28	0.25	33.2	0.90	17.4	72
Igneous Rock (1-3)												
mean	9.0	7.7	+197	150	54	0.21	0.00	0.44	55.0	0.05	5.3	40
std. dev.	2.0	0.0	15	23	22	-	-	-	-	0.08	0.5	19

Table 2. Parameter values, standard deviation and number of samples analyzed in parentheses for the Gulf Coastal Plain Region. Note that each sample was not always analyzed for every parameter.

Formation No. of Measurements	Temp. °C	pH Units	Eh Volts	Sp. Cond. μmhos per cm 25°C	Total Alkalinity mg/l as $CaCO_3$	NO_3 as N ppm	NH_3 as N ppm	PO_4 as P ppm	SO_4 ppm	U ppb	He ppm	Depth feet
Midway (4-6)												
mean	12.0	8.2	+ 45	79	19	0.39	0.10	0.47	20.9	0.04	5.6	60
std. dev.	2.1	0.9	115	36	15	0.36	0.13	0.21	14.3	0.03	0.6	28
Wilcox (52-95)												
mean	12.1	7.4	+215	99	22	0.54	0.26	0.34	20.9	<0.04	6.2	72
std. dev.	4.9	1.0	114	124	41	0.34	0.52	0.32	28.1	0.05	5.7	79
Claiborne (20-23)												
mean	22.7	6.2	+178	193	63	0.43	0.29	0.64	26.3	<0.04	6.1	73
std. dev.	4.5	1.0	102	200	84	0.39	0.41	0.62	33.7	0.04	1.0	59
Jackson (11)												
mean	21.8	6.3	+189	294	39	0.43	0.35	0.49	27.8	0.09	5.6	85
std. dev.	3.5	1.1	107	396	57	0.38	0.47	0.35	34.5	0.11	0.6	83
Terrace Deposits (34-39)												
mean	17.6	6.8	+216	89	14	0.65	0.16	0.35	9.2	<0.04	5.5	36
std. dev.	6.2	0.9	89	61	16	0.26	0.30	0.31	11.5	0.05	0.4	26
Alluvium (7-11)												
mean	13.5	7.5	+166	57	29	0.68	0.09	0.22	9.4	<0.04	5.7	23
std. dev.	3.9	1.0	100	26	58	0.24	0.11	0.16	10.0	<0.04	0.7	7
All Formations (126-185)												
mean	15.3	7.1	+201	117	27	0.54	0.23	0.40	18.7	<0.04	6.0	62
std. dev.	6.4	1.1	110	159	48	0.33	0.42	0.39	26.1	0.06	4.5	67

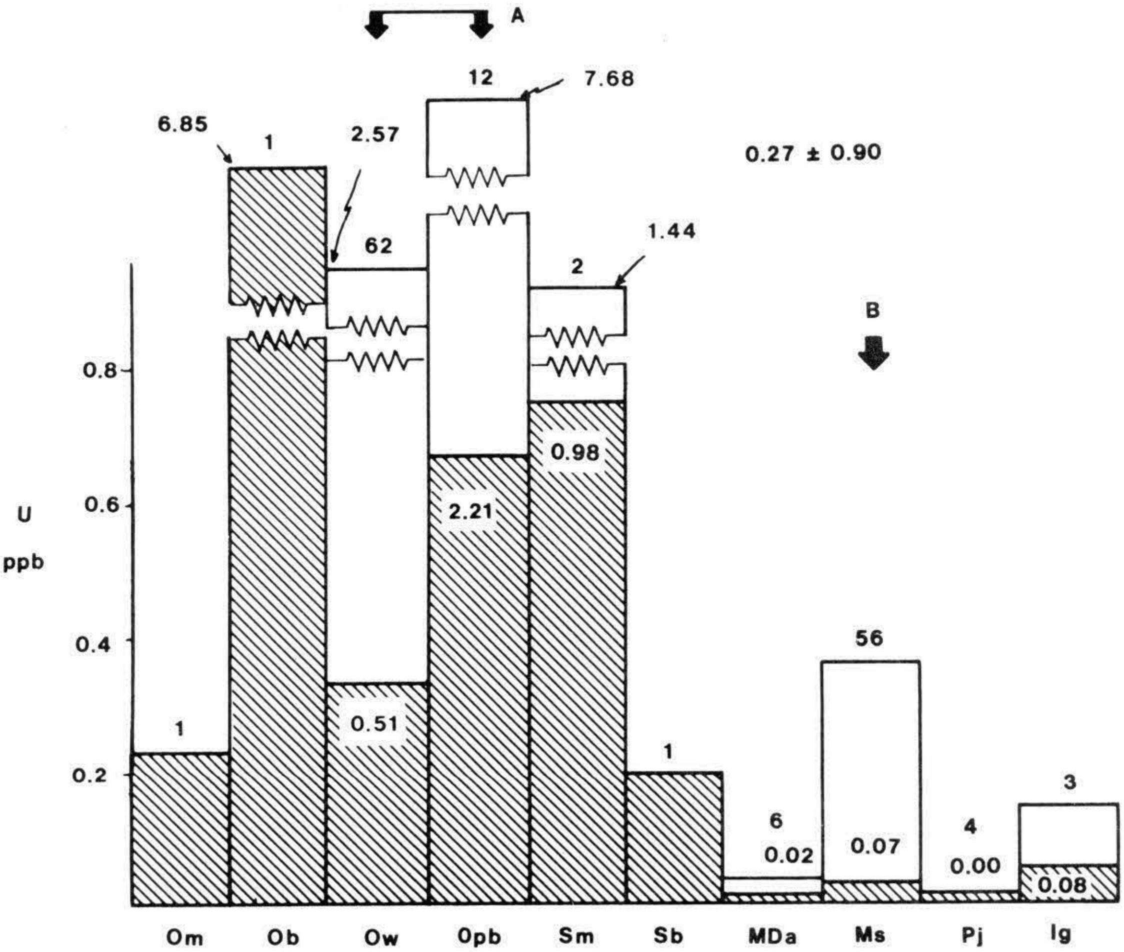


FIGURE 6 — Means, standard deviations, highest values and number of samples for each formation from the Ouachita Mountains region. The mean is read from the top of the lined column and the standard deviation is given within the column. The number of samples is given in ( ). Formations with "A" designation are indistinguishable statistically in terms of uranium content and are of greater concentration than the one designated by "B". The mean value and standard deviation for the Ouachita Mountain region is given at the top right. Ig = igneous rocks which are not included as part of the Ouachita Mountain region mean.

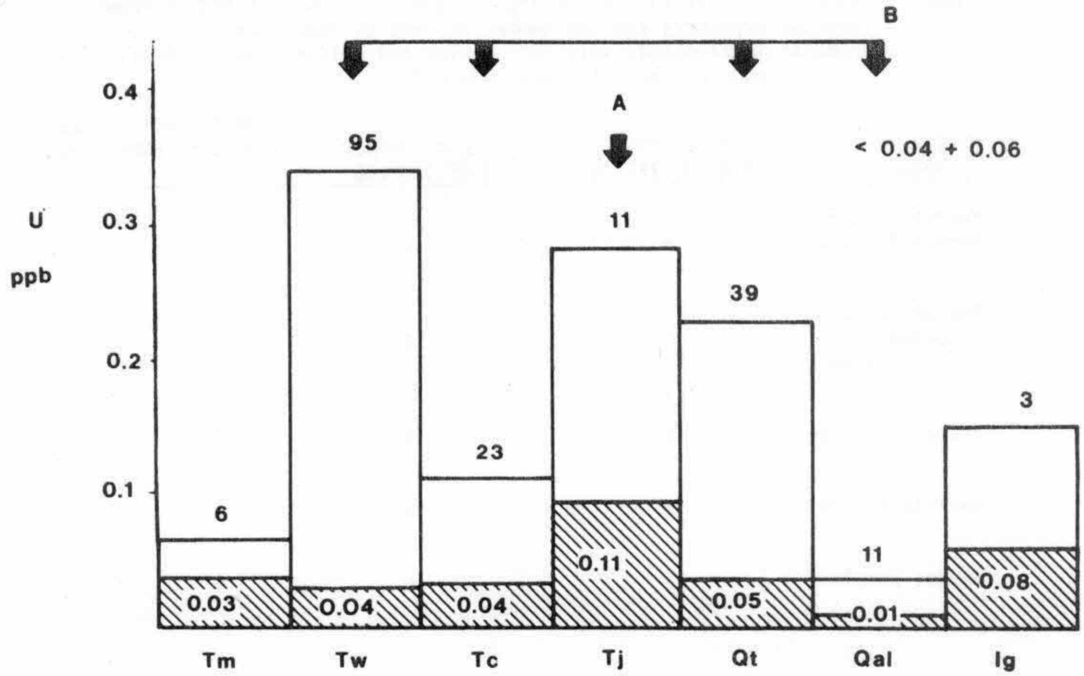


FIGURE 7 — Mean, standard deviations, highest values and number of samples for each formation from the Gulf Coastal Plain region. The mean is read from the top of the lined column and the standard deviation is given in ( ). Formations with "A" designation are indistinguishable statistically in terms of uranium content and are of greater concentration than those designated "B". The mean value and standard deviation for the Gulf Coastal Plain region is given at the top right. Ig = igneous rocks which are not included as part of the Gulf Coastal Plain region mean, but are presented for comparison.

The Womble Shale ground water samples represent 58% of the total 62 samples above the 80% cumulative frequency value for uranium in ground water in the Ouachita Mountain region and 6% exceed the 95% cumulative frequency value.

The ground water samples from the Gulf Coastal Plain region with the largest uranium values are from the Wilcox Group (0.34 ppb), Jackson Group (0.28 ppb) and the Quaternary (0.23 ppb) deposits (Fig. 7). All of the mean ground water uranium values for the Gulf Coastal Plain region formations are much lower than those for the Ouachita Mountains region (.27 $\pm$ 0.90 and $<$ 0.04 $\pm$ 0.06 ppb, respectively). The Duncan multiple range test indicates that the uranium content of ground water is similar for samples from the Wilcox Group, Claiborne Group, Quaternary and alluvium deposits (all with mean values of $<$ 0.04 ppb) and that the samples from the Jackson Group are not similar and have the highest uranium values (mean 0.09 ppb). All of the Gulf Coastal Plain formations have several samples which exceed the 80% cumulative frequency value ($>$ 0.05 ppb) for uranium concentration in the ground water of this region. Of the formations with at least 10 samples, the Wilcox Group has 17% of its 95 samples above the 80% cumulative frequency value, the Claiborne Group has 26% of its 23 samples, the Jackson Group has 55% of its

Table 3. Number of sites within 2 miles of igneous intrusions and/or known uranium prospects and the number of samples that exceed the 80% cumulative frequency value of uranium and helium. Due to areal overlap some of the sites are combined.

MINERALIZED AREA	MILES FROM MINERALIZATION	TOTAL NUMBER OF SAMPLES	SAMPLES WITH VALUES >80% COM. FREQ. VALUE U	HE
Magnetic Cove Runyan Prospect	2	13	1	1
Potash Sulfur Springs "V" Intrusive	2	10	2	0
Chandler Prospect	2	4	1	0
Bauxite Region	2	16	3	2
Benton Complex	2	4	4	0

11 samples and the Quaternary has 21% of its 39 samples. Only the Wilcox, Jackson and Quaternary deposits have samples exceeding the 95% cumulative frequency value of uranium (0.16 ppb) in ground water from the Gulf Coastal Plain region.

SITES NEAR URANIUM MINERALIZATION

There are seven known igneous areas and uranium deposits in the survey area (Magnet Cove Complex, Potash Sulfur Springs Complex, Benton Complex, "V" Intrusive, Saline County nepheline syenite intrusions in the Bauxite area, Chandler Prospect, and Runyan Prospect). Although there are not reports available on the uranium content of the rocks at the Benton Complex, "V" Intrusive, and Bauxite area intrusions, they are included because of their similarity to the other igneous complexes. All samples within one and two miles of these deposits were tested for uranium concentrations greater than the 80% and 95% cumulative frequency values, i.e. greater than 0.14 ppb and 1.00 ppb respectively for the Ouachita Mountain region and 0.05 ppb and 0.16 ppb for the Gulf Coastal Plain region, respectively.

Forty-eight of the 335 samples are within 2 miles of these "mineralized" areas and only 12 of these 48 samples exceed the 80% cumulative frequency value of uranium concentration. The Bauxite area of the Gulf Coastal Plain region contains 3 of these 12 samples, the Benton Complex 4 samples and the Potash Sulfur Springs - "V" Intrusion area, 2 samples. The Chandler Prospect and Magnet Cove Complex - Runyan Prospect areas each have one sample that is greater than the 80% cumulative frequency value for ground water uranium content within this 2 mile radius (Table 3). Thus there are only 25% of the samples within 2 miles of the uranium mineralized areas that exceed the 80% cumulative frequency value. However, the Benton Complex area samples all contain much higher uranium concentration samples. Although the percentage of samples with higher uranium concentrations is not much greater near uranium mineralized deposits, it would be difficult to determine that *all* of the deposits have no effect. The small size of these deposits may help explain the lack of major uranium enrichment in the ground water.

These same samples were also tested for having He values which exceed the 80% cumulative frequency level of He concentration in ground water; however, only 3 samples exceeded this value. Thus, He concentrations exhibit even less relationship to the uranium mineralized deposits than the uranium contents.

COMPARISON WITH OTHER REGIONS

The mean uranium concentration for the Ouachita Mountains region is 0.27 ppb which is essentially the same as the 0.3 ppb mean ground water uranium content reported by Scott and Barker (1962) for the Ozark - Ouachita System. The mean uranium ground water value for the Ouachita Mountains region is also similar to the mean value of 0.2 ppb for the Atlantic and Gulf Coastal Plain regions as a whole. The Appalachian Belt has a somewhat higher mean ground water uranium concentration of 0.5 ppb and the Rocky Mountain Orogenic Belt has a considerably higher mean value of 1.7 ppb.

The mean uranium content of ground water, < 0.04 ppb, from the Gulf Coastal Plain region of the survey area is much lower than the mean values listed above. Two Gulf Coastal Plain formations, Claiborne and Wilcox, of Tennessee have 0.2 ppb and 0.1 ppb mean uranium content of ground water, respectively. These same two formations are present in the Gulf Coastal Plain region of the survey area; however the mean values for the Claiborne and Wilcox Groups in Arkansas are considerably less, both are < 0.4 ppb.

CONCLUSION

Ground water from the Ouachita Mountain region has significantly higher uranium concentration (about 7X) than ground water from the Gulf Coastal Plain region (Tables 1 and 2). The higher values for the Ouachita Mountain region are associated with marine black shales deposited slowly, e.g. the Womble Shale Formation. For example, although the Stanley Shale Formation contains marine black shale, it was deposited rapidly and based on the few analyses available, has lower uranium content (about 10 ppm or less) than the Womble Shale (about 20 ppm) Landis, 1962). Thus, original uranium content of rocks appears to be the major factor affecting uranium content of the ground water. This hypothesis is consistent with the fact that there is no significant correlation between uranium concentration and other parameters. However, ground water from sites near known or expected uranium mineralization are not greatly affected by the mineralization. This observation may be the result of the small and erratic occurrence of mineralization at these sites and/or complex ground water movement.

The anomalous uranium concentrations of ground water near the Benton Breccia, and the low uranium values for ground water from the Claiborne and Wilcox Groups in Arkansas relative to values in Tennessee are noteworthy. There are no uranium analyses available for rocks from the Benton Breccia, however, syenite dikes associated with the explosion breccia may be uranium bearing, and/or uranium may have been concentrated in a volatile phase associated with formation of breccia. Thus, higher uranium content of the rocks near the breccia may be the explanation for the anomalous uranium content of ground water in this area. The uranium content of ground water from the Claiborne and Wilcox Groups in Tennessee is about 5 times greater than for ground water from the same units in Arkansas. The lower uranium content for Arkansas may mean that (1) more uranium has been leached from the rocks in Arkansas, (2) the uranium is present in a less soluble form in Arkansas, (3) the present ground water chemistry for the two areas is different, or (4) the original uranium content of the Claiborne and Wilcox Groups in Arkansas was lower. The latter possibility seems to be least likely, and in order to adequately evaluate the other possibility, more data is needed.

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ABSTRACTS

STRUCTURAL CROSS SECTIONS OF THE ARKOMA BASIN, ARKANSAS

By Mohamad Karim Amini, 1980
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Abstract

Rocks of Paleozoic Age have been penetrated by oil and gas companies' drilling in the eastern part of the Arkoma basin. Lower Pennsylvanian rocks in the area are capable of producing natural gas. Most wells drilled by oil companies have been logged. Electric, gamma ray, and other mechanical logs are used to establish the general structural configuration of the Arkoma basin.

Rocks younger than Devonian Age have been penetrated in most of the wells. Correlation of these wells indicates numerous faults. Characteristics of the log signatures were used to draw cross sections of the basin. Faults found by the log signatures were traced on a surface structure map. The structural configuration of the basin is shown by the cross-sections made in this report.

REMOTE SENSOR LINEAR ANALYSIS AS AN AID FOR PETROLEUM EXPLORATION ARKOMA BASIN, ARKANSAS

By Marcus X. Borengasser, 1980
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Abstract

Enhanced imagery techniques are analyzed in a search for a relationship between linears and gas production.

Imagery enhancement techniques include gaussian distribution stretch, uniform distribution stretch, enhanced color, and high pass filtering. Several types of imagery are considered; four bands each of Landsat summer and winter scenes and L-band radar parallel-polarized (HH) and cross-polarized (HV) imagery. The imagery is evaluated on the basis of linear detection capability. The Landsat winter scene, band 7, uniform distribution stretch is consistently better for linear detection than other Landsat scene-enhancement combinations. Analysis of L-band radar imagery enhancement is inconclusive in terms of linear detection but more linears are detected with the parallel-polarized (HH) than the cross-polarized (HV).

Statistical analysis using the Pearson correlation coefficient indicates a positive correlation between linear density and gas production from carbonate strata having a high chert content. A slight negative correlation is indicated between gas production and the distance to the nearest linear intersection. Further study reveals that the number of linear intersections is dependent upon linear density. The only relationship found is an increase in gas production from carbonate strata with an increase in linear density.

Two gas productive areas, the Rock Creek field and the Batson field, are studied in greater detail. Many linears are detected in the Batson field, where production is predominantly from the Boone Formation. Few linears are detected in the Rock Creek field where very little gas is produced from the Boone Formation. Structure contour maps for the top of the Boone Formation show structural highs in both of these fields. The structural highs in the Batson field are coincident with greatest linear density. Wells penetrating these structural highs produce much gas from the Boone Formation. In the Rock Creek field, wells that penetrate the structural highs of the Boone Formation are essentially dry holes in that formation.

The findings indicate that both linear density and structural highs are necessary for gas production from the carbonate strata in the Arkoma basin.

A model for the origin of the linears in the Batson field involves draping and differential compaction on a pre-existing high. In addition, the Batson field is at the position of maximum curvature on a regional monocline. The monocline is a result of the transition from the essentially horizontal strata of the Ozark platform to the dipping strata of the Arkoma basin. Increased fracturing occurred in the Batson field because of its location with respect to the hinge of the monocline.

SEASONAL FLUCTUATIONS OF THE HYDROGEOCHEMISTRY OF SELECTED SPRINGS AND WELLS IN Ba, Mn, AND Hg MINERALIZED AREAS, OUACHITA MOUNTAINS, ARKANSAS

By Philip N. Cavendor, 1980
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Abstract

Thirteen groundwater samples (ten springs, two artesian wells, and one private well) were selected from 88 groundwater samples in the Ouachita Mountains of Arkansas to determine if seasonal

fluctuations in precipitation caused substantial variations in the chemical composition of the selected samples. These thirteen samples were selected on the basis of their anomalous character with respect to certain physical and chemical parameters, and were collected over a one year period, two times representing a wet period and two times representing a dry period.

The results of this study suggest that no significant variations of measured parameters occur in the majority of the samples, although there are fluctuations in pH, specific conductance, calcium, barium, strontium, lead, and mercury values for some sites. The parameters of temperature, total alkalinity, nitrate, ammonia, sulfate, chloride, silica, sodium, potassium, magnesium, lithium, iron, manganese, zinc, cobalt, and nickel do not seem to vary to any significant degree. Copper and phosphate concentrations showed erratic and random variations. The variation seen in certain samples is believed to be due to mixing of vadose and phreatic groundwaters creating a decrease or increase in concentrations depending upon the measured parameter and the local hydrologic conditions.

From this study, it appears that hydrogeochemical prospecting for Ba, Mn, and Hg is a viable mineral exploration method for the Ouachita Mountains of Arkansas. Based on the results of the seasonal sampling, the most feasible time to collect groundwater samples for Ba would be during the summer or late spring periods; for Hg during the summer period; and for Mn during the winter and early spring because these periods yield the highest values.

Sample sites 526 and 527 appear to be influenced by a connate brine source, and site 921 is a warm spring. The compositions of these springs are consistent with the composition of other "brine" springs and thermal springs.

HYDROGEOLOGIC EVALUATION OF THE BOONE–ST. JOE CARBONATE AQUIFER

By Manouchehr Chitsazan, 1980
University of Arkansas

Abstract

A hydrogeological study of the Boone–St. Joe aquifer was conducted in northern Washington County, Arkansas. Thirty pumping tests were performed on the aquifer to determine the capacity of this aquifer to store and transmit water. The range of the specific capacity was found to be 0.04 to 15.0 gpm/ft and correspond laterally with a range of the coefficient of transmissibility of 25 to 9900 gpd/ft.

A classification scheme based on aquifer properties was developed from the pumping test data. Six classes were developed as follows: (1) wells with nearly uniform permeability, (2) wells intersecting a recharge boundary, (3) wells intersecting a barrier boundary, (4) wells intersecting caves with recharge boundaries, (5) wells intersecting caves without recharge, and (6) wells with delayed yield.

Seasonal water level fluctuation data from eight wells show that the Boone–St. Joe aquifer is under water table conditions with uniform recharge from precipitation. There was less than 12 feet of change between the highest and lowest water levels.

A statistical comparison between photo lineament proximity or transmissibility and well yield (as gpm) was found at a 90 percent probability level. Therefore, it is concluded that the use of photo-lineaments for locating high yield water wells is advantageous to random drilling. The thickness of the regolith is not statistically related to yield or photo-lineament proximity. This suggests that there is not a significant relationship between the difference in weathering depth and yield or photo-lineament proximity.

Finally, a piezometric surface map of the Boone–St. Joe aquifer was produced. It shows that the aquifer is primarily unconfined with many base-level, spring discharge points. Ground water and surface divides correspond. Ground-water flow is generally east to the White River or west to the Illinois River from the north-south oriented divide.

LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS IN THE UPPER BLOYD AND LOWER ATOKA FORMATIONS IN SOUTH–EASTERN JOHNSON, WESTERN POPE, EASTERN LOGAN, AND NORTHERN YELL COUNTIES, ARKANSAS

By Billy J. Crabtree, 1980
University of Arkansas

Abstract

The upper Bloyd and lower Atoka succession in the Arkoma basin of Arkansas is composed of

alternating units of sandstone, siltstone, and shale. The interval considered in this report is bounded below by the Kessler Limestone Member of the Bloyd Formation and above by the top of the Casey sandstone unit in the Atoka Formation. It ranges from 765 feet thick in the northern part of the study area to a maximum of over 1400 feet thick in the south.

Nine sandstone units have been recognized within this interval. In ascending order they are the Spiro, Patterson, Cecil Spiro, Paul Barton, Dunn C, Jenkins, Sells, Vernon, and Casey sandstone units. Each unit is bounded above and below by laterally persistent shale units which accumulated during marine transgressions. The Atoka in the subsurface of the Arkoma Basin includes units correlated to the Trace Creek Shale Member of the Bloyd Formation. These units include the informally-named Spiro and Patterson sandstones.

Information derived from 68 mechanical well logs was used to prepare cross sections, isopach maps, and log signature maps illustrating the stratigraphic framework, the geometry, and the depositional environments of the sandstone units in the interval.

Sandstone units within the upper Bloyd and lower Atoka accumulated as regressive blanket sands in a variety of transitional environments in high-constructive lobate and elongate deltas and in high-destructive wave-dominated deltas. Subsidence as a result of the compaction of water-saturated clays and abandonment of distributary channels caused widespread marine transgressions and the accumulation of the laterally extensive shale units separating the blanket sands.

ANALYSIS OF SEASAT RADAR IMAGERY FOR GEOLOGIC MAPPING IN LOUISIANA, ARKANSAS, AND OKLAHOMA

By Janet A. S. Demarcke, 1980
University of Arkansas

Abstract

On August 21, 1978, the Seasat satellite provided a radar image of Arkansas, Oklahoma, and Louisiana. The Seasat synthetic aperture radar (SAR) operated at a 23-cm, L-band wavelength. This study provides a description of radar operation, as well as the characteristics of the remote sensors (Seasat, Landsat and aircraft radar imagery utilized).

The Louisiana part of the Seasat imagery was analyzed for geologic application in mapping lithology, drainage patterns, and potential for detecting salt domes. Tonal and textural changes on the Seasat imagery delineated areas of recent alluvial deposits along the Gulf coast and in the river valleys. Drainage patterns from the Seasat imagery provides important supplementary information, which could not be obtained with the Landsat imagery. Circular anomalies interpreted from the Seasat and Landsat imagery represent ancient meander scars, salt domes at the surface, or circular highs in the subsurface of non-salt origin.

In the Boston Mountains region of Arkansas, the Seasat radar imagery was compared to Landsat and aircraft radar imagery to determine the geologic value as an additional source of information in linear studies. The comparisons of remote sensor data in the linear study illustrate the illumination direction dependence of both Seasat and Landsat systems. It is recommended that to maximize the information potential for linear mapping, two or more image types with different illumination directions should be utilized.

Analysis of the Seasat imagery revealed a number of anomalously high returns associated with three distinctly different environments: urban, agricultural and forested swamp. Geologically, the most significant anomalous returns were from the forested swamp areas (with standing water), which provide evidence that the L-band Seasat radar penetrates the vegetative canopy and delineates the underlying water boundary. This operational capability map provides timely observations of flooded areas while flooding is in progress and when clouds are normally present, a situation which limits remote sensor applications within other spectral regions.

A TRI–POTENTIAL RESISTIVITY STUDY OF FRACTURES, CAVES, AND PHOTO–LINEAMENTS IN THE BOONE–ST. JOE AQUIFER, NORTHWEST ARKANSAS

By Paul Southworth Eddy, Jr., 1980
University of Arkansas

Abstract

The tri-potential method of resistivity was conducted over fractures, solution cavities and a fault in Washington and Benton Counties, Arkansas to test theoretical responses against known and unknown geologic conditions. Most of the 28

traverses were conducted near wells in which pumping tests had been previously performed in order to statistically compare the results of the pumping tests with resistivity anomalies. Although no correlation could be established at an alpha level of 0.1, a definite trend was noted. High production wells frequently were located at or near resistivity anomalies that were interpreted as being water filled fractures, whereas low production wells tended to have no associated resistivity anomalies.

The following relationships were found between the investigated structure and the different arrays:

1. Water-Filled Fractures: The apparent resistivity decreases in the cppc and cpcp configurations, but it increases in the ccpp configuration. The delta per cent values normally increase at the edge of the weathered zone associated with the fracture.

2. Air-Filled Fractures: The apparent resistivity increases in the cppc and cpcp configurations, but it decreases in the ccpp configuration. The delta per cent normally show increases at the edges of the weathered zone associated with the fracture.

3. Water-Filled Caves: The response in the arrays vary according to the depth to the top of the cave, the radius of the cave, and the a-spacing change. In general, the apparent resistivity decreases for the cppc and cpcp configurations and increases for the ccpp configuration. At shallow depths, three peaks form with the center and lowest peak (highest in the ccpp configuration) being located over the cave. At greater depths, it becomes impossible to differentiate between a water-filled fracture and a water-filled cave.

4. Air-Filled Caves: The responses in the different arrays will vary with the depth to the top of the cave, the radius of the cave, and any a-spacing changes. As the traverse crosses an air-filled cave, the apparent resistivity for all three configurations will increase.

5. Faults: One fault was crossed and at the points where an electrode crossed the fault, there was a change in slope of the graphs of the apparent resistivity. A "W" was formed by each of the graphs. The "W" was formed as each of the two inner electrodes crossed the fault and when the fault plane was in the center of the array.

Six traverses made below the new sanitary landfill near Wheeler, Arkansas, show the presence of several fractures that will probably collect and transport leachate that might escape from the landfill. This situation could cause ground water supplies in the area to become unfit for further use and increase the pollution of Clear Creek.

The author found the following advantages to the tri-potential method of resistivity surveying:

1) The three resistivity readings allow a quick cross-check in the field to insure that the probes had been correctly spaced and good contact with the ground had been made.

2) The three configurations aid in the interpretation of anomalies because the cpcp and ccpp configurations are more responsive than the cppc configuration (Standard Wenner configuration).

3) The tri-potential method locates weathered zones associated with fractures in either the presence or absence of water.

STRUCTURAL STYLE OF THE OUACHITA CORE NEAR CADDO GAP, ARKANSAS

By David Paul Evansin, 1976
Southern Illinois University

Abstract

The Ouachita Mountains of west central Arkansas are a mountain belt of folded Ordovician through Pennsylvanian shale, sandstone, and novaculite. The deformation history of the Paleozoic rocks is a matter of controversy as to whether the deformation was true polyphase deformation with differently oriented stress fields operating at discreetly different times or it was the result of a stress field which maintained essentially the same orientation and magnitude throughout the deformation, although the Paleozoic strata may have rotated relative to the stress field.

The mesoscopic structural features of a small area near Caddo Gap, Arkansas, were examined. Fold, fracture, and fault orientations were the major structural elements measured. Bedding plane attitude was used to calculate attitudes of macroscopic folds and of partially covered mesoscopic folds.

Three subareas of apparently different structural style were delineated: the Caddo Mountains in the north, the South Fork Valley, and in the south the Cossatot Mountains. Two sets of mesoscopic folds and one set of macroscopic folds were observed in the Caddo Mountains. The valley of the South Fork of the Caddo River yielded one set of mesoscopic folds and one set of macroscopic folds. The Cossatot Mountains suggest two sets of mesoscopic folds and one macroscopic set.

The sequence of folds determined was initial mesoscopic folding followed by macroscopic folding, both about an east-west horizontal axis. The second phase of mesoscopic folding either preceeded the macroscopic folding or was parasitic to it, but insufficient data has been collected to make a definite determination of that timing.

The folding phases are essentially coaxial and are interpreted to be the result of a uniformly oriented stress field.

LITHOSTRATIGRAPHY AND DEPOSITIONAL SYSTEMS OF THE BLOYD AND HALE FORMATIONS, (PENNSYLVANIAN), IN THE WESTERN ARKOMA BASIN OF ARKANSAS

By Ronald R. Foshee, 1980
University of Arkansas

Abstract

The Morrowan Series in the subsurface of the Arkoma Basin is a sequence of alternating sandstone, limestone, and shale units. The interval includes the Hale and Bloyd Formations and ranges in thickness from a minimum of 286 feet in the northwest to a maximum of 1200 feet in the east. The Hale Formation is subdivided into the Cane Hill and Prairie Grove Members, and the Bloyd Formation includes the Brentwood, Woolsey/Cannon, Dye, and Kessler Members. The Morrow rests unconformably on Chesterian strata and is overlain by the lower Atoka deltaic sequence.

Mechanical well logs from 149 petroleum exploration wells were obtained and correlated in this study. Subsurface cross-sections and isopach maps were prepared to illustrate the orientation of thickness trends and determine the distribution of individual units. Lithologic variations were determined from well log signatures and from analyzing bit-cut samples. This information was used to reconstruct the depositional systems which were active in depositing Morrowan sediments.

Deposition occurred as early Pennsylvanian seas migrated across a shallow marine shelf. Transgressions and regressions allowed most sandstone and limestone units to accumulate in shallow near-shore areas, dominated by coastal and tidal processes. The shale units were generally deposited in offshore quiet water areas, with the exception of the terrestrial Woolsey and Cannon Members.

GEOCHEMISTRY, GEOTHERMOMETRY, AND MINERALOGY OF QUARTZ AND BASE METAL VEIN DEPOSITS, MONTGOMERY COUNTY, ARKANSAS

By Andrew William Kurrus, III, 1980
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Abstract

Hydrothermal vein deposits of Pb-Zn-Ag-Cu bearing minerals were mined and prospected in a 10 mile^2 area around the community of Silver in Montgomery County, Arkansas in the late 1800's. Manganese and barite deposits were subsequently discovered farther west in Montgomery County. Manganese was mined in the mid- to late 1950's, and barite is currently being mined and prospected for. All of these ore deposits are associated with or are located proximal to vein quartz deposits.

Three stages of mineralization were recognized at the Silver Pb-Zn-Ag-Cu area from twenty-two polished ore specimens and numerous hand specimens, as follows:

1) An early hydrothermal stage consisting of quartz, calcite, and pyrite;
2) A late hydrothermal stage consisting of quartz, calcite, sphalerite, chalcopyrite, galena, tetrahedrite-freibergite, and possibly argentite;
3) A final stage consisting of numerous oxidized minerals.

Geothermometric analysis of fluid inclusions in sphalerite, calcite and quartz from the Silver area indicates that the Pb-Zn-Ag-Cu quartz veins are best classified as epithermal. Quartz from the Silver area crystallized at temperatures ranging from 170°C to 276°C, calcite at temperatures ranging from 194°C to 202°C, and sphalerite from 186°C to 222°C. Some of these temperatures exceed the upper limit for epithermal deposits; however, many are below 200°C, and the mineral assemblage of these veins is typical of epithermal deposits. Assays of galena, sphalerite, and freibergite from the Waterloo mine reveal that significant quantities of silver are present in these minerals.

Geochemical analysis of pyrite from the Hog Jaw manganese mine and from the Waterloo Pb-Zn-Ag-Cu mine indicates similar trace element compositions of these specimens. Associated quartz crystals from both mines contain fluid inclusions which gave similar homogenization temperatures. Thus, the pyrite-quartz veins at the Hog Jaw manganese mine are probably genetically related to pyrite-quartz veins located at the Silver area.

STUDY OF A STRATA-BOUND BARITE DEPOSIT, DEMPSEY COGBURN MINE, MONTGOMERY COUNTY, ARKANSAS

By Stephen E. Laney, 1980
University of Arkansas

Abstract

The Dempsey Cogburn barite deposit is located in Sec. 32 and 33, T4S, R26W, of Montgomery County, Arkansas. The barite occurs as strata-bound lenses up to 90 meters long near the base of the Stanley Shale Formation of Lower Mississippian Age. High-grade ore consists of a massive, blue-gray crystalline barite which grades into baritic shale and nodular shale around and between the ore lenses.

Prior to 1960, Arkansas barite was regarded as replacement deposits resulting from the alkali igneous intrusions emplaced in the Ouachita system during the Cretaceous. Subsequent studies indicate the barite may have been precipitated syngenetically from seawater during the deposition of Stanley sediment. This study cites evidence for a diagenetic-epigenetic origin for the barite.

Ore textures indicate the barite was deposited by replacement and open-space filling within shaley sediment. Crystal growth textures and undeformed and preserved radiolaria within the barite indicates the ore was emplaced before the sediment underwent appreciable compaction and dewatering.

The barite was formed by the mixing of seawater and barium-rich fluids within unconsolidated Stanley sediment. The ore was emplaced during the major subsidence of the Ouachita trough and before the Ouachita orogeny.

LITHOSTRATIGRAPHY AND DEPOSITIONAL SYSTEMS OF PENNSYLVANIAN SANDSTONES IN THE ARKOMA BASIN

By Lu-Anne P. Lonsinger, 1980
University of Arkansas

Abstract

The upper Bloyd and lower Atoka Formations are composed of siltstone, shale and sandstone units. An interval bounded by the Kessler Member of the Bloyd Formation below and the informally named Frieburg sandstone unit of the Atoka Formation above contains nine sandstone units that are proven natural gas reservoirs in the Arkoma Basin. These sandstone units are laterally persistent in the subsurface of the area of investigation and are individually bound by equally persistent shale units. Linearity of producing zones within the sandstones suggest depositional rather than structural parameters effecting lithic characteristics conducive to reservoir conditions.

Using mechanical well logs, cross-sections, log signature and isopach maps the overall geometry of the sandstone units was determined. Lithic successions inferred from log signatures and geometry were used to determine the stratigraphic framework. Numerous depositional environments were constructed that comprise two major depositional systems; the high constructive delta and high destructive delta.

Five of the sandstone units are believed to have been deposited in high constructive lobate deltas, the sandstone units are: Spiro, Cecil Spiro, Dunn C, Sells, and Casey. The Patterson, Paul Barton, Jenkins and Vernon sandstone units are believed to have been deposited in high destructive wave dominated deltas.

The Spiro sandstone is a series of coalescing distributary mouth bars whose deposition was terminated due to marine transgression which reworked and redeposited the delta front sands as shoal sands. The Spiro was deposited in a high constructive delta lobe which later experienced a destructive phase. The Patterson sandstone displays longshore bar facies deposited in a high destructive wave dominated delta lobe. Two distinct distributary channel system and interdistributary areas represent high constructive lobate deltaic depositional system responsible for emplacement of the Cecil Spiro. The Paul Barton displays numerous feeder systems to a high destructive wave dominated delta lobe. Reworked sediments by east prevailing longshore currents were deposited on the delta front as longshore bar sands.

Sheet sands were deposited by a minor transgression near the end of the Dunn C emplacement. A high constructive delta delivered sediment to the receiving basin which was then redeposited by active marine processes. The Jenkins emplacement began as a destructive phase during which longshore bar sedimentation occurred. A constructive phase followed and mouth bar sands were deposited as active distributary channels prograded seawards. The Sells sandstone was emplaced by a high constructive delta. The emplacement of bar finger sands resulted from distributary mouth bars progradation and subsidence of the sands into the underlying water saturated prodelta clays. Sporadic sediment supply to a wave dominated basin is the depositional system responsible for emplacement of the Vernon sandstone. The Casey sandstone is characterized by distributary mouth bar sands and the immature sands of interdistributary areas which were deposited in high constructive delta depositional systems.

STRATIGRAPHY OF LOWER ATOKA AND UPPER BLOYD STRATA IN WESTERN ARKANSAS AND EASTERN OKLAHOMA

By Hugh Kenneth McMurrough, Jr., 1980
University of Arkansas

Abstract

Seven sands of the upper Bloyd and lower Atoka Formations were investigated within the subsurface of the Arkoma basin in eastern Oklahoma and western Arkansas. Cross-sections, isopach maps, isolith maps, and mechanical well log signature maps were prepared from mechanical well logs to aid in the reconstruction of the ancient depositional environments responsible for the emplacement of the investigated sands.

The sands were deposited as blanket sands in transitional marine environments which were fed by fluvial systems to the north. Sand accumulations occurred as prograding units within high-constructive fluvial-dominated and high-destructive marine-dominated delta systems. Periodic shale intervals, representing widespread northward marine transgressions, effectively encase each of the regressive sand units.

STRUCTURE OF THE WESTERN OUTCROPS OF THE COLLIER SHALE NEAR MOUNT IDA ARKANSAS

By George Thomas Merrifield, Jr., 1979
Southern Illinois University

Abstract

The core area of the Ouachita Mountains near Mount Ida, Arkansas, exposes Lower Ordovician rocks which have experienced multiple phases of deformation. Mapping of the Collier Shale, the oldest formation in the area, and overlying formations indicates that at least two distinct phases of deformation are superimposed upon these rocks. Early, east-west, mesoscopic and macroscopic fold axes are best preserved in the southern portions of the study area north of the Crystal Mountains.

The second deformation phase, consisting of four progressive events, is characterized by the development of a subhorizontal cleavage parasitically related to at least one macroscopic, northward-transported, recumbent fold. Analysis of the cleavage and other microstructures indicates that pressure solution was a dominant deformation mechanism. Mesoscopic fold axes and late extensional increments of mesoscopic fibrous quartz growths plunge northwest in the hinge area of this fold, except to the west where a left-separation, tear fault appears to have altered mesoscopic fabric locally. Northward-displacement in the breached anticlinal core of the recumbent fold occurred along a thrust fault to the west. Elliptical, conical, fold-axis fabric near the thrust fault-to fold transition most likely developed during the second deformation phase. Elsewhere in the core of this anticline and in the anticline to the south, mesoscopic fold axes of the second phase of deformation commonly parallel fold axes of the first phase of deformation.

North-south cross sections through the study area must explain the relationship of the poorly exposed klippen to other macroscopic structures. One partial cross section illustrates southward overturning which may represent a third deformation phase.

PALYNOLOGICAL CORRELATION OF UPPER CHESTERIAN AND MORROWAN STRATA OF NORTHWEST ARKANSAS WITH THEIR WESTERN EUROPEAN EQUIVALENTS

By Patricia Ann Jameson Rezaie, 1980
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Abstract

Various palynological processing techniques were compared and modified to provide maximum recovery of miospores from selected shale intervals within the Upper Missi.-ippian (Chesterian) and Lower Pennsylvanian (Morrowan) of northern Arkansas. The technique, which was developed, requires: (1) soaking the sample in hydrochloric acid (20 percent by volume) for 12 to 24 hours, (2) soaking the sample in hydrofluoric acid (48 percent by volume) for 24 to 48 hours; (3) oxidizing in nitric acid (70 percent by volume) for 5 to 10 minutes; (4) providing reducing conditions for two minutes by the use of ammonium hydroxide (4 percent by volume); (5) specific gravity separation using stannic chloride (1.9 specific gravity), (6) filtering the lighter portion recovered from specific gravity separation through 20 micron Nitex cloth; and (7) staining the filter residue with Safranin O prior to mounting on permanent slides.

Spores identified on the processed slides were compared with taxa used for the established miospore

zonations for the Carboniferous System of western Europe. There was general agreement between correlations based on miospores from northern Arkansas and their European equivalents. The upper Fayetteville is correlated to the *Bellispores nitidus-Reticulatisporites carnosus* (NC) Zone (E_1). Established ammonoid correlations were employed to assign the Pitkin Formation to the upper NC and lower *Stenozonotriletes triangulus-Rotaspora knoxi* (TK) Zone (upper E_1 and E_{2a}) in the absence of miospore recovery. The TK Zone ranges through the base of the succeeding Imo Formation. The boundary of the TK and the succeeding *Lycospora subtriquetra-Kraeuselisporites ornatus* (SO) Zone is placed near the middle of the Imo (E_{2b}-E_{2c}). The Mississippian-Pennsylvanian boundary coincides with the SO and *Crassispora kosankei-Grumosisporites varioreticulatus* (KV) boundary (R_{1a}). Palynomorphs recovered from the upper Cane Hill Member of the Pennsylvanian Hale Formation suggest a horizon near the KV and *Raistrickia fulva-Reticulatisporites reticulatus* (FR) Zone (R_{2a}) boundary. This correlation does not agree with the ammonoid age assignment (R_{2b}). This difference may be the result of stratigraphic leakage or time transgression of the Cane Hill-Prairie Grove boundary. Ammonoid correlations place the base of the Brentwood Member of the Bloyd Formation within zone FR. The upper Brentwood and Woolsey Members were included within the *Triquitrites sinani-Cirratriradites saturni* (SS) Zone (lower G_2), while the Dye and Kessler Members were placed within the *Radiizonates aligerens* (RA) Zone (middle G_2). The boundary between the Bloyd and Atoka Formations coincides with the base of the *Microreticulatisporites nobilis-Florinites junior* (NJ) Zone (Westphalian A-B boundary). All these correlations are compatible with other biostratigraphic assignments.

STRUCTURAL STYLE OF THE OUACHITA CORE IN A PORTION OF THE McGRAW MOUNTAIN QUADRANGLE ARKANSAS

By Paul George Soustek, 1979
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Abstract

The Ouachita Mountains of west central Arkansas comprise a mountain belt of thrust and folded Ordovician through Pennsylvanian shales, sandstones, limestones and novaculites.

Detailed structural mapping was conducted on a small portion of the core area, included in the U.S.G.S. McGraw Mountain 7.5 minute Quadrangle. Mesoscopic folds, cleavages and bedding surfaces were measured in the field, and the orientations of large faults were inferred from surrounding structural styles.

Two subareas of differing structural styles were delineated: a northern area centered near Hickorynut Mountain, and a southern area represented by McGraw and Crystal Mountains. The southern area contains two sets of macroscopic folds, three mesoscopic fold sets, and a structural window. The northern portion has three sets of both macroscopic and mesoscopic folds. The northern area also shows macroscopic structures overturned toward the south and a highly folded thrust fault.

The fold sequence began with east-west mesoscopic folding associated with northward thrusting. This was followed by a phase of macroscopic east-west folding. The next deformation episode included the development of northeast trending mesoscopic folds throughout the area. At the same time, coaxial, northeasterly trending macroscopic folds were developed in the northern portion only. The development of the northeasterly trending macroscopic fold set accompanied and was probably caused by northward thrust transport of the southern block. The thrust fault underlying the northern part of the area was also folded at this time.

The southern vergence of macroscopic structures is attributed to backfolding of the thrust plates.