STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

William V. Bush, State Geologist, Director

MISCELLANEOUS PUBLICATION NO. 8

RELATIONSHIP OF IGNEOUS ACTIVITY TO MINERAL DEPOSITS IN ARKANSAS

By

Charles G. Stone and Philip J. Sterling

Little Rock, Arkansas
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(Reprinted 1996)

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PREFACE

The information in this report represents a compilation of data from publications, open file reports and investigations recently completed or in progress. Direct bibliographic references are made where pertinent data is presented. However, for the sake of simplicity the sources of generalized material are incompletely credited. All references used are tabulated in the bibliography at the end of the report.

RELATIONSHIP OF IGNEOUS ACTIVITY TO MINERAL DEPOSITS IN ARKANSAS

By

Charles G. Stone and Phillip J. Sterling

ABSTRACT

Igneous rock is exposed over less than 0.03 per cent of the surface area of Arkansas, but this is no measure of the importance of igneous activity to the origin of ore deposits in the State. Bauxite, barite, and diamonds are attributed to the intrusion of alkalic to ultrabasic igneous rocks in or near the Ouachita Mountain area. These rocks of Mesozoic age characteristically have a relatively high content of titanium, columbium, and vanadium, especially in the Magnet Cove region. Deeper bodies of similar character have been encountered in the subsurface of southeastern Arkansas.

Certain nickel-bearing serpentine and talc bodies in central Arkansas are believed to be derived from igneous rocks of Paleozoic age. Granite and rhyolite of probable Precambrian age have been encountered by deep drilling both in northwestern Arkansas and, more recently, in west-central Arkansas near Fort Smith.

Because Mesozoic and Paleozoic igneous activity are closely related to or immediately responsible for many of the known occurrences of metallic minerals in Arkansas, an understanding of these relationships is important when looking for new mineral deposits.

INTRODUCTION

Igneous rocks intrude Paleozoic and younger sedimentary rocks at many places in the Central and Eastern Interior, and in the Gulf Coastal Plain of the United States. Igneous activity in this region occurred from Ordovician to Cretaceous, but most intrusive bodies are probably Cretaceous in age. The intrusive bodies form stocks, plugs, pipes, sills, and dikes. Petrographic studies show that the volume of alkalic rocks predominates in surface outcrops. In the subsurface subalkalic rocks seem to predominate.

Igneous rocks in Arkansas outcrop at widely scattered localities and occupy a total surface area of only fifteen square miles (Fig. 1). The principal areas of exposed igneous rocks are: the peridotite pipe at Murfreesboro, deep-seated syenite intrusives at Magnet Cove, at Potash Sulphur Springs (now known as Wilson Springs) northwest of Magnet Cove, at Bauxite in Saline County and at Granite Mountain near Little Rock. Mineral deposits of economic interest are associated with each of these major igneous occurrences. Moody (79) from a study of drilling records points out that this igneous activity was not limited to the outcrops along the margin of the Coastal Plain, but also occurred within the Gulf Coastal Plain of Arkansas where it is now under thick Tertiary and Upper Cretaceous cover (Fig. 2).

In this report the igneous rocks of Arkansas are divided into three age groups in order of decreasing known economic importance: Mesozoic, Paleozoic, and Precambrian.

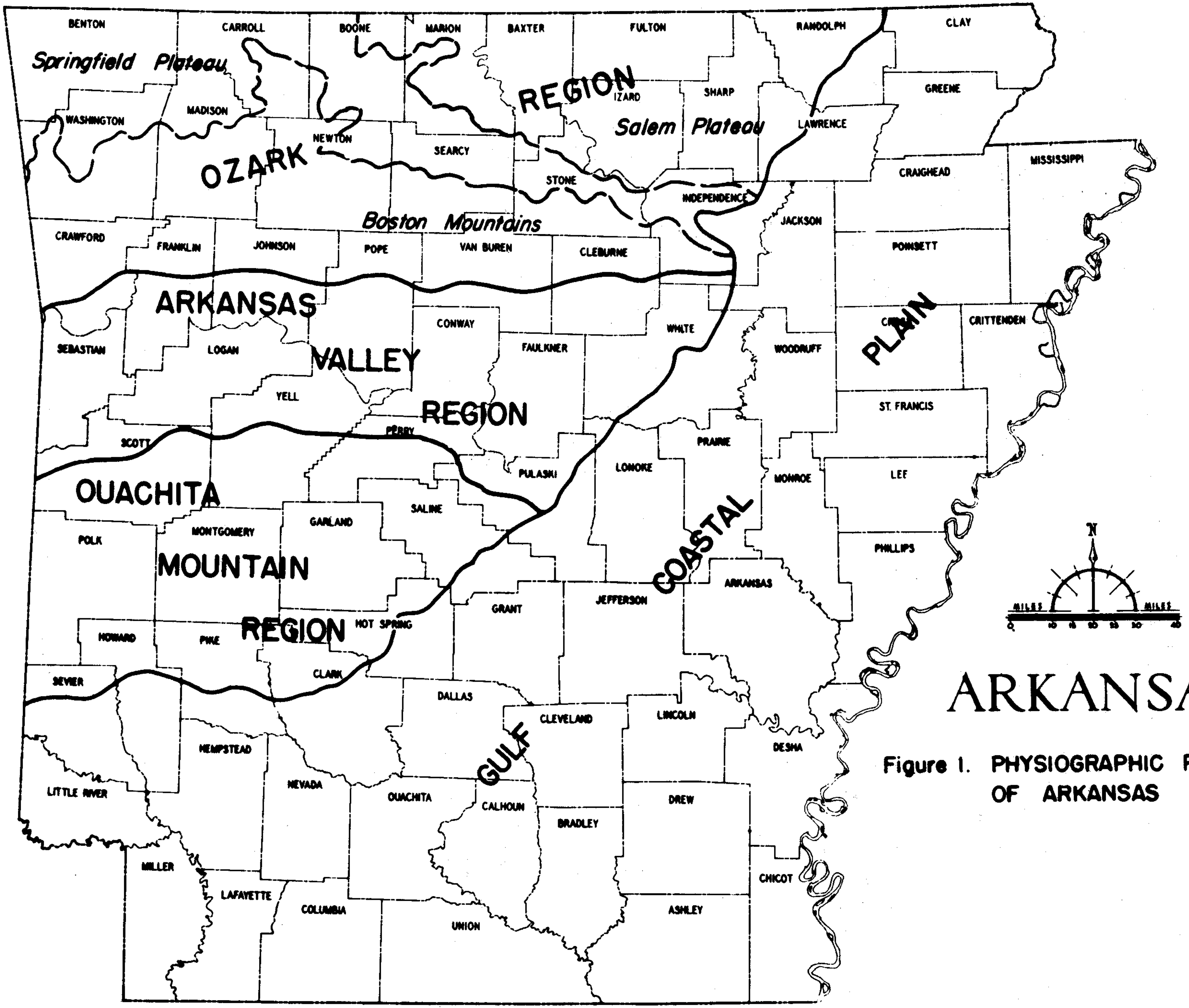

Figure 1. PHYSIOGRAPHIC PROVINCES OF ARKANSAS

MESOZOIC IGNEOUS ROCKS

Varieties of alkalic to subalkalic igneous rocks intruded older sedimentary rocks of Arkansas during the Mesozoic Era. More specifically, these rocks are thought to be generally Cretaceous in age although some may be Triassic.

Surface

Igneous rocks of the Ouachitas and adjacent physiographic provinces generally outcrop over an area defined by Pike County peridotites on the southwest, by Scott County dike rocks on the northwest, and by syenites near Little Rock on the east; the area is roughly bounded by the Coastal Plain on the southeast and by the Arkansas River on the north.

A fairly complete compilation of igneous localities can be made from the reports of Williams (108), Miser and Purdue (74), Purdue and Miser (83), Ross, Miser and Stephenson (88), Cröneis and Billings (20), Fryklund and Holbrook (32), Erickson and Blade (25), and Sterling, Stone and Holbrook (99).

Plutonic and Hypabyssal. Four small stocks of nepheline syenite and associated dike rocks outcrop between Little Rock and Hot Springs, Arkansas. The largest of these, known as Granite Mountain, is located directly south of Little Rock (Fig. 2). Here a mass of phaneritic nepheline syenite has intruded complexly folded Paleozoic sedimentary rocks of the Ouachita Mountains. This intrusive was partially exposed during Paleocene and Eocene times. Fifteen miles southwest of Granite Mountain, near Bauxite, the Saline County nepheline syenite outcrops as small inliers through the Midway (Paleocene) and Wilcox (Eocene) Groups. The economically important bauxite deposits of the State are related to lateritic weathering and erosion of the Granite Mountain and Saline County masses during Eocene times.

Twenty-five miles west and slightly south of Bauxite, an elliptical stock-like mass of alkalic to basic rocks three miles in diameter has intruded sharply folded sedimentary rocks of the Ouachita Mountains. This area, known as Magnet Cove (Fig. 2), receives its name from lodestone that occurs near the center of the complex. The igneous rocks have intruded novaculite, sandstone, and shale of Paleozoic age. Six miles west of Magnet Cove are the smaller, but petrologically similar, Potash Sulphur Springs and "V" intrusives.

Magnet Cove rocks, and those of the smaller complex at Potash Sulphur Springs, consist chiefly of varieties of nepheline syenite and related basic rocks and are similar to alkalic rocks in Colorado, Norway, Germany, South Africa, and other places. Abundant titanium is a common feature of these complexes; relatively abundant columbium is also characteristic of many.

The nepheline syenite found in the Arkansas stocks is typically composed of alkali feldspar and nepheline plus subordinate amounts of pyroxene and dark mica. Variations in the abundance and nature of both light and dark-colored minerals give rise to rock types ranging from quartz syenite to jacupirangite.

Hundreds of genetically related dikes and sills occur in the general vicinity of the larger intrusives. They fall into two major groups: tinguaites, or aegirite-bearing phonolites; and monchiquites, lamprophyres composed of olivine, pyroxene, and usually mica or amphibole, in a base of analcime. Three rocks originally named from the Little Rock region are: pulaskite, a nepheline syenite with trachytic texture; fourchite, an olivine-free monchiquite; and ouachitite, a fourchite, containing abundant biotite.

The authors have recently discovered an explosion breccia (petrography by Jackson (55)) at the northern city limits of Benton, Arkansas (Fig. 2). The outcrop is irregular in shape with a maximum length of one thousand feet. It has a wide textural and compositional range containing varied sizes of many types of igneous rocks as well as several varieties of sedimentary rocks. A magnetic and geologic survey made recently indicates that two intrusives in the area, one basic, the other alkalic, preceded the explosion breccia.

More recently members of the Arkansas Geological Commission have investigated a breccia outcrop about one acre in size in the SE¼ Sec. 8, T. 2 S., R. 15 W., Saline County. It appears that a basic dike with large biotite crystals has intruded a fine-grained alkalic (?) mass.

Peridotite intrusives are exposed in four relatively small areas in Pike County, near Murfreesboro (Fig. 2). Three varieties of peridotite are directly associated with these intrusives: Massive porphyritic peridotite, breccia, and tuff. After intrusion, violent explosions fragmented the porphyritic variety and produced the breccia and tuff. Most of the diamonds are found in soft, weathered portions of the peridotite breccia of the main intrusive pipe. A few diamonds have also been found in the two smaller pipes, in streams adjacent to the pipes, and reportedly from the Woodbine Formation three to four miles south of Corinth, Arkansas. Miser and Purdue (74) determined the peridotite near Murfreesboro to be of Late Cretaceous age.

Farther north, in Perry and Conway Counties, certain small brecciated areas described by Croneis and Billings (20), were originally interpreted as volcanic necks. Clarence Ross of the United States Geological Survey suggested some years ago that they might be vein dikes. Fragmental igneous rocks in the brecciated areas are plutonic or hypabyssal in appearance, and it is not known whether the magma reached the surface.

The age of the plutonic alkaline intrusives cannot be precisely determined from field evidence. However, K-Ar determinations were made by Messrs. H. H. Thomas, R. F. Marvin, Paul Elmore, and H. Smith of the United States Geological Survey on two concentrations of biotite from nepheline syenite samples submitted by the Arkansas Geological Commission from the Big Rock quarry at Granite Mountain. The two determinations give an average age of 89 million years (or Late Cretaceous) for this intrusive.[1] The similar Saline County intrusive is assumed to be of the same general age.

Lead-alpha age determinations were made by Thomas W. Stern (written communication in Erickson and Blade (25)) on zircon separated from a feldspathoidal syenite pegmatite dike about 500 feet west of the Magnet Cove Complex. The zircon gave ages of 178 and 184 million years (Triassic). No zircons were found within Magnet Cove proper, therefore, the usefulness of this age determination in relation to the main igneous complex is questionable. Erickson and Blade (25) state that the evidence indicates that the igneous rocks at Magnet Cove are Mesozoic in age; igneous activity may have extended from Triassic to Cretaceous time. Possibly the same age should be assigned to the Potash Sulphur Springs and "V" intrusives.

Volcanic. Water-laid volcanic debris is common in some units in the northern Gulf Coastal Plain of the United States. Phonolitic lapilli and ash are widespread in lower Upper Cretaceous rocks, and occur in lesser amounts in rocks of middle Late Cretaceous age. The Woodbine of Arkansas and Oklahoma contains volcanic debris in sufficient amounts to classify some beds as tuffs.

Miser and Ross (76) indicate that the thickest known deposits of tuff occur in Pike, Howard and Sevier Counties, Arkansas (Fig. 2). No evidence of surface volcanic vents (except the peridotite plugs near Murfreesboro) have been discovered. Miser and Ross (76) postulate volcanoes near Lockesburg and Nashville and indicate others may occur in the region; these would be concealed by beds of Late Cretaceous and Quaternary ages. An aeromagnetic profile of the State (26) showed a small magnetic high near the community of Tokio that could be an indication of one of these postulated volcanoes.

The Tokio Formation of Arkansas and the Eutaw and Tuscaloosa Formations of Mississippi include beds of tuffaceous sandstone that closely resemble the better known Woodbine pyroclastics. Some tuffaceous fragments also occur in the sandy portion of the Ozan and Brownstown Formations of Arkansas. Crider (18) describes volcanic ash ranging from early Late Cretaceous to Eocene in Louisiana and Arkansas. The igneous debris in the outcropping formations suggests widespread volcanic activity in the northern Coastal Plain during early and middle Late Cretaceous time.

Metamorphic. Some degree of contact metamorphism is in evidence near all the larger masses of exposed igneous rock. At most localities, however, effects of metamorphism diminish a few feet away from the igneous mass. Metamorphism was probably greatest at Magnet Cove, Potash Surphur Springs, and the "V" intrusives.

Metamorphic rocks of Magnet Cove were briefly described by Williams (108) and Erickson and Blade (25) who recognized them as being generally restricted to the periphery of the intrusive mass. Fryklund and Holbrook (32) describe metamorphosed novaculite as the dominant rock at the Hardy-Walsh and Christy brookite properties which occur at the eastern margins of Magnet Cove.

Subsurface*

More than one hundred of the thousands of exploratory wells that have been drilled in search of oil and gas in the northern Gulf Coastal Plain of the United States have penetrated Mesozoic igneous rocks, most of which are considered Cretaceous in age. Evidence from exploratory wells shows that igneous activity occurred over a large sector of the northern Gulf Coastal Plain that is now under thick Tertiary and Upper Cretaceous cover.

Practically all these igneous rocks occur in the southern half of the Gulf Coastal Plain in Arkansas (Fig. 2). However, Caplan (12) describes three wells in western Tennessee, adjacent to northeast Arkansas, which encountered igneous rock.

Subsurface occurrences of igneous rocks have been discovered in wells at depths ranging from a few hundred to over 11,000 feet.

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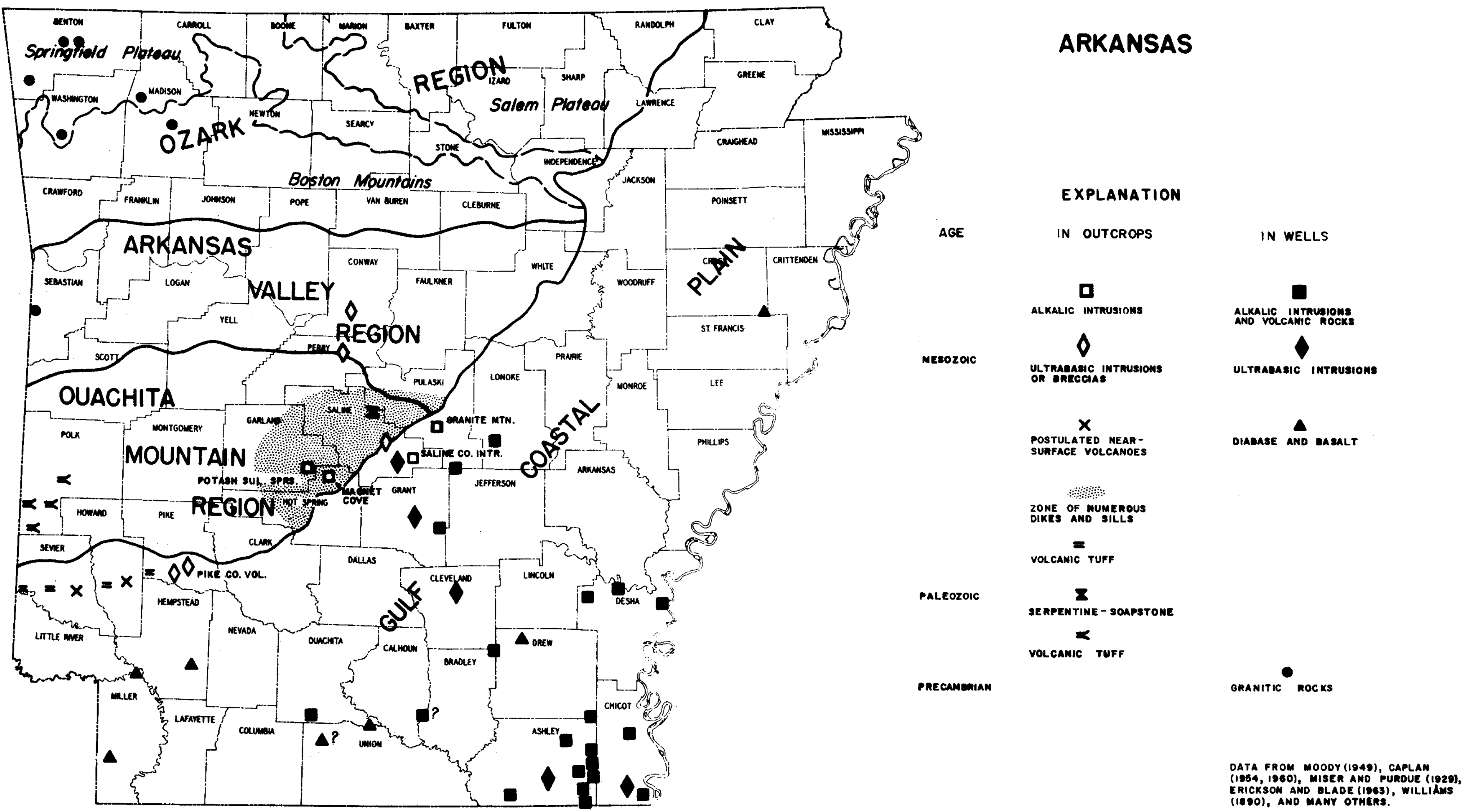
[1] The overall analytical error is approximately five percent of the quoted age value.

* Unless otherwise stated the data in this section on subsurface igneous rocks is summarized from Moody (79).



DATA FROM MOODY (1949), CAPLAN (1954, 1960), MISER AND PURDUE (1929), ERICKSON AND BLADE (1963), WILLIAMS (1890), AND MANY OTHERS.

FIGURE 2. GENERALIZED DISTRIBUTION OF IGNEOUS ROCKS

Plutonic. Rocks of phaneritic texture have been found in at least ten wells in the Coastal Plain of Arkansas. Six of these occurrences are discussed in the approximate order of increasing basicity.

1. Quartz syenite - Quartz is a rare mineral in the Arkansas Coastal Plain igneous rocks. In the Texas Company's No. 1 Guy well in Ashley County, a quartz-bearing syenite was found overlain by Upper Cretaceous sediments.

2. Syenite - In Desha County, The Columbian Gas Company's Victoria Cross Lumber Company test near Dumas drilled into a normal syenite at a depth of 4,865 feet.

3. Augite syenite - In Chicot County a coarse plutonite, cut by a minette dike, was cored in the Texas Company's No. 1 Hammon well.

4. Pyroxenite - The first plutonic rock discovery in a Coastal Plain well was made in 1927 in the Shafer Oil Refining Company's Youngblood No. 1 in Grant County.

5. Peridotite - In Cleveland County, the Arkansas Natural Gas Company's Tate well bottomed in a dark, granular intrusive rock below about 250 feet of slightly metamorphosed Paleozoic sedimentary rocks that lie unconformably beneath Upper Cretaceous strata. The peridotite is composed of serpentinized olivine, some augite, phlogopite, magnetite, and the rare mineral perovskite.

6. Breccia - Caplan (12) states that an unpublished report by Kidwell indicates the Crossett Lumber Company No. 1 A. Plummer in Ashley County, encountered what appears to be a breccia-filled volcanic pipe. The breccia consists of fragments of sedimentary and igneous rock and individual mineral grains in a fine-grained matrix of calcite, limonite, serpentine, and comminuted rock fragments. This material was apparently encountered at around 3,300 feet and 1,148 feet were drilled without total penetration. The breccia apparently represents a volcanic pipe of explosive origin, similar to the diatremes in southeastern Missouri, southern Illinois and the breccia near Benton, Arkansas. This pipe probably formed as a result of tremendous gas pressure, attendant upon the crystallization of local magma cupulas.

No feldspathoids have been found in plutonic rocks discovered in Coastal Plain wells. The link that would complete the chain connecting the deep well syenites of the Coastal Plain with the feldspathoidal rocks of the Little Rock area awaits discovery.

Hypabyssal. Dike rocks are relatively abundant in the Coastal Plain Province. Five main types have been identified: trachyte porphyry, tinguaite, nephelinite, monchiquite, and diabase. In view of the close association with alkaline syenites throughout the world, rocks of the first four groups may be regarded as related dike types produced by late differentiation of a parent peralkaline magma. Diabase on the other hand, is generally thought to be the product of crystallization of basaltic magma under hypabyssal conditions and is regarded by some as genetically unrelated to the alkaline rocks.

Six deep wells in Arkansas have encountered diabase. The material in one well is as old as Late Jurassic. Occurrences of diabase-diorite in the Gulf Coastal Plain are described by Moody (79) and Flawn (28) as probably Triassic or Early Jurassic and certainly pre-Cretaceous in age.

Volcanic. Volcanism, contemporaneous with the accumulation of some of the formations in the Upper Cretaceous of the Coastal Plain, is indicated by well samples containing fragments of volcanic rocks in association with the common detrital minerals of sediments.

Two distinct groups of pyroclastics occur in the volcanic centers of the northern Gulf Coastal Plain. They are the alkaline tuffs and the basaltic tuffs. Basaltic tuffs are limited to northeastern Louisiana. Lavas have been identified with certainty from some wells in Mississippi and possibly elsewhere in the subsurface of the region. Some are considered as Lower Cretaceous but Pre-Comanche in age; however, the bulk of the material is of Late Cretaceous age.

Metamorphic. Little direct evidence of contact metamorphism has been reported from wells in which igneous rocks occur. Only those drilled just outside the periphery of the plutonic mass could be expected to encounter material reflecting the effect of the intrusion, and very few such wells have been drilled. However, general induration and, in places, partial fusion of the sediments near the intrusive centers have been observed in cuttings from certain wells.

Geophysical Data*

Many of these igneous rocks have specific gravities in excess of those of the associated sedimentary rocks; some have lower. A few have very high elastic constants and high specific resistivity. Gravimetric and surface magnetic surveys and electric well logging have often led to the discovery of buried igneous rock. Seismograph surveys have been

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*Unless otherwise stated the geophysical data in this section is summarized from Moody (79).

extensively used, but have not been conspicuously helpful in predicting the presence or absence of buried igneous rock.

Gravimetric surveys reveal relatively large distortions in the earth's gravitional field in the northern Gulf Coastal Palin. Bouguer anomalies ranging from −30 to +40 milligals appear within or adjacent to the territory in which igneous rocks have been found. Every deep well that has been drilled on a circular or elliptical positive anomaly of twenty or more milligals has penetrated igneous rock. All of the plutonic rocks are centered in anomalies of this character. Hypabyssal rocks are usually not predictable. The surface stocks of the Little Rock area are in a region of abrupt gravity anomalies, but only the highly differentiated Magnet Cove complex, with its ultrabasic core, gives rise to a circular anomaly like those of the buried plutonic areas.

Magnetic vertical-intensity surveys follow rather closely the field distortions of the gravity maps. Magnetic anomalies range in magnitude from −2,000 to +17,000 gammas. The large anomalies coincide with the plutonic areas and strongly support the conclusion drawn from gravimetric surveys that the prominent circular anomalies of the northern Gulf Coastal Plain reflect deeply-buried, highly-differentiated stocks. Several of these subsurface areas were apparently centers of Cretaceous volcanoes.

Surface magnetic maps are available on the Bauxite and Magnet Cove areas and sharply define these masses. These maps indicate that the Magnet Cove Complex has a greater magnetism than the nepheline syenite stocks of the bauxite region.

Conclusions

1. Moody (79) concluded that magmas invaded the northern Coastal Plain (and Ouachita Mountain area) during successive intervals in the Mesozoic Era. The first invasion possibly took place in Triassic time; the last major invasion was middle Late Cretaceous.

2. The bulk of the igneous activity occurred in early Late Cretaceous time.

3. Moody (79) states that two different magmas probably existed, the earlier basaltic, the latter both alkaline and basaltic.

4. Erickson and Blade (25) conclude that the regional magma (presumably the latter magma) generated in the Ouachita geosyncline was an undersaturated olivine basalt, and further, that fractionation of this magma produced peridotite, and other ultrabasic rocks on the one hand, and a highly alkaline undersaturated phonolitic end fraction on the other.

5. Moody (79) states that both magmas reached the surface in certain areas and, during later invasions gave rise to volcanoes that contributed significant amounts of lapilli and ash to contemporaneous sediments.

Related Mineral Deposits

Bauxite. Bauxite was first identified in Arkansas by John C. Branner, State Geologist, in 1887, and it has been mined commercially since 1899. Currently, Arkansas produces about 97 per cent of the bauxite mined in the United States.

The known commercial bauxite deposits are associated with the Granite Mountain and Saline County nepheline syenite intrusives from which the deposits were derived (Fig. 2).

These nepheline syenite, and related igneous rocks of Cretaceous age, were intruded into highly folded Palezoic beds. Subsequent erosion exposed some parts of these intrusives to weathering and some parts to burial by sediments of Tertiary age.

The bauxite deposits are the result of weathering of the nepheline syenite either in place or as detritus derived from these intrusives. The principal source rocks were the coarse grained varieties of nepheline syenite. According to Gordon, Tracey and Ellis (36) the bauxite deposits can be classified into four types (Fig. 3).

(1) residual deposits on the upper slopes of partly buried nepheline syenite hills

(2) colluvial deposits at the base of the Berger Formation

(3) stratified deposits within the Berger Formation

and

(4) conglomeratic deposits at the base of the Saline Formation.

The principal mineral in the bauxite is gibbsite (aluminum trihydrate). The chief impurities are silica, iron, and titanium.

Bauxite production from 1896 through 1949 was about 32 million long tons. In 1953 the U. S. Bureau of Mines conservatively estimated the reserves of bauxite ore suitable for alumina production by present metallurgical standards to be 44 million short dry tons. A significant concentration of gallium is present in the bauxite and is recovered as a valuable by-product. According to Calhoun (11) and Nieberlein, Fine, Calhoun and Parsons (80) titanium, iron, and columbium-bearing black sands and red muds are a waste product of the two alumina plants. The minerals of possible economic interest in these waste products are siderite, siderite altered to magnetite, and manganilmenite. It is estimated that at one alumina plant alone, the waste products discarded in one year contain 15,209 tons of titanium and 46,173 tons of iron. Muds and black sands impounded from previous operations are estimated to contain 4,800,000 pounds of columbium. Reserves of commercial grade barite are estimated to contain 62 million pounds of columbium.

Large bauxite deposits with a high iron content are present in the Arkansas bauxite region and might be of commercial importance is a process were developed whereby both the alumina and iron could be recovered.

Extensive deposits of high-alumina clay occur in association with the bauxite deposits and constitute a large future reserve of aluminum ore.

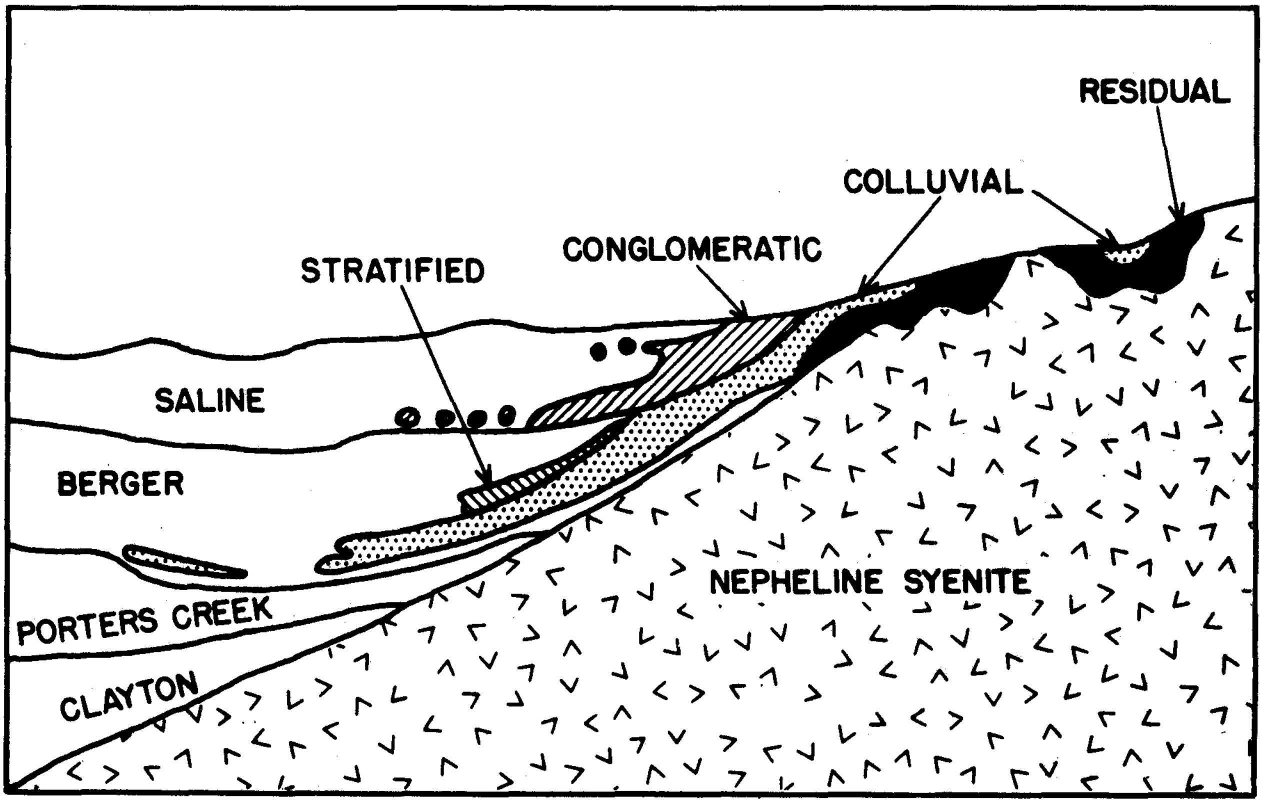
Barite. Arkansas presently ranks second in the production of barite, producing about 35 per cent of the nation's output from a single deposit. Although barite was first reported from the Ouachita Mountains of Arkansas in 1888, it was not until 1939 that production began.

In Arkansas, barite deposits occur in portions of the Ouachita Mountains and in the southwestern Gulf Coastal Plain. Three types of barite deposits have been described: bedded, cemented, and fissure veins.

Scull (89) has ascribed a strictly hydrothermal origin (generated by alkalic igneous intrusives of Mesozoic age) to all three types of deposits. Zimmerman (112) and others believe that the bedded type deposit is actually primary in origin, essentially because of its restricted stratigraphic range. Zimmerman (112) also placed much importance on the numerous large and small-scale sedimentary features. It has been suggested that the cemented deposits might also be primary in origin.

The bedded deposits are the most important and account for most of the known barite reserves. These deposits are restricted to the lower part of the Stanley Formation of Mississippian age and for the most part are confined to synclinal folds. The largest and most productive of these occurs in the Chamberlain Creek syncline which is truncated by the Magnet Cove intrusive. This is the largest known barite deposit in the world; its maximum length is 3,200 feet, maximum width is 1,800 feet, and the average thickness of the commercial ore is about 60 feet (Fig. 4). The ore is impure and flotation is necessary to obtain a marketable product. Other deposits of this type are found in the western Ouachitas of Arkansas in the Fancy Hill district (Fig. 7).

The cemented deposits occur in the Pike Gravel and in two sand zones of the Lower Cretaceous Trinity Formation. The ore occurs as a cementing material in



CROSS SECTION SHOWING RELATION OF BAUXITE DEPOSITS

AFTER GORDON, TRACY AND ELLIS (1958)

Figure 3

the sands and gravels. Barite was first produced from these deposits in 1961, but there is no production at present.

The fissure veins of barite occur in the Pike County peridotite area, in the cinnabar district twelve miles northwest of Murfreesboro, and in southeastern Oklahoma where it occurs as a gangue mineral. At the Hatfield district in the western Ouachitas of Arkansas, barite occurs either as concordant veins or as a bedded deposit in the middle Arkansas Novaculite (Devonian-Mississippian). Barite is not known to occur in fissure veins in commercial quantities.

During the period 1939-1961, Arkansas produced over seven million tons of barite valued at approximately 70 million dollars. Almost all of this production came from the Chamberlain Creek deposit.

Iron. Various types of iron deposits are associated with Mesozoic igneous rocks. However, none have proven of sufficient quantity to support a large-scale mining operation.

Iron deposits are found in Magnet Cove and to a lesser extent in the similar intrusive at Potash Sulphur Springs and iron is associated with bauxite deposits as siderite.

At Magnet Cove magnetite is found:

(1) disseminated in jacupirangite (magnetite pyroxenite)

(2) as disseminations and pods in a lime silicate rock (a local alteration zone in a country rock of biotite-garnet ijolite) and

(3) as a residual weathering product of the jacupirangite and lime silicate rock.

Small amounts of magnetite have been mined from open pits in the weathered zone of the lime silicate rock at the Kimzey Magnetite deposit (Fig. 5). The magnetite in this area is typically high in iron, low in silica and phosphorus and contains considerable titanium. A large magnetic anomoly (in excess of 10,000 gammas) is known to exist in the southern part of Magnet Cove which cannot be explained by surface rock.

In the high-iron bauxite deposits, iron occurs primarily as iron oxide (magnetite) and as iron carbonate (siderite), the latter of which is partially altered to magnetite through calcining of the ore. Magnetite and siderite are concentrated in the so-called "black sands" and "brown sands" of the waste material during the processing of the bauxite into alumina.

Titanium. Titanium deposits in Arkansas were productive from 1932 through 1944. Interest has recently increased in these deposits mainly because of the associated columbium and vanadium.

The three major sources of titanium are:

(1) vein deposits of rutile and brookite at Magnet Cove

(2) fossil beach sand concentrations in the Tokio Formation and

(3) titaniferous waste material from alumina plants.

Fryklund and Holbrook (32) state that there are two types of titanium veins at Magnet Cove:

(1) feldspar-carbonate-rutile veins in igneous rock near the center of the Cove and

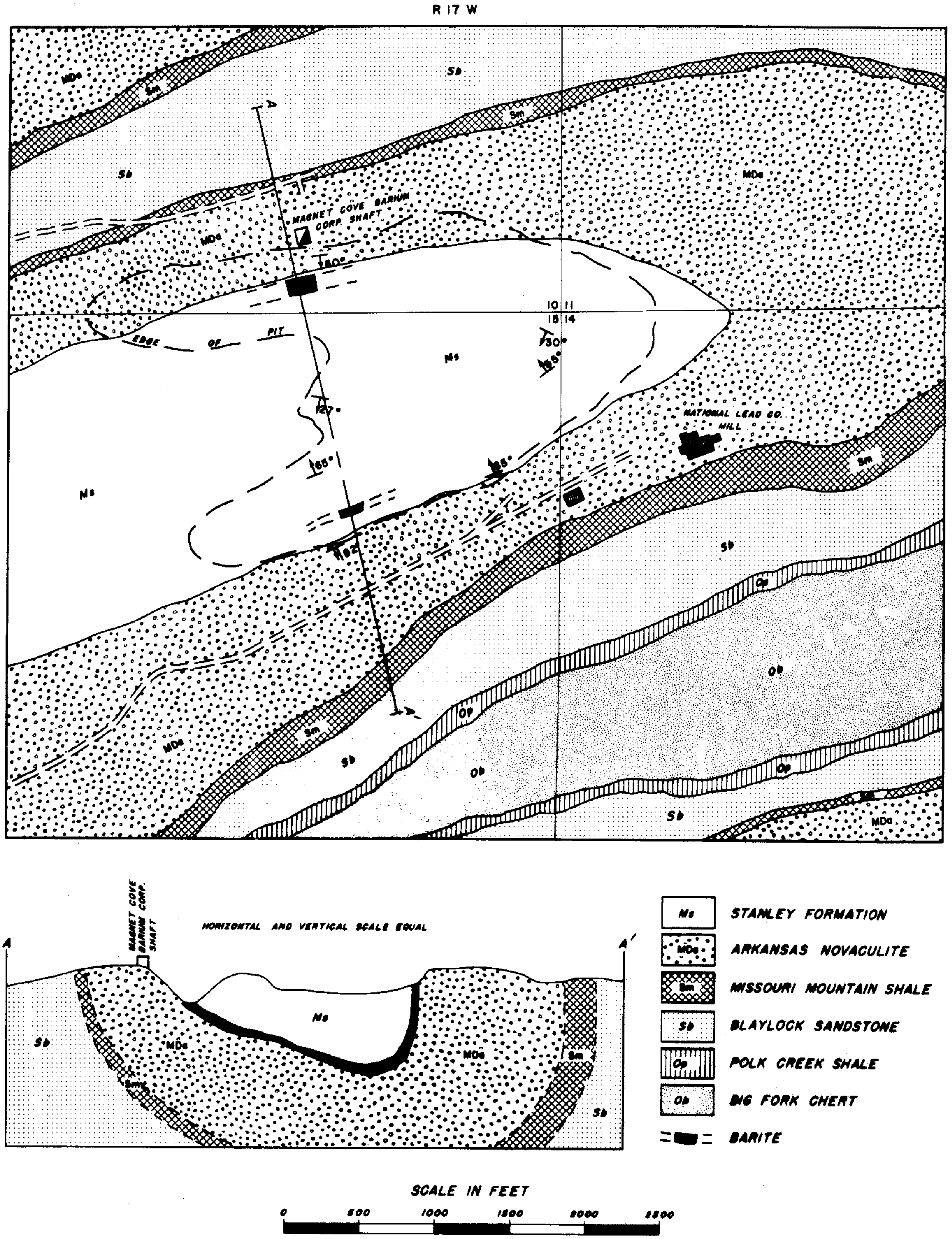
(2) brookite-quartz veins in altered Arkansas Novaculite in the rim of the Cove (Fig. 5).

Three of these titanium deposits have been partially investigated by Nieberlein, Fine, Calhoun and Parsons (80), and, while the full extent was not determined, they conservatively estimated at least eight million tons or ore containing 4-8 per cent TiO_2 and 0.05-0.15 per cent columbium. The columbium content of these reserves is estimated to be twelve million pounds.

The estimated average grade of titanium concentrates (rutile and brookite) from three of the principal titanium deposits at the Cove contain 92 per cent TiO_2 and 1.73 per cent columbium and 0.5 per cent V_2O_5. The mineral perovskite, a calcium titanate, is quite common in a large carbonatite body near the center of the Cove (Fig. 5). This mineral averages about six per cent columbium and ranges up to nine per cent columbium and 4.2 per cent tantalum.

According to Holbrook (47) the ilmenite sands occur in the Tokio Formation of Late Cretaceous age. The only known occurrences of these sands are in southern Howard County. The source of these sands is probably the underlying water-laid volcanics in the Woodbine Formation. These deposits have not been explored sufficiently to estimate any reserves.

Molybdenum. Molybdenite was first recognized in a pyrite deposit in Magnet Cove in 1939. This is the only major occurrence of molybdenite in the State. A few thin molybdenite veins also occur at Magnet Cove in the carbonatite. Recent drilling on a magnetic high south of Benton, Arkansas, revealed a mass of rock similar to the Magnet Cove intrusive with veins containing trace amounts of molybdenite (chemical analysis by Mr. Troy W. Carney of our staff).



GEOLOGIC MAP OF THE CHAMBERLAIN CREEK BARITE DEPOSIT
HOT SPRING COUNTY ARKANSAS

AFTER B. J. SCULL 1958

Figure 4

Holbrook (46) describes the major molybdenite-bearing veins at the Mo-Ti Corporation prospect at Magnet Cove as occurring in a fractured jacupirangite (magnetite pyroxenite) country rock and consisting mainly of orthoclase and pyrite with minor amounts of quartz, apatite, plagioclase, molybdenite, and brookite (Fig. 5). The veins vary in thickness from less than one-half inch to five feet, trend approximately northwest-southeast, and dip steeply toward the northeast. The larger veins are exposed over an area about 225 feet long and ten to thirty-five feet wide at the northwest end of the main pit. Trenching on the north side of Cove Creek indicated that the total length of the deposit is about 400 feet. Jacupirangite adjacent to the veins has been hydrothermally altered to a soft, green clay rock. Unaltered jacupirangite is a hard black coarse-grained rock composed mainly of diopside and magnetite. Surface samples indicate that the average grade of the vein material in the larger veins at the northwest end of the main pit is about 1.07 per cent molybdenum sulfide. Because of the unreliability of samples obtained by diamond-drilling, however, no tonnage estimates of molybdenum ore were made.

Columbium. It has been known since 1890 that columbium (niobium) occurs in Arkansas. Recently there has been much interest in its occurrence, but there has been no production.

Occurrences of possible commercial interest are:

(1) columbium-bearing ilmenite in the bauxite area

(2) columbium-bearing titanium deposits in the Magnet Cove intrusive and

(3) columbium-bearing pyrochlore in the Potash Sulphur Springs intrusive.

The first two occurrences are discussed under bauxite and titanium respectively. Fryklund, Harner and Kaiser (33) indicate that trench samples show 0.1 to 0.9 per cent columbium at the Wilson Prospect at Wilson Springs a few miles east of Hot Springs. Individual samples also show relatively high concentrations of uranium and vanadium.

Diamonds. Arkansas is the only state in North America in which diamonds have been found in place. They were discovered near Murfreesboro in 1906 and over 48,000 stones averaging one-fourth carat have been found since then. Mining operations have been intermittent since 1906, but now the area is operated as a tourist attraction.

Most of the diamonds are found in the Pike County peridotite pipe, and according to Miser and Purdue (74) the surface area of the pipe is roughly triangular in shape and encompasses approximately 73 acres. It is divisible into three distinct rock units that are usually deeply weathered:

(1) intrusive peridotite

(2) volcanic breccia and

(3) tuff and fine grained breccia.

The diamonds almost entirely occur in the volcanic breccia although a few have been found in the intrusive peridotite.

About 90 per cent of the stones are classified as industrial diamonds, the remainder of gem quality. St. Clair (94) thought that with few exceptions previous sampling operations and recovery techniques were characterized by a lack of experience in both diamond mining and diamond recovery.

Miscellaneous Mineral Deposits. Numerous other mineral deposits area associated with Mesozoic igneous rocks. These include vanadium, rare earths, uranium, phosphate, agricultural limestone, fluorite, nepheline syenite (for use as a ceramic raw material), and fuller's earth.

Vanadium occurs both in the Magnet Cove intrusive and the Potash Sulphur Springs intrusive. Spectrographic analysis of a 1.5-foot channel sample from the Wilson Prospect at Potash Sulphur Springs shows between one and nine per cent vanadium; a nine-foot channel sample from the same locality shows 0.1 to 0.9 per cent vanadium. A sample of dark green rock composed almost entirely of a variety of hornblende found as float in the creek on the south edge of Potash Sulphur Springs contained 1.3 per cent V_2O_5. There is an estimated 0.5 per cent V_2O_5 in the average grade of titanium concentrates from the various prospects at Magnet Cove. One core from the Christy Brookite property on the east edge of Magnet Cove has an interval of ten feet containing over two per cent V_2O_5 and 6.54 per cent TiO_2. Another core shows over 31 feet containing an average of 1.36 per cent V_2O_5 and 8.35 per cent TiO_2.

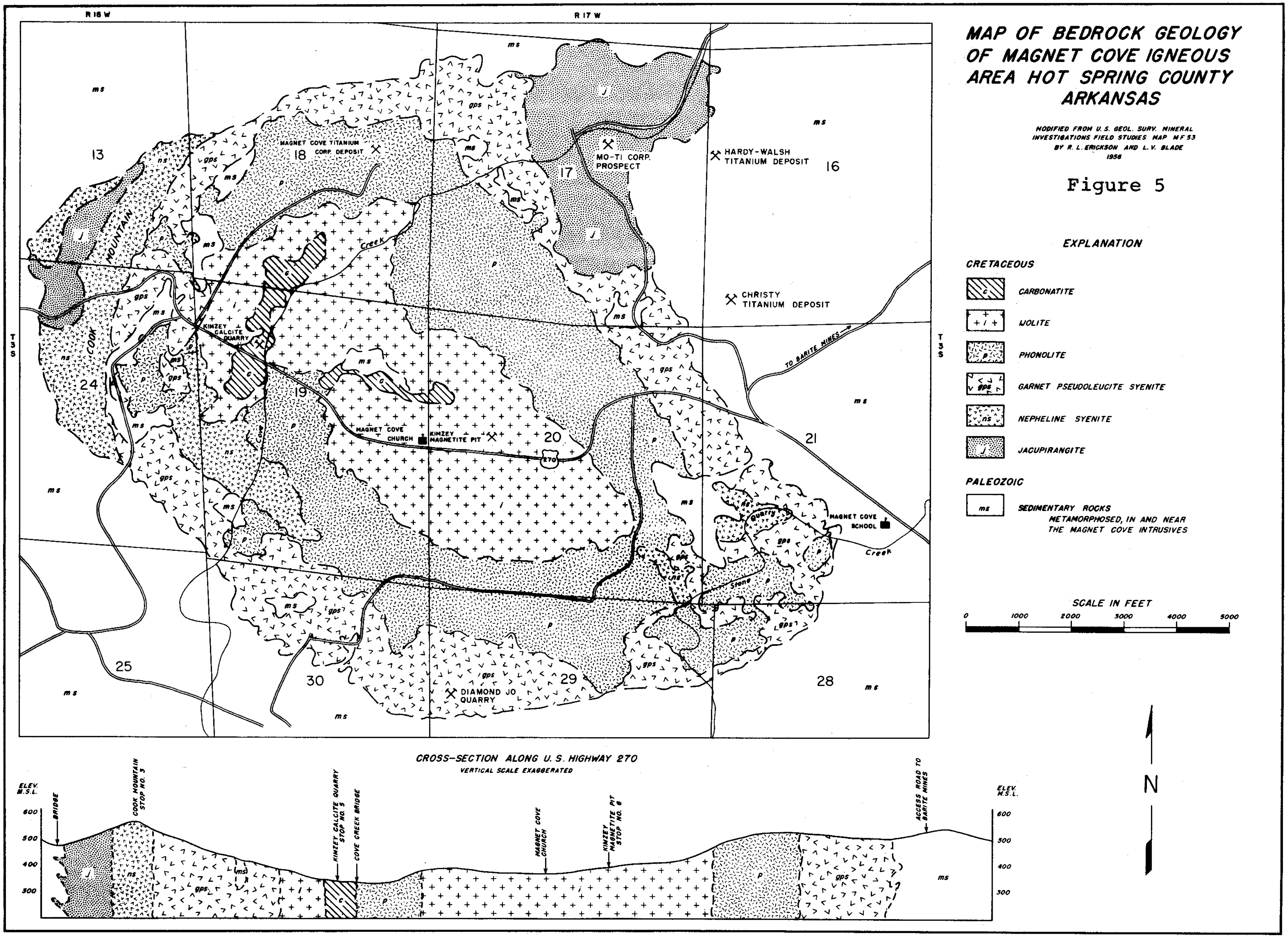
Rare earths were first detected by the Arkansas Geological Commission chemist in samples from the Magnet Cove area. Subsequent investigation of auger drill samples from the center of Magnet Cove revealed up to 4.3 per cent combined rare earths. Magnet Cove apatite contains rare earths of the lanthanum-group. Erickson and Blade (25) indicate that perovskite taken from the carbonatite contains an average of 1.0 per cent lanthanum. Also a spectrographic analysis showed rare earth elements to be present in the pyrochlore of Potash Sulphur Springs.

Uranium ore containing up to 0.4 per cent

MAP OF BEDROCK GEOLOGY OF MAGNET COVE IGNEOUS AREA HOT SPRING COUNTY ARKANSAS

MODIFIED FROM U. S. GEOL. SURV. MINERAL INVESTIGATIONS FIELD STUDIES MAP MF 53 BY R. L. ERICKSON AND L. V. BLADE 1956

Figure 5



U_3O_8-Beroni (5), but apparently not in commercial quantities, occurs at Wilson Springs. The uranium occurs in the mineral pyrochlore. Small occurrences of thorium and uranium have also been noted at Magnet Cove.

Fluorite is usually found in small veins and as disseminations in a host rock of nepheline syenite. The largest known vein containing fluorite is at the "V" Instrusive in the SE¼ Sec. 19, T. 2 S., R. 18 W., on the south shore of Lake Catherine in Garland County. Several pits over an area of several acres expose veins of fluorite, pyrite and chalcedony up to two feet wide that cut basic to alkalic igneous rocks. Purdue and Miser (83) and Erickson and Blade (25) have also identified traces of galena, barite, zeolite(?) and witherite in the veins. Charles Milton (written communication) has in addition identified abundant anatase and rutile and lesser quantities of sulphur, goethite, taeniolite, sphalerite, dolomite, zircon, and tourmaline from these veins.

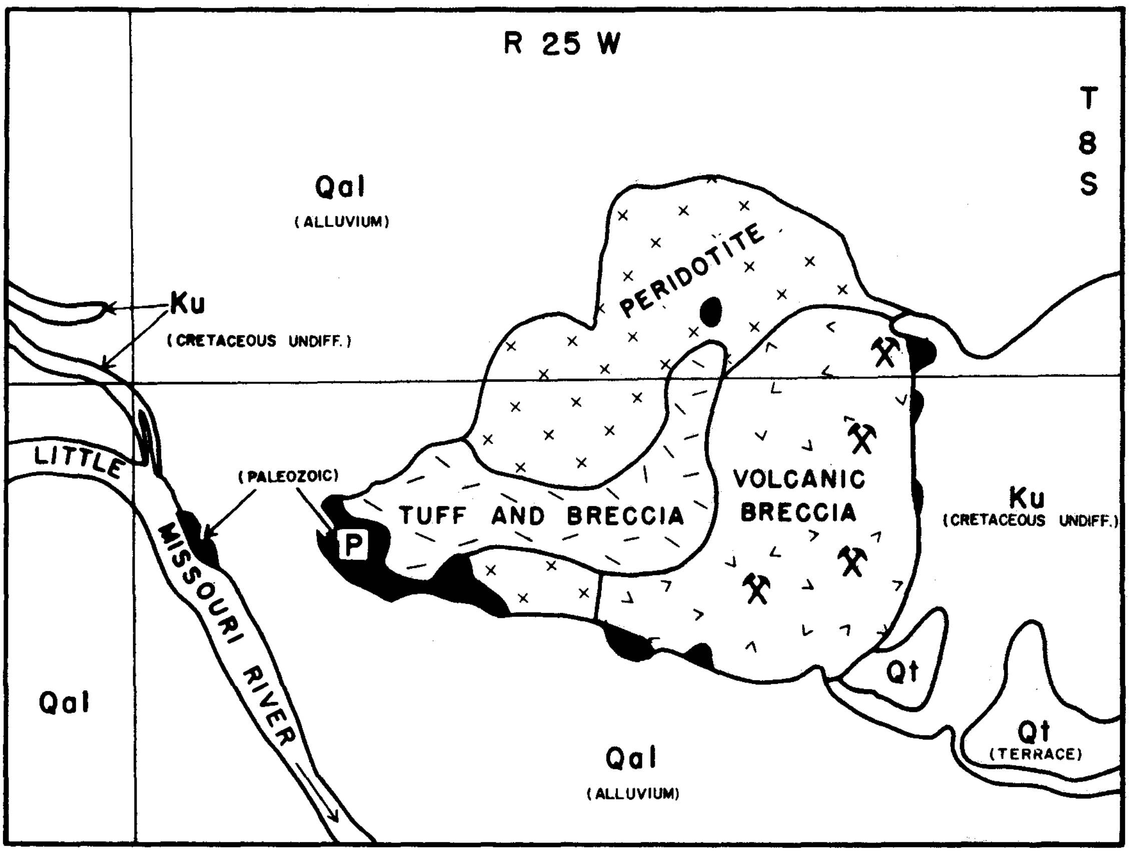
Further studies are currently being undertaken in this area.

The vein rock contains gold and silver slightly in excess of trace amounts. Fluorite has not been found in commercial concentrations, but its persistent association with nepheline syenite indicates that such concentrations are possible. Exploration, again, is hampered by a lack of exposures. One encouraging factor in future exploration for fluorite is the ready market provided by the aluminum industry in Arkansas.

Nepheline syenite has in the past been used as a building, monumental, and paving stone. Presently, it is being used for roofing granules, road materials, concrete aggregate, and riprap. A future additional use of this rock is in the ceramic industry. Williams, Smothers and Reynolds (110) state that such application would depend on the economics involved in its benefication rather than on the availability of the rock.

In Saline County, fuller's earth deposits exist that were derived through the alteration of basaltic Mesozoic igneous dikes and sills. These deposits usually have steep dips and would have to be mined underground. They have been mined intermittently since their discovery in 1891, but presently there is no production.

According to Erickson and Blade (25) weathering of the carbonatite in the Magnet Cove intrusive (Fig. 5) produces a phosphate-rich residual material with a rare earth content near 1.0 per cent. The phosphate content of this material is attributed to weathering of apatite. The grade is adequate for commercial phosphate. However, more drilling and sampling is



GEOLOGIC MAP OF PIKE COUNTY DIAMOND PIPE

Figure 6

500 FEET

AFTER MISER AND PURDUE (1929)

needed to determine the available tonnage. Apatite veins are another unexplored potential source of phosphate in this area.

The large masses of carbonatite at Magnet Cove are a potential source for agricultural limestone and sporadically small amounts are produced for this purpose. Columbium-rich (four to nine per cent) perovskite crystals in the carbonatite might be recovered as a by-product.

Miser and Stevens (78) and Milton (written communication) describe small occurrences of taeniolite from Magnet Cove and from the "V" Intrusive which averages 3.1 per cent lithium. Erickson and Blade (25) also describe minor occurrences of thomsonite which contain as much as 0.02 per cent beryllium.

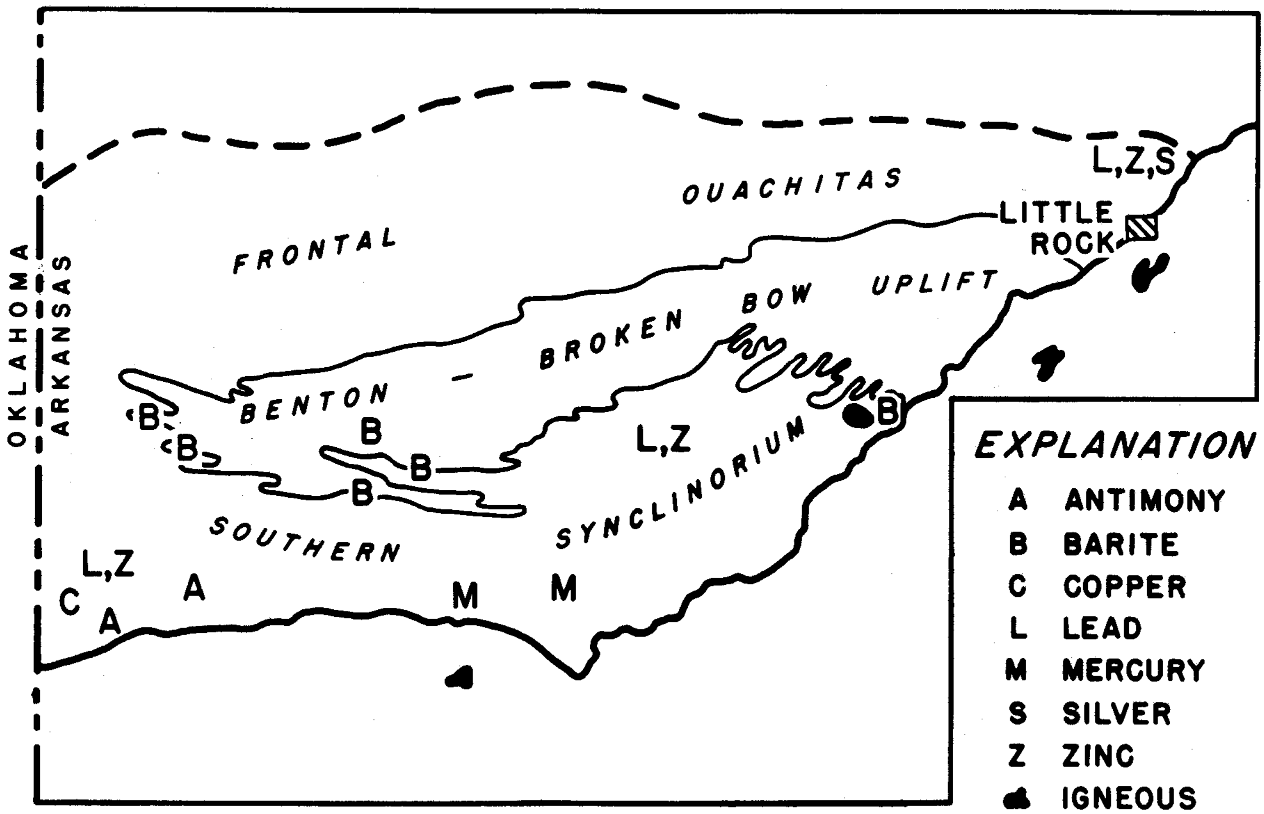
Mineral Deposits of Questionable Age and Origin. Deposits of mercury, antimony, lead, zinc, silver, and copper occur in the Ouachita Mountains of Arkansas (Fig. 7). Holbrook and Williams (48) give a more complete summary of these deposits. These deposits are found in epithermal fracture-filling veins which occur in highly folded sedimentary rocks of Paleozoic age. Scull (90) states that this mineralization is related to Mesozoic igneous activity. Miser (72), Engel (23), Gallagher (34), and others, however, believe that most of these deposits were formed during the Pennsylvanian deformation of the Ouachita Mountains. Recently, Miser and Milton (73) state that the quartz veins containing needle quartz, rectorite, cookeite, and associated minerals at the Jeffrey quarry in North Little Rock, Pulaski County, are likely the result of contact metamorphism adjacent to the early Late Cretaceous Granite Mountain and related intrusives. Thus, some mineralization associated with quartz veins in portions of the Ouachita Mountains is probably related to Mesozoic igneous activity.

Oil and Gas. It is not the intent of this paper to investigate the effects these Mesozoic intrusives had on the oil and gas possibilities in the area. For our purpose it is sufficient to quote Moody (79) who states that exploratory experience in the northern Gulf Coastal Plain leads to the sweeping conclusion that igneous activity has had no unfavorable influence whatever on the regional processes which operated to bring about the prodigious concentration of Mesozoic oil and gas in that province.

Future Exploration Considerations

The exploration potential of these Mesozoic igneous rocks will be discussed in the following order:

(1) Granite Mountain and Saline County intrusives
(2) Magnet Cove intrusive



AFTER HOLBROOK AND WILLIAMS (1963) AND SCULL (1959).

Figure 7
MINERALIZATION IN THE ARKANSAS OUACHITAS

(3) Potash Sulphur Springs intrusive

(4) Pike County peridotite area

(5) miscellaneous areas

(6) subsurface intrusives.

Granite Mountain and Saline County Intrusives. The district still has a promising future, although many of the shallow, high grade, large tonnage bauxite deposits have largely been mined. Much of the earlier bauxite mining and exploration took place in an atmosphere of wartime boom and occasionally new deposits are found under old pits and dumps of overburden. Vast reserves of lower grade and deeper deposits are known. Further technology is needed to transform huge deposits of high-iron bauxite and high-alumina clay into a commercial product. Accessory elements in the bauxite are not fully recovered during processing. While gallium is extracted, iron, columbium and titanium are not. Columbium analyses of bauxite ore averages 0.05 per cent, black sand waste products 0.07 per cent and a sample of the kaolinitic underclay was found to contain 0.1 per cent.

There is still some chance of discovering new minerals of economic value in this old mining district as surface exposures are poor and hinder exploration. Hydrothermal mineralization similar to that found at Magnet Cove and Potash Sulphur Springs is possible. In fact, traces of molybdenum and vanadium have been detected in the pyrite and siderite in the bauxite deposits and were undoubtedly derived from these igneous rocks. Reports also mention veins in the nepheline syenite containing a mineral resembling galena or stibnite.

Big Rock Stone and Material Company at Granite Mountain is a major producer of crushed stone used for many purposes, varying from roofing granules to riprap. An unlimited supply of nepheline syenite is available.

Magnet Cove Intrusive. Surprisingly little has been accomplished in mineral exploration at this famous mineral collecting locality. This is perhaps due to:

(1) the complexity of the rocks and minerals involved

(2) the sparsity of outcrops due to deep weathering and

(3) the false belief that the intrusive has been thoroughly prospected.

Molybdenum is known to occur at the Mo-Ti Corporation prospect (Fig. 5). The average grade of the larger veins at the prospect is 1.07 per cent MoS_2. The prospect is located in the flood plain of Cove Creek and the alluvial cover averages six to eight feet in thickness. The vein material is loosely consolidated and the adjacent igneous rock has been altered by hydrothermal activity making diamond drill exploration difficult. This difficulty in exploration has partially discouraged previous attempts to exploit the deposit.

Large deposits of columbium- and vanadium-bearing rutile and brookite are known to exist in the area. They await a greater demand for titanium and an economic means of extracting the columbium and possibly the vanadium. The mineral perovskite is another possible source of titanium, columbium and rare earths, but to date it has not been found in commercial concentrations.

Magnetite deposits are confined to a few fairly small surface occurrences. Large magnetic anomalies occur in the area; however, no subsurface exploration has taken place.

Barite deposits are stratigraphically and possibly structurally confined, and future exploration largely depends on a good knowledge of the surface geology. Geochemical testing by the U. S. Geological Survey has shown promise in detecting barite. Magnetic surveys would be useful in indicating new igneous intrusives that might have related barite deposits.

Rare earth occurrences have been known since 1890, but have received very limited investigation. Little is known of these occurrences; therefore, no speculations are made of their future potential.

Commercial phosphate in apatite veins and agricultural lime deposits in the carbonatite may well exist and rare earths- and columbium-rich minerals might be recovered as a by-product. The advantages of nearby railroad transportation, natural gas lines and a large agricultural market should encourage exploration of these deposits.

Potash Sulphur Springs Intrusive. Unlike Magnet Cove no detailed geological maps exist on this intrusive. Little is known of its possible mineral potential because of the lack of outcrops caused by deep weathering.

The initial mineral exploration conducted in the area was concentrated on the Wilson prospect which is located on the eastern contact of the igneous complex in a highly weathered syenitic rock. Significant concentrations of uranium, columbium, and vanadium were found. Exploration on this prospect consisted of bulldozed trenches, isorad and geochemical sampling by the Atomic Energy Commission and eleven core holes drilled by the Lisbon Uranium Corporation. The uranium mineralization was found to disappear at a depth of seven feet and the prospect was abandoned. Actually, it is a matter of speculation whether the mineralization pinched out, was faulted away, was enriched by surface weathering processes or follows an erratic pattern that was somehow missed by the drill holes. Pyrochlore is the only mineral as yet identified that is carrying these elements. Perovskite, rutile or brookite have not been reported from this area. The intrusive is currently being thoroughly prospected.

At the "V" intrusive on the south side of Lake Catherine immediately south of Potash Sulphur Springs, interesting amounts of fluorite, anatase and rutile, and gold and silver have been noted. The igneous rocks, veins, and adjacent contact rock have not been thoroughly investigated to date.

Pike County Peridotite Area. Since the discovery of diamonds near Murfreesboro in 1906, numerous attempts have been made to develop a mine. St. Clair (94) believes there is still little valid information as to grade and tonnage of the ore at this deposit, because, in his opinion, reliable sampling techniques have not been employed. Other economic possibilities in the area are:

(1) placer diamonds in alluvial and terrace gravels along the Little Missouri River

(2) a magnetic survey of the region might locate additional intrusives with associated diamond deposits. (This survey might also delineate magnetite-ilmenite placer deposits.)

(3) the extraction of columbium-bearing dysanalyte known to occur in the peridotite

(4) the extraction of nickel (0.23 per cent) and related elements from the peridotite and

(5) the ilmenite-bearing fossil beach placers in the Tokio Formation of Upper Cretaceous age which have not been checked for columbium content of the ilmenite or for the possibility of associated diamonds. Placers may also exist in the water-laid volcanics of the Woodbine Formation.

Miscellaneous Occurrences. A discussion of future exploration would not be complete without mentioning the numerous igneous dikes and sills located, usually, near the major intrusive masses. These bodies range in composition from phonolite to peridotite. Mineralization of a minor nature is frequently associated with them. One small highly-weathered dike near Little Rock (Mr. Norman F. Willisms, personal communication) reportedly contains 10 per cent TiO_2. An explosion breccia, as well as numerous dikes and sills, are near the millerite-bearing veins of the Rabbits Foot nickel prospect near Benton, and may constitute the source of the nickel.

In most instances, these smaller igneous bodies are highly-weathered and poorly exposed. Magnetic surveys would aid in the search for the more basic dikes and sills. Radiometric surveys may also add additional data.

Subsurface Intrusives. Moody (79) and others describe intrusives ranging from syenite to peridotite in the subsurface especially in the Coastal Plain region of central and southern Arkansas.

With one exception these intrusives were encountered by petroleum exploration drilling. The magnetic high south of the town of Benton was recently drilled by a mining company. The rock encountered greatly resembles the jacupirangite (magnetite pyroxenite) at Magnet Cove. Veins containing traces of molybdenite were found. Evaluation of the cores is still in progress.

Information from the earlier wells encountering igneous rock is generally fragmentary, however, some were examined and described by highly competent geologists. Caplan (12)-data from C. L. Moody and also C. S. Ross- describes the Arkansas Natural Gas Corp., No. 1 Tate well drilled in 1928 on a magnetic anomaly near Rison in Cleveland County. It encountered at 3,363 feet what appeared to be sediments altered by contact metamorphism and containing abundant magnetite, ilmenite and leucoxene. At 3,561 feet a peridotite of variable composition was encountered characterized by abundant magnetite and perovskite. From 3,600 feet to 3,616 feet this rock contained 42 per cent of both altered and primary magnetite and 31 per cent perovskite. It is further stated that this rock is probably most closely allied in mineral composition with the diamond-bearing peridotite of Pike County. Since some individual crystals of perovskite from the carbonatite at Magnet Cove contain nearly 9 per cent columbium and 4.2 per cent tantalum, this is indeed an interesting occurrence. In addition these samples were not analyzed. This occurrence may only be of academic interest due to the great depth involved.

A ground magnetometer survey was made of the Rison anomaly by the Arkansas Geological Commission. This survey delineated the highest intensity magnetic anomaly in the State. A report and map on the project are now available. Currently, a deep drilling exploration program is in progress, however, the results have not been made public.

Jespersen (56) from aeromagnetic data indicates a probable nepheline syenite mass southeast of Granite Mountain, which may have been exposed in Tertiary time affording some possibilities for bauxite accumulations.

Fairchild Aerial Surveys (26) recently made a magnetic profile across the State of Arkansas from Flippin in the north central Ozarks to Texarkana in the southwestern Coastal Plain. South of Tokio in Pike County some anomalies appear that may represent some of the intrusive Mesozoic pipes postulated by Miser and Ross (76) as occurring in the region. A detailed magnetometer survey of southern Howard and Pike Counties would more accurately delineate such intrusives if they are present.

In order to stimulate exploration of subsurface igneous or basement rocks, the Arkansas Geological Commission has begun a ground reconnaissance magnetic survey on a county basis.

PALEOZOIC IGNEOUS ROCKS

The only known exposures of intrusive igneous rock of probable Paleozoic age which outcrop in Arkansas occur in a small area 15 miles west of Little Rock in Saline County (Fig. 2). This rock occurs in five open pits, three of which are currently being mined for soapstone. It is believed that the irregular lense-shaped soapstone deposits occur along an east-west trending, sill-like serpentine intrusion.

The serpentine is considered by the authors (98) to be the result of automorphism of an ultrabasic intrusive. Petrographic data by Jackson (55) indicates that the original rock type was in fact a variety of peridotite.

The relationship of the serpentine-soapstone bodies to the quartz veins indicates that the quartz veins are younger in age. According to Engel (23) most quartz veins in the Ouachitas are dated as late Middle Pennsylvanian. The serpentine-soapstone bodies cut portions of the Womble-Bigfork Formations which are dated as Middle Ordovician. Thus, the intrusion of the original igneous mass probably occurred between Middle Ordovician and Late Pennsylvanian times.

Low - temperature hydrothermal solutions chiefly along the edges of the mass caused steatitization of the serpentine body forming talc, dolomite and soapstone. There is a roughly zonal arrangement of the principal rock units in the soapstone deposits proceeding from the sedimentary contact inward to the core as follows: talcose shale, milky quartz veins, soapstone, dolomite and serpentine rock (Fig. 8).

Honess (49) and Miser (72) describe two small diorite dikes about four miles north of the town of Glover in McCurtain County, Oklahoma, which are intruded into Ordovician rocks. Petrographically this rock is identified as a quartz free-diorite. These diorite bodies are extensively fractured and considered to be pre-Late Pennsylvanian (pre-deformation).

There also exists the possibility that some igneous dikes and sills of the Ouachita Mountain region, which have been tentatively dated as Mesozoic, are in reality of Paleozoic age.

Miser and Purdue (74) describe several beds of tuff near the base of the Stanley Formation (Mississippian) in Polk County, Arkansas and by Honess (49) in McCurtain County, Oklahoma. The lowest and thickest of the tuff beds is the Hatton tuff lentil. It reaches a thickness of 90 feet. The tuffs are composed largely of devitrified and silicified volcanic glass. The original rock type was probably a rhyolite or quartz latite. Recently, Danilchik and Haley (22) and Zimmermann (112) have noted some tuff beds near the base of the Stanley Formation in Hot Spring County. Honess (49) also describes volcanic ash and breccia in two horizons in the Arkansas Novaculite of Devonian-Mississippian age in McCurtain County, Oklahoma. In addition, volcanic ash has been reported in the Missouri Mountain Shale (Silurian).

Numerous authors have suggested that some of the thick sequences of Ordovician and Devonian-Mississippian chert, novaculite and siliceous shale in the Ouachita Mountains were derived in part, from fine pyroclastic material from widespread volcanic activity to the south.

Frezon and Schultz (31) describe possible bentonite beds, particularly from wells, in the Atoka Formation (Pennsylvanian) in the Arkansas Valley of Arkansas and Oklahoma.

Bentonites and high volcanic ash contents have been suggested to occur in several other Paleozoic formations in Arkansas.

Related Mineral Deposits

Soapstone. Soapstone is a major constituent of the Paleozoic igneous intrusive of Saline County, Arkansas. The soapstone-serpentine bodies are zoned with the greatest alteration usually occurring along the edges of the masses and becoming progressively weaker towards the core (Fig. 8).

The deposits were first described in 1888 by Comstock (17), however, there has only been significant production in recent years. The Milwhite Mining Company sporadically operates five open pit mines at these deposits. In 1962, 21,000 tons of soapstone were produced. No reserve estimates are available, but at current production the proven reserves seem adequate for the immediate future.

Nickel. During geologic mapping the authors (98) observed nickel-bloom on some of the soapstone-carbonate rocks in the soapstone-serpentine deposits of Saline County. Further examination indicated nickel to be in the iron-sulphides of the unweathered soapstone-serpentine rock and in iron and manganese oxides of the weathered soapstone-serpentine rock. An unknown quantity of nickel is probably present in the silicate structure of the serpentine itself. The nickel content of the weathered zones was usually higher than in the unweathered equivalents, indicating lateritic enrichment. Phil Wicklein and Alden Carpenter (written communication) have identified the nickel minerals as pentlandite and hexahydrate. In addition they have noted pyrrhotite, and minor amounts of native iron and chromite.

The nickel in the sulphides and in the serpentine was probably derived from olivine during serpentinization of the original ultrabasic intrusive. The nickel in the oxides of the weathered zone is a result of the oxidation and residual concentration of the nickel from the sulphides.

Assays of samples from the soapstone pits range from a trace to 15 per cent nickel. During the superficial surface examination of these soapstone-serpentine bodies nickel of acceptable tenor was not found in commercial tonnages.

Future Exploration Considerations

There has been only limited exploration for the soapstone-serpentine deposits. Although the known masses are close to the surface and follow a general strike, they are extremely irregular in outline and pinch and swell. An extensive drilling program would be required for complete exploration of the area. The soapstone-serpentine rarely outcrops since it normally tends to decompose during weathering faster than the surrounding rocks. The minor amounts of iron-rich minerals in these deposits make magnetic surveys of doubtful value. Geochemical prospecting may be helpful because of the nickel content and the sulphides present indicate that electrical geophysical methods might be effective.

The possibility of finding concentrations of nickeliferous sulphides in any newly discovered Paleozoic ultrabasic intrusive is always present. Another possibility is that there exists masses of more deeply weathered intrusives containing larger tonnages of enriched oxides. Other elements commonly associated with nickel and ultrabasic rocks may also be found in any newly discovered mass.

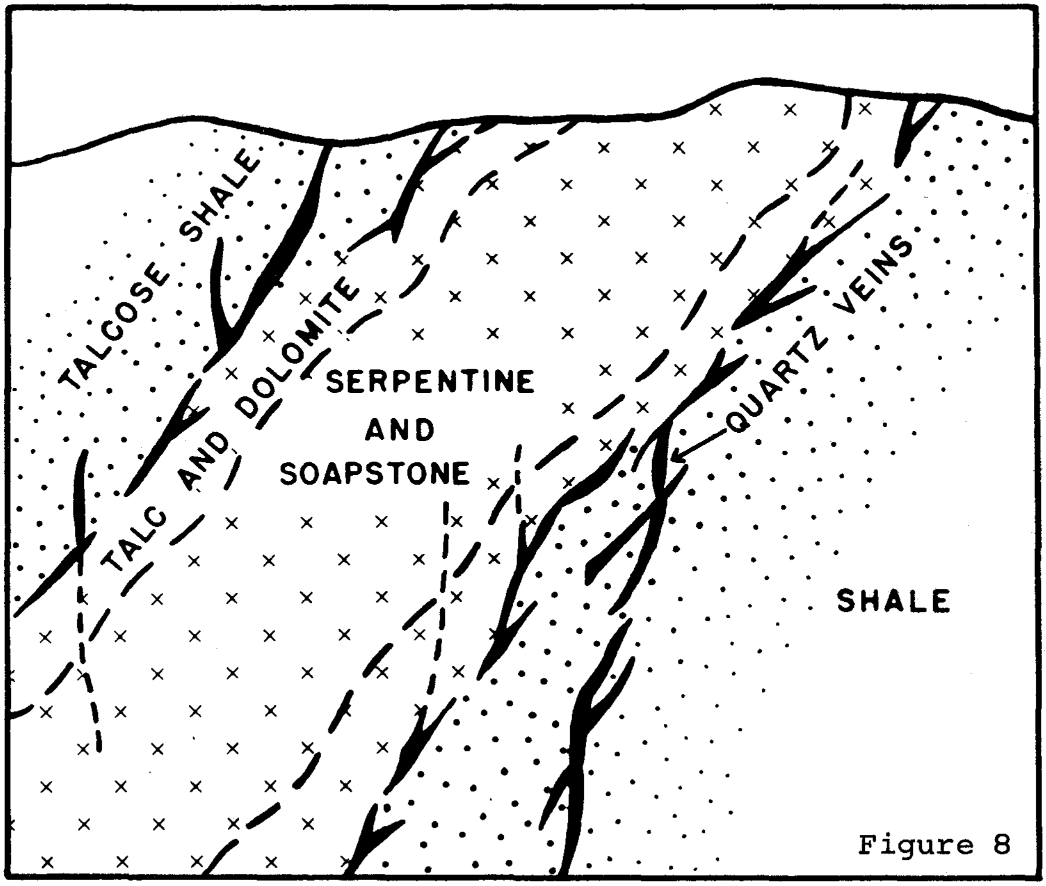


Figure 8

CROSS SECTION OF SOAPSTONE DEPOSIT

PRECAMBRIAN IGNEOUS ROCKS

Precambrian igneous rocks do not outcrop in Arkansas, however, Caplan (14 and 15) indicates they have been tentatively identified from seven oil and gas exploration wells (Fig. 2). Six of these wells were drilled in northwest Arkansas, in Benton, Madison, Washington Counties and one was drilled in Sebastian County in Western Arkansas.

Ozark Region

The six wells drilled in the northwestern portions of the Arkansas Ozarks encountered Precambrian at depths varying from 2,200 to 2,500 feet. Caplan (14) indicates over thirty additional wells have penetrated pre-Everton formations.

Caplan (14) states that three wells encountered Precambrian rock in Benton County. Croneis (19) reports that the drillers log of the Arkansas Publicity Bureau No. 1 Lay well (T. D. 2,430 feet) indicates that "syenite" was apparently encountered at 2,365 feet. According to Caplan (14) the Millsap Oil and Gas Company No. 1 Jones well (T. D. 2,338 feet) was reported abandoned in granite with no reference to the depth at which the granite was encountered. It is assumed that the well was abandoned upon encountering igneous rock or after penetrating a relatively small footage of igneous rock. The Ozark Production Company No. 1 Curry well (T. D. 2,236 feet) encountered light gray to pink igneous rock, containing chiefly feldspar and quartz, between 2,205 and the total sample depth of 2,222 feet. Caplan (14) also indicates that the basal Cambrian age Lamotte Sandstone contains arkosic material in the Curry and Jones wells.

Caplan (14) states that two wells have penetrated Precambrian rock in Madison County. Miser and Ross (77) gave the first recorded discovery of Precambrian igneous rocks in Arkansas in the War Eagle Oil and Gas Company No. 1 Brenner well (T. D. 2,320 feet), which encountered porphyritic rhyolite at depth of 2,286 feet and drilled 34 feet into it. They believe the rock was a volcanic flow or an intrusive of limited size. According to Caplan (14) the Independent Oil and Gas Company No. 1 Banks well (T. D. 2,515 feet) penetrated gray to red, very finely granular rhyolite between 2,397 feet and the total sample depth of 2,504 feet.

One well encountered Precambrian rock in Washington County. According to Croneis (19) and Caplan (14) the Hulsey-Fletcher-Bailey Oil Corp. (Legion O & G Co.) No. 1 Baggett-Maupin well (T. D. 2,485+ feet) encountered red granitic arkose "basement at 2,485 feet and drilling was continued into the granite itself for some unknown distance.

Arkansas Valley

The Shell Oil Company No. 1 Western Coal and Mining Company well drilled a few miles south of Fort Smith in Sebastian County in the Arkansas Valley possibly encountered Precambrian rock. The well was in Precambrian or Cambro-Ordovician beds according to Caplan (15) depending upon the identification and association of the granitic rock at total depth of 10,025 feet.

Future Exploration Considerations

It is possible that the Precambrian igneous rocks of northern Arkansas which are similar in composition to those of Missouri will be found to give rise to iron, lead, and zinc deposits of a similar nature. In an effort to locate Precambrian magnetic highs in this area the Arkansas Geological Commission and the Missouri Geological Survey have jointly proposed to the Area Redevelopment Administration that funds be allotted to provide for an aeromagnetic survey of approximately 3,630 square miles in northern Arkansas and a similar sized area in adjoining southern Missouri.

A magnetic study of the core area of the Ouachitas should afford much valuable and reliable data on the Precambrian igneous rocks, including depth to basement, basicity of rock and economic mineral potential.

It is hoped that this magnetic mapping will be accomplished and thus be an aid in the exploration of both areas.

REFERENCES

1. Adams, G. I., 1933, General Geology of the Crystallines of Alabama: Jour. Geo., Vol. 41, No. 2.

2. Arndt, R. H., and Kuroda, P. K., 1953, Radioactivity of Rivers and Lakes in Parts of Garland and Hot Spring Counties, Arkansas: Econ. Geol., Vol. 48, No. 7. pp. 551-566.

3. Anderson, R. J., 1942, Mineral Resources of Montgomery, Garland, Saline and Pulaski Counties, Arkansas: Ark. Geol. Survey, County Mineral Report 3.

4. Beloussov, V. V., 1960, Development of the Earth and Tectogenesis: Jour. Geophys. Research, Vol. 65, No. 12.

5. Bence, Alfred E., 1964, Geothermometric Study of Quartz. Deposits in the Ouachita Mountains, Arkansas: M. A. Thesis University of Texas.

6. Beroni, E. P., 1955, Maps Showing Radiometry and Geochemical sampling at Wilson's Prospect, Garland County, Arkansas: open file data from U. S. Atomic Energy Commission.

7. Bramlette, M. N., 1936, Geology of the Arkansas Bauxite Region: Arkansas Geol. Survey Inf. Circ. 8.

8. Branner, G. C., and others, 1929, Geologic Map of Arkansas: Arkansas Geol. Survey.

9. Branner, J. C., 1908, The Clays of Arkansas: U. S. Geol. Survey Bull. 315.

10. Brock, M. R., and Heyl, A. V., Jr., 1961, Post-Cambrian Igneous Rocks of the Central Craton, Western Appalachian Mountains and Gulf Coastal Plain of the United States: U. S. Geol. Survey Prof. Paper 424-D.

11. Calhoun, W.A., 1950, Titanium and Iron Minerals from Black Sands in Bauxite: U. S. Bureau of Mines Rept. of Investigations 4621.

12. Caplan, William M., 1954, Subsurface Geology and Related Oil and Gas Possibilities of Northeastern Arkansas: Ark. Res. & Dev. Comm. Bull. 20.

13. Caplan, William M., 1957, Subsurface Geology of Northwestern Arkansas: Ark. Geol. & Cons. Inf. Circ. 18.

14. Caplan, William M., 1960, Subsurface Geology of Pre-Everton rocks in Northern Arkansas: Ark. Geol. & Cons. Comm. Inf. Circ. 21.

15. Caplan, William M., 1962, Current Gas Developments in Northern Arkansas: Mississippi Geol. Soc. Guidebook for 1962.

16. Clegg, K. E., and Bradbury, J. C., 1956, Intrusive rocks of Illinois and Their Economic Significance: Illinois Geol. Survey Rept. Inv. 197.

17. Comstock, T. B., 1888, Report on Preliminary Examination of the Geology of Western Central Arkansas: Ark. Geol. Survey Ann. Report for 1888, Vol. 1.

18. Crider, A. F., 1923, Relation of Upper Cretaceous to Eocene Structure in Louisiana and Arkansas: Amer. Assoc. Petrol. Geologists Bull.,Vol. 7, No. 4, p. 381.

19. Croneis, Carey G., 1930, Geology of Arkansas Paleozoic Area with Especial Reference to Oil and Gas Possibilities, Ark. Geol. Survey Bull., Vol. 3.

20. Croneis, Carey G., and Billings, Marland P., 1930, Igneous Rocks in Central Arkansas: Ark. Geol. Survey Bull. 3., p. 149-162.

21. Dane, C. H., 1929, Upper Cretaceous Formations of Southwestern Arkansas: Ark. Geol. Survey Bull. 1.

22. Danilchik, Walter and Haley, Boyd R., 1964, Geology of the Paleozoic Area in the Malvern Quadrangle, Garland and Hot Spring Counties, Arkansas: U. S. Geol. Survey Misc. Geologic Inv. Map I-405.

23. Engel, A. E. J., 1951, Quartz Crystal Deposits of Western Arkansas: U. S. Geol. Survey Bull. 973-E.

24. Erickson, R. L., and Blade, L. V., 1956, Map of Bedrock Geology of Magnet Cove Igneous Area Hot Spring County, Arkansas: U. S. Geol. Survey Min. Inv. Map MF 53.

25. Erickson, R. L., and Blade, L. V., 1963, Geochemistry and Petrology of the Alkalic Igneous Complex at Magnet Cove, Arkansas: U. S. Geol. Survey, Prof. Paper 425.

26. Fairchild Aerial Surveys, 1963, Aeromagnetic Profile from Flippin to Texarkana, Arkansas: on file at Arkansas Geol. Comm.

27. Flawn, P. T., 1956, Basement Rocks of Texas and Southeast New Mexico: University of Texas Pub. 5605.

28. Flawn, Peter T., Goldstein, August Jr., King, Philip B., and Weaver, C. E., 1961, The Ouachita System: Texas Bur. of Econ. Geology, Pub. No. 6120.

29. Fleischer, Michael, Murata, K. F., Fletcher, J. D., and Nartem, P. E., 1952, Geochemical Association of Niobium (Columbium) and Titanium and Its Geological and Economic Significance: U. S. Geological Survey Circ. 225.

30. Frezon, S.E., and Glick, E. E., 1959, Pre-Atoka Rocks of Northern Arkansas: U. S. Geol. Survey Prof. Paper 314-H.

31. Frezon, Sherwood E., and Schultz, Leonard G., 1961, Possible Bentonite Beds in the Atoka Formation in Arkansas and Oklahoma: U. S. Geol. Survey Short Paper Article 181.

32. Fryklund, Verne C. Jr., and Holbrook, Drew F., 1950, Titanium Deposits of Hot Spring County, Arkansas: Ark. Res. and Dev. Comm. Bull. 16.

33. Fryklund, V. C., Harner, R. S., and Kaiser, E. P., 1954, Niobium (Columbium) and Titanium at Magnet Cove and Potash Sulphur Springs, Arkansas: U. S. Geol. Survey Bull. 1015-B.

34. Gallagher, David, 1942, Quicksilver Deposits near the Little Missouri River, Pike County, Arkansas: U. S. Geol. Survey Bull. 936-H.

35. Gibbons, John F., 1962, A Systematic Study of Fracture Patterns in Northwest and West Central Arkansas: M. S. Thesis University of Arkansas.

36. Gordon, MacKenzie, Jr., Tracey, Joshua I., and Ellis, Miller W., 1958, Geology of the Arkansas Bauxite Region: U. S. Geol. Survey Prof. Paper 299.

37. Gravity Meter Exploration Company and Fairchild Aerial Surveys with Geologic Section by W. H. Bucher, 1961, Aeromagnetic-Geologic Profile of Arkoma Basin, Oklahoma: free booklet at 1961 Fort Smith Geol. Society field trip.

38. Grohskopf, John G., 1955, Subsurface Geology of the Mississippi Embayment of Southeast Missouri: Missouri Geol. Survey & Water Resources, Vol. XXXVII, 2nd Series.

39. Ham, William E., 1959, Correlation of Pre-Stanley Strata in the Arbuckle-Ouachita Mountain Region: Ouachita Symposium, Dallas and Ardmore Geological Societies, p. 71-86.

40. Ham, William E., 1961, Andesite Tuff and Dacite Basement Rocks of Northeastern Oklahoma: Okla. Geol. Survey Geology Notes, Vol. 21, No. 5.

41. Ham, W. E., Denison, R. E., and Merritt, C. A., 1960, Basement Rocks of Southern Oklahoma: (abs.) Geol. Soc. of America Bull., Vol. 71, No. 12, Part 2.

42. Hayes, William C., 1962, Configuration of the Precambrian Surface Showing Major Structural Lineaments: Missouri Geological Survey and Water Resources.

43. Hendricks, T. A., and Parks, Bryan, 1950, Geology of the Fort Smith District Arkansas: U. S. Geol. Survey Prof. Paper 221-E.

44. Hess, F. L., 1908, Antimony Deposits of Arkansas: U. S. Geological Survey Bull. 340, p. 241-252.

45. Holbrook, D. F., 1947, A Brookite Deposit in Hot Spring County, Arkansas: Arkansas Geol. Survey Bull. 11.

46. Holbrook, D. F., 1948A, Molybdenum in Magnet Cove, Arkansas: Arkansas Geol. Survey Bull. 12.

47. Holbrook, D. F., 1948B, Titanium in Southern Howard County, Arkansas: Arkansas Geol. Survey Bull. 13.

48. Holbrook, D. F., and Williams, Norman F., 1963, Ore Deposit Geology of the Ouachita Mountains: paper presented to Society of Economic Geologists, Dallas, Texas.

49. Honess, C. W., 1923, Geology of Southern Ouachita Mountains of Oklahoma: Okla. Geol. Survey Bull. 32.

50. Howe, Wallace B., Koenig, John W., 1961, The Stratigraphic Succession in Missouri: Missouri Geological Survey and Water Resources, Vol. XL, 2nd Series.

51. Howell, J. V., and Lyons, Paul L., 1959, Oil and Gas Possibilities of the Ouachita Province: Ouachita Symposium, Dallas and Ardmore Geological Societies, p. 57-61.

52. Huffman, George C., 1958, Geology of the Flanks of the Ozark Uplift: Okla. Geol. Survey Bull. 77.

53. Imlay, Ralph W., 1949, Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities: Arkansas Div. of Geology Circ. 12.

54. Ireland, H. A., 1955, Pre-Cambrian Surface in Northeastern Oklahoma and Parts of Adjacent States: Amer. Assoc. Petroleum Geologists Bull., Vol. 39, no. 4.

55. Jackson, Kern C., 1962, Petrographic Determinations for Arkansas Geological and Conservation Commission: unpublished open file data, Arkansas Geol. Comm.

56. Jespersen, Anna, 1964, Aeromagnetic Prospecting for Bauxite Deposits in the Mississippi Embayment; Arkansas and Missouri: U. S. Geological Survey Geophysical Investigations Map GP-370.

57. Jones, T. A., 1948, Barite Deposits in the Ouachita Mountains, Montgomery, Polk and Pike Counties, Arkansas: U. S. Bureau of Mines Rept. Inv. 4348.

58. Keller, Fred, Jr., Henderson, John R., et al., 1963, Aeromagnetic Map of the Magnet Cove Area Hot Spring County, Arkansas: U. S. Geological Survey, Geophysical Inv., Map GP-409.

59. Kidwell, Albert L., 1947, Post-Devonian Igneous Activity in Southeastern Missouri: Missouri Geological Survey and Water Resources Rept. of Inv. No. 4.

60. Kun, N. D., 1962, The Economic Geology of Columbium (Niobium) and of Tantalum: Econ. Geology, Vol. 57, p. 377-404.

61. Kuroda, P. K., Damon, P. E., and Hyde, H. I., 1954, Radioactivity of the Spring Waters of Hot Springs National Park and Vicinity in Arkansas: Am. Jour. Sci., Vol. 252, No. 2, p. 76-87.

62. Lonsdale, J. E., 1927, Igneous Rocks of the Balcones Fault Region of Texas: University of Texas Bur. Econ. Geol. Bull. 2744.

63. Lyons, P. L., 1950, A Gravity Map of the United States: Tulsa Geol. Soc. Digest, Vol. 18.

64. Malamphy, Mark C., and Vallely, James L., 1944, Geophysical Survey of the Arkansas Bauxite Region: Geophysics, Vol. 9, No. 3.

65. Malan, R. C., and Nash, W. L., 1954, Airborne Reconnaissance in Southwestern Arkansas: U. S. Atomic Energy Commission, RME 1052.

66. McElwaine, Robert B., 1946, Exploration for Barite in Montgomery County, Arkansas: U. S. Bureau Mines Rept. Inv. 3971.

67. McKnight, E. T., 1935, Lead and Zinc Deposits of Northern Arkansas: U. S. Geol. Survey Bull. 853.

68. Merriam, Daniel R., Hambleton, William W., and Cole, Virgil B., 1962, Precambrian Basement Rock Types in Midcontinent Region: (abs.) Amer. Assoc. Petroleum Geologists Bull., Vol. 46, No. 2.

69. Merritt, C. A., 1960, Petrography of Spavinaw Granite: Okla. Geol. Survey Geology Notes, Vol. 20, No. 9.

70. Miser, Hugh D., 1912, Developed Deposits of Fuller's Earth Arkansas: U. S. Geol. Survey Bull. 530.

71. Miser, Hugh D., 1938, Volcanoes of the Gulf Coastal Plain: (abs.) Jour. Washington Acad. Sci., Vol. 28, No. 9.

72. Miser, Hugh D., 1959, Structure and Vein Quartz of the Ouachita Mountains of Oklahoma and Arkansas: Ouachita Symposium, Dallas and Ardmore Geological Societies, p. 30-43.

73. Miser, Hugh D., and Milton, Charles, 1964, Quartz, Rectorite, and Cookeite from the Jeffrey Quarry, near North Little Rock, Pulaski County, Arkansas: Ark. Geol. Comm. Bull. 21.

74. Miser, Hugh D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas: U. S. Geol. Survey Bull. 808.

75. Miser, Hugh D., and Ross, C. S., 1922, Peridotite Dikes in Scott County, Arkansas: U. S. Geol. Survey Bull. 735-H.

76. Miser, Hugh D., and Ross, Clarence S., 1925, Volcanic Rocks in the Upper Cretaceous of Southwestern Arkansas and Southeastern Oklahoma: Amer. Jour. of Science, Vol. IX.

77. Miser, Hugh D., and Ross, Clarence S., 1925, Pre-Cambrian Rhyolite Discovered in Well in Northwestern Arkansas: Amer. Assoc. Petrol. Geologists Bull., Vol. 9, No. 7.

78. Miser, Hugh D., and Stevens, R. E., 1938, Taeniolite from Magnet Cove, Arkansas: Am. Mineralogist, Vol. 23, p. 104-110.

79. Moody, C. L., 1949, Mesozoic Igneous Rocks of Northern Gulf Coastal Plain Amer. Assoc. Petroleum Geologists Bull., Vol. 33, No. 3.

80. Neiberlein, V. A., Fine, M. M., Calhoun, W. A., and Parsons, E. W., 1954, Progress Report on Development of Columbium in Arkansas for 1953: U. S. Bureau of Mines Rept. of Inv. 5064.

81. Parks, Byran, and Branner, G. C., 1932, A Barite Deposit in Hot Spring County, Arkansas: Ark. Geol. Survey Inf. Circ. 1.

82. Penrose, R. A. F., Jr., 1891, Manganese-Its Uses, Ores, and Deposits: Ark. Geol. Survey Ann. Rept. for 1890, Vol. 1.

83. Purdue, A. H., and Miser, H. D., 1923, Description of the Hot Springs District: U. S. Geol. Survey Geol. Atlas Folio 215.

84. Quinn, James H., 1963, Subsidence Structures in Northwestern Arkansas: Okla. Geol. Survey Notes, Vol. 23, No. 8.

85. Reed, D. F., 1949a, Investigation of Christy Titanium Deposit, Hot Spring County, Arkansas: U. S. Bur. Mines Rept. Inv. 4592.

86. Reed, D. F., 1949b, Investigation of Magnet Cove Rutile Deposit, Hot Spring County, Arkansas: U. S. Bur. Mines Rept. Inv. 4593.

87. Reed, J. C., and Wells, F. G., 1938, Geology and Ore Deposits of the Southwestern Arkansas Quicksilver District: U. S. Geol. Survey Bull. 886-C.

88. Ross, C. S., Miser, H. D., and Stephenson, L. W., 1929, Water-laid Volcanic Rocks of Early Upper Cretaceous Age in Southwestern Arkansas, Southeastern Oklahoma and Northeastern Texas: U. S. Geol. Survey Prof. Paper 154-F.

89. Scull, Berton J., 1958, Origin and Occurrence of Barite in Arkansas: Ark. Geol. Survey Inf. Circ. 18.

90. Scull, Berton J., 1959, The Age of Mineralization in the Ouachita Mountains of Arkansas and Oklahoma: Ouachita Symposium, Dallas and Ardmore Geological Societies, p. 62-70.

91. Skillman, Margaret W., 1948, Pre-Upper Cambrian Sediments of Vernon County, Missouri: Missouri Geol. Survey & Water Resources, Rept. of Inv. No. 7.

92. Spencer, R. V., 1946, Exploration of the Magnet Cove Rutile Company, Property, Magnet Cove Area, Hot Spring County, Arkansas: U. S. Bur. Mines Rept. Inv. 3900.

93. Spooner, W. C., 1935, Oil and Gas Geology of the Gulf Coastal Plain in Arkansas: Ark. Geol. Survey Bull. 2.

94. St. Clair, John Q., 1956, Mining Geologists' Report on Arkansas Diamond Property: unpublished open file data at Ark. Geol. Comm.

95. Staff, 1958, Uranium in Arkansas: Ark. Geol. and Cons. Comm.

96. Stearn, N. H., 1930, A Geomagnetic Survey of the Bauxite Region in Central Arkansas: Ark. Geol. Survey Bull. 6.

97. Stearn, N. H., 1936, The Cinnabar Deposits in Southwestern Arkansas: Econ. Geology, Vol. 31, No. 1, p. 1-28.

98. Sterling, Philip J., and Stone, Charles G., 1961, Nickel Occurrences in Soapstone Deposits Saline County, Arkansas: Econ. Geology, Vol. 56, No. 1.

99. Sterling, Philip J., Stone, Charles G., and Holbrook, Drew F., (field work completed), Geology of the Benton 15-Minute Quadrangle, Eastern Ouachitas of Arkansas: Ark. Geol. Comm.

100. Stone, Charles G., and Sterling, Philip J., 1962, New Lithologic Marker Horizons in Ordovician Rocks, Eastern Ouachitas of Arkansas: Amer. Assoc. Petroleum Geologists Bull., Vol. 46, No. 3.

101. Stone, Charles G., 1965, New Unusual Mineral and Rock Localities, Central Arkansas: Misc. Rept., Ark. Geol. Comm.

102. Stroud, Raymond B., 1962, The Mineral Industry in Arkansas: U. S. Bureau of Mines Minerals Yearbook.

103. Swanson, Vernon E., and Landis, Edwin R., 1962, Geology of a Uranium-Bearing Black Shale of Late Devonian Age in North-Central Arkansas: Ark. Geol. and Cons. Comm. Info. Circ. 22.

104. Thoenen, J. R., Hill, R. S., Howe, E. G., and Runke, S. M., 1949, Investigation of the Prairie Creek Diamond Area: U. S. Bureau Mines Rept. Inv. 4549.

105. Tilton, G. R., Wetherill, G. W., and Davis, G. L., 1962, Mineral Ages from the Wichita and Arbuckle Mountains, Oklahoma, and the St. Francis Mountains, Missouri: Jour. Geophy. Research, Vol. 67.

106. Washington, H. S., 1900, Igneous Complex of Magnet Cove, Arkansas: Geol. Soc. America Bull., Vol. 21.

107. Weeks, W. B., 1938, South Arkansas Stratigraphy with Emphasis on the Older Coastal Plain Beds: Amer. Assoc. Petrol. Geologists Bull., Vol. 15, No. 9.

108. William, J. F., 1890, The Igneous Rocks of Arkansas: Ark. Geol. Survey Ann. Rept., Vol. 2.

109. Williams, Norman F., and Plummer, Norman, 1951, Clay Resources of the Wilcox Group in Arkansas: Ark. Res. and Dev. Comm. Info. Circ. 15.

110. Williams, Norman F., Smothers, Norman J., and Reynolds, Harry J., 1952, Ceramic Evaluation of Arkansas Nepheline Syenite: Ark. Res. and Dev. Comm. Info. Circ. 16.

111. Young, Edward J., 1958, An Occurrence of Gorceixite in Arkansas: Am. Mineralogists, Vol. 43, p. 762.

112. Zimmermann, Richard A., 1964, The Origin of Bedded Arkansas Barite Deposits (with Special Reference to the Genetic Value of Sedimentary Features in the Ore): unpublished PhD. Thesis University of Missouri at Rolla.

Addendum (1968)

Mining was started at the Wilson Springs vanadium operation in 1966 and it is the only mine in the United States developed for vanadium as the only product. Although the Wilson Springs area was investigated in the 1950's for uranium and columbium, the economic vanadium potential was not determined until 1960. Two open pit mines are presently being developed.

The ores contain approximately one percent vanadium pentoxide which is recovered in this plant by hydrometallurgical methods. The majority of the vanadium produced will ultimately be alloyed in steel.

The ore deposits occur in the vicinity of the contact between the Potash Sulfur Springs alkalic igneous complex and the surrounding Paleozoic sedimentary rocks. The intrusive complex, which was probably emplaced in early Late Cretaceous time has a crude ring structure similar to Magnet Cove. The outer ring is alkali syenite and fenite, and much of the central part of the complex is nepheline syenite. Jacupirangite, melteigite, ijolite, and carbonatite are present, as well as several breccias.[1]

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[1] Hollingsworth, J. S., 1967, Geology of the Wilson Springs Vanadium Deposits Garland County, Arkansas: Guide Book to Central Arkansas Economic Geology and Petrology compiled for Geol. Soc. of America, prepared by Ark. Geol. Comm., p. 22-28.