STATE OF ARKANSAS

Arkansas Geological and Conservation Commission

Norman F. Williams, Geologist-Director

INFORMATION CIRCULAR 18

ORIGIN AND OCCURRENCE OF BARITE IN ARKANSAS

By

BERTON J. SCULL

Little Rock, Arkansas

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ORIGIN AND OCCURRENCE OF BARITE IN ARKANSAS

By B. J. Scull

ABSTRACT

The use of barite in the drilling muds of the petroleum industry has greatly increased the demand for this mineral over the last two decades. About one-quarter of the world production is mined from one deposit in the Chamberlain Creek syncline in the Magnet Cove district of the Arkansas Barite Region. Barite is obtained by strip mining by the Baroid Division of the National Lead Company in the eastern part of the deposit; and with underground methods by the Magnet Cove Barium Corporation, a Dresser Industry, in the western part of the deposit.

The mode of origin, time of emplacement, paragenesis, and genetic relationships of the various barite deposits of the region were determined by an integration of information obtained from mapping the deposits, with chemical, spectrographic, and petrographic analyses of selected samples.

The Arkansas barite region includes portions of the Ouachita Mountains and the Gulf Coastal Plain. The sedimentary rocks exposed in the Ouachitas are well-indurated shales, sandstones, and novaculite and other cherts, with minor amounts of limestone, conglomerate and tuff. The Bigfork chert (Middle Ordovician) is the oldest formation exposed within the barite region. It is succeeded by the Polk Creek shale (Upper Ordovician), the Blaylock sandstone (Silurian), the Missouri Mountain shale (Devonian?), the Arkansas novaculite (Middle Devonian to Lower Mississippian), the Stanley shale (Mississippian), the Jackfork sandstone (Pennsylvanian?), and the Atoka formation (Pennsylvanian). The aggregate thickness of these units is in excess of 20,000 feet.

The Paleozoic sediments were strongly compressed into eastward trending belts during a late Pennsylvanian orogeny. Some fold belts such as the Zig Zag Mountains stand transverse to the general trend of folding. The anticlinal folds persist as anticlinal mountains and ridges because of cores of Arkansas novaculite, which is highly resistant to erosion. The Mazarn synclinorium, a topographic basin, at its extremities is the loci of the major known barite deposits of the region.

The sediments of the Gulf Coastal Plain are chiefly gravel, sand, clay and marl, with chalk, gypsum, tuff and organic limestone well-developed in some areas. Cretaceous, Tertiary and Quaternary sediments are exposed within the barite region although only the Lower Cretaceous Trinity formation including the Pike gravel and the Dierks and De Queen limestones are of significance in this barite study. These sediments dip southward at low angles and are devoid of prominent relief.

The Paleozoic and Lower Cretaceous sediments were intruded by syenitic and peridotitic masses and dikes during lower Upper Cretaceous time. These igneous rocks are comparatively rich in barium, strontium, titanium, and carbonate. Sub-silicic norms and a high titanium content apparently characterize the lower Upper Cretaceous igneous rocks of the western part of the Gulf Coast. The chemistry of these rocks indicate an intimate relationship with the barite deposits.

The Arkansas barite region is arbitrarily divided into six districts; the Magnet Cove district at the eastern end of the Mazarn basin and the Pigeon Roost and Fancy Hill districts, 45 and 60 miles respectively, west of Magnet Cove, are characterized by metasomatically emplaced barite; the Hatfield district in the western part of the Arkansas Ouachitas is characterized by concordant veins of barite; the Cinnabar district of the Athens plateau is characterized by discordant veins of barite; and the Dierks district in the western part of the Arkansas Gulf Coastal Plain is characterized by barite as cement in sediments.

The metasomatic replacement deposits are restricted to the lower part of the Stanley formation. Ordinarily there are two to twenty feet of black shale between the base of the mineralized zone and the underlying Arkansas novaculite. The mineralized zones rarely exceed a few tens of feet in thickness. Over 95 percent of the replacement barite occurs in synclinal folds although there are minor concentrations associated with anticlines and faults.

The barite of the replacement deposits is in order of decreasing abundance; finely crystalline in massive beds, dense cryptocrystalline in massive beds, nodular zones, and coarsely granular in lentils. The bedding of the host rock is well preserved in all but the last of these ore types. Host rock relics and replacement embayments are common only in the finely crystalline barite. These relics readily show that silty and sandy shales were replaced but the rather pure clay shales were not.

The concordant veins of barite were emplaced along bedding planes in the Middle Arkansas novaculite. The barite is coarsely crystalline, and the veins are ordinarily less than two feet thick with a maximum strike length of sixty feet.

The discordant veins of barite occur as gangue in the cinnabar deposits, and as casuals in the diamond-bearing peridotite plugs at Murfreesboro and the tufa domes at Magnet Cove. The barite in these veins is coarse to extremely coarse and in limited volumes. The association of these veins substantiates the consanguinity of the barite deposits and the igneous rocks.

The sediment-cementing barite occurs in the Pike gravel and two sand zones of the Lower Cretaceous Trinity formation. The barite formed large crystals that incorporate a number of sand grains and pebbles and "floating" grains are abundant. These crystals have a maximum dimension of four inches. Radial aggregates that weather out of the enclosing sediments as barite "roses" are common. The barium sulfate was deposited in open pore spaces and there is only minor replacement of the sand grains.

The metasomatic barite was emplaced along capillary openings within the Stanley sediments. The replacement was controlled by the size and type of openings, the degree of saturation of the pervading fluids, the heterogenous forces affecting the surfaces of the replaced minerals, and the texture and chemical composition of the host rocks.

The Chamberlain Creek syncline which contains the largest known barite deposit of the region is truncated at the western end by the Magnet Cove intrusive masses and is cut by numerous alkalic and mafic dikes. The feldspars of the cove intrusives are saturated with barium and excesses of titanium and carbonate from the magmas constitute the rutile-carbonate-feldspar vein deposits of Magnet Cove. The trace element suites of the igneous rocks and the barite are quite similar.

The structural relationships, the gross chemistry, the uniform trace element suites and the proximity of the Chamberlain Creek deposit and the Cove complex indicate a common origin. The other barite deposits in the Magnet Cove district and those of the Pigeon Roost and Fancy Hill districts are identical with the Chamberlain Creek deposit with respect to stratigraphy, structure, types of ore, chemistry and trace elements. Even though intimate igneous associations cannot be proved, it is presumed that all deposits of this type are genetically related.

Both the concordant and discordant barite veins are associated temporally and spatially with the igneous rocks and the replacement barite deposits of the region. Uniform trace element suites confirm the relationship.

The barite cementing parts of the Trinity formation is not comparable to the replacement barite in mode of distribution, stratigraphically or in physical appearance. The barite in the Trinity has a comparable trace element suite and was deposited in proximity to igneous masses and the cinnabar deposits. It is genetically related to the replacement deposits although the sites of deposition were probably controlled by intermingling of barium-transporting fluids and formation waters.

The abundance of barium, strontium and titanium in the igneous rocks, and of strontium and titanium in the barite deposits; similar trace element suites in the igneous rocks and the barite of each type of deposit; and the spatial and temporal relationships of the igneous rocks, barite deposits and metalliferous deposits of the region indicate that the barite is a product of the lower Upper Cretaceous intrusive phase.

ORIGIN AND OCCURRENCE OF BARITE IN ARKANSAS

INTRODUCTION

Foreword

The occurrence of barite in the Ouachita Mountains of Arkansas has been known since 1890. Early attempts to develop the deposits were unsuccessful as the ore proved to be too impure for use in the chemical and paint industries — the then principal barite consumers. With the development of the use of ground barite as a weighting agent in oil well drilling muds, renewed interest was shown in the Arkansas deposits and in 1939 the Magnet Cove Barium Corporation found that an acceptable drilling mud barite could be obtained from the ore by flotation. The company then began producing barite from the deposit near Magnet Cove in Hot Spring County, and in 1941 the Baroid Division of the National Lead Company started mining and milling operations on a portion of the same deposit. Annual production from this deposit, the only one being mined, expanded rapidly from 2,500 short tons in 1939 to over 468,000 short tons in 1957. Arkansas is now the leading barite producer in the nation.

Recognizing the importance of the barite industry to the economy of the state, this report has been prepared to provide both individuals and operating companies a sound basis for searching for new deposits that would strengthen and expand the barite industry.

Scope of the Investigation

All the known barite deposits and prospects in the state are described in this report. The larger deposits are described in detail with respect to stratigraphy, structure, nature of the ore and paragenesis, whereas the small deposits and prospects are treated less thoroughly. A theory is proposed for the origin and emplacement of the barite deposits, and an economic section containing prospecting recommendations is included.

Methods of Investigation

In preparing geologic maps of the barite region, maximum use was made of published maps and reports of the U. S. Geological Survey and reports of individuals and companies. Where suitable maps were not available the surface geology was mapped on aerial photos on a scale of 500 feet to the inch.

The core drill data made available by the operating companies and from reports by the U. S. Bureau of Mines were used to control structural interpretations during the aerial mapping, to verify structural and lithologic data obtained from underground mapping, and to establish the extent of mineralization of some of the deposits.

Numerous hand samples were collected from each deposit and studied under the binocular microscope. From 150 selected samples thin sections were made for petrographic analysis. Forty samples were analyzed chemically, most of them by the chemists of the Arkansas Geological Survey and twenty samples were analyzed spectrographically by laboratories of the U. S. Geological Survey.

Data obtained from the field and laboratory studies were used to establish the time and mode of origin of the barite deposits.

Previous Work

The first mention of the occurrence of barite in Arkansas in the available literature is in the **Annual Report of the Geological Survey of Arkansas for 1888** (J. C. Branner). In Volume I of this report a list of the minerals of West Central Arkansas is included in the gold and silver report of T. B. Comstock. Comstock stated that seams and pockets of "barytes" of a very good quality were common in Montgomery County and predicted that this was an industry worthy of consideration.

Other than this report, only the work of Purdue and Miser has been of regional significance. In their reports on the Hot Springs quadrangle (1923) and the De Queen and Caddo Gap quadrangles (1929) these authors developed the stratigraphic terminology now used in the region. Their maps of these three quadrangles are the only areal maps of appreciable extent for areas within the Arkansas portion of the Ouachitas. Considering the complexity of the geology and the physical difficulties involved in mapping these quadrangles, the work is remarkably accurate and established the geologic framework for subsequent students in the region.

Local but useful information was obtained from several papers concerned with the now inactive cinnabar district along the southern border of the Ouachitas. Reed and Wells (1938) and Stearn (1936) present most of the data on stratigraphy, structure, and age relations of the ores that are useful in regional interpretations as related to the barite problem.

Maps and descriptions in the reports of Washington (1900), Holbrook (1947), and Fryklund and Holbrook (1950) show, to a large extent, the distribution and relationships of the various igneous and sedimentary rocks of the Magnet Cove intrusion.

In 1932 Parks and Branner published a report describing the barite deposits near Magnet Cove. The field work was done by Parks, and the mapping in the vicinity of the barite-bearing zone was detailed and rather accurate. The regional map, however, is subject to considerable revision. Two U. S. Bureau of Mines reports by McElwaine and one by Jones were used extensively for orientation, location of known deposits, descriptions of pits and trenches now filled, and other useful data. McElwaine described the barite deposits in the Magnet Cove area (1946A) and in the Montgomery County area (1946B). Jones (1948) described the barite deposits known in the western part of the Arkansas Ouachitas.

Acknowledgments

This study of the Arkansas barite was suggested by Norman F. Williams, the State Geologist of Arkansas, who rendered full support and cooperation in every phase of the project. Mr. Drew F. Holbrook of the Arkansas Geological and Conservation Commission was particularly helpful in obtaining photographs for field work.

Officials of the Baroid Division of the National Lead Company and the Magnet Cove Barium Corporation generously granted the writer access to all the holdings of their respective companies and made available the geologic data on file, including core hole information.

Mr. Paul Timbrook and Mr. Al Higgins, Baroid engineers, aided in compiling location maps and in sorting file data.

Mr. Dan Martin, Magcobar engineer, served as a guide in the underground workings and compiled the original data for the underground cross sections.

Mr. Robert B. McElwaine supplied maps of the barite deposits in the Dierks district and served as a geologic guide during that phase of the study.

Mr. Albert Hess, Milwhite engineer, furnished cores from several properties in the region.

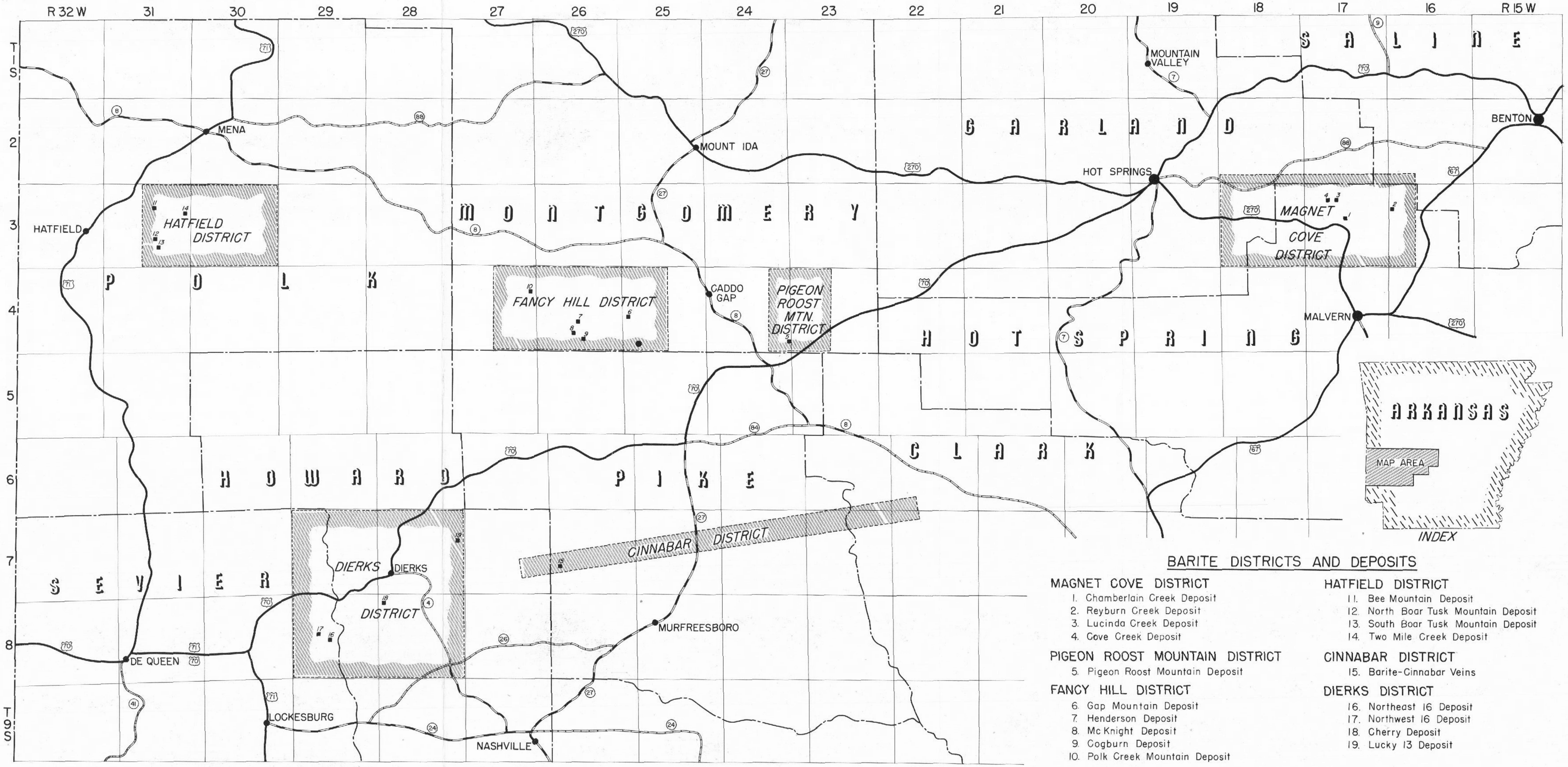
Dr. Ralph E. Erickson, Mr. Lawrence V. Blade and Mr. Walter Danilchek of the U. S. Geological Survey gave the writer considerable chemical and field data and aided in the interpretations of the origin of the barite.

Mr. Troy Carney, Chief Chemist, Arkansas Geological and Conservation Commission, made most of the chemical analyses used in the report. Mr. Wallace Griffitts, U. S. Geological Survey, obtained the spectrographic analyses.

Mr. Howard G. Schoenike, Chief Geologist, Baroid Division, helped in a number of ways: in geological and geographic orientation, in obtaining geological data, in discussions of geological problems, and, perhaps most important, as a congenial and competent field companion.

Dr. Hugh Hunter, School of Geology, University of Oklahoma, made several valuable suggestions after visiting the problem area and reading the original manuscript.

The report was written under the helpful guidance of Dr. Clifford A. Merritt, School of Geology, University of Oklahoma.



LOCATION MAP SHOWING BARITE DISTRICTS AND LARGER KNOWN DEPOSITS

GEOGRAPHY

The barite region of Arkansas comprises about 2700 square miles and includes portions of Hot Spring, Garland, Montgomery, Polk, Howard and Sevier Counties. The region includes the southern part of the Ouachita Mountain system and the northernmost part of the West Gulf Coastal Plain of Arkansas.

The Ouachita Mountain system, consisting of several ranges and intermontane basins, extends westward from near Little Rock, Arkansas, to near Atoka, Oklahoma. In the mountainous area the major features are narrow ridges and valleys with picturesque transverse water gaps. The ridges trend nearly east or northeast, are characterized by steep debris-covered slopes, and, except for isolated peaks, have even crests. The relief is about 1800 feet near the Arkansas-Oklahoma line. The up-land altitude increases from about 750 feet near Little Rock to about 2850 feet near the state line.

The various mountain ranges bound wide valleys or intermontane basins. The terrain within these basins is undulating and in places rough with low sharp ridges separating steep-sided narrow valleys. Except for Pigeon Roost Mountain (900 feet), the maximum relief is slightly over 250 feet. The general level of the basins rises from about 450 feet above sea level on the east to over 1000 feet near the state line.

The northern part of the Gulf Coastal Plain in Arkansas is essentially a low-lying, gently undulating surface, forest covered and transected by southward flowing streams. Low gravel-covered divides, stream terraces and low cliffs afford the relief of the area. Elevations range from 350 feet in the larger stream valleys to 675 feet on the highest ridges.

Lines of the Missouri Pacific Railroad skirt the mountainous area along the southeastern margin of the region. Branch lines serve Hot Springs and Norman. Lines of the Chicago-Rock Island and Pacific serve Malvern, Butterfield and the barite mines. U. S. Highway 70 and Arkansas State Highways 6, 8 and 27 connect the larger towns within the region (see Plate 1).

The region is one of moderate climate. Extreme cold or appreciable amounts of snow are rare and of short duration. The summers are hot and periods of drought are not uncommon. In normal years rainfall is abundant with the maximum during the spring and early summer months. The aggregate precipitation is sufficient to produce a thick forest cover over most of the region. Only cultivated areas along the streams, the soilless steeper slopes and novaculite-capped ridges are free from vegetation. The climate and the cover of vegetation are such that the winter months are the most suitable for field work.

Mesozoic

Upper Cretaceous

Woodbine formation—tuffaceous sands and clays

Lower Cretaceous

Trinity formation—Pike gravel member at base, overlain by loosely consolidated sandstones with Dierks and DeQueen limestone lentils, some gypsum and celestite beds, maximum thickness 600 feet.

Paleozoic

Pennsylvanian

Jackfork sandstone—thick massive sandstone units separated by thinner and less extensive shale units, maximum thickness 6000 feet.

Mississippian

Stanley formation—gray-green weathering dark gray shale with thick siltstone and sandstone members, locally tuff beds near base, maximum thickness 6,000 feet.

Devonian-Mississippian

Arkansas novaculite

Upper Division—tan to gray massive calcareous novaculite, locally quartzitic, maximum thickness 120 feet.

Middle Division—thin-bedded dark colored novaculite and shale, maximum thickness 450 feet.

Lower Division—white to gray, dense, thick-bedded novaculite, maximum thickness 450 feet.

Devonian

Missouri Mountain shale—black, green and red fissile shale, maximum thickness 300 feet.

Silurian

Blaylock sandstone—tan to gray, fine to medium-grained, thin to medium-bedded quartzitic sandstone, intercalated gray to black graptolitic shale, maximum thickness 1500 feet.

Ordovician

Polk Creek shale—contorted and crumpled black graptolitic shale, maximum thickness 300 feet.

Bigfork chert—gray to black medium-bedded chert, thin black graptolitic shale partings, strongly crumpled, maximum thickness 800 feet.

Fig. 1 — Stratigraphic units of the Arkansas barite region

AREAL GEOLOGY

General Statement

The Arkansas barite region comprises portions of two geologic provinces: The Ouachita Mountains, including the Athens Plateau, and the Gulf Coastal Plain. The sedimentary rocks exposed in the Ouachitas are well-indurated Paleozoic shales, sandstones, novaculite and chert, with minor amounts of limestone, conglomerate and tuff. They were strongly compressed, in many places overturned, during periods of folding and faulting of Permo-Pennsylvanian age. Syenitic and peridotitic masses and a variety of dikes were intruded into the Paleozoic rocks in the earlier part of Upper Cretaceous time. The Athens Plateau is a dissected piedmont along the southern margin of the mountainous area. Lower Cretaceous sediments, with a low south dip, cover the southern part of the piedmont.

The sediments of the Gulf Coastal Plain are chiefly gravel, sand, clay and marl, with chalk, gypsum, tuff and organic limestone well developed in some areas. They dip southward about 100 feet per mile, but local structures are present. Cretaceous, Tertiary and Quaternary units are exposed in the province, but only Lower Cretaceous and lower Tertiary formations are exposed over appreciable areas within the barite region.

Stratigraphy

General Discussion

The barite of this region is associated with four stratigraphic units: the Middle Arkansas novaculite, the Stanley shale, the Pike gravel and the lower Trinity sandstones. In order to maintain structural control for these units it was necessary to map units ranging in age from Middle Ordovician (Bigfork chert) to Upper Trinity (De Queen limestone). Rather complete descriptions of the sedimentary rocks of the Ouachita Mountains and the northern part of the Gulf Coastal Plain are given by Miser and Purdue (1923, 1929). The following descriptions are, to a large extent, condensations from their publications, but are modified by more recent paleontological data and other information.

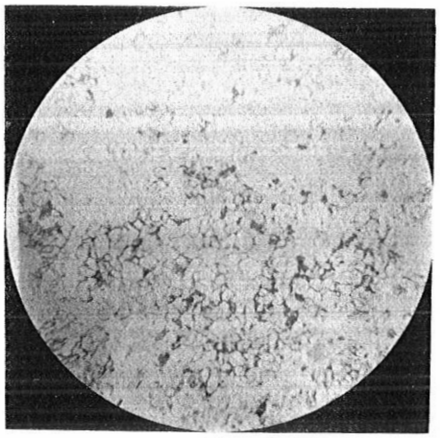
Paleozoic Rocks

Bigfork chert. The type locality of the Bigfork chert (Purdue, 1909, pp. 30-35) is the exposures of the formation in the vicinity of the Big Fork Post Office in the northwest corner of the Athens quadrangle. The formation is composed of chert interbedded with minor amounts of shale and limestone. The chert is brittle and intensely crumpled so that the true thickness could not be measured. It is black on fresh surface and weathers to various shades of gray. In some places the chert weathers so as to resemble a gray porous sandstone which, in isolated exposures, cannot readily be separated from some of the younger sandstones in the region. Along some stream banks and in road cuts the Bigfork chert is composed of even-bedded layers of which most are 3 to 6 inches thick, but beds ranging up to 3 feet in thickness are not uncommon. The chert is highly jointed in all exposures examined. Black siliceous and carbonaceous shale layers ranging from paper thin to several feet thick are unevenly distributed through the formation. Because of the closely spaced joints and the shale interbeds, the chert layers have little rigidity and tend to disintegrate into knobs made up of accumulations of small blocks. The Bigfork conformably overlies the Womble shale and grades upward with a diminishing amount of chert into the Polk Creek shale.

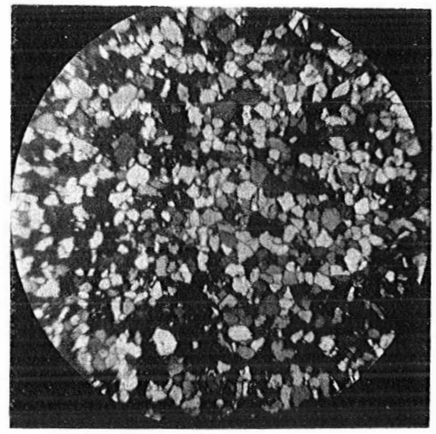
Ulrich, as cited by Miser and Purdue (1929, pp. 38-39), classified the Bigfork chert as Middle Ordovician, probably Trenton, in age on the basis of graptolites found in the formation. Decker (1952, pp. 1-145) more definitely established a Trenton age for the formation by correlating the graptolite fauna with that of the Athens shale.

Polk Creek shale. The Polk Creek shale (Purdue, 1909, pp. 30, 36) was named for Polk Creek in the Athens Quadrangle. It is typically developed along the headwaters of the creek in the Missouri Mountains. The Polk Creek shale, like the underlying Bigfork chert, is so crumpled that the true thickness could not be estimated. It ranges from a few inches to a maximum of 300 feet in thickness. Where the formation is less than 50 feet thick some evidence of truncation can be found. The shale is black, fissile and carbonaceous; in places, hard, slaty and siliceous; in places, soft and graphitic enough to soil the fingers. In most exposures examined where the cleavage is parallel to bedding planes, the cleavage surfaces are marked by abundant graptolite remains or impressions. Small pyrite crystals are common in fresh exposures of the slaty portions of the formation. Most of the

PLATE 2



(A)



(B)

(A) Photomicrograph of Blaylock sandstone showing interlocking of grains to give quartzitic nature, nose of anticline north of Chamberlain Creek syncline, sec. 21, T. 3S., R. 17 W. Plane polarized light; X 13.

(B) Same view with nicols crossed.

exposures of the formation are composed of weathered, gray platy cleavage fragments. Where the shale has weathered to clay the position of the unit was mapped as the topographic low between the Bigfork chert and the Blaylock sandstone. Although the Polk Creek appears to change gradually downward into the Bigfork chert, the graptolitic suites of the two formations indicate a depositional gap between their respective periods of accumulation. Because portions of the Bigfork are less cherty toward the top of the formation, the lithologic separation of the two formations is not accurate as mapped in all cases.

The Polk Creek shale appears to be conformable with the overlying Blaylock sandstone in most exposures. However, as noted by Miser and Purdue (1929, p. 44), in a few places a conglomerate is present at the base of the Blaylock. The Blaylock and Polk Creek were truncated by erosion prior to the deposition of the Missouri Mountain shale.

Decker (1935, pp. 698-700) classified the Polk Creek as Richmond (uppermost Ordovician) on the basis of the graptolites found in the formation.

Blaylock sandstone. The Blaylock sandstone (Purdue, 1909, pp. 30, 36) was named for Blaylock Mountain on the Little Missouri River in the Athens quadrangle. The sandstone, like the underlying units, is so thoroughly crumpled that the true thickness cannot be ascertained. Miser and Purdue (1929, p. 43) estimate the maximum thickness to be on the order of 1500 feet. The formation is thickest to the south and thins rapidly northward. Exposures of Blaylock have not been found north of the Missouri Mountains. A section of the formation exposed on the north side of the Cossatot Mountains in the S½ sec. 29, T. 4 S., R. 26 W., has enough continuity to be measured, although the top and bottom of the section are obscure because of structural features. The formation here is over 600 feet thick; however, less than three miles to the north it is absent (see measured section Table 1).

Sandstone is the chief rock type of the formation, but in some places shale is predominant. The more shaly portions may have been mapped as Missouri Mountain shale in some localities. The sandstone is mostly fine-grained, tan to gray, locally gray-green, and in even-bedded layers of which most are 1 to 6 inches thick, but some range up to three feet or more in thickness. Much of the sandstone is hard, quartzitic and closely jointed. Some is soft and laminated. Tan to brown weathered blocky joint fragments mark the surface trace of the formation in most of the region. The joints, most with thin quartz vein coatings on the edges, are of considerable help in distinguishing between the Blaylock and some of the more quartzitic sandstones of the Stanley formation. In a few places the sandstone contains flattened clay pellets which may mark a horizon within the formation, but this could not be proved because of the crumpled condition of the layers. Examinations of thin sections from widely separated areas within the region indicated that the Blaylock sandstone units are rather uniform in composition. Fine-grained, angular, interlocking quartz grains make up 80-85 percent of the rock, with clay minerals the next most abundant (Plate 2). Minor amounts of mica and chlorite are present in each section and all have some plagioclase, orthoclase, zircon, tourmaline, garnet, pyrite, limonite and leucoxene.

The Blaylock was deposited essentially parallel with the bedding of the underlying Polk Creek shale, but the presence of conglomerate locally suggests some degree of unconformity. The Blaylock and Polk Creek formations were considerably eroded before the overlying Missouri Mountain shale was deposited. The maximum amount of material removed during this period of erosion was about 1700 feet. There is conglomerate at the base of the Missouri Mountain in some places, but in most of the region the exposures are such that the stratigraphic relations could not be established.

Ulrich, as reported by Miser and Purdue (1929, p. 45), placed the Blaylock in the Lower Silurian on the basis of the graptolite fauna. Decker (1936, p. 309) correlated the formation with the lower Middle Silurian of England.

The period of deformation and erosion that followed the deposition of the Blaylock sandstone was of considerable importance in the geologic history of the Ouachita Mountain region. The Blaylock and older formations are strongly crumpled and closely joined. Quartz and calcite veins are more common than in the younger strata. However, the degree of metamorphism, which is slight, is not much greater than it is in the younger formations. The jointing, cleavage and crumpling patterns were probably only moderately developed during this period of deformation and became strongly developed in succeeding and more intense orogenic periods.

TABLE 1

Section of the Blaylock sandstone on the north flank of the Cossatot Mountains, S ½ of section 29, T. 4 S., R. 26 W.

Lithological Description	Thickness in Feet	
	Of Unit	To Base of Formation
Faulted zone, Stanley formation in contact with Blaylock sandstone.		
Concealed, mixed sandstone and novaculite float.	87	
Sandstone, tan to gray, fine to medium-grained, medium-bedded, highly jointed.	12	607
Shale, gray, micaceous and sandy.	13	595
Sandstone, gray, fine-grained, thin bedded, and intercalated gray shale.	18	582
Sandstone, gray, tan weathering, fine-grained, abundant quartz-lined joint faces.	13	564
Concealed.	18	551
Sandstone, brown, medium-grained, massive, some cross bedding.	8	533
Crumpled zone, thin-bedded tan sandstone and dark gray shale, thickness 40 to 150 feet.	50 ?	525
Sandstone, gray, brown weathering, medium-grained, thin to medium-bedded, highly jointed.	6	475
Concealed, stream fill.	18	469
Sandstone, tan to brown, fine to medium-grained, quartz-lined joint faces, quartz crystals abundant in float, thin to medium-bedded, some paper thin shale partings.	17	451
Shale, light gray, micaceous, blocky.	5	434
Sandstone, tan to brown, medium to coarse-grained, massive.	3	429
Sandstone, gray, fine-grained; shale, gray, sandy; and shale, dark gray, in thin lenticular beds.	23	426
Sandstone, gray, tan weathering, fine-grained, medium-bedded, highly jointed, abundant quartz seams and crystals.	19	403
Concealed.	6	384
Shale, gray, sandy, micaceous, unevenly distributed clay pellets.	9	378
Concealed.	16	369
Shale, black, micaceous, fissile.	18	353
Sandstone, tan, medium-grained, medium-bedded, scattered coarse quartz grains.	13	335
Sandstone, gray-green, fine-grained, thin-bedded, dark gray shale partings.	28	322
Sandstone, dark brown, fine to medium-grained, medium-bedded, some cross bedding, highly jointed.	7	294
Concealed, isolated patches of black fissile shale and thin-bedded sandstone.		
Sandstone, light gray, medium-grained, massive.	4	239
Crumpled zone, thin-bedded tan to gray sandstone and gray to dark gray shale, thickness 30 to 200 feet.	50 ?	235
Sandstone, gray, tan weathering, fine-grained, medium-bedded, abundant clay pellets 2 to 6 feet above base.	34	185
Shale, gray, finely micaceous, light gray siltstone stringers.	21	151
Overturned and faulted, 5 to 30 feet of section covered.	10 ?	130
Sandstone, tan, fine-grained, massive, some small quartz pebbles, some cross bedding.	14	120
Sandstone, dark gray to brown, fine-grained, thin-bedded, highly jointed, quartz seams along joint faces, some shale partings.	10	106
Concealed, stream fill.	11	96
Sandstone, brown, fine-grained, massive, minor cross bedding.	9	85
Sandstone, gray, tan weathering, fine-grained, highly jointed, abundant quartz seams, some shale lenses.	18	76
Shale, dark gray, sandy, brown fine-grained sandstone and siltstone streaks and lenses.	27	58
Sandstone, tan to brown, fine to medium-grained, medium-bedded.	6	31
Shale, dark gray, micaceous, silty.	2	25
Sandstone, tan to brown, fine-grained, medium-bedded, jointed, paper thin shale partings.	23	23
Concealed.	86	
South limb of anticlinal structure, Blaylock highly contorted where exposed.		
Total section measured		717

Missouri Mountain shale. The Missouri Mountain formation (Purdue, 1909, p. 37) was named for the Missouri Mountains in the Athens quadrangle. In most of the areas mapped during this study, the position of this unit was marked by the topographic low between a high ridge of Arkansas novaculite and a low ridge of Blaylock sandstone. Novaculite float is the surface cover in most of these areas. The formation is commonly referred to as slate, but the bulk of it probably should be classed as argillite. Miser and Purdue (1929), p. 46) give a range in thickness from 50 to 300 feet and state that sandstone, quartzite and conglomerate are present near the base and near the top of the formation in some localities. Petrographic studies could only affirm the excellent descriptions of Dale (1914, pp. 63, 64).

The formation, where observed in contact with Blaylock sandstone, appears to be conformable, but the conglomerate at the base and the overlap of the Blaylock and Polk Creek indicate the presence of an unconformity. In all exposures where the contact of the Missouri Mountain formation with the Arkansas novaculite could be studied, the strata were conformable. In some areas the formations appear to have a gradational contact. The massive beds of novaculite are underlain by interbedded shale and thin layers of novaculite. Megascopically, and, as far as could be determined microscopically, the shale is not different in any respect from the gray and black or red shale in the upper part of the Missouri Mountain. In other areas, notably in the vicinity of Hot Springs, Arkansas, and southeastern Oklahoma, a conglomerate separates the two formations.

Miser and Purdue (1929, pp. 48, 49) in discussing the age of the Missouri Mountain formation, state:

> No fossils have been found in the Missouri Mountain slate. Its correlation is therefore based upon its stratigraphic position and lithologic character. The position of the slate between the Blaylock sandstone, of early Silurian age, and the Arkansas novaculite, the lower part of which is Onondaga (middle Devonian) age, indicates that this slate is Silurian or Devonian. The nearest exposures of Silurian and Devonian rocks outside the Ouachita Mountains are in the Ozark region in northern Arkansas and northeastern Oklahoma, in the Arbuckle Mountains in southern Oklahoma, and on the southwest flank of the Nashville dome in Tennessee. The rocks of these systems are poorly represented in the Ozark region and Arbuckle Mountains, and no part of them resembles in lithology the Missouri Mountain slate. They are, however, well developed on the southwestern flank of the Nashville dome, where strata of Silurian age are succeeded by strata of Helderberg, Oriskany, Onondaga and later age, in the order named. Although the Silurian rocks of Tennessee consist mainly of limestone, they contain considerable thicknesses of earthy and shaly limestone, which, in the basal part of the strata of Niagara age, change in color from gray to red as the Mississippi embayment is approached. The rocks of Devonian age earlier than the Onondaga in Tennessee contain no beds with a red color. It seems reasonable, therefore, to assume that the Missouri Mountain slate is equivalent to at least a part of the Silurian rocks in Tennessee.

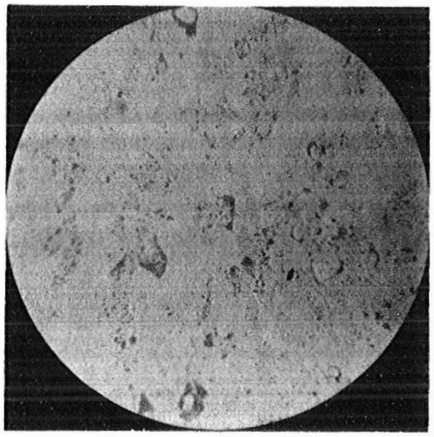
From a different line of reasoning, the writer would prefer to place the Missouri Mountain formation in the Helderberg (lower Devonian). In most exposures where the contact of the Missouri Mountain shale and the Lower Arkansas novaculite can be studied, the formations appear to be gradational. The Lower Arkansas novaculite contains no diagnostic fossils, but nearly all who have studied the formation place it in the Onondaga of the Devonian on a lithic and stratigraphic basis. The pre-Mississippian rocks in the Arbuckle Mountain region of Oklahoma are predominately carbonate, although thick sandstone and shale members are present. As shown by Decker (1935A, 1935B) and others, many of the zones in the Arbuckle Mountains can be directly correlated on the basis of paleontologic data with more siliceous zones in the Ouachita Mountains. The Haragan marl (Helderberg) of the Arbuckle region changing eastward by loss of carbonate into the Missouri Mountain shale is a less pronounced change than Woodford shale to novaculite or Viola limestone to Bigfork chert.

If the Missouri Mountain formation is more closely related to units in western Tennessee than those in the Arbuckle Mountains, the Olive Hill formation of Helderberg age is the most likely equivalent. The Olive Hill formation consists of clastic and carbonate members and contains zones of oolitic hematite which could be related to the source of the red iron oxide coloring much of the Missouri Mountain.

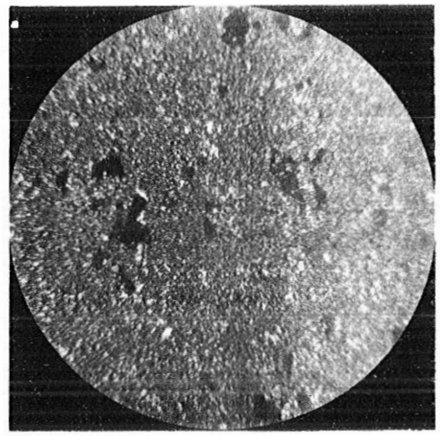
Arkansas novaculite. The Arkansas novaculite (Purdue, 1909, pp. 30, 45, 46) consists chiefly of an extremely fine-grained siliceous rock which is similar to, or a variety of chert. According to Griswold (1892, p. 20), Henry Schoolcraft in 1819 first applied the term novaculite to this rock. The formation contains appreciable amounts of shale, sandstone, and conglomerate. Nearly all the sandstone is quartzitic.

No type locality has been designated for the formation. The exposures at Caddo Gap along the Caddo River and Arkansas State Highway 27 are probably the most suitable to serve as

PLATE 3



(A)



(B)

(A) Photomicrograph showing rhomboid cavities lined with limonite (black) formed by leaching of carbonate crystals, lower upper novaculite, south limb of Chamberlain Creek syncline, Magnet Cove district. Plane polarized light; X 46.

(B) Same view with nicols crossed to show texture of novaculite.

examples of typical development of the formation. The formation is thicker in other places, but the exposures are not as good. Miser and Purdue (1929, pp. 54, 55) present a detailed measured section of the formation at this locality, and Hass (1951) made a comprehensive study of the conodonts found in the formation at this locality.

At Caddo Gap and many other places in the Ouachita Mountains, the formation is readily separated into three members, the characteristics of which are remarkably consistent throughout the region. The formation ranges in thickness from 250 to over 950 feet.

The lower division is made up almost entirely of massive white novaculite, the middle division consists of thin-bedded dark shale and novaculite, and the upper division is mostly massive, calcareous, light-colored novaculite. Each division differs from the others in color and character locally, but when more than one unit is exposed they can be separated readily.

Lower division. In most exposures in the region, the lower division ranges in thickness from 150 to 350 feet, but reaches a minimum of 10 feet in the northwestern part of the Caddo Mountains and a maximum of 450 feet in the Zig Zag Mountains. The upper portion of this unit consists of massive even-bedded layers of white novaculite which are 2 to 10 feet thick. Lentils of shale, sandstone, and breccia are present locally. However, these lithologies make up less than one percent of this part of the formation. In the lower portion of this division the novaculite beds are, in general, thinner than those of the upper portion. The lower units, in many places, are dark colored with black in predominance, but reds, yellows, and grays are well represented. Shale members up to 15 feet in thickness are also present in this portion of the section.

The most recent discussion of the age of the lower division of the Arkansas novaculite was given by Hass (1951, p. 2534).

> Only one fossil has been reported from the lower division of the Arkansas novaculite. This fossil, as previously stated, is the fragmentary brachiopod that Honess (1923, p. 117, text figure 4-2) discovered near the top of the lower division in southeastern Oklahoma on Boggs Springs Mountain in section 5, T. 3 S., R. 27 E. This specimen is now in the collection of the U. S. National Museum where it bears the catalog number 92762. Honess (1923, p. 117) submitted it as **Leptocoelia flabellites** and this determination has been accepted by some stratigraphers as establishing a Devonian age in the lower division of the novaculite. However, G. A. Cooper who recently examined Honess' specimen is of the opinion (oral communication, May, 1950) that Schuchert's identification was not justified because the fossil is very poorly preserved. On lithological grounds the lower division of the Arkansas novaculite has been correlated with the Pine Top chert, Ulrich (1927, p. 33), Miser (1934, p. 974), Miser (1944, pp. 134, 135); the Penters chert, Miser (1944, pp. 132, 134), Kenny (1946, pp. 611, 612); and the Camden chert, Miser (1917, p. 71), Purdue and Miser (1923, p. 5), Miser and Purdue (1929), p. 19), and Kenny (1946, p. 611). All these formations are classified by the U. S. Geological Survey as Lower or Middle Devonian.

Middle division. The middle division of the formation ranges in thickness from about 10 feet to 450 feet. It is composed of thin-bedded, dark novaculite, ordinarily in beds 1 to 6 inches thick and black to dark gray, fissile to slaty shale in beds ranging in thickness from a fraction of an inch to over 75 feet. In a few places the shale is red. In many places beds of conglomerate from 1 inch to 2 feet thick occur in this portion of the novaculite. The matrix and most of the contained pebbles are composed of novaculite, although pebbles of quartzitic sandstone and siltstone are not rare.

Hass (1951, pp. 2535-37) after studying the conodont assemblage in the middle division of the Arkansas novaculite classified the uppermost part of this division as Mississippian (Kinderhook) in age, with the portion below this Kinderhook section being Upper Devonian.

Upper division. The upper division is less extensive than the underlying divisions. Where it has not been removed by erosion it is 20 to 100 feet thick. It is light gray to black in color and because of a rather high carbonate content weathers to white or tan porous massive rock (Plate 3). In most exposures there are some layers of white chalcedonic novaculite, which, as seen in thin section, are less calcareous than the darker members. In the Zig Zag Mountains this division contains rather thick beds of quartzitic sandstone interbedded with white massive novaculite. The quartzitic nature of these sandstones is due to the interlocking of angular and irregular grains rather than to siliceous cement.

Hass (1951, p. 2540) on the basis of conodonts collected from this division of the novaculite in a road cut on U. S. Highway 71, 0.5 of a mile south of Hatton, Arkansas, places this division in uppermost Kinderhook or Osage of the Mississippian.

A large number of postulated origins of the Arkansas novaculite are presented in the literature. Branner (1888, pp. 368-371), Miser and Purdue (1929, pp. 55-57), Honess (1923), and Harlton (1953, p. 778), review all these postulates and defend some of them. It is the writer's opinion that it would be virtually impossible for silica to replace hundreds of cubic miles of calcareous rock and not leave some evidence of the replacement; therefore, he considers the novaculite to have been originally deposited as a chemical precipitate of silica.

TABLE 2

Section of the Arkansas novaculite through water gap, Reyburn Creek, SE 1/4 of section 13, T. 3 S., R. 17 W.

Formational Description	Thickness in Feet	
	Of Unit	To Base of Formation
Stanley shale—		
Shale, gray, blocky micaceous.	6	44
Shale, dark gray, platy, silt streaks.	13	38
Concealed, novaculite float and soil.	25	25
Upper novaculite—		
Novaculite, white, medium-bedded, blocky fractures.	6	818
Novaculite, gray, thin-bedded, with dark gray shale partings, poor exposures.	18	812
Novaculite, white to gray with black streaks, massive, breaks into blocks 3′ to 8′ in diameter.	42	794
Novaculite, dark gray and shale, dark gray to black, in thin beds (½″ to 4″), some slickensides.	9	752
Novaculite, gray to buff, massive breaks into small triangular blocks.	26	743
Middle novaculite—		
Novaculite float, white, yellow, red and gray.	45	717
Novaculite, light gray, chalcedonic, bedding or psudo-bedding ⅛″ to ¼″ to 2′ to 4′ units separated by 6″ to 18″ units of intercalated black shale and dark gray novaculite. Surface is mostly covered with rectangular blocks.	75	672
Novaculite float, mostly light gray chalcedonic, conchoidal fracture predominate.	28	597
Novaculite, black, dense, 2″ to 12″ layers with intercalated shale, black, siliceous, platy. Section intensely jointed, surface mostly covered with 2″ to 4″ rectangular chips.	110	569
Concealed.	12	459
Lower novaculite—		
Novaculite, white, massive, blocky joints, some slickensides.	80	447
Novaculite, white, dense, medium to thick-bedded, some laminated translucent sections.	115	367
Concealed.	32	252
Novaculite, white to light gray, dense, medium-bedded, intensely jointed; novaculite breccia float zone probably occurs near the top of this unit; it was not found in place and may come from the overlying concealed zone.	185	220
Novaculite, black, dense, thin to medium-bedded, some intercalated shale, black, siliceous, platy.	35	35
Missouri Mountain shale—		
Shale, black, green to red weathering, fissile to slaty; black novaculite stringers near top.	62	62
Blaylock sandstone—		
Sandstone, gray to brown, mostly tan, quartzitic, fine to medium-fine grained, gray shale partings, quartz veins abundant, breaks into characteristic rectangular blocks.	18	18
Concealed.		
Total section measured		942

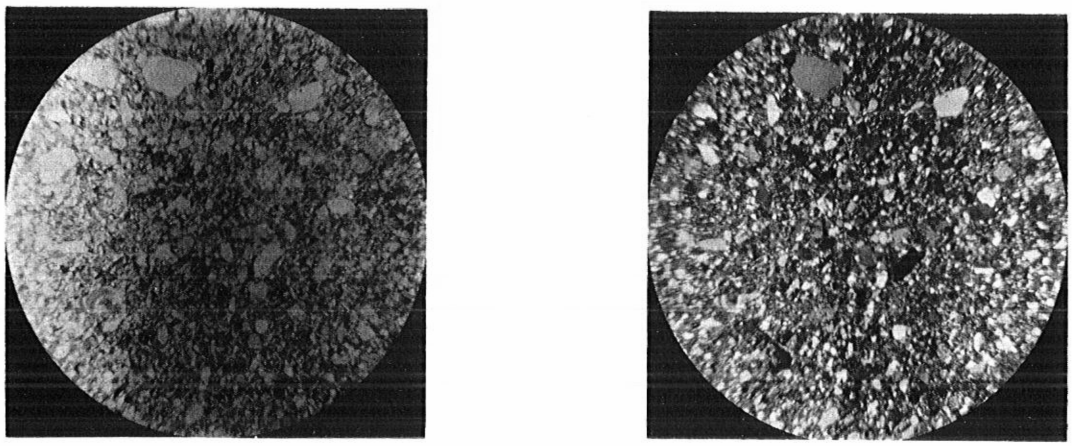
Stanley shale. The general character of the Stanley shale (Taff, 1902) has been excellently described by Miser and Purdue (1929, pp. 59, 60), who state:

> The Stanley shale took its name from the village of Stanley (formerly spelled Standley), in Pushmataha County, Oklahoma. It consists mainly of shale, though it contains much sandstone and a little tuff and conglomerate. The thickest bed of tuff, which is near the base, has been mapped and is herein described as the Hatton tuff lentil, taking its name from the village of Hatton, in the De Queen quadrangle, where it is excellently exposed. In places shale at the base has been changed to a slate that was formerly called the "Fork Mountain slate," from Fork Mountain, where it is well developed. The Stanley belongs to the Carboniferous system, and represents a part of the Mississippian series. Except the tuff and the conglomerate none of the beds have distinguishable characteristics. On this account and because the formation is much folded, the exact determination of the thickness is impossible, but an approximate thickness of 6000 feet was measured from 1 to 2 miles southwest of Glenwood, in the Caddo Gap quadrangle. The Stanley shale is the surface rock in the Mazarn and Cove Basins, over most of the Athens Plateau, and in the narrow valleys in the mountainous districts—an area of outcrop much larger than that of any other formation. The sandstone of the Stanley weathers so easily that it nowhere produces prominent ridges. In fact, the formation is exposed only in valleys, basins, or low plateaus.

Only the lower 1500 feet of the Stanley was studied in the barite areas, and except where correlatable information was available only the lower 100 to 300 feet could be studied with any accuracy in relationship to thickness and lithological composition. In almost all of these areas the Stanley is predominantly shale, most of it silty, although there are thick sandstones and siltstones and some conglomerate present in the lower part of the formation. This shale, where fresh, is dark gray to black, ordinarily rather micaceous, in places fissile, in places blocky. The shale weathers to a yellowish green which is typical of the Stanley.

The sandstones are light to dark gray and mostly fine-grained, although medium-grained

PLATE 4



(A) (B)

(A) Photomicrograph of a sandy siltstone in the lower part of the Stanley formation in southern Montgomery County. Plane polarized light; X 13.

(B) Same view with nicols crossed.

phases are present. Quartzitic, sandy siltstones are more common than sandstones. The sandstones and siltstones less than three feet in thickness ordinarily contain from 20 to 50 percent clay, chlorite, and micaceous minerals. The thicker sandstones and siltstones which range up to 65 feet ordinarily contain less than 10 percent clay, chlorite, and mica. In many places the siltstones and particularly the sandstones are weathered to a punky, porous rock. On the south side of Gap Mountain, sec. 19, T. 4 S., R. 25 W., a conglomerate lentil ranging up to 18 inches in thickness is present 15 feet above the top of the novaculite. It consists of a matrix of black chert and of pebbles of novaculite, slate, and quartzite that range from pea size up to an inch and one-half in diameter. This conglomerate overlies a silt-free clay shale and underlies a very silty shale.

Studies of thin sections show that there are three predominant types of shale in the lower part of the Stanley. These types grade into each other horizontally and vertically, and cannot be used for stratigraphic or structural control. The most abundant type, which makes up perhaps 60-65 percent of the Stanley shale, is a silty variety. It contains 30-40 percent silt-size particles of which about 95 percent are quartz, the rest being feldspar grains. Clay minerals make up 40-60 percent of this rock type, with mica and chlorite each making up 5-10 percent of the rock. Minor amounts of pyrite, magnetite and carbonate are present in all sections examined. Zircon and tourmaline are the only consistent accessory minerals. Rutile and garnet were noted in some thin sections. P. T. Flawn considers the garnet an indicator for the Stanley in the Ouachita belt of Texas (personal communication). Honess (1923) noted the presence of irregular garnet grains in the Stanley of Southeastern Oklahoma.

The next most abundant type is called clay shale. It contains less than one percent silt-sized particles, less than 5 percent mica, and less than 5 percent chlorite. The bulk of the rock is made up of clay particles. Magnetite and pyrite are persistent accessory minerals. The third type is called carbonaceous shale. It is characterized by enough carbonaceous material to soil the fingers when crushed. It contains up to 15 percent siltsized particles, less than 10 percent carbonaceous material, and some mica, chlorite, and carbonate. However, most of the minerals are masked by the black carbonaceous material and iron oxides.

Studies of thin sections of the siltstones and sandstones show that these rocks when composed of fine-grained material are characterized by angular to subangular fragments (Plate 4). When only small percentages of mica, chlorite, and clay are present, these angular fragments, mostly quartz, are interlocking and give the rock a quartzitic nature. Siliceous cement is present in some of these rocks, but ordinarily clay is the binding material.

In the southern part of the Arkansas Paleozoic region the Stanley shale, as far as can be determined, conformably overlies the upper member of the Arkansas novaculite. To the north the Stanley was laid down on an erosion surface truncated as deeply as the Bigfork chert prior to the Stanley deposition. The Stanley rests on the Bigfork in the Mount Ida quadrangle, which is near the center of the Ouachita Mountains; and consequently the erosion interval represented by the stratigraphic gap is presumably associated, at least in part, with the post-Blaylock-pre-Missouri Mountain period of erosion.

In the Hot Springs quadrangle (Purdue and Miser, 1923) the Stanley overlies the Hot Springs sandstone which is a lenticular unit resting on the novaculite. In this quadrangle much of the basal portion of this unit is conglomerate which is as much as 35 feet thick in places. The Hot Springs sandstone has not been traced east or west out of the Hot Springs quadrangle; and as conglomerate occurs beneath shale and above the novaculite in many other parts of the region, the Hot Springs sandstone is probably a facies of the basal part of the Stanley and should not be considered as a separate formation. The Stanley is conformably overlain by the Jackfork sandstone.

Hass (1950, pp. 1578-84) on the basis of conodonts collected from the Stanley shale at Caddo Gap on Highway 27, places the lower part of the Stanley shale in the Meramec (Mississippian).

Jackfork sandstone. The Jackfork sandstone (Taff, 1902) was named for Jackfork Mountain in Pittsburg and Pushmataha Counties, Oklahoma. Only partial sections of the formation are exposed in the barite areas, and no attempt was made to establish the thickness. Miser and Purdue (1929, p. 75) recorded a maximum thickness of 6,600 feet for the Jackfork in the De Queen and Caddo Gap quadrangles. The exposures of the formation observable in these quadrangles indicate that the Jackfork consists of over 90 percent sandstone. Shale and a minor amount of conglomerate comprise the other lithologies within the formation. In the northern part of the Ouachita Mountains of Arkansas, the Jackfork consists of over 25 percent of shale and over 70 percent of sandstone.

The sandstone units within the Jackfork range in thickness from two or three inches to over eighty feet. The grain size ranges from fine to pebble, but over 50 percent of the grains are in the medium grain category. The pebble lentils are irregularly distributed within the formation. Honess (1923, pp. 196-202) in describing similar lentils in the Stanley, gives several of the more reasonable modes of origin for these coarse-grained aggregates.

The sandstones of the Jackfork, where fresh, are light gray to gray and weather to tans and browns. In places, the sandstones are strongly bound with siliceous cement (the orthoquartzite of many sedimentary petrologists) and disintegrate during weathering into an angular talus. Where the cementation is lacking the sandstones disintegrate into sand hills. The topographic relief of these sand hills appears to be related to grain size. Inspection of grab samples from several localities indicated that the higher hills were composed of coarser material.

In thin section studies of Jackfork sandstone, minor amounts of thoroughly altered feldspar, chlorite, magnetite, pyrite, zircon and tourmaline were observed. Less than two percent of any of these sections is made up of non-quartz minerals. In some sections carbonaceous material was present in amounts ranging up to five percent.

The Jackfork conformably overlies the Stanley shale throughout the Ouachita belt of Arkansas and Oklahoma. In the southern part of the Arkansas Ouachitas, the Jackfork conformably underlies the Atoka formation. Elsewhere in the Ouachitas the stratigraphic relations of the upper part of the Jackfork are not well defined. This is particularly true in southeastern Oklahoma where the geologic and paleontologic complexities are better developed. The main controversy centers about the John's Valley boulder-bearing shale which apparently overlies the Jackfork and underlies the Atoka. The actual relationships of the Atoka, John's Valley, Jackfork, Stanley and the Chester and Morrow units of the Arkansas Valley and the Ozark region cannot be established until the frontal Ouachitas have been adequately mapped.

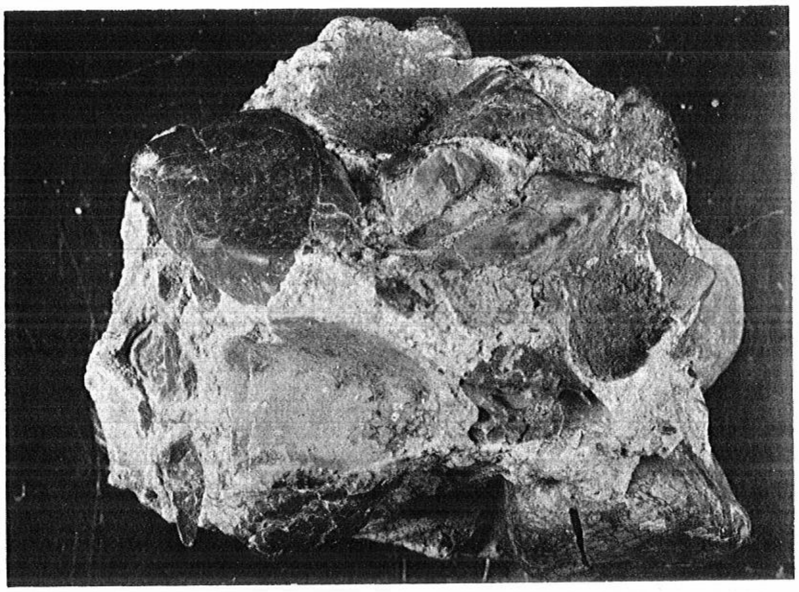
The evidence already available seems adequate to form a generalized opinion on the age of the Jackfork. In the Ozark region the Atoka overlies the lower Pennsylvanian Morrowan formations. Regional studies indicate that only the upper Atoka is represented in this region. In the Arkansas Valley the Morrowan is overlain by middle and lower Atokan units. The lower part of the Stanley shale is Meramec. There is a maximum of 11,000 feet of Stanley and Jackfork between the known Meramec and post-Morrow. The flora and fauna in this section indicate either upper Mississippian or lower Pennsylvanian depending on the philosophy of the investigator. The systemic boundaries were established in highly fossiliferous carbonates and comparatively thin clastic sediments. It is doubtful that the systemic boundary is represented by a distinctive lithologic change or floral or faunal development within Stanley-Jackfork sequence. It would seem that at least part of the Jackfork is equivalent to the Morrow of the Arkansas Valley, and that the Mississippian-Pennsylvanian boundary is nearer the zone where the predominant shale of the Stanley is succeeded by the predominant sandstone of the Jackfork than to the top of the Jackfork.

Cretaceous Rocks

Trinity formation. The Trinity group (Hill 1888, p. 21) was named for its extensive exposures around the headwaters of the Trinity River in Texas. From this area it crops out in an almost continuous belt northward into southern Oklahoma and eastward into southwestern Arkansas. Miser and Purdue (1929, p. 80), in describing the Trinity, state:

> It consists of clay, sand, gravel, limestone, gypsum, and celestite, the most abundant named first and the least abundant last. The limestone occurs in two beds; the Dierks limestone lentil, the older, near the base, and the De Queen limestone member, the younger, near the middle of the formation. The first was named from Dierks, in the De Queen quadrangle, near which it is exposed, and the second was named from De Queen, where it is exposed. The gravel also occurs as two beds, the Pike gravel member at the base, and the Ultima Thule gravel lentil, which is above the Dierks limestone. The Pike gravel was named from the village of Pike, in the Caddo Gap quadrangle, and the Ultima Thule gravel was named from the village of Ultima Thule, in the De Queen quadrangle. These four lentils and members and the interbedded sand and clay of the Trinity dip about 100 feet to the mile toward the south. Although the Trinity lies nearly horizontal, it rests upon the truncated upturned edges of steeply dipping shale and sandstone of Carboniferous age, which, however, form a floor that has only minor irregularities and undulations. A pronounced unconformity, therefore, occurs at the base of the Trinity. A notable though less striking unconformity exists at the top of the formation, as shown by the eastward truncation of its beds, and the resulting overlap of the Woodbine for-

PLATE 5



Photograph of calcite cemented Pike gravel, Dierks district, natural size. (Photographer, Harry Smith, Jr.)

mation and the overlying Tokio formation, both of Upper Cretaceous age.

The Trinity examined for this report crops out in Tps. 7 and 8 S., Rs. 26 to 30 W., in an area roughly bounded on the east by the Muddy Fork River and on the west by the Cossatot River. Within this area the clastic parts of the group are quite variable in thickness, but the carbonates are consistent enough to serve as suitable mapping horizons. The Pike gravel within this area ranges in thickness from 20 to 120 feet and the sand overlying it ranges from 50 to 100 feet in thickness. The Dierks limestone ranges from a minimum of 10 feet in thickness to a maximum of 50 feet. On the average it is about 40 feet thick. Its base is 100 to 200 feet above the base of the Trinity throughout most of the area; however, in a few localities it overlaps Carboniferous sandstone which jutted out into the old Cretaceous sea as a rocky headland. Throughout most of the area the base of the De Queen limestone is about 150 feet above the top of the Dierks limestone. The intervening section consists of various sand and clay lentils and the Ultima Thule gravel. The De Queen limestone is about 70 feet thick and is of particular interest because near its base in certain areas are gypsiferous beds and in a few localities celestite lentils.

As a whole the clastics of the Trinity are bound by clay or are loosely consolidated. In some areas iron oxide cements the gravels and the sands forming a rather resistant rock which stands up as low ridges along the summits of low hills. In a few areas calcium carbonate serves as cementing material (Plate 5). In some localities near Dierks, barite cements the lower sand and the Pike gravel of the Trinity.

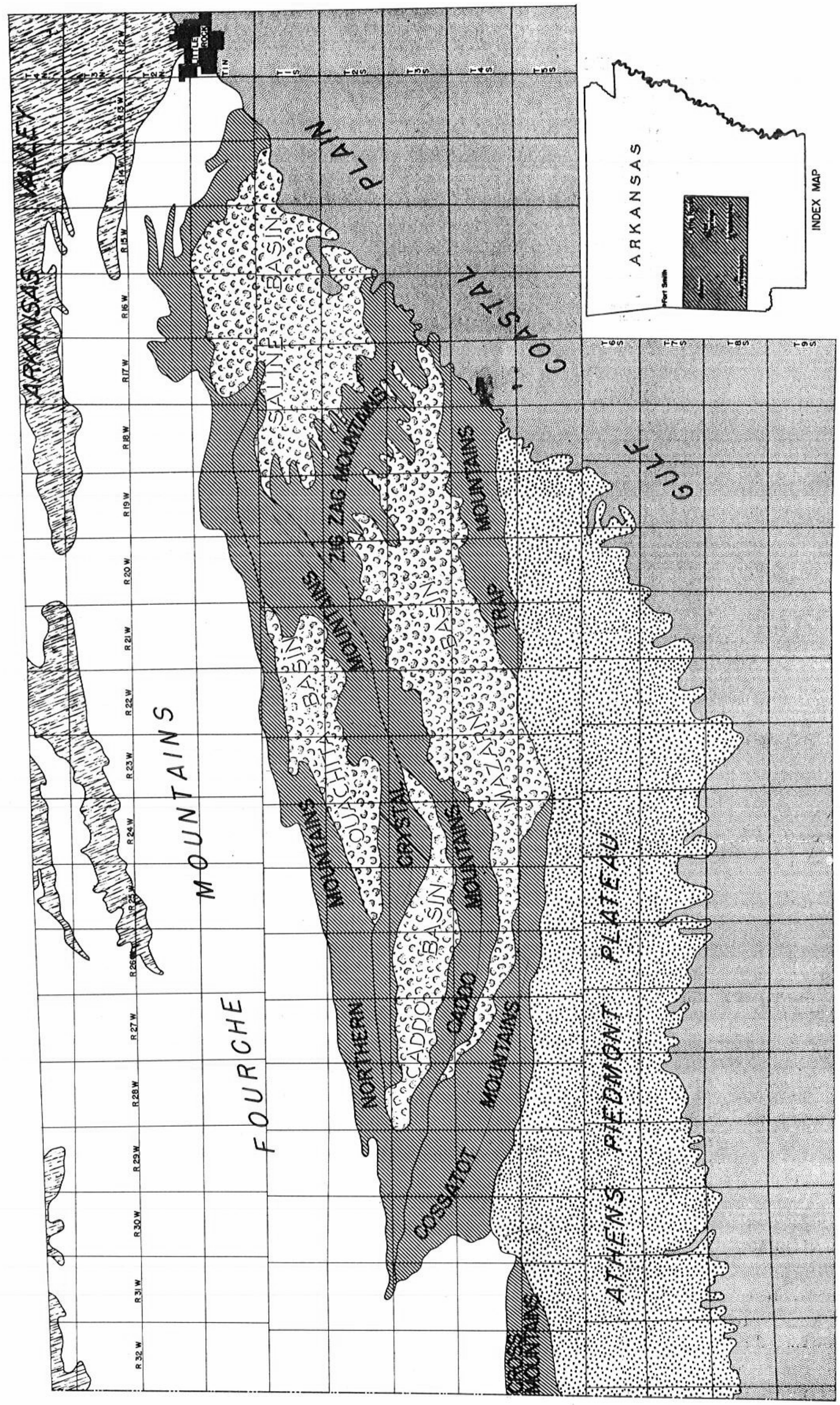
Both the Dierks and the De Queen limestones contain brackish water and marine molluscan elements. T. W. Stanton, as reported by Miser and Purdue (1929, p. 85), stated that they occur in the Trinity group of Texas and show a definite relationship to those of the Glenrose limestone of that state.

Woodbine formation. The Woodbine formation (Hill, 1901, p. 293) was named for exposures at Woodbine, Cook County, Texas. At the type locality and northward in Texas and in parts of southern Oklahoma, the formation is predominantly sand, but eastward in southeastern Oklahoma and southwestern Arkansas tuffaceous material make up a large part of the formation. The Woodbine is the basal unit of the Upper Cretaceous in the area studied and unconformably overlies the Lower Cretaceous Trinity. A rather complete description of the formation is given by Miser and Purdue (1929, pp. 86-90). Although the Woodbine crops out south of the known barite deposits of the region discussed in this report, it is of considerable importance because its volcanic component is one of the factors used in determining the age of the barite mineralization.

Igneous rocks. Igneous rocks occupy only a small area in the Arkansas barite region; however, these rocks form one of the most interesting suites of igneous rocks in the world. They have an unusual chemical and mineralogical composition and contain well formed mineral crystals, many rare, that for the last 150 years have been sought by collectors.

Intrusive igneous masses crop out in five well-defined areas in southwestern Arkansas: the Pulaski County region immediately south of Little Rock; the Saline County region a few miles east of Benton; the Magnet Cove region in Hot Spring County a few miles west of Malvern; the Potash Sulphur Spring region in Garland County, a few miles east of the town of Hot Springs; and the Pike County area southeast of Murfreesboro. In the first four areas, the rocks are predominantly syenitic and mafic varieties, although the rock types in each area are somewhat distinctive from those in other areas. The syenites in Pulaski and Saline Counties are the parent rock from which the Arkansas bauxite deposits were derived. In the Murfreesboro area the igneous rocks are peridotitic plugs which are particularly noted for the diamonds they contain. Outside of these five typical areas there are numerous dikes which as far as their petrographic character is concerned could be associated with any or all of the plutonics. The rocks in the syenitic areas and the dikes undoubtedly have a common source. It cannot be definitely demonstrated whether they are related to the plugs at Murfreesboro. As all of these rocks are Cretaceous in age, it is probable that they are genetically related.

In the subsurface of southern Arkansas, northern Louisiana, and eastern Texas, wells drilled by the petroleum industry have encountered igneous rocks that can be demonstrated in many cases to be of Cretaceous age. In Texas, at least as far southwest from Murfreesboro as Austin, igneous rocks are exposed at places at the surface. Mineralogically, and chemically, these rocks in Texas appear to be genetically related to the syenites of Arkansas. The writer believes that all the surface and



GENERALIZED REGIONAL STRUCTURE MAP OF THE OUACHITA MOUNTAINS, ARKANSAS subsurface igneous rocks of Cretaceous age in Arkansas represent one period of igneous activity. The rocks are all of a silica-deficient variety (Moody, 1949; Williams, 1891), are characterized by a rather high titanium content, and nearly all contain more carbonate than the average igneous rock.

For more detailed information on the igneous rocks of Arkansas the reader should consult Williams (1891) for references to those rocks outcropping at the surface; Miser and Ross (1923) who have described the peridotite of Pike County; and Moody (1949), who has described many of the igneous rocks encountered in the subsurface in this area.

Regional Structure

General Statement

The region under consideration comprises elements of the Ouachita Mountains and the Gulf Coastal Plain. The barite region is arbitrarily defined and contains the southern part of the Ouachita Mountain system and the northernmost part of the Gulf Coastal Plain.

Ouachita Mountains

General discussion. The structural configuration of the Ouachita Mountain system has been described by Griswold (1892), Purdue (1909), Purdue and Miser (1923), Honess (1923), Miser and Purdue (1929), Croneis (1930), and van der Gracht (1931). In all these reports the structural pattern of the Ouachita Mountain system is described only in a general manner because the details of the structure of this region have not as yet been mapped.

The deformational history of the Ouachita Mountain system has been such that primary, secondary, and tertiary orders of folding can be recognized. The primary or central axis of the deformation has been variously called the Ouachita anticline, the Ouachita Mountain anticlinorium, and the novaculite uplift. The writer prefers the term Ouachita Mountain anticlinorium because of the geographic connotation and the implication of relationship to subsidiary structures. This axis of deformation extends from near Little Rock to the Arkansas-Oklahoma border where it plunges to the west, then rises again to form the Ouachita Uplift of the southeastern Oklahoma mountainous area. To the north and south of this main axis are various mountain ranges which in themselves are anticlinoria or synclinoria. These comprise the second order of folding. The individual synclines and anticlines in these mountainous areas are the tertiary order of folding.

The barite region of Arkansas as defined (Plate 6) contains elements of the Crystal, Caddo, Cossatot, Cross, Zig Zag, and Trap Mountains, and portions of the Caddo, Cove, Mazarn, and Saline basins. The Athens Plateau is stratigraphically and structurally related to these other features.

Mountain systems. Cross Mountains. The Cross Mountains are an extension of an anticlinorium rising in McCurtain County, Oklahoma. The anticlinorium as a whole has a length of about 30 miles, of which the eastern 11 miles is in Arkansas. Its greatest width is about 4 miles in the Arkansas portion of the mountains. The Blaylock sandstone is the oldest formation exposed; however, in McCurtain County, Oklahoma, the Bigfork chert is exposed at the core of the mountains. These mountains are formed by anticlinal ridges which along much of their flanks are overturned to the south so that the beds dip to the north on both sides of the ridge. The Athens Plateau forms the southern boundary of the Cross Mountains and the Cove Basin forms the north boundary.

Cossatot Mountains. The Cossatot anticlinorium extends north and west 45 miles from Glenwood in T. 5 S., R. 24 W. The greatest width of the anticlinorium is about 7 miles in the central part where the amount of uplift was the greatest. The axis of maximum uplift is just north of Pryor, Blaylock, Brushheap, and Raspberry Mountains. The Bigfork chert, the oldest strata exposed in this system, crops out in a belt along the axis. The belt of Bigfork exposure is about 14 miles long and a tenth to a half-mile in width. Although the rocks in the Cossatot anticlinorium are intensely folded (see Miser and Purdue, 1929, Pl. 6, p. 20, fig. 6, p. 122), their regional position is essentially as tightly folded wrinkles on the south flank or monocline of the Ouachita Mountain anticlinorium. There are several high-angle thrust faults within the Cossatot Mountains. They strike parallel to the ridges and therefore parallel to the anticlinal axes. The strike length of these faults ranges from 1 to 15 miles. The stratigraphic displacement along most of them can be measured in hundreds of feet. However, the physical displacement cannot be ascertained accurately as the formations within the mountain system are repeated numerous times because of the intense folding. Displacement along some of these faults may be measured in thousands of feet. The Cossatots are bounded on the south by the Athens Plateau and on the north by a westward extension of the Mazarn Basin. However, in their northwestern portion they abut against the folds of the Caddo Mountains.

Caddo Mountains. The Caddo Mountains trend a little south of east from T. 2 S., R. 31 W., to Caddo Gap, from where they trend northeastward to the Ouachita River in T. 2 S., R. 21 W. These mountains have a total length of 65 miles and range in width from 2 to 10 miles. West of the Caddo River they are aligned in parallel ridges. On the east side of the Caddo River they are in echelon or zig-zag arrangement. The Bigfork chert is the oldest formation exposed within these mountains, and the Stanley, which crops out in some of the closely folded synclines, is the youngest. The western one-fourth of the Caddo Mountains are structurally aligned along the westward plunging axis of the main Ouachita Uplift. The other parts of this range are anticlinoria on the south flank of the main uplift. The western end of the Caddo Mountains, like the Cossatots, is overturned in such a way that the overall picture of these structures is that of a fanfold. In the western part of the Caddo Mountains there are a great number of high-angle thrust faults, most of which are less than 2 miles in strike length. The fault at Caddo Gap is one of the most readily recognized faults in the area. All the ridges in this mountain range have cores of the resistant Arkansas novaculite. Most of the longer ridges have a simple anticlinal structure, although many are monoclinal or synclinal throughout their entire length or part of it. Many of the higher peaks are of a complex structure, with as many as five folds being present.

Crystal Mountains. There is considerable confusion in the literature concerning the Caddo Mountain and Crystal Mountain topographic units as related to their structural relationships (Griswold, 1892, pp. 196-200; Croneis, 1930, pp. 338-44; Miser and Purdue, 1929, pp. 118-22). The Crystal Mountains as a topographic unit extend from the northernmost part of T. 3 S., R. 27 W., slightly south of east to T. 3 S., R. 24 W. From there the trend is northeastward to the middle fork of the Saline River in T. 1 N., R. 18 W. Throughout this length the structure is a single anticlinorium whose axis coincides with the axis of the main Ouachita Mountain anticlinorium. The Caddo Mountains where they are separated from the Crystal Mountains by the Caddo Basin have a major axis and form a separate anticlinorium. At their western end, however, because erosion has not stripped back this portion of the younger sediments from the anticlinorial structure of the older sediments of the Crystal Mountains, the Caddo Mountain anticlinorium coincides in this area with the Crystal Mountain anticlinorium. This is the area where the Ouachita Mountain anticlinorium plunges to the west.

The sedimentary rocks exposed in the Crystal Mountains are all older than the Bigfork chert and are not involved in the barite problem. The Collier shale, the oldest known formation in the Ouachita Mountains, is succeeded in ascending order by the Crystal Mountain sandstone, Mazarn shale, Blakely sandstone, Womble shale. The Mazarn, Blakely, Womble, and Crystal Mountain are Ordovician in age, and although on the state geologic map the Collier is shown as Cambrian, in the writer's opinion it is also probably Ordovician.

Zig Zag Mountains. The Zig Zag Mountains adjoin the Caddo Mountains near Mountain Pine in T. 2 S., R. 20 W. They extend eastward to the Gulf Coastal Plain in R. 16 W. The range is bounded on the north by the Saline Basin and on the south by the Mazarn Basin. The individual anticlines and synclines in this range trend northeastward almost at right angles to the general trend of the Ouachita Mountain anticlinorium. The Bigfork chert (Ordovician) is the chief formation exposed in the Saline Basin and the Stanley shale (Mississippian) is the chief formation exposed in the Mazarn Basin, indicating that the Zig Zags stand as transverse structures on the flank of the Ouachita anticlinorium. Tongues of Bigfork chert extend southwestward along the crests of the truncated anticlines, and tongues of Stanley shale extend northeastward in the synclinal structures. Most of the folds are isoclinal with axial plane vertical or overturned to the south. Some of the overturning reported in earlier papers is the result of slumping of nearly vertical massive beds of Arkansas novaculite and not wholly the result of structural deformation. The Zig Zags at their southeastern extremity may merge with the Trap Mountains on the south.

Trap Mountains. The Trap Mountains may have overridden the Zig Zag Mountains by thrust faulting. At their eastern end, in Tps. 3 and 4 S., R. 17 W., the Trap Mountains are overlapped by the Tertiary sediments of the Gulf Coastal Plain. This mountain range extends 35 miles slightly south of west from the coastal plain to the northernmost part of T. 5 S., R. 22 W. The mountains consist of about 30 steeply folded, elongate, narrow anticlinal ridges, with narrow steep intervening synclinal valleys. Many of the folds are overturned to the north, but many others are fanfolds. In the northeastern portion of the range a few of the anticlines are broken by thrust faults. The amount of displacement is not known. In a few places small patches of Bigfork chert and Polk Creek shale crop out. The Blaylock sandstone and the Missouri Mountain shale are exposed in the more deeply eroded anticlines. Nearly all of the ridges are held up by the Arkansas novaculite; however, a few toward the western end are composed of resistant sandstones of the Stanley. The Trap Mountains are bordered on the north by the Mazarn Basin and on the south by the eastward extension of the Athens Plateau.

Basins. Cove Basin. Cove Basin, like the Cross Mountains, extends into Arkansas from the area of its maximum development in Oklahoma. On the south Cove Basin is bounded by the Cross Mountains and on the northeast and east by the Cossatot Mountains and Athens Plateau. Its narrowest portion, the southeast extension between the Cross and Cossatot Mountains, has a minimum width of 6 miles. Structurally, the basin is a synclinorium with low, narrow, steep-sided, eastward-trending ridges in which sandstones of the Stanley formation are the chief components. As there is no marker bed suitable as a mapping datum in this formation, detailed delineation of local structures is difficult. However, on the larger anticlines, erosion has been sufficiently deep to expose the tuffaceous beds that occur near the base of the formation. These tuff beds are excellent datum planes for mapping local structure.

Caddo Basin. The Caddo Basin lies between the Caddo Mountains on the south and the Crystal Mountains on the north. The rocks exposed in the Caddo Basin are the intensely crumpled Ordovician formations. The topography is more diverse and somewhat more rugged than the surrounding areas where the long narrow ridges of novaculite control the erosion pattern. The Caddo Basin lies along the main axis of the Ouachita Mountain anticlinorium in its western portion, and along the south flank in its eastern portion.

Saline Basin. The Saline Basin lies north of the Zig Zag Mountains. It is bordered on the north by the Northern Mountains. As in the Caddo Basin, the surface rocks belong to the Ordovician, and are highly crumpled. The main axis of deformation is the main axis of the Ouachita Mountain anticlinorium. The eastern end of the Saline Basin is overlapped by the Tertiary sediments of the Gulf Coastal Plain.

Mazarn Basin. The Mazarn Basin is a large synclinorium on the south flank of the Ouachita Mountain anticlinorium. It is bounded on the north by the Caddo and Zig Zag Mountains and on the south by the Cossatot and Trap Mountains. The basin is completely surrounded by novaculite ridges except on the south side where the Stanley shale is the surface formation for about 7 miles. The length of the basin is about 60 miles and its greatest width is about 10 miles. The surface is marked by low parallel sandstone ridges and narrow valleys, most of which trend slightly north or south of east. Except for novaculite in Pigeon Roost, a prominent anticlinal mountain in T. 4 S., R. 23 W., and the alluvium of the stream valleys, the Stanley shale is the surface formation throughout the basin. The beds of Stanley are closely folded and ordinarily lack any distinguishing features which would make it possible to map structures. Locally, persistent quartzitic siltstones can be traced for several miles and recognized in adjoining folds. The major structural axis of the Mazarn synclinorium is of the same order, secondary, as the axes of the various mountain ranges. South of this axis, the axial planes of the tertiary folds are overturned to the north; north of it they are overturned toward the south.

Athens Plateau. Miser and Purdue (1929, pp. 123, 124), in discussing the Athens Plateau state:

> The general structure of the Athens Plateau is that of a southward-sloping monocline corrugated with many minor folds. These folds are nearly parallel and have a general south of west trend. Toward the west their trend and that of the Ouachita anticline diverge and they pass on both sides of the eastward-plunging Cross Mountains anticline. The most conspicuous and easily distinguishable folds are formed by the Jackfork sandstone and the Atoka formation. Although each of these formations is about 6000 feet thick, the beds stand at steep angles, having dips that commonly exceed 50°, and in some places they are overturned. The usual direction of the overturning is from the south.
>
> Although the Stanley shale, which is also exposed on this plateau, has a thickness of 6000 feet, it is folded many times and doubtless much faulted and overturned in its wide beds of outcrop, but the lack of distinctive beds, except the Hatton tuff lentil and the associated beds of tuff, makes the determination of the folds nearly impossible. Although the dips and strikes differ somewhat, most of the strikes have an eastward trend and most of the dips are 40° or more.

These writers (p. 125) describe a cross fault in T. 6 S., Rs. 23 and 24 W., with a displacement, probably mostly horizontal, of several thousand feet. After the discovery of quicksilver in 1930, Branner (1932, p. 11), in discussing these deposits, named the Amity fault. During the 1930's there were a number of papers written concerning the quicksilver district of Arkansas. Most of these are summarized individually in Reed and Wells (1938, pp. 18-20). This mineralized belt extends along the strike of the sediments, essentially south of west except at its eastern end where it makes a southeastward bend along the Amity fault. A major thrust, first recognized by Stearn (1936) and named the Cowhide thrust by Reed and Wells (1938, p. 33), extends from one end of the district to the other. The quicksilver district, as defined by these authors, extends from sec. 13, T. 7 S., R. 27 W., in eastern Howard County, to sec. 5, T. 7 S., R. 22 W., in Clark County. The belt has a maximum width of six miles. Throughout the length of this thrust zone, the sediments are broken by tear faults and several prominent sets of fractures. Cross folds also are numerous. Much of this district is now under the waters of Lake Greeson formed by the impounding of the Little Missouri River.

Age of the Ouachita Orogeny

The writer has spent most of the last four years studying the rocks of the Ouachita Mountain region and those of the adjoining geologic provinces. During this period, surface mapping, both reconnaissance and detail, subsurface studies in mines and of the samples and electric logs of drilled wells, the measurement and construction of two geologic cross sections (jointly with K. D. White, Continental Oil Company) from the Gulf Coastal Plain northward across the Ouachitas and the Arkansas Valley to the Ozark Platform, and extensive and critical review of the available literature concerning the region has led the writer to the formulation of definite opinions on the age of the Ouachita orogeny. These opinions are tempered by information from discussions with geologists such as E. B. Brewster, B. H. Harlton, H. D. Miser and C. W. Tomlinson, all of whom are authorities on one or more facets of the Ouachita problem.

Assuming that the rocks which make up the Atoka formation in the northern or frontal Ouachitas were deposited at a fairly uniform rate, and, lacking other criteria, divide this section of rocks into lower, middle, and upper divisions, it can be stated that the initial uplift of the Ouachita orogeny occurred at least by the upper part of lower Atoka time. The nature and distribution of upper middle Atoka sediments were affected locally by structures which involved the lower Atoka sediments. By the end of Atoka time the Ouachita Mountain area was completely emergent.

The Hartshorne sandstone, which overlies the Atoka in the area immediately north of the present Ouachita Mountains, is in its southern exposures composed chiefly of sand grains derived from the Jackfork sandstone. There are only minor amounts of coarse clastic material in the middle and upper Atoka units and in the Hartshorne sandstone, indicating a low magnitude of uplift and consequently a low order of erosional truncation of the uplifted area. The Jackfork sandstone is the only post-novaculite formation in which the sand grains are of sufficient size to have been the source material for the Hartshorne. The Hartshorne is succeeded by a sequence of shales and sandstones of Middle Pennsylvanian age which contains no appreciable amounts of coarse material. These formations are thickest in their southern exposures and thin rather rapidly to the north. The lack of coarse clastics and the general thickness patterns indicate that the Jackfork and Stanley were the chief sources of material deposited to form these formations. Paleozoic formations younger than Middle Pennsylvanian are not present in Arkansas, and in Oklahoma the debris from the Wichita and Arbuckle Mountain uplifts dominates the coarse clastic phase of the later Paleozoic rocks. Tomlinson (1929) postulated that the chert conglomerates in the Devils Kitchen member of the Deese formation in the area of the Criner Hills in southern Oklahoma were derived from the Ouachitas. W. E. Ham (personal communication) of the Oklahoma Geological Survey has recently found material in the Devils Kitchen that may be used to prove a Ouachita source area. The Devils Kitchen member occurs near the base of the Deese formation and was deposited at about the same time (lower Des Moinesian) the Hartshorne sandstones were being laid down to the east. It is doubtful that at any time during the Pennsylvanian the Ouachita Mountains were uplifted high enough to be a source of much coarse clastics. During this period of the orogeny, lasting longer than twenty million years, the amount of uplift and accompanying erosion was on the order of 15,000 to 20,000 feet. Probably there was no appreciable topographic relief until the resistant beds of the Arkansas novaculite were exposed.

Only negative evidence can be used to support further discussion of the history of this orogeny. Some of the more salient points are: (1) Novaculite pebbles up to 8 inches in diameter are found in present-day stream channels at least 25 miles from the nearest possible source. (2) Trinity formation is the only post-Atoka formation that contains appreciable amounts of conglomerate composed in part of cobbles and boulders of Arkansas novaculite. The upper Paleozoic and Jurassic beds known only in the sub-surface of the Gulf Coastal Plain contain little or no coarse clastic material along their northern limits. (3) There has been a minimum of 4000 feet of pre-Stanley beds removed from the core of the Ouachita Mountains. These features suggest that the slow spasmodic movement of the Ouachita area continued well up into the Permian and perhaps later, but at no time was the area sufficiently elevated to empower the streams to carry coarse cobbles of novaculite any appreciable distance. These opinions are supported, to a large extent, by the metamorphic character, or rather the lack of it, of the rocks in the Ouachita Mountains. The aggregate uplift at the core of the mountains has been 3 to 5 miles and the lateral compression is on the order of 50 percent. The rate of uplift and compression was sufficiently slow so that the individual mineral grains were maintained by physical adjustments. Physical-chemical adjustments (metamorphism) are restricted to a few local areas where they represent the lowest grade of metamorphism.

From the records available in the rocks, one can say that only during the Lower Cretaceous, when the downwarping of the Gulf Coastal Embayment increased the gradient of the streams draining the Ouachita Mountains, were these streams able to carry coarse material some distance from their source area. Therefore, with respect to the age of the Ouachita orogeny, it can be said that it was initiated probably in Morrow time, but no later than the lower Atokan. If the Ouachita facies and structural history of Arkansas are in continuity with the Ouachita facies and structural history of southwest Texas, the orogeny lasted until at least Middle Permian time. The downwarping of the Athens Plateau during the initial Trinity deposition and zones of weakness invaded by the lower Upper Cretaceous igneous rocks may indicate that the last stages of the Ouachita deformation are as young as Lower Cretaceous time. It is more likely that these features are more related to the subsidence of the Gulf Coast, but this cannot be proved with the information available at present. There is no evidence indicating a maximum period of deformation.

Gulf Coastal Plain

The structural history of the Gulf Coastal Plain includes at least three periods of movement. The initial movement in this area was part of a regional subsidence in the region now called the Gulf Coastal Plain. For a long period of time prior to this subsidence, the Paleozoic rocks in this area had been beveled by erosion almost to a peneplain. The advent of this subsidence was followed by the deposition of the sediments of the Trinity formation on the beveled surface. The lower member of the Trinity, the Pike gravel, is made up mostly of pebbles from one-half to one inch in diameter. Cobbles and boulders are abundant in this member, as are extensive lenses and facies of clay and sand. The fossils in this member consist of wood fragments and vertebrate remains. These non-marine fossils and poor sorting of the gravel, as shown by the sand and clay indicate (1) that the seas advanced rather rapidly and did not winnow out the fine debris from the pebbles, and (2) that the gravels were deposited as a blanket when the gradients of the streams were altered by the encroaching seaways. This latter possibility is substantiated somewhat by the presence of cobbles and boulders of novaculite in the gravel.

The writer believes that there must have been some uplift in the mountainous region of the Ouachitas to empower the streams to carry this coarse debris, even though their length, and consequently their base level, was being altered by the encroaching marine water. The subsidence of the Paleozoic floor of Trinity deposition was sufficient for 600 feet or more of this formation to be laid down. The various sandstones, gravels, oyster-bearing limestones and possibly evaporites in this formation indicate considerable oscillation of the seaways. Following the deposition of the Trinity and the overlying Lower Cretaceous units, a more widespread subsidence occurred in the Texas-Arkansas area. There are two phases of this second period of subsidence, which were first discussed by Veatch (1905, p. 22).

> As a result of this submergence (Upper Cretaceous) the low-lying area in western North America became a great mediterranean sea, which connected the Gulf of Mexico and the Arctic Ocean. In the Texas-Arkansas area the depression was at first greatest to the southwest, but during the latter part of the Cretaceous the movement was reversed and the western region was gradually elevated as the area near the Mississippi was depressed. This resulted finally in

the development of the Mississippi embayment and in the severing of the connection between the Gulf and the interior sea, which was thus converted into a series of great inland lakes which persisted through much of the Tertiary. Because of this east-west and then west-east tilting the lower portion of the Upper Cretaceous, which in central Texas is characterized by thick limestone and light-colored marl beds, is in Arkansas and Indian Territory composed entirely of near-shore sands with no marine fossils; while the upper portions, which in Texas are dark-colored calcareous clays, contain in Arkansas, Mississippi, and Alabama a large percentage of chalk and chalk marls.

In the region covered in this report, the westward tilting of the early Upper Cretaceous is indicated by the unconformity at the base of the Woodbine. Toward the east end of the region the Woodbine overlying the unconformity rests on the lower sandstone member of the Trinity. From this area westward the Woodbine lies on succeedingly younger members of the Trinity and at the west end of the region almost the entire 600 feet of the Trinity is preserved beneath the Woodbine. The eastward tilt of Upper Cretaceous is indicated by the southeastward dip of the Paleozoic floor, and isopachous maps of the Cretaceous (Caplan, 1954). There was a general withdrawal of the seas in the Arkansas area and adjoining states at the end of the Cretaceous. This may have been the result of eustatic uplift of the continent or a general deepening of the ocean basin.

Another period of subsidence accompanied the opening of the Tertiary; however, Tertiary sediments are present only at the eastern end of the barite region. They overlap the eastern end of the Athens Plateau, the Trap Mountains, the Zig Zag Mountains, and the Saline Basin.

Sometime after this early Tertiary subsidence, either in late Tertiary or the Quaternary, perhaps extending through both of them, the general Ouachita Mountain area was uplifted from 350 to 500 feet. This is indicated by the valleys of the major streams in the area. In the mountainous area many of the valleys are over 350 feet deep, with streams still actively eroding the valley floors with little terrace or flood plain development along them.

Igneous Structure

Peridotite. The peridotite necks and pipes that occur near Murfreesboro in the Caddo Gap Quadrangle appear to be the result of three distinct but closely related stages of igneous activity (Purdue, 1908, p. 526; Miser and Ross, 1923, pp. 279-322; Miser and Purdue, 1929, pp. 140-41). The first phase consisted of intrusion of ultramafic magma into the Paleozoic and Lower Cretaceous rocks. The second phase was volcanic explosions that resulted in the accumulation of fragmental material in the form of volcanic breccia. This breccia consists of peridotite, shale, sandstone, and novaculite fragments. A second period of volcanic eruptions added fragmental volcanic material to marine sediments accumulating in the adjacent seas. Miser and Purdue (1929, p. 141), in discussing the age of this period of activity, reasoned:

That the several phases of volcanic activity took place after Trinity (Lower Cretaceous) time and during or before Tokio (Upper Cretaceous) time is shown by the facts (1) that the peridotite has penetrated and cut across the nearly flat-lying beds of the Trinity formation (figs. 4 and 5), (2) that it is overlain at places by the Tokio formation (fig. 5), and (3) that pebbles of it occur in the lower part of the Tokio. The pebbles of the peridotite in the Tokio were probably ejected as fragmental material during the volcanic eruptions, and if so the eruptions took place during the time when the Tokio was being deposited. The several phases of volcanic activity probably accompanied the diastrophic movements that produced the downwarping of the Mississippi embayment early in Upper Cretaceous time.

Magnet Cove. The Magnet Cove igneous area includes a roughly elliptical basin 2 by 3 miles in extent, almost completely enclosed by a rim which rises 200 to 300 feet above the basin floor. The area is located near the center of the state of Arkansas in northern Hot Spring County, occupying the west central part of T. 3 S., R. 17 W., and the east central part of T. 3 S., R. 18 W., in the northeastern part of the Malvern quadrangle. Magnet Cove is one of the most interesting areas of mineralization on the North American continent. It compares with the Franklin Furnace area in New Jersey and the Crestmore area in California for number and variety of unusual rocks and minerals present. The Magnet Cove igneous rocks were intruded into the extreme eastern end of the Mazarn Basin. The northern part of the intrusions truncates southwestward-trending folds of the Zig Zag Mountains (Plate 25). The southern arc intrudes, in part, into the northernmost ridges of the Trap Mountains. The structure of the Magnet Cove intrusives has been subjected to quite divergent interpretations. Williams (1891, p. 342), in discussing the structure of the area, states:

The igneous rocks of Magnet Cove are divided into three genetically distinct groups whose structure and mode of occurrence show that they were formed during three distinct periods of igneous activity.

The oldest of these consists of the basic, eleolitic, abyssal rocks which constitute a large part of the interior Cove basin. The large masses of these rocks are holocrystalline granitic in their structure and were cooled slowly and under pressure. About the edges of this mass a porphyritic variety of these rocks often occurs and in some cases cracks in the surrounding rocks are filled with materials from this basic magma thus forming basic, eleolitic, porphyritic and lamprophyric dikes.

The next period of igneous activity is one which corresponds to the dike forming epoch of the Saline County region. During this period the rock in and about the Cove which had been disturbed and heated by the intrusion of the masses of abyssal rocks cooled, and cracks opened in all directions. These cracks are filled with monchiquitic rocks of all varieties which appear as the basic, dark, non-eleolitic dikes, so numerous in the neighborhood of the Cove and in fact everywhere throughout that part of the state. (See Chap. XIII.)

The third and last period of igneous activity is that in which the eleolitic and leucitic rocks of the "Cove ring" were formed and during which the numerous tinguatic dikes of all varieties were intruded. The rocks of this period are all of an intrusive character, a fact which is shown both by their structure and mode of occurrence.

These youngest rocks cut both the abyssal rocks (p. 188) and the dikes of monchiquite (p. 174), and are therefore proved to be younger than either of those groups.

All the igneous rocks are younger than the surrounding Paleozoic rocks and have forced their way into them. They were formed after the folding and bending and after some of the erosion of the Paleozoic rock had been accomplished, probably during late Cretaceous time.

Washington (1900, p. 392) believed that the igneous mass was a laccolithic intrusion, which had differentiated in place to produce the various igneous rock types. Landes (1931, pp. 313-26) presented evidence to show that the igneous mass was not concordant, but cut across the structure of some of the sedimentary rocks. He interpreted the mass to be a stock which differentiated in place. Ross (1941, p. 24), after examining the rocks of some of the rutile deposits within the cove area reached the conclusion that at least part of the Magnet Cove area is composed of volcanic material. Fryklund and Holbrook (1950, pp. 35, 36) cast considerable doubt on Ross' interpretation. Erickson and Blade (1955) are completing a detailed study of the Magnet Cove igneous rocks. Their findings should answer many of the problems connected with this highly mineralized area.

Summary of Geologic Events

The Ouachita Mountain region from Cambrian or earliest Ordovician time until early Silurian time was a geosynclinal area receiving thick deposits of mud and lesser amounts of sand and carbonate. Minor changes of the seaways or land masses caused local changes in the character of the sediments. These sediments were lithified and now comprise the formations ranging from the Collier shale to the Blaylock sandstone. After the deposition of the Blaylock sandstone, in Silurian time, and before the deposition of the Missouri Mountain formation in uppermost Silurian or lower Devonian time, the region now forming the central part of the Ouachita Mountains was uplifted sufficiently for erosion to remove several hundred feet of sediments. There may have been some folding associated with this period of uplift, but it was minor. This period of uplift and erosion was followed by a new advance of the seaways over the area. Other than small patches of conglomerate, only fine muds, which became the Missouri Mountain shale, were deposited in the new seaway as initial sediments. Toward the end of the period of deposition of muds which make up the Missouri Mountain formation a considerable change took place in the source of material of the sediments; near the top of the Missouri Mountain siliceous material now transformed into novaculite was laid down with the muds. Several hundred feet of this siliceous material was laid down on top of the Missouri Mountain and lithified into the Arkansas novaculite. This period of deposition was not everywhere continuous. There is considerable range in thickness of each of the three members of the Arkansas novaculite and there is considerable difference in their composition. The lower member is chiefly novaculite, the middle member is about equal parts of novaculite and shale, and the upper member is highly calcareous novaculite. Locally, there is conglomerate and breccia at the tops or bottoms of each of these members and at places in them.

This period of predominantly silica deposition lasted from uppermost Silurian or lower Devonian to lower Mississippian, at which time the seas withdrew over much, but not all, of the region.

This period of withdrawal was followed by a period of great subsidence lasting from the middle Mississippian to middle Pennsylvanian during which the area was downwarped a minimum of 18,000 and a maximum of 24,000 feet. Over much of this period of time the accumulation of debris from the land masses adjoining the downwarped area was so rapid that the seaways were not able to maintain themselves, except in local embayments. This is indicated by the tremendous accumulation of non-marine clastic rocks, which locally contain coal and plant remains, and the paucity of marine fossils in these sediments. The only known marine fossil horizons found in the strata deposited during this period of accumulation are found in the frontal Ouachitas where sedimentation was not rapid enough to block spasmodic marine invasions.

In the middle Pennsylvanian this process of downwarping was reversed because of compressive forces from the south. During this deformation period, the Ouachita orogeny, the Ouachita Mountain region was folded and faulted into its present configuration. The time span of this orogenic period has not been established. However, as there is no thick accumulation of coarse clastics of upper Paleozoic age along the flanks of these mountains, it is presumed that the uplift was spasmodic and slow and probably continued well up into the Permian, or later. This diastrophic period was followed by a long period of erosion, perhaps including part of the Permian, all the Triassic, and Jurassic periods.

Early in the Cretaceous period the beveled surface of the Ouachita structural province was downwarped to the south, and encroaching marine waters received the sediments of the Trinity and succeeding Lower Cretaceous formations. The seas withdrew at the end of the Lower Cretaceous and after some south of west tilting re-entered early in the Upper Cretaceous. At the same time a period of igneous activity was initiated with both intrusive and volcanic rock being formed and cutting through the Paleozoic and Lower Cretaceous formations. Alkalic tuffs are present in the Woodbine, the lowest Upper Cretaceous formation, with ultramafic tuffs forming part of the overlying Tokio formation. The ultramafic plugs near Murfreesboro cut the Trinity and are overlain by the Tokio and, therefore, are effectively dated. The age of the igneous rocks at Potash Sulphur Springs, Magnet Cove, Bauxite, and Little Rock are less accurately known.

Toward the middle of Cretaceous time, the initial westward tilt of the coastal region was reversed to the east. Later, toward the end of the Cretaceous, the seas withdrew from the region and readvanced in lower Tertiary time. The Tertiary sediments overlapped much of the Cretaceous and the eastern end of the Ouachita Mountains. Following, or perhaps causing, the withdrawal of the Tertiary seas, the Ouachita Mountain area was uplifted 250-500 feet, as indicated by the topography of the major streams of the Ouachita Mountain region.

ORIGIN, PARAGENESIS, AND AGE OF THE ARKANSAS BARITE DEPOSITS

Location of the Barite Districts

The discussion of the origin of the barite requires frequent reference to the various districts in the region. The districts are defined strictly on the geographic basis and are not necessarily comparable geologically, in area or with respect to the the type or amount of barite present (Plate 1). The Magnet Cove district is in northern Hot Spring County and includes the area in Tps. 3 and 4 S., Rs. 17 and 18 W. The Pigeon Roost district is in the southeast townships of Montgomery County, T. 4 S., Rs. 23 and 24 W. The Fancy Hill district is in the southwest quarter of Montgomery County and includes the barite deposits in T. 4 S., Rs. 25, 26, and 27 W. The Hatfield district is in the central part of Polk County and includes the barite prospects in Tps. 3 and 4 S., Rs. 29, 30, and 31 W. The Cinnabar or Quicksilver district strikes across Howard, Pike, and Clark Counties as discussed in the previous chapter. The Dierks district includes the barite deposits of western Howard County and eastern Sevier County in Tps. 7 and 8 S., Rs. 27, 28, and 29W. There are numerous isolated barite prospects throughout the southwest part of the Ouachita Mountains, but present information does not indicate sufficient barite in these localities to warrant a district name.

Classification of the Deposits

The Arkansas barite deposits have been classified into three categories on the basis of their mode of emplacement as follows:

(1) Replacement deposits
(2) Cemented deposits
(3) Fissure vein deposits

The replacement deposits are the most important of the three types as they contain most of the known barite reserves and have yielded all the commercial production.

Replacement Deposits

General. The replacement type barite deposits in Arkansas occur in the Magnet Cove, Pigeon Roost and Fancy Hill districts. They are judged by the writer to have formed in the same manner and at essentially the same time. The ore bodies within these districts have the same relationships to major and minor structures, are limited to the same stratigraphic horizon, and have the same types of ore and are closely related chemically and physically.

Relation to Structure

The three districts named above lie within the confines of the Mazarn Basin or along the margins where intense folding and subsequent stratigraphically deeper erosion has exposed folded Arkansas novaculite. Every deposit within these districts lies on the flanks of or extends across a syncline. Within these synclines minor folds and faults as well as the stratigraphy are ordinarily the controlling factors of the exact localization of the barite ore. The role of these minor features is discussed under the description of the individual deposits.

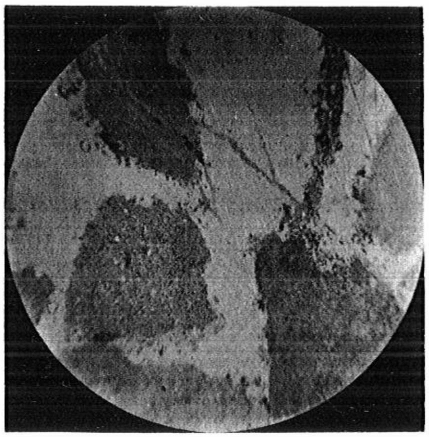
Relation to Stratigraphy

The replacement barite bodies of these districts are confined to the lower 300 feet of the Stanley formation. In most deposits a black shale, (Plate 27 B), ranging in thickness from 1 to 30 feet and having a basal congolomerate from one-half to 4 inches thick lies between the base of the barite zone and the base of the Stanley formation. This black shale forms the footwall of the barite mineralization zone. There is no definite hanging wall in some deposits. In most cases the vertical range of the mineralization is less than 100 feet although it extends in a few places to 300 feet. Ordinarily 25 to 65 feet of the mineralized zone can be considered commercial ore.

Character of the Barite

Although the districts in which the replacement type of deposits occur are many miles apart, the barite ore is remarkably similar in all of these deposits, (Table 3). The individual bodies of barite contain several types of ore. The most abundant type is a massive gray to dark gray, finely crystalline ore which is referred to as the limestone-appearing ore in some reports. Where weathered, this ore has a lighter color and appears to be faintly to strongly banded. Much of the banding parallels the bedding, but some of it is caused by differential oxidation and hydration of iron oxides along joint and cleavage surfaces. The replacement nature of this finely crystalline barite is best seen in thin section. However, the well-preserved bedding planes of the host rock and isolated patches of non-mineralized shale are indicative of the replacement. In thin section, the metasomatic effects are readily discernible. Incompletely replaced shale "islands" (Plate 7) are not uncommon; partially breached bedding planes

PLATE 7



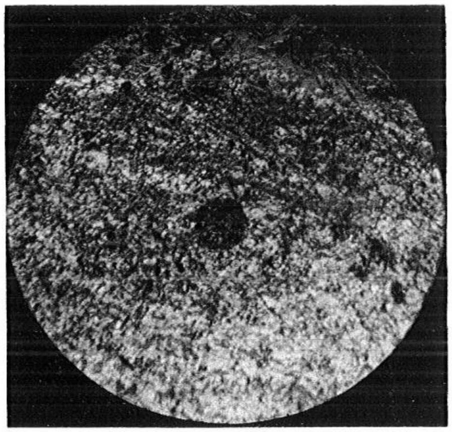
(A)

(B)

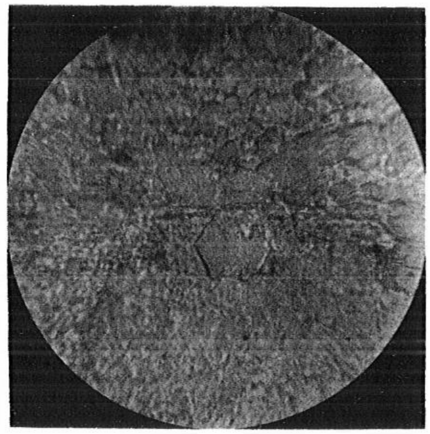
(A) Photomicrograph of barite (light gray) replacing shale (gray), near east end Baroid pit at Magnet Cove. Plane polarized light; X 13.

(B) Same view with nicols crossed showing vermicular nature of the barite.

PLATE 8



(A)

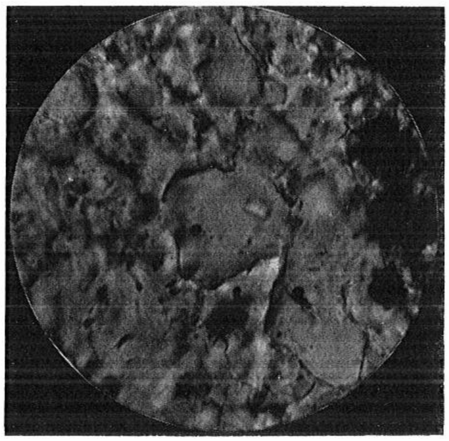


(B)

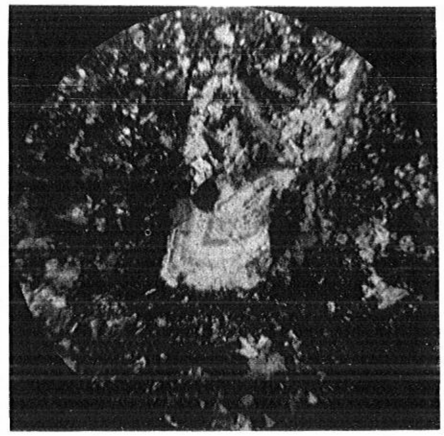
(A) Photomicrograph of barite replacing shale, Henderson property, Fancy Hill district. Plane polarized light; X 46.

(B) Photomicrograph of partially replaced quartz crystal (in relief, near center) in massive barite bed, near base of mineralized zone, underground working, Magnet Cove district. Plane polarized light, X 208.

PLATE 9



(A)

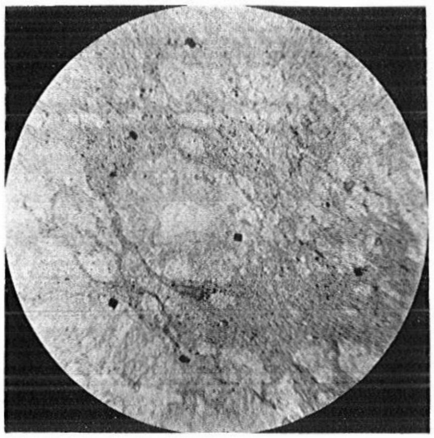


(B)

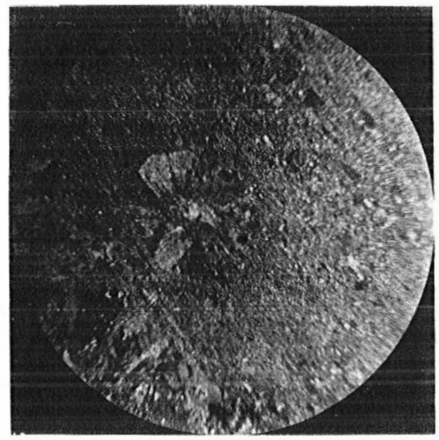
(A) Photomicrograph of quartz remnants (in relief) in massive barite bed, near top of mineralized zone, underground workings, Magnet Cove district. Crossed nicols; X 625.

(B) Photomicrograph showing the zonal growth of a barite crystal in a massive ore bed, McKnight property, Fancy Hill district. Crossed nicols; X 46.

PLATE 10



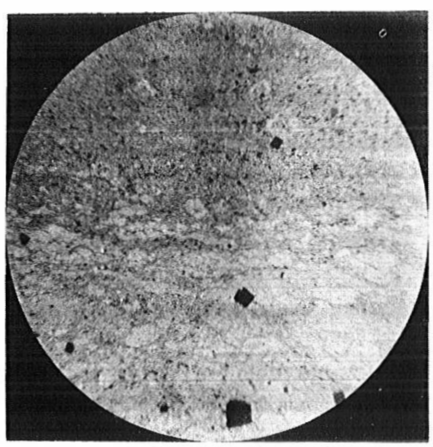
(A)



(B)

(A) Photomicrograph showing the types of barite in a high-grade (87% $BaSO_4$) ore zone in the underground workings of the Magnet Cove Barium Corporation. Plane polarized light; X 13.

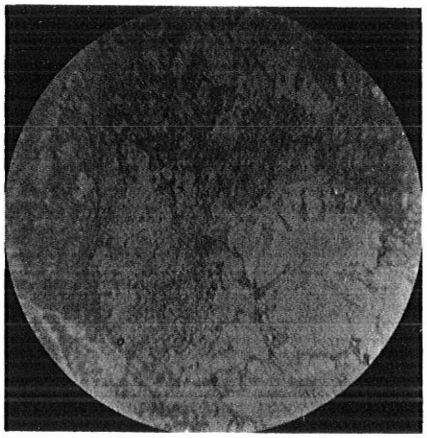
(B) Same view with nicols crossed.



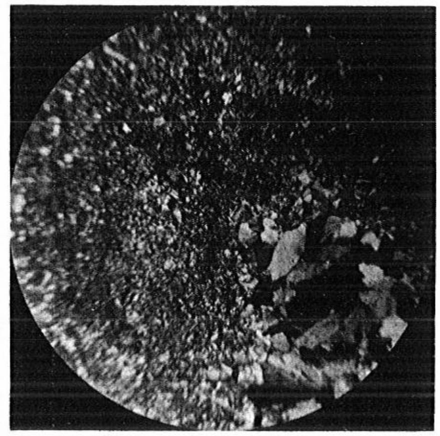
(C)

(C) Same section as (A) and (B), different field. Note pyrite cubes, black. Plane polarized light; X 13.

PLATE 11



(A)

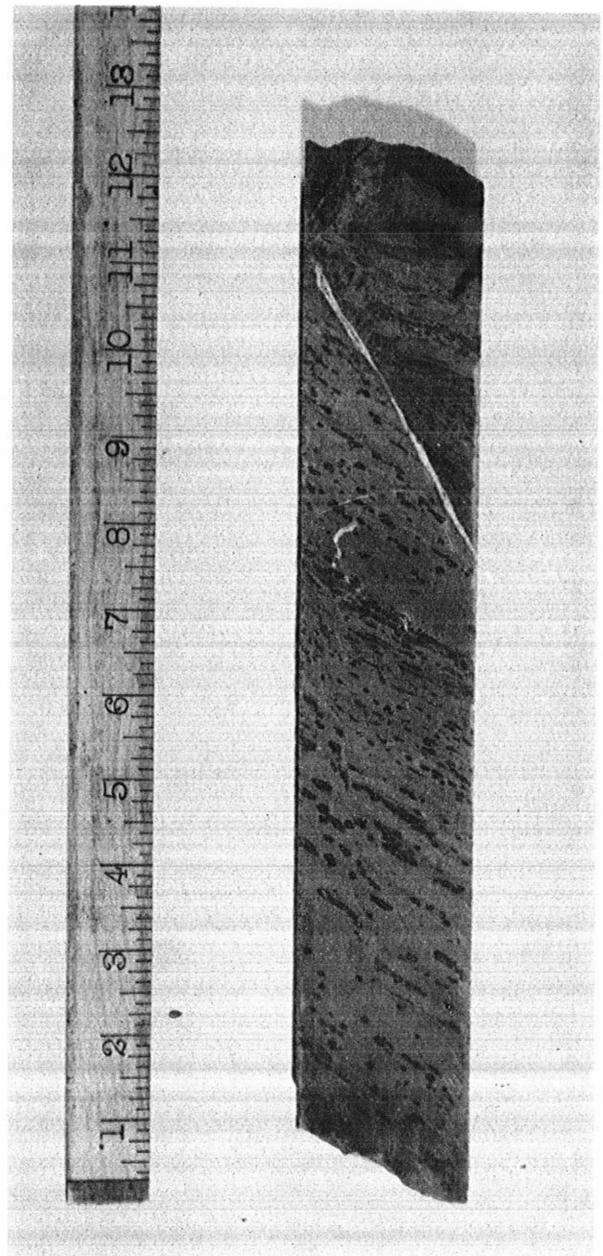


(B)

(A) Photomicrograph of high-grade barite from Henderson property, Fancy Hill district. Compare with high-grade ore from Magnet Cove district, Plate 10. Plane polarized light; X 13.

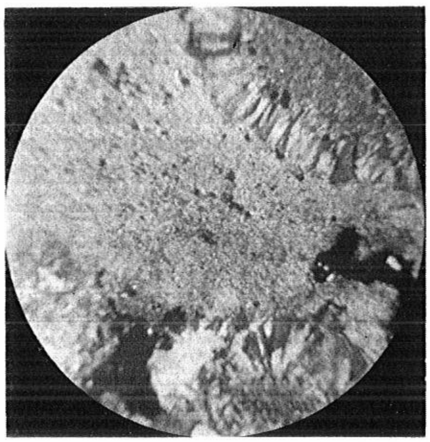
(B) Same view with nicols crossed.

PLATE 12

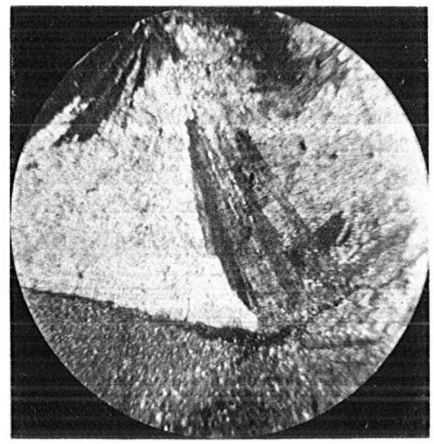


Photograph showing the nature of the nodular ore, Magnet Cove district. Black barite nodules in gray baritic shale, cut by carbonate seam (white).

PLATE 13



(A)

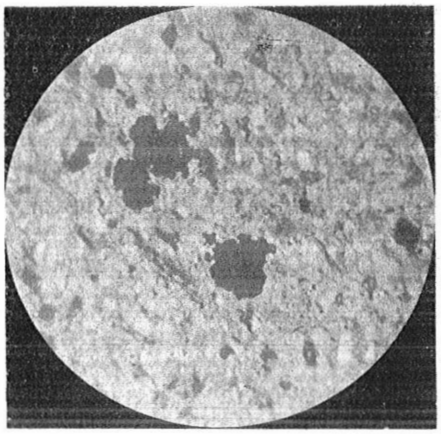


(B)

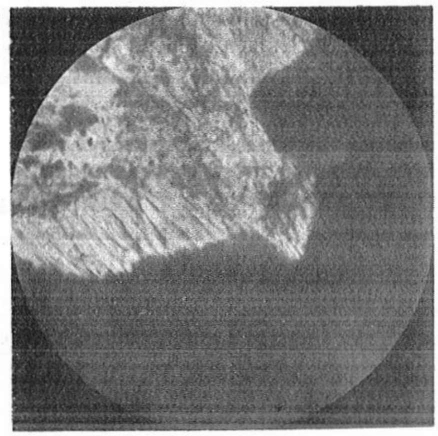
(A) Photomicrograph of radial barite developed around clay pellets in the Stanley shale above the high-grade ore zone, Baroid pit, Magnet Cove district. Crossed nicols; X 13.

(B) Photomicrograph of a barite nodule in which the accretion lines extend uninterrupted across the various barite blades, Pigeon Roost district. Crossed nicols; X 13.

PLATE 14



(A)



(B)

(A) Photomicrograph showing pyrite (black) partly replaced by fibrous barite, massive barite zone, underground workings, Magnet Cove district. Crossed nicols; X 46.

(B) Photomicrograph of a portion of the field of (A); crossed nicols; X 625.

were observed in a few sections (Plate 8-A), and replaced embayments in individual grains were noted in nearly all thin sections of this type of ore that were examined (Plate 8-B).

A second type of ore is gray, extremely fine-grained, and has a texture ranging from earthy to extremely dense. At a few places it resembles gray novaculite from which it can be readily distinguished because it is easily scratched and is much heavier. This ore type like the one discussed above was emplaced without destroying bedding planes. However the replacement was so complete that identifiable host rock constituents are rare (Plates 9A and B).

A third ore type is massive, dark gray to black, and its granular nature can be detected with the unaided eye. This is the least abundant ore type, but it has a higher grade where it does occur. This type of barite either replaced massive beds or the bedding planes were obliterated during the mineralization. In all thin sections of the granular ore some lineation is apparent (Plate 10). However, in only a few of the sections was the lineation parallel to the bedding of the adjoining stratigraphic units.

The fourth type is nodular ore in which the nodules range from one-tenth of an inch to two inches in greatest diameter (Plate 12). The average diameter of these nodules is approximately one-half inch, with the nodules of any particular horizon tending to be rather uniform in size. Some if not all these nodules were clay pellets in the Stanley shale before the invasion of the barite-bearing solutions. The studies of thin sections of several of these pellets show that the degree of replacement ranges from a minute quantity of barite dispersed through the clay minerals to a complete replacement of the nodules by barite (Plate 13 A and B). Granular and radial forms of barite occur in these nodules. In some the central portion is granular and the outer portion is radial. These textural differences, especially where the granular and radial types occur in the same nodule, suggest that the granular textured nodules were formed by the replacement of clay pellets and that the nodules of the radial type grew from a central point, possibly a small opening in which the barite mineralization was initiated, or some nucleus whose chemical makeup initiated the precipitation of the barium sulfate.

Replacement Processes

The petrographic and chemical studies of the host rock remnants in the replacement deposits and the rock units adjoining these deposits indicate that quartz, mica, clay, and pyrite (Plate 14) are the replaced minerals. The replacement processes were comparatively simple because, other than minor amounts of brookite (rutile) and pyrite, barite was the only replacement mineral.

The writer believes that the following processes were the most effective during the metasomatic activity. As the mineralizing solutions pervaded the capillary openings, the first reaction was between the minerals of the wall rock and the solute-deficient surface film of the solutions. The reaction principally was hydrolysis of the wall rock minerals along the ionically disorganized surfaces of the mineral particles, resulting in some dissolution of the mineral particles and disorganization of the newly exposed surfaces. The hydrolysis, disorganization and dissolution of the wall rock minerals allowed dispersion of Ba^{++} S^{--} into these minerals. Chemical reaction between the ions of the invading solutions and those of the invaded particles resulted in precipitation of barium sulfate and removal in solution of the host material. Penecontemporaneous precipitation of barium sulfate in the capillary openings occurred because the invading solutions became supersaturated with barium salts when the surface film of water was adsorbed during the hydrolysis of the host minerals. These reactions continued until the host minerals were completely replaced, precipitated barite plugged the capillary openings, or the supply of mineralizing solutions was exhausted.

An idealized reaction series for the replacement of quartz is given below. A similar series for clay and mica would be more complicated, and for pyrite less complicated.

$$SiO_2 + H_2O \longrightarrow 2H^+ + SiO_3^{--} \text{ hydrolysis}$$

$$Ba^{++} S^{--} \longrightarrow S^{--}\downarrow + Ba^{++}\downarrow \text{ dispersion}$$

$$H_2S + BaSiO_3$$

$$H_2S + 4H_2O \longrightarrow 2H^+ SO_4^{--} + 4H_2 \uparrow$$

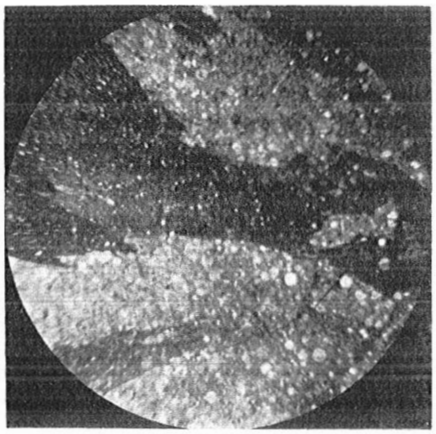
$$BaSiO_3 \longrightarrow SiO_3^{--}\downarrow + Ba^{++}$$

$$H_2SiO_3 + BaSO_4 \downarrow$$

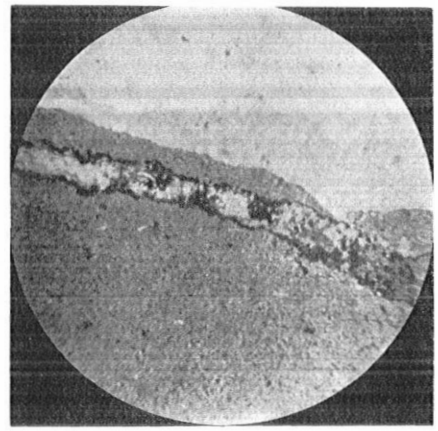
$$H_2SiO_3 \longrightarrow H_2O + SiO_2$$

The quartz veins cutting the mineralized zone and the overlying strata may represent the end product of this series (Plates 19, 20). Dispersion effects are shown by the zoning in some of the larger barite units (Plate 13B). Replacement ordinarily proceeds from the exterior of the host particle toward the interior.

PLATE 15



(A)

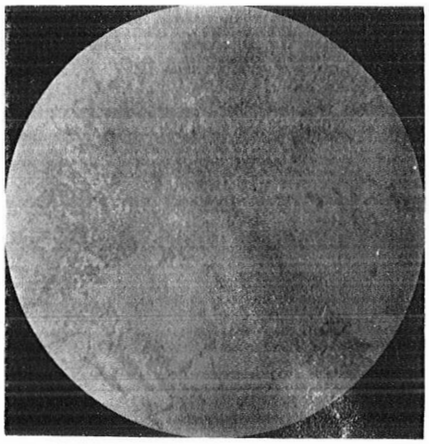


(B)

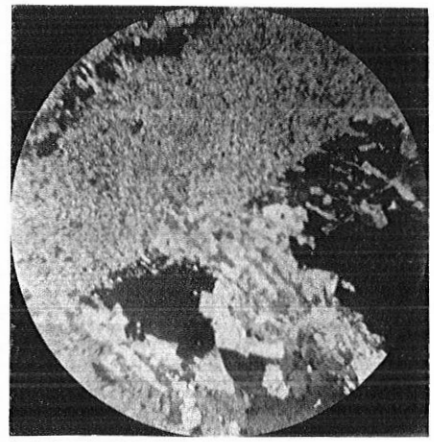
(A) Photomicrograph showing differential replacement of silty shale (black) by barite (gray); white specks are barite crystals and spherulites. North wall Baroid pit, Magnet Cove district. Crossed nicols; X 46.

(B) Photomicrograph of veinlet of barite (white) cutting shale (gray) and partly replaced by pyrite (black). Above massive ore zone, Baroid pit, south limb of Chamberlain Creek syncline. Plane polarized light; X 13.

PLATE 16



(A)



(B)

(A) Photomicrograph of barite (mottled gray) partly replaced by calcite (light gray), late stage vein cutting barite ore body. Baroid pit, Magnet Cove district. Plane polarized light; X 13.

(B) Same view with nicols crossed.

The effectiveness of replacement along capillary openings is well illustrated by the nature of the host rocks of the Arkansas barite. The silty shales are more completely replaced than any other type of rock within the region (Plate 15A). The silt grains disrupt the layerings of the clay minerals sufficiently to form capillary openings. The mineralizing fluid attacked both the clay minerals and the silt grains. In the clay shales the only paths of migration available to the mineralizing fluids were bedding planes and fractures. The sandstones that contain only a small percentage of clay were not subject to grain replacement because the size of openings available to the barium sulfate-bearing solutions were too large for the surface layers of the solutions to react strongly with the wall rock minerals, which mostly are rather insoluble quartz. The sandstones that contain appreciable amounts of clay were subjected to the capillary processes, and much of the quartz was replaced by barite.

For the most part in these Arkansas deposits, the barite did not preserve the outlines of the individual grains of the country rock, but the larger structures such as nodules and bedding planes are readily identified.

In the cemented siltstones and sandstones within or adjacent to replacement deposits the barite is present mostly as pore filling. There is no evidence that barite replaced a previous cementing material. There is only a minor amount of replacement of quartz grains, and this only around the outer rim. Pyrite and novaculite grains in these rocks were subjected to more replacement than the quartz grains. As in the quartz grains, the replacement is restricted to the outer margins.

The clay shales that are in or adjacent to replacement deposits are relatively free of barite. In these shales the barite occurs only in fractures and along bedding planes where it is present as veins of radiating or fibrous aggregates (Plate 15B).

Chemical Data

Chemical analyses (Table 3) show a similarity in composition between the replacement ores from the various barite districts. There is also a marked similarity in the trace element assemblage of all these ores as shown by the spectrographic analyses in Table 4. It should be noted, however, that the barite deposits in the Magnet Cove district have been partially replaced by carbonates (Plate 16), while those of the other districts have not.

The barite deposits in the Magnet Cove district lie within a mile of the Magnet Cove intrusive complex. Within this complex there have been at least four stages of carbonate introduction. The older masses are coarsely crystalline carbonatite invaded and metamorphosed by later igneous rocks. The later phases are chiefly feldspar-carbonate veins associated with the period of titanium mineralization in the Cove, (Fryklund and Holbrook, 1950, pp. 26-35). The writer feels the carbonate mineralization in the Cove replacement barite deposits can be related to the carbonates within the Magnet Cove intrusive on the basis of the proximity of the two.

In the Pigeon Roost and Fancy Hill replacement deposits, however, barite and pyrite are the only metasomatically introduced minerals, presumably because the igneous source of the solutions was more remote from the area of deposition.

Localization of the Replacement Deposits: The replacement barite deposits have been found only in the basal part of the Stanley shale, primarily in synclines. The ore zones have a definite footwall but no definite hanging wall. How and why the barium-bearing solutions were localized in the basal part of the Stanley formation cannot definitely be established with the information now available. The writer believes that differential slippage of the Stanley units over the more massive novaculite during deformation created openings that allowed the migration of the mineralizing solutions. The migration, for the most part, occurred along the Stanley-novaculite contact in synclines, as these down-folded structures were the first available to the ascending hydrothermal solution (see Figure 2). The barium-bearing solutions migrated essentially vertically into the basal Stanley units along fractures and joints. The capillary processes effected the metasomatic replacement of the Stanley by barite.

Source of the Barium

The writer believes that the barite in all the replacement orebodies was deposited from hydrothermal solutions generated in nearby alkalic igneous intrusives of Cretaceous age.

In the Magnet Cove district a genetic relationship between the replacement deposits and the Magnet Cove intrusives is indicated by the fact that the intrusives truncate the lower end of the Chamberlain Creek syncline, the locus of the barite deposits (Plate 25).

According to Erickson and Blade (1954) the igneous rocks in the Magnet Cove intrusions contain from about 0.17 to about 2.25 percent barium and are therefore essentially saturated

TABLE 3

Partial chemical analyses of selected samples from the Arkansas barite region

Sample Number Sample Type	1 Shale	14 Shale	15 Novaculite	25 Barite	47 Barite	89 Barite	95 Barite	98 Barite	136 Shale	145 Sandstone
loss	4.43	8.97	0.34	0.76	N	N	N	N	0.02	0.96
SiO_2	70.00	68.52	98.65	21.73	7.74	28.08	18.94	16.70	83.16	92.57
Fe_2O_3	3.20	8.00	----	tr	0.80	2.00	2.80	2.60	8.80	5.00
Al_2O_3	12.30	13.40	----	tr	1.25	2.95	1.00	0.55	7.09	1.80
CaO		----	----	tr	0.99	0.93	0.26	2.36	tr	tr
$BaSO_4$	1.21	1.20	----	77.56	86.91	64.29	76.59	78.44	0.20	0.16
$SrSO_4$	0.17	0.57	----	0.18	0.41	0.39	0.31	0.36	0.34	0.16
MgO	0.26	0.37	----	tr	tr	tr	tr	tr	tr	tr
Na_2O	N	N	N	N	N	N	N	N	0.11	0.10
K_2O	N	N	N	N	N	N	N	N	0.96	0.34
TiO_2	0.73	0.68	----	tr	tr	0.56	0.44	0.57	tr	tr

Analyst: T. W. Carney

N — not determined: ---- —not detected
Total Fe reported as Fe_2O_3

Sample description and location

Sample No.

1. Stanley shale—20′ above Novaculite south side Lucinda Creek syncline; NW¼ SW¼ sec. 10, T. 3S, R. 17W.

14. Footwall black shale—east end Chamberlain Creek syncline; NW¼ NW¼ sec. 14, T. 3S, R. 17W. SE¼ SE¼ sec. 13, T. 3S, R. 17W.

15. Massive Arkansas novaculite—6′ below No. 14.

25. Barite—34′ above Novaculite, north limb Reyburn Creek syncline;

47. Massive barite ore—south rim Chamberlain Creek syncline; NE¼ NE¼ sec. 15, T 3S, R. 17W.

89. Massive barite ore—Gap Mountain deposit; SE ¼ SE¼ sec. 24, T. 4S, R. 26W.

95. Nodular ore—Henderson property, Fancy Hill district; NW¼ NW¼ sec. 29, T. 4S, R. 26W.

98. Massive ore—10′ below No. 95.

136. Siliceous shale zone below barite—Yount property, Gap Mountain deposit; SE¼ SE¼ sec. 24, T. 4S, R. 26W.

145. Pebbly sandstone—Mazarn Ridge; NE¼ NW¼ sec. 30, T. 4S, R. 23W.

Table 4.—Spectrographic analyses for trace elements in selected samples from the Arkansas barite region.

Sample Number- Sample Type-	1 Shale	14 Shale	25 Barite	32 Carbonate	47 Barite	49 Dike	76 Barite	85 Barite	87 Barite	89 Barite	171 Barite	121 Barite	122 Barite	204 Tufa
ELEMENT														
Nb	O	O	O	O	O	.OX	O	O	O	O	O	O	O	O
Cu	.OX	.OOX	.OOOX	.OOOX	.OX	.OX	.OOX	.OOX	.OOOX	.OOX	.OOX	.OOOX	.OOOX	.OOOX
Ag	O	.OOOX	O	O	O	O	O	O	O	O	O	O	O	O
Mo	O	.OOX	O	O	.OOX	O	O	.OOX	O	O	O	O	O	O
Pb	.OOOX	.OOOX	O	O	O	O	O	O	O	O	O	O	O	O
Mn	.OOX	.OX	.OOOX	.X	.OX	.OX	.OX	.OOX	.OOOX	.OOX	.OOX	.OOX	.OOX	.OOX
Co	O	.OOOX	O	O	.OOOX	.OOX	.OOX	O	O	O	.OOX	O	O	.OOX
Ni	O	.OOX	O	O	.OOX	.OOX	.OOX	O	O	O	O	O	O	O
Fe	X.	X.	.X	.OOX	.X	X.	X.	X.	.OX	.X	.X	.X	.X	.OX
Ga	.OOX	.OOX	O	O	O	.OX	.OOX	.OOX	O	.OOOX	O	O	O	O
Cr	.OX	.OX	.OOOX	.OOOX	.OOX	.OOOX	.OOX	.OOX	.OOOX	.OOX	.OOOX	.OOOX	.OOOX	.OOOX
V	.OX	.OX	.OOX	.OOX	.OOX	.OX	.OOX	.OOX	.OOOX	.OOX	O	.OOX	.OOX	O
Sc	.OOX	.OOX	O	O	.OOOX	.OOX	.OOX	.OOX	.OOOX	.OOX	O	O	O	O
Y	.OOX	.OOX	O	O	O	.OOX	.OOX	.OOOX	O	O	O	O	O	.OX
Yb	.OOOX	.OOOX	O	O	O	.OOOX	.OOOX	.OOOX	O	O	O	O	O	.OX
La	O	O	O	O	O	.OX	O	O	O	O	O	O	O	O
Ti	.X	.X	.OX	.OOX	.OX	X.	.X	.X	.OOX	.X	.OX	.X	.X	O
Zr	.OX	.OX	.OOX	O	.OOX	.OX	.OX	.OX	O	.OOX	O	O	O	O
Be	.OOOX	.OOOX	O	O	O	.OOOX	O	O	O	O	O	O	O	O
Mg	.X	X.	.X	.X	.X	X.	X.	.X	.OX	.X	.OOX	.OX	.OX	.OOX
Ca	.OOX	.OOX	.OX	M.	.X	X.	X.	.CX	.OX	.X	.OX	.OOX	.OOX	.OX
Sr	.OOX	.OOX	.X	X.	.X	.X	.X	.X	X.	X.	X.	.X	.OX	X.
Ba	X.	X.	M.	M.	M.	X.	M.	M.	M.	M.	M.	M.	M.	M.
B	.OX	.OX	O	O	.OX	.OOX	.OX	.OX	.OOX	.OX	O	O	O	O

Tested for but not found: Au, Hg, Ru, Rh, Pd, Ce, Ir, Pt, W, Re, Ge, Sn, As, Sb, B, Ta, Zn, Cd, Tl, In, Tb, Td, U, Li, Na, K, P.

Analyses Courtesy of U. S. Geol. Sur. in agreement with Ark. Geol. & Cons. Com.

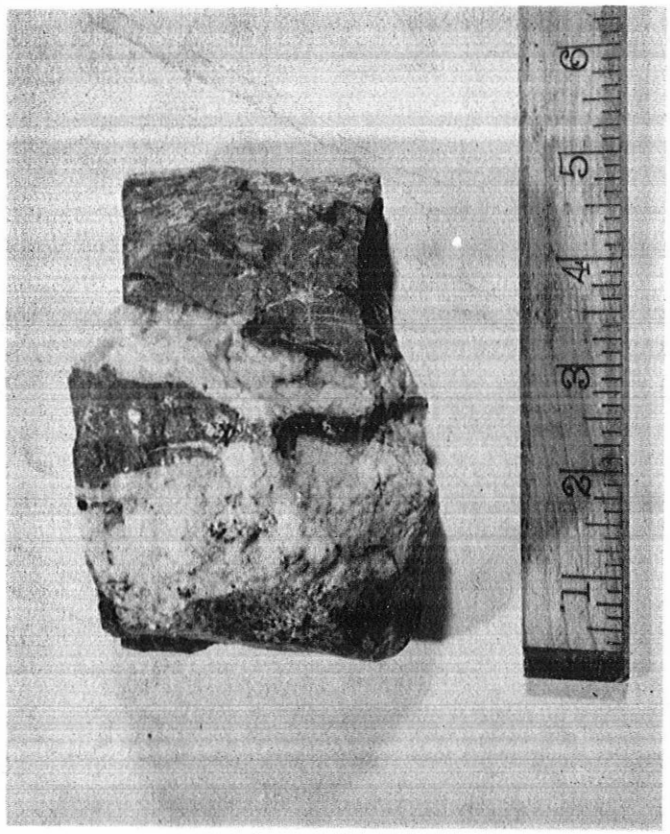
X. = 1 — 10%
M. = over 10%

Sample description and location

Sample No.

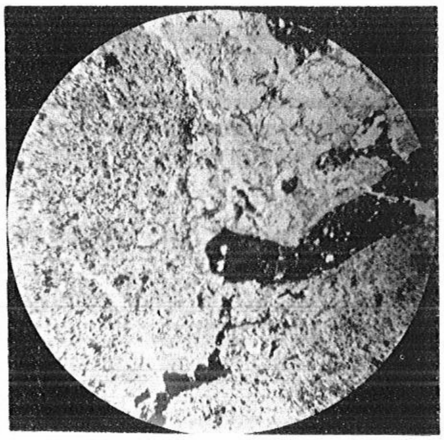
1. Stanley shale 20′ above novaculite—South side Lucinda Creek syncline— SE, NW, SW, Sec. 10, 3S, 17W.
14. Footwall black shale—East end Chamberlain Creek syncline—NE, NW, NW, NW, Sec. 14, 3S, 17W.
25. Barite 34′ above novaculite—North rim Reyburn Creek syncline—NE, SE, SE, Sec. 13, 3S, 17W.
32. Carbonate dike—Footwall ramp Baroid pit—NW, SW, SW, Sec. 10, 3S, 17W.
47. Massive barite ore—South rim Chamberlain Creek syncline—SE, NE, NE, Sec. 15, 3S, 17W.
49. Altered dike—Baroid pit "A" Chamberlain Creek syncline—SW, NE, NE, Sec. 15, 3S, 17W.
76. Massive barite ore—Kimzey drift Magcobar underground mine—Chamberlain Creek syncline—NW, Sec. 15, 3S, 17W.
85. Nodular barite—Henderson property, Fancy Hill district—NW, NW, NW, Sec. 29, 4S, 26W.
87. Massive barite ore—McKnight property, Fancy Hill district—SE, NE, Sec. 30, 4S, 20W.
89. Massive barite ore—Gap Mountain deposit—SW, SE, SE, Sec. 24, 4S, 26W.
171. Massive barite ore—Pigeon Roost district—SW, NE, Sec. 30, 4S, 23W.
121. Barite cement—Trinity formation—Lucky 13 deposit—Dierks district—SE, NW, SW, Sec. 13, 7S, 28W.
122. Barite cement—Pike gravel—Lucky 13 deposit—Dierks district—SE, NW, SW, Sec. 13, 7S, 28W.
204. "Tufa"—Magnet Cove intrusive zone—SW, NW, Sec. 20, 3S, 17W.

PLATE 17

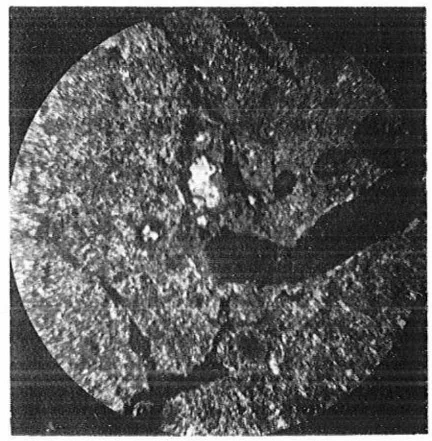


Photograph of barium, strontium and calcium carbonate veins (white) cutting dense barite (black). Foot wall ramp, Baroid pit, Magnet Cove district.

PLATE 18



(A)



(B)

(A) Highly altered dike of ouachitite (?) with the biotite (black) later than the analcite (?) (light gray to gray). Barite (whitish gray) cuts both igneous minerals. South rim of Baroid pit, Magnet Cove. Plane polarized light; X 46.

(B) Same view with nicols crossed. Barite at extinction.

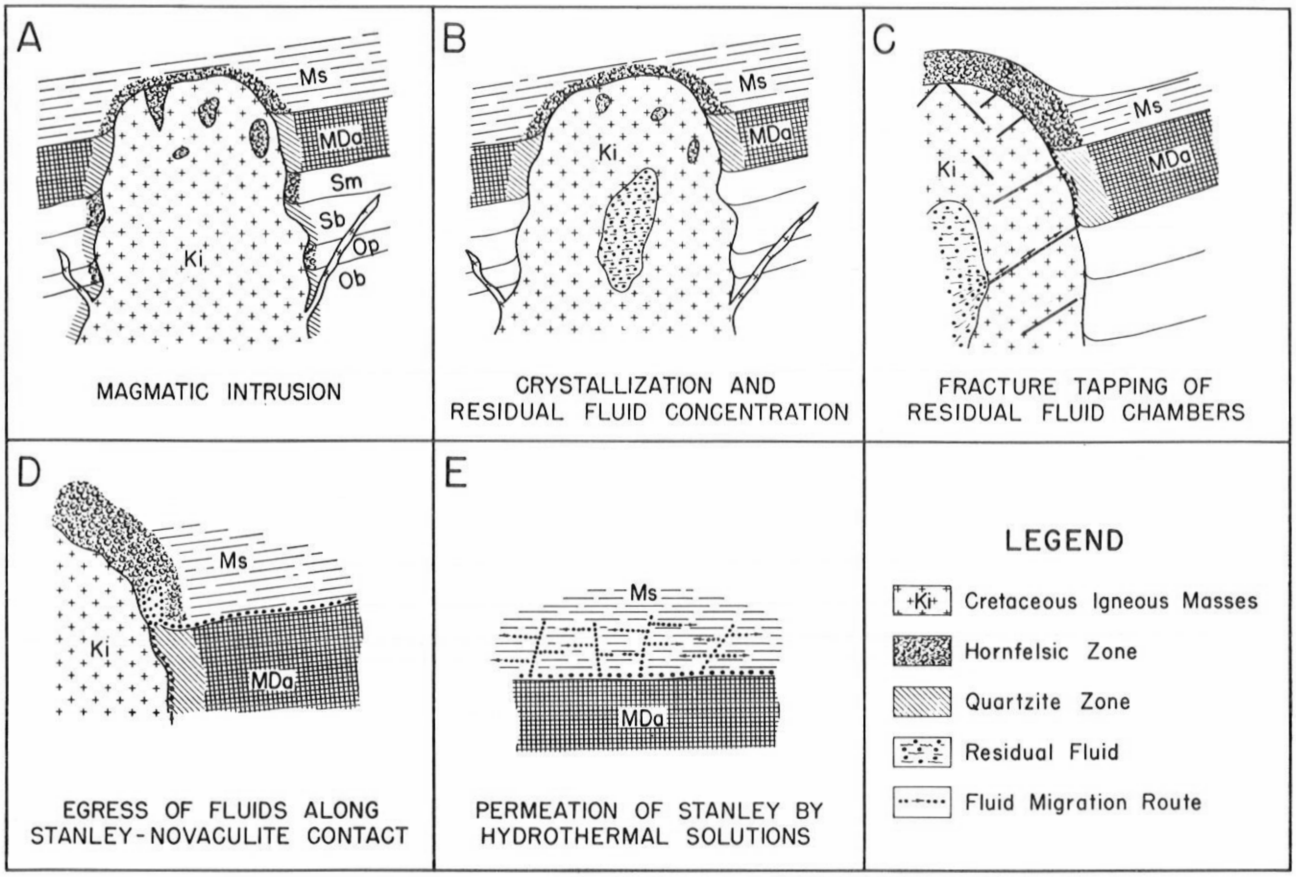


Figure 2. — Sketches showing probable sequence in the development of barite replacement deposits, Arkansas barite region.

with barium. They also noted that barite was present in the "tufa" or sinter domes in the Cove.

In the Pigeon Roost and Fancy Hill districts a close spatial relationship cannot be demonstrated between the replacement barite deposits and igneous intrusives since the nearest igneous rock outcrops are more than 15 miles distant. However, trace element studies of rocks of the Gulf Coastal Cretaceous igneous province show that these rocks contain higher than average percentages of barium and titanium. The studies further show that the trace element assemblage in these igneous rocks is remarkably similar to the elements found in the replacement barite ores (Table 4) including those from the Pigeon Roost and Fancy Hill districts.

Paragenesis

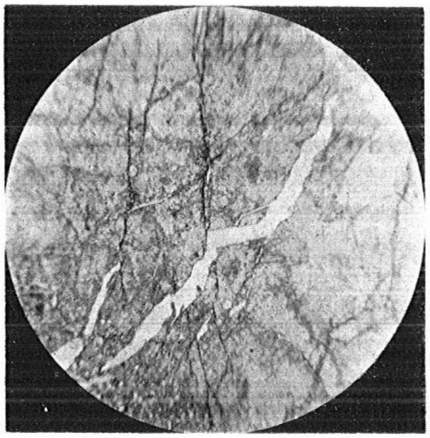
The paragenetic sequence in the replacement barite deposits is uncomplicated, but relating them to the stages of igneous activity is difficult. The writer believes that in the Chamberlain Creek (Magnet Cove) deposit the barium-bearing solutions invaded the sequence of siltstones, silty shales and clay shales, some members of which contained indigenous pyrite. In the later stages of the barite formation pyrite was precipitated from solution and continued to form for some time after the barium sulfate precipitation had ceased. After this period of sulfate and sulfide precipitation the sequence of solutions rich in carbonates invaded the mineralized zone replacing the barite in part (Plate 16). The carbonate is mostly calcite but it contains a relatively high percentage of strontium (Plate 17). It is believed that the titanium found in the barite is contemporaneous with the brookite (rutile) deposits occurring at the southwest end of the Chamberlain Creek syncline. The sequence of deposition was probably barite, brookite and carbonate.

The fact that the dikes cutting the sediments in the Chamberlain Creek syncline are mineralized (Plate 18) indicates that the barite, brookite, and carbonate mineralization were associated with the final stages of the Magnet Cove intrusive activity.

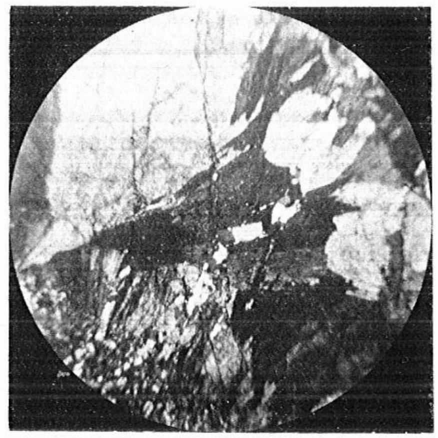
PLATE 19

Photograph showing vugular quartz veins transecting bedding planes of the Stanley shale. Bright specks in the vugs are metalliferous sulfides. Above barite zone, Magnet Cove district.

PLATE 20



(A)

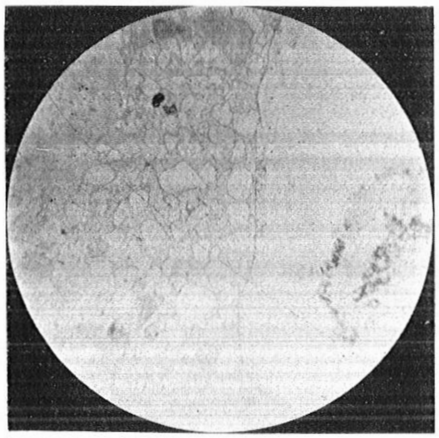


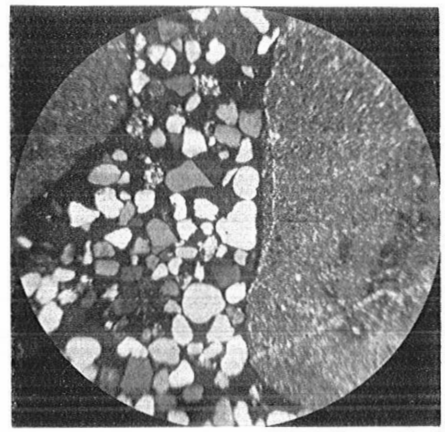
(B)

(A) Photomicrograph of quartz veins (light gray) cutting fractured barite (gray), Henderson property, Fancy Hill district. Plane polarized light; X 13.

(B) Same view with nicols crossed.

PLATE 21



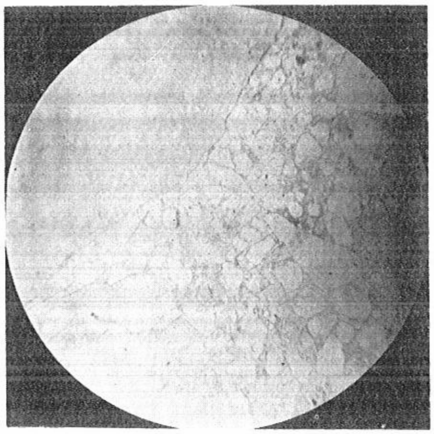


(A) (B)

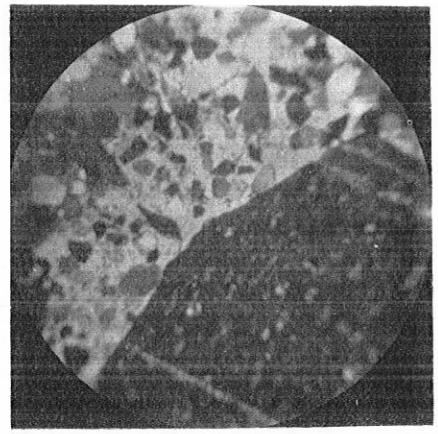
(A) Photomicrograph of barite (gray, higher relief) cemented gravel containing novaculite pebbles (light gray, upper and lower left parts of picture) and quartz grains (light gray, lower relief). Cherry deposit, Dierks district. Plane polarized light; X 13.

(B) Same view with nicols crossed. Optically continuous barite is at extinction (black).

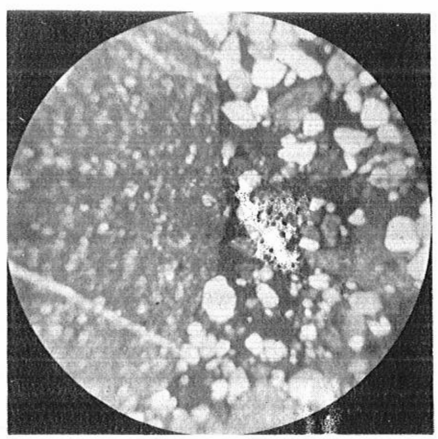
PLATE 22



(A)



(B)



(C)

(A) Photomicrograph of novaculite pebble (mottled gray) and quartz grains (whitish gray) cemented by barite. Lucky 13 deposit, Dierks district; Plane polarized light; X 13.

(B) Same view with nicols crossed to show optical continuity of barite.

(C) Same view with nicols crossed and barite at extinction position.

The barite bodies of the Pigeon Roost and Fancy Hill districts contain about the same percentage of titanium as do the barite zones in the Magnet Cove district, but the carbonate phase is not present in these western districts. The paragenetic sequence in these districts is barite succeeded and partly overlapped by pyrite with a later stage suggested for the titanium. Small veinlets and seams of crystalline barite may have formed during the period of introduction of titanium, or they may represent a much later stage of secondary concentration.

In all three of these replacement districts small irregular veins of quartz are present in the Stanley shale. A few of these veins cut the ore zone but most of them are stratigraphically above it. The relations of these quartz veins to the country rock are best seen in the cores made available from the diamond-drill coring programs of the companies operating in these districts (Plate 19). Some of the shale adjoining and nearly all of that included in the quartz veins has been chloritized. Sulfides, particularly in vugs and fissures, are abundant in the quartz veins and the adjoining wall rock. Pyrite forms over 95 percent of the sulfides, but arsenopyrite, molybdenite, sphalerite, and galena were recognized. Most of the sulfides are later than, and were deposited on, the quartz, but some of the sulfide crystals are enclosed within the quartz veins. Some of these quartz veins cut the barite ore (Plate 20) showing that they are later than the barite, but other than that their age has not been determined.

CEMENTED DEPOSITS

General. The deposits in which barite is present as a cementing material in clastic rocks are restricted to the Dierks district where the barite occurs as a cement in the Pike gravel and the lower sandstones of the Trinity. The barite cement of these units was deposited from solutions in such a manner that large crystals incorporating a number of sand grains were formed. Many of these crystals have a maximum dimension of 3 or 4 inches. In many of these individuals the force of crystallization was sufficient to isolate the individual sand grains from each other (Plates 21, 22). At some places in these deposits the barite crystals were deposited as radial aggregates. When these aggregates are freed from the enclosing rock by weathering and erosion, they have the form of sand barite 'roses' similar to barite roses from the Permian of Oklahoma.

The barite-bearing zones in the Trinity are lenticular and the grade of ore changes quite rapidly horizontally and vertically.

In the conglomerates the solutions from which the barite was precipitated dissolved the rims of some novaculite and quartzite pebbles. In the sandstones there is little evidence that the quartz grains were attacked by the solutions.

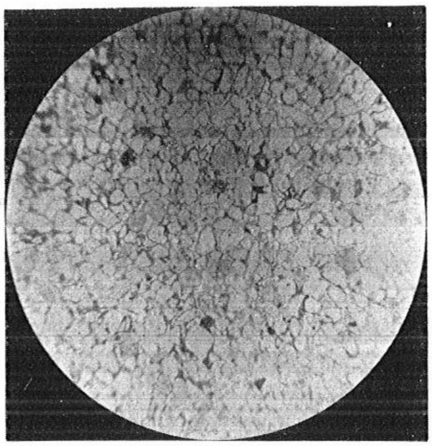
The study of the thin sections of these barite-cemented sediments yielded no evidence that the barium sulfate replaced a previous cementing material, and as much of the Trinity sand is not cemented (Plate 23) the writer believes that the barite was deposited in open pore spaces.

Origin and Emplacement

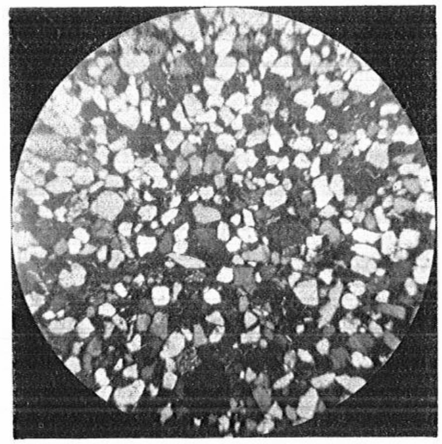
In most cases where barite occurs as a cement in sandstone or conglomerate the concentration of the barium sulfate has been attributed to the action of ground water or precipitation from marine water (Ham and Merritt, 1944). The available evidence indicates that the barite cement in the members of the Trinity was precipitated from hydrothermal or, perhaps, telemagmatic solutions, but that ground water controlled to some extent the sites of deposition. The zones of barite concentration in these deposits are lenticular and quite irregular vertically and horizontally. In the sandstones the zones of barite concentration are governed as far as can be determined by concentration of clays and iron oxides that control the porosity. However, this is not true in the gravels. Vertical veinlets of coarsely crystalline barite suggest that the barium sulfate-bearing solutions may have migrated from one zone to another vertically as well as horizontally.

The writer has carefully evaluated the data pertaining to the origin of the barite occurring in the Trinity beds. The possible origins considered were precipitation from marine waters, precipitation from ground waters, precipitation from surface waters, precipitation from hydrothermal solutions, and an emplacement involving two or more of the above processes. Precipitation from marine waters appears to be the weakest interpretation. The barite occurs in the lower units of the Trinity, which are essentially coarse clastics. An area of deposition of coarse clastics is not ordinarily also an area of deposition of chemical precipitate at rates and in amounts sufficient to produce large crystals. Precipitation from ground water is not the most satisfactory interpretation for the origin of the barite cement because there is no apparent source of barium in the rocks immediately adjacent to the Trini-

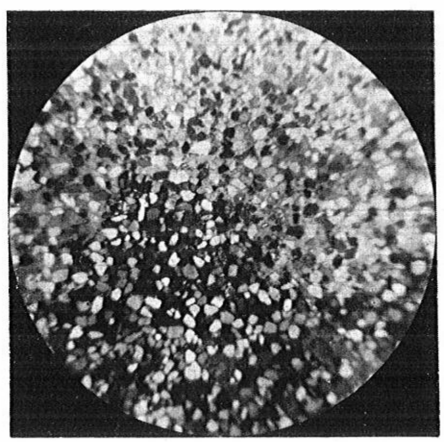
PLATE 23



(A)



(B)



(C)

(A) Photomicrograph to show porosity of uncemented Trinity sandstone, south of Cherry deposit, Dierks district. Plane polarized light; X 13.

(B) Same view with nicols crossed.

(C) Photomicrograph of barite cemented Trinity sandstone, Northwest 16 deposit, Dierks district. Crossed nicols; X 13.

ty beds. It cannot be presumed that the relatively insoluble barium sulfate could be transported any great distance in ground water with ordinary temperatures and chemical makeup. The irregular geographic and stratigraphic distribution of the barite cement almost precludes the possibility that barium chloride or other readily soluble barium salt-bearing ground water reacted with sulfide or sulfate-bearing interstitial fluids to precipitate barite.

The theory that the barite in the Trinity was derived from the barite in the older sediments is based on several suppositions. Such a theory presumes that barium carbonate or sulfate in the Ouachita Mountains was more subject to chemical than mechanical erosion, and that a drainage system similar to the present drainage pattern transported the barium in solution to the margin of the Gulf Coastal Plain, where the change in stream velocity enabled the barium-bearing waters to seep down into the porous zones of the lower Trinity beds, and deposit the barite. The major arguments against this theory are that there is little or no barium carbonate in the exposed barite deposits in the Ouachita Mountains, and as far as can be determined, the barite in the mountainous area is being removed by mechanical rather than chemical erosion. It is doubtful if appreciable amounts of barium would stay in solution in the well-aerated waters of mountainous streams for considerable distances.

The available data support to a large extent the theory that the barite in the Trinity sediments was derived from igneous sources. Cinnabar-bearing barite veins almost certainly of hydrothermal origin occur less than six miles east of and nearly along the strike of the Trinity units which contain the barite zones. The peridotite plugs in which barite veins occur are less than 20 miles east of south from the barite zones in the Trinity. Ross, Miser, and Stephenson (1929, p. 190), after an extensive study of the tuffaceous beds of the Cretaceous in southwestern and northeastern Texas concluded, on substantial evidence, that volcanic necks are present in the vicinity of Lockesburg and Nashville. These postulated centers of igneous activity are 8 to 15 miles south of the barite areas. There are no known igneous masses nearer to the sites of barite deposition than these, although one or more could be present beneath the Cretaceous cover.

Not only are possible igneous parent rocks present in the vicinity of these barite deposits, but the trace element suite of this barite is similar to the suites in the replacement-type barite deposits and the igneous rocks of the Gulf Coastal Plain province (Table 4).

The erratic distribution of the barite in the Trinity beds suggests that the concentration of the barite was effected by more than one process. The writer believes that barium-bearing hydrothermal solutions derived from igneous masses associated in time and position with the nearby plugs, volcanic necks, and cinnabar-barite veins were the sources of the barium sulfate cementing the Trinity clastics. These solutions migrated up dip or along strike to sites where intermingling with ground water occurred. This intermingling was most pronounced in the more porous zones of the Trinity as these zones contained larger amounts of formational water. The hydrothermal solutions were cooled so that the barium sulfate was precipitated. The volume of hydrothermal solutions must have been much greater than that of the ground water because the cooling was not so rapid as to inhibit the growth of large barite crystals. The rate of precipitation was probably uniform, as the large barite crystals display no growth or zoning lines.

Associated sulfates. The Dierks limestone is in the zone which contains the barite bodies. Celestite beds or veins occur in the shale or sandstone unit overlying the Dierks limestone. This zone is considered by Miser and Purdue (1929, p. 83) to be in the lower part of the DeQueen limestone member of the Trinity. Gypsum also occurs in this member. The gypsum horizon is above the celestite horizon and may represent a period of partial evaporation of the Trinity seaway. The gypsum beds are stratigraphically conformable with the adjoining strata, which suggests that they were deposited as part of the sedimentary sequence. The granular nature of the gypsum has no significance as to source for the writer. The celestite bodies are lenticular and coarsely crystalline. The exposures examined were too poor to determine if the bodies were concordant or discordant with the containing strata. The observable discordance may be more apparent than real because the bodies are lenticular. However, the writer believes that the celestite bodies are veins, are slightly discordant, and are associated spatially and in time with barite in the underlying Trinity clastics. The barite in the Dierks district, as did the barite in the other districts of the region, yielded significant percentages of strontium sulfate in chemical and spectrographic analyses.

It could be argued that the sulfates in the Trinity formation, the barite, celestite, and gypsum, with their ascending distribution represent a discontinuous evaporative sequence. The writer does not accept this possible interpretation. The Dierks limestone and thick coarse clastic beds occur above the barite and below the celestite and gypsum horizons. Coarse sand and clay beds occur between the gypsum and the celestite. There is no evaporative sequence discernible in any of the sulfate zones. A common sedimentary origin and a progressive relationship for these sulfate zones seems highly improbable.

The geographic and stratigraphic proximity of the sulfate zones seems to indicate a genetic relationship for these sulfate zones. The presence of 0.1 to 2.0 percent of titanium in the barite, the relative abundance of barium and titanium in the igneous rocks of the region, and igneous rocks and metalliferous barite veins in the general vicinity of the cemented zones strongly suggest to the writer that the barite cement was derived from igneous sources. The high percentage of strontium in the barite in all of the districts within the region indicates that the celestite and barite of the Trinity are genetically related. Other than its proximity, the writer has no evidence to relate the gypsum to the other sulfates. If the gypsum is genetically related to the celestite and barite it probably was deposited as anhydrite and altered to gypsum by hydration.

Fissure Vein Deposits

The fissure vein deposits of barite in the Ouachita Mountains probably are not in commercial quantities. They are discussed chiefly because of their role in dating and establishing the mode of origin of the barite in the replacement and cementing deposits.

The barite veins in the Ouachita Mountain region can be subdivided into two types. The first, or discordant vein type, is exemplified by the white, coarsely crystalline barite in the peridotite area of Murfreesboro and the colorless extremely coarse crystalline barite veins at the west end of the Cinnabar district. It is doubtful if either of these types of veins has any commercial significance.

Type II, the concordant vein, is characteristic of the Hatfield district, but also occurs in other localities of the region. Veins of this type were formed in and parallel to the bedding of the middle member of the Arkansas novaculite. They consist of dark gray to black, fine to coarsely crystalline barite, and generally are less than two feet thick. Only a few of the veins can be traced more than 60 feet along the strike length.

Discordant Veins

Peridotite area. In the peridotite plugs at Murfreesboro, particularly in the Ozark mine, crystalline barite occurs as a cement in the volcanic breccias and as fracture filling. Chalcedonic to massive quartz surrounds the barite crystals in many places. Magnetite and serpentine are the only minerals associated with the barite and they are probably present as inclusions rather than vein minerals. The only paragenetic sequence that can be established is barite followed by quartz.

Cinnabar district. The barite veins in the Cinnabar district occur 12 miles northwest of the Murfreesboro peridotite. The cinnabar-bearing barite occurs as fracture filling and emplacements along a fault zone. Nearly all the mines in this district are full of water and interpretations must be based on material that is available on the mine dumps and from the collections of the local citizens. The paragenetic sequence was cinnabar, stibnite, cinnabar and stibnite, barite, barite and cinnabar, presumably extending over some period of time and accompanied locally by minor deformation.

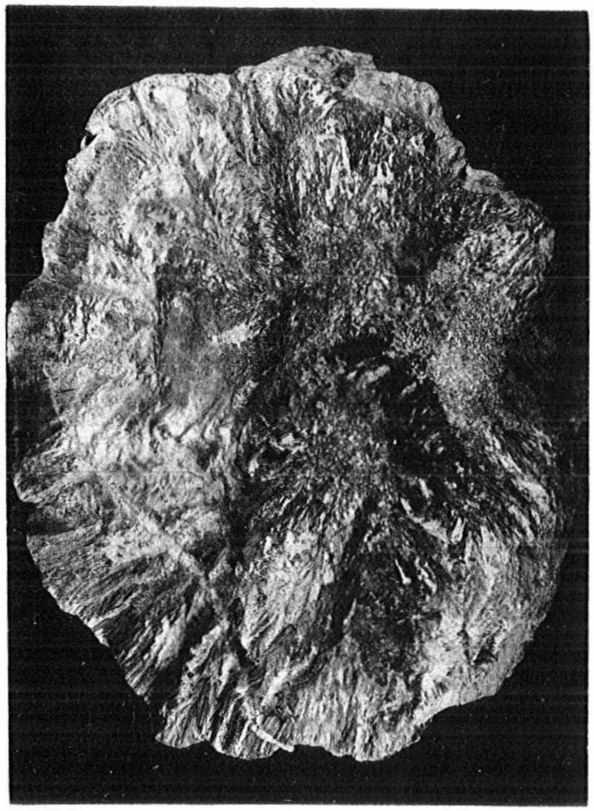
Southeastern Oklahoma. Vein barite in all probability related to those veins under discussion has been reported by Honess (1923, p. 39) from a mine two miles southwest of Watson in sec. 33, T. 1 S., R. 26 E., in the Ouachita Mountains of Oklahoma. The barite here is associated with sphalerite, dolomite, and quartz, with a minor amount of pyrite being present. In this report Honess presents rather conclusive evidence that deformation accompanied at least parts of the mineralization.

Concordant Veins in the Middle Arkansas Novaculite

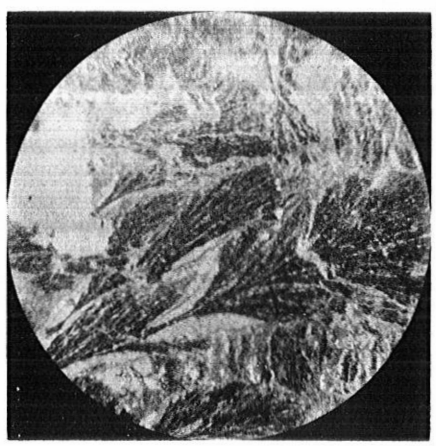
The barite veins in the Middle Arkansas novaculite were emplaced along slippage zones between shale and novaculite beds, in fractured and brecciated zones, and along relatively undisturbed bedding planes. All of these veins occur on the steeply folded flanks or the plunging noses of anticlinal structures. In all but one of these vein deposits, the barite is dark gray to black, fine to coarsely crystalline, and exhibits no unusual texture or structural features. The single exception occurs in southwestern Montgomery County where the barite is present in nodules with a feather-like radiating structure (Plate 24).

The veins are post-deformation (post-Paleozoic), as they occupy fissures created during the orogenic disturbances. Manganese, to some

PLATE 24



(A)



(B)

(A) Photograph of radial barite nodule from Polk Creek Mountain deposit, Fancy Hill district. X 13.
(Photographer, Harry Smith, Jr.)

(B) Photomicrograph of section of nodule above. Plane polarized light; X 13.

extent concentrated by ground water (Miser, 1917, pp. 59-122, is associated with some of the vein barite. The manganese occurs as fracture and fault plane filling but also occurs in concentration as pore filling. The manganese was indigenous to and disseminated in the lower and upper novaculite. It is probable that the barite-bearing hydrothermal solutions were more effective concentrating agencies than ground water, at least locally.

Regional Relations of the Barite Mineralization

General Statement

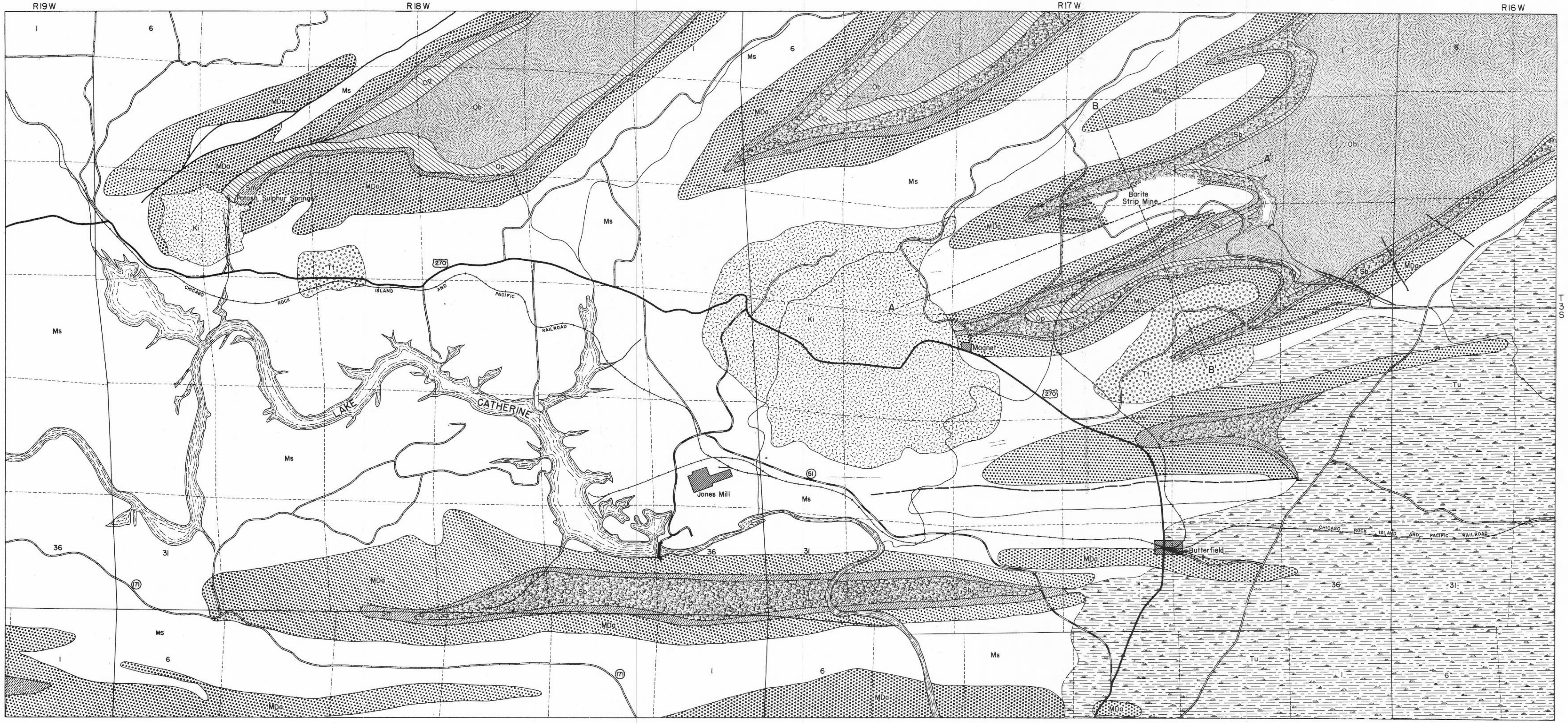
The data presented in the foregoing section are presumed to be sufficient to show that the barite and associated minerals in this region were deposited from hydrothermal solutions derived from igneous sources. In this region two periods of igneous activity can be clearly demonstrated. The earlier occurred in lower Mississippian time when volcanic activity gave rise to the Hatton tuff and the associated pyroclastics. The second period of igneous activity occurred in the lower Upper Cretaceous; namely, post-Trinity-pre-Brownstown. Many writers, including Honess (1923), Stearn (1936), Reed and Wells (1938), and Miser (1943), have postulated a period of igneous activity related to the final stages of the Ouachita orogeny which they place in middle Pennsylvanian time. These writers ascribe the metalliferous deposits in the Ouachita Mountains as well as the remarkable quartz crystals to this period of igneous activity.

The writer believes that the Ouachita orogeny continued into Permian time, that much but not all of the quartz crystal and vein formation took place during the later part of the Ouachita orogeny, and that the metalliferous deposits are not associated with this period of quartz vein formation but are associated with the Cretaceous igneous activity.

The writer's deduction as to the age and magnitude of the Ouachita orogeny are discussed in Chapter II. Miser (1943) and Engel (1946, pp. 598-618) have offered strong evidence to show that the quartz crystals and veins of the Ouachita Mountain region were formed during the later stages of the Ouachita orogeny. However, the quartz veins in the ultramafic rocks near Murfreesboro, those formed from reconstituted novaculite by thermal waters at Hot Springs, and the quartz veins associated with the brookite at Magnet Cove show that there was some post-Paleozoic quartz vein formation.

In previous sections evidence has been presented to show that a barium-rich igneous suite of Cretaceous age occurred in the Gulf Coastal province and the adjoining parts of the Ouachita Mountains. The available data were interpreted as indicating that these igneous rocks were the sources of the barite occurring in the region. As the cinnabar of the region is associated with barite veins, it was concluded that the cinnabar is also of Cretaceous age. Stibnite is associated with the cinnabar, suggesting a genetic relationship between the quicksilver belt and the antimony deposits of northern Howard and southern Polk Counties to the north. Lead, zinc, and copper sulfides are associated with the stibnite in the antimony deposits, indicating that the sphalerite-galena-chalcopyrite deposits of central Polk County and lead-zinc deposits with barite gangue in southeastern Oklahoma are related to the barite-cinnabar deposits and are Cretaceous in age.

The foregoing suggested age and genetic relationships are supported by the nature of the sulfide minerals and their spatial occurrence. Stibnite and particularly cinnabar are epithermal minerals and are ordinarily deposited within a few hundred feet of the surface of the ground. Six to 12,000 feet of Atoka and Jackford strata had to be removed by erosion before the mineralized zones were close enough to the surface to serve as loci for cinnabar-stibnite deposition. The writer does not believe that this amount of truncation could have occurred after the Atokan deposition and before middle Pennsylvanian or even lower Permian time without leaving some record of rapid denudation in the strata of the adjoining regions. Therefore the spatial relationships of the sulfide deposits are considered as further evidence that the metalliferous deposits of the Ouachita Mountains are genetically related to the barite and are Cretaceous in age.



EXPLANATION

CENOZOIC SEDIMENTS

- Tu — TERTIARY SEDIMENTS UNDIFFERENTIATED
- Tt — TERTIARY TERRACE GRAVELS

PALEOZOIC SEDIMENTS

- Ms — STANLEY FORMATION
- MDa — ARKANSAS NOVACULITE
- Sm — MISSOURI MOUNTAIN SHALE
- Sb — BLAYLOCK SANDSTONE
- Op — POLK CREEK SHALE
- Ob — BIGFORK CHERT

MESOZOIC IGNEOUS

- Ki — CRETACEOUS IGNEOUS WITH INCLUDED METAMORPHICS UNDIFFERENTIATED

- ALKALIC DIKE
- FAULT
- LINE OF CROSS SECTION

Modified From Culp 1948 and Parks 1932
Base From U.S.G.S. Malvern Quadrangle

GENERALIZED GEOLOGIC MAP OF THE MAGNET COVE BARITE DISTRICT

SCALE IN MILES

0 1 2 3 4 5

THE BARITE DEPOSITS—MINES AND PROSPECTS

Magnet Cove District

General Statement

The Magnet Cove district includes parts of Tps. 3 and 4 S., Rs. 16, 17 and 18 W., in the northeast part of the Malvern quadrangle and lies wholly within Hot Spring County. The Paleozoic rocks exposed in the district range from the Ordovician (Bigfork chert) to the Mississippian (Stanley shale). The Mesozoic is represented by the Magnet Cove igneous rocks of Cretaceous age, and the Cenozoic is represented by the lower Tertiary Midway formation, which overlaps the Paleozoic rocks on the southeast side of the district (Plate 25). Structurally, the district incorporates the eastern end of the Mazarn basin, part of the Zig Zag Mountains, the northernmost part of the Trap Mountains, and the Magnet Cove intrusive masses. The major barite deposit, the only one presently being mined in Arkansas, is located in the Chamberlain Creek syncline, one of the southwestward plunging synclines of the Zig Zag Mountains. Minor amounts of barite are present in the Cove Creek syncline northwest of the Chamberlain Creek syncline, in the Reyburn syncline on the southeast, and in the Trap Mountains to the south. Most of the barite in the Cove Creek structure is of the nodular type; that in the Reyburn syncline and the Trap Mountains is mostly massive.

Chamberlain Creek Syncline

History of Development. The discovery and earlier investigation of barite in the Chamberlain Creek syncline have been discussed by Parks (1932, pp. 8-9):

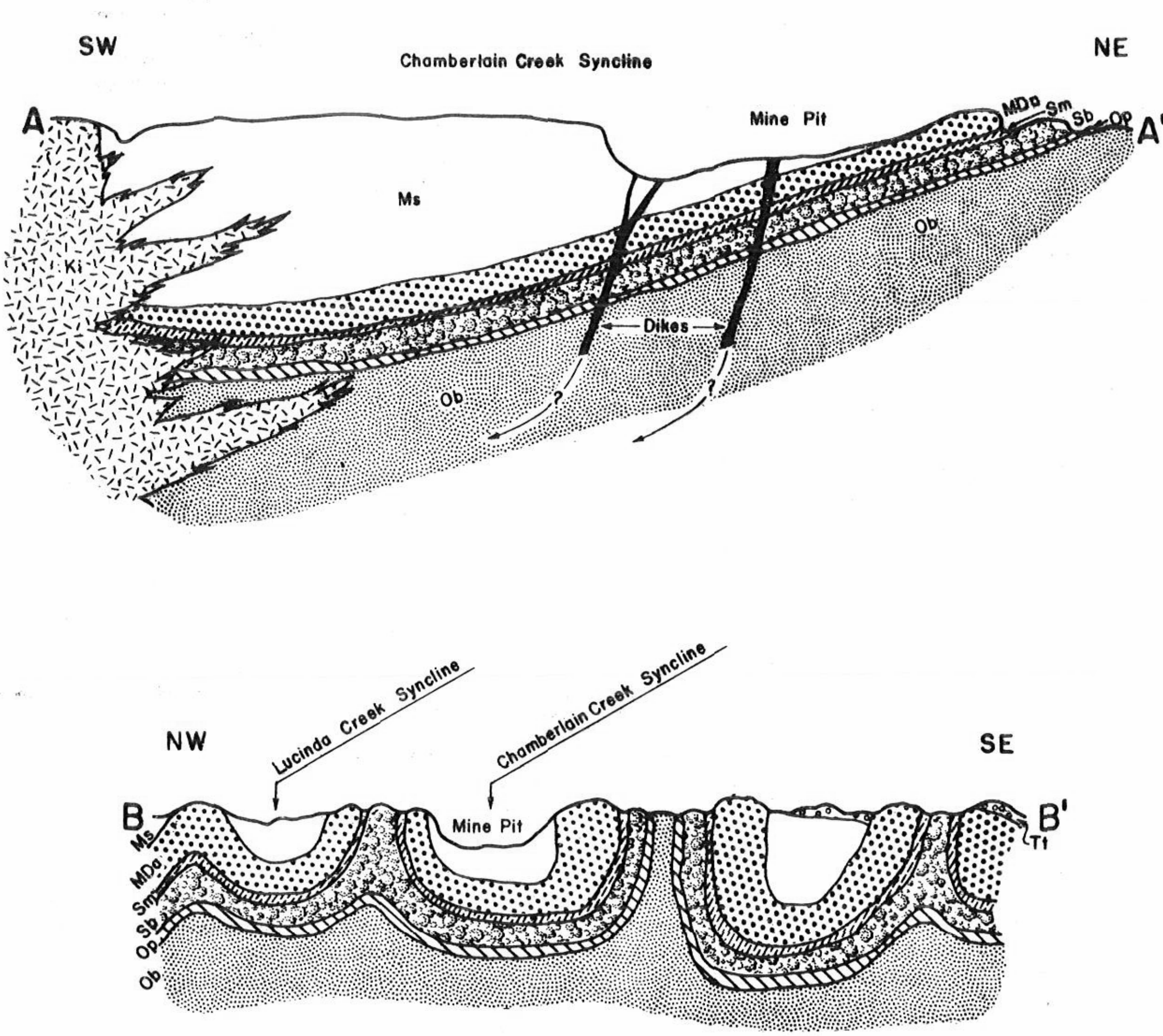
> Barite was first discovered in Arkansas in Hot Spring County about 1900 when a water well was dug on the Casey homestead two miles east of Magnet Cove. Because of its heavy weight, the mineral was thought to be a lead mineral and some search for lead minerals was made in this vicinity. Then in 1911 when the well was cleaned out, some of the barite was seen by John Inglis, Hot Spring County Surveyor, of Magnet, Arkansas, who recognized that it was not a lead mineral but who was unable to make a correct identification. Mr. Inglis later took samples to Joe Kimzey, of Magnet, and to A. E. Perkins, a mining engineer, both of whom identified the mineral as barite. -In 1915, Mr. Kimzey, in examining the locality, found small fragments of barite mixed with clay and gravel which had been brought to the surface by uprooted trees near the Casey well. By examining the pits made by the uprooting of these trees, Mr. Kimzey was able to trace the barite in a narrow zone for approximately three-fourths of a mile, and by digging in the bottom of the pits encountered solid barite in a few places.
>
> Samples of the barite were first brought to the Arkansas Geological Survey in September, 1928, by E. E. Bonewits, of Little Rock. A specimen was analyzed and found to contain 82.60 percent barium sulfate and 12.98 percent silica, the samples being identified as pure barite. The locality in which the mineral occurred was recommended for testing to several persons including Moritz Norden, of the Wil-Nor Development Company, who was referred to Joe Kimzey by the Survey in the late summer of 1930 in regard to the location of the deposit. Mr. Norden became interested and, through the Wil-Nor Development Company, acquired leases and began prospecting.

Parks mapped the barite and the related rocks in intermittent periods from November, 1930, to June, 1931. The only exposures of barite available to Parks for study were those in the trenches and shafts dug by the Wil-Nor Company. However, in May, 1931, the Southern Acid and Sulphur Company of St. Louis, Missouri, entered into an agreement with the Wil-Nor Company and drilled 34 holes on the north side of the deposit. Parks was permitted to study the analyses of the cuttings from these drill holes, but was not allowed to publish the results. This period of prospecting terminated in June, 1931.

Parks' (1932, pp. 46-52) report contains metallurgical reports from the U. S. Bureau of Mines and the Denver Equipment Company showing that the barite ore from the Chamberlain Creek area could readily be concentrated to about 90 percent barium sulfate and by reflotation even higher concentrates could be obtained. In spite of these favorable reports, no sustained effort was made to mine and mill barite in this area until 1939 when the Magnet Cove Barium Corporation started operations. In 1941 the National Lead Company began mining a portion of the same deposit.

The annual production of barite from this district from 1935 to 1955 is shown in Table 5. Nearly all of the barite produced by these companies is sold for use as weighting material in drilling mud. **Magcobar** is the trade name of the Magnet Cove Barium Corporation, and **Baroid** is the trade name for the National Lead Division.

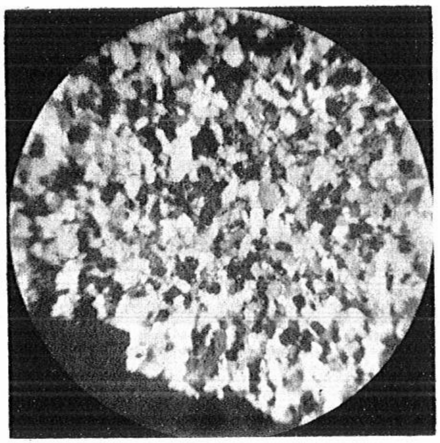
Local structure. The Chamberlain Creek syncline is truncated on the southwestern end by the Magnet Cove intrusives in the eastern part of Sec. 17, T. 3 S., R. 17 W. (Plate 25). From this locality, the syncline extends northeastward with a subsymmetrical outline for



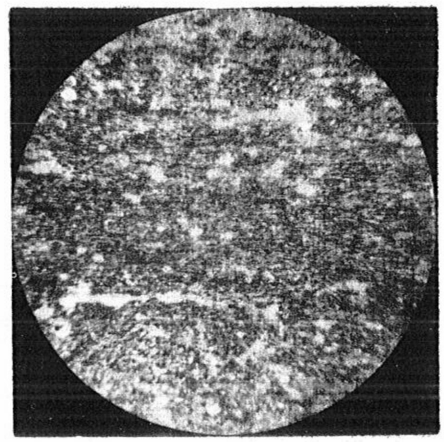
Note: (Symbols and lines of sections shown on PLATE 25)

SCHEMATIC CROSS-SECTIONS SHOWING GENERAL STRUCTURAL RELATIONSHIPS IN THE MAGNET COVE DISTRICT

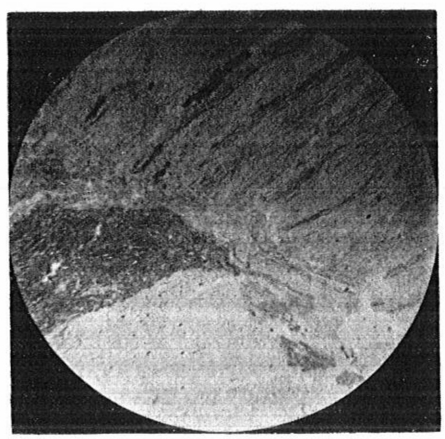
PLATE 27



(A)



(B)

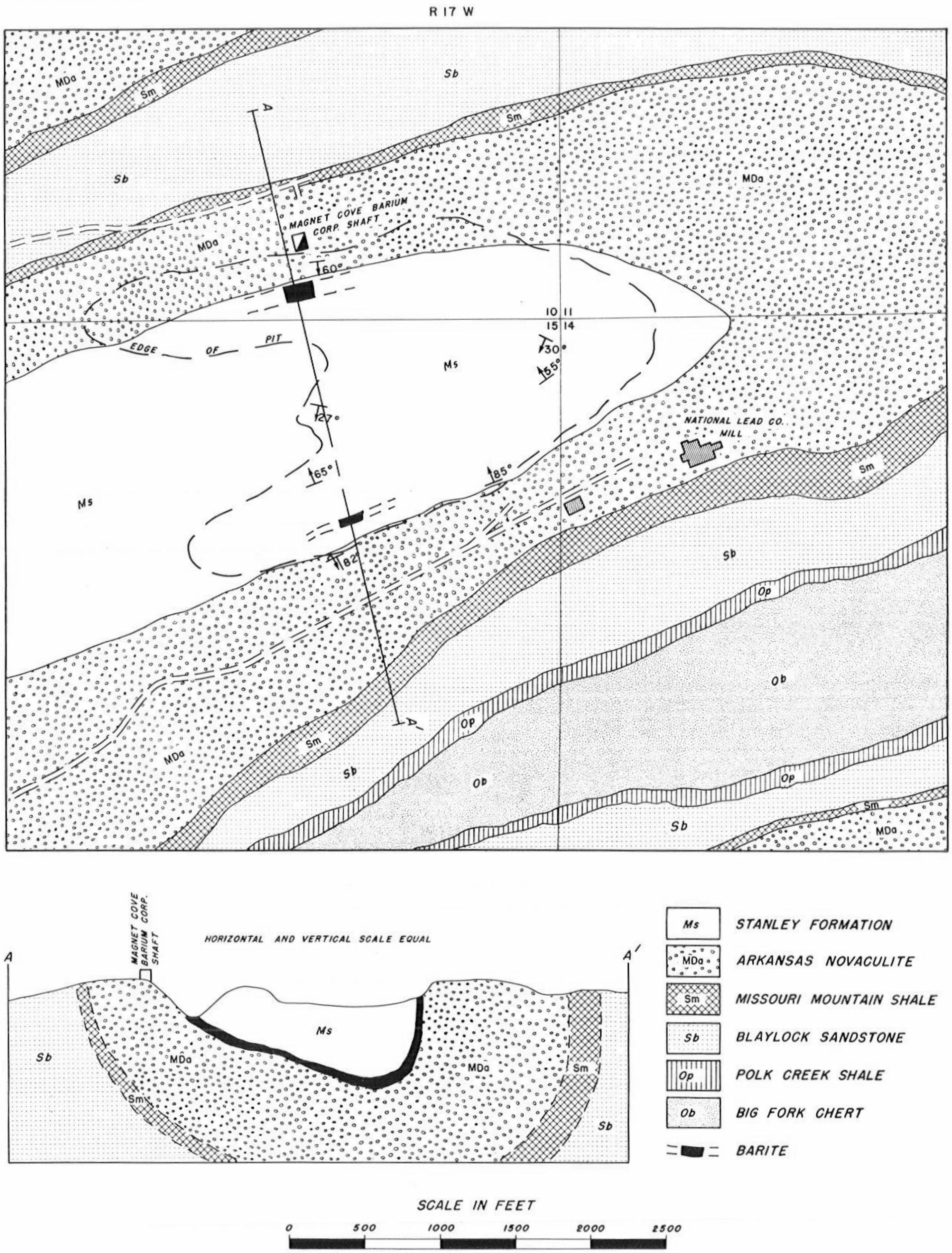


(C)

(A) Photomicrograph showing the quartzitic nature of the Upper Arkansas novaculite in the Chamberlain Creek syncline. Crossed nicols; X 13.

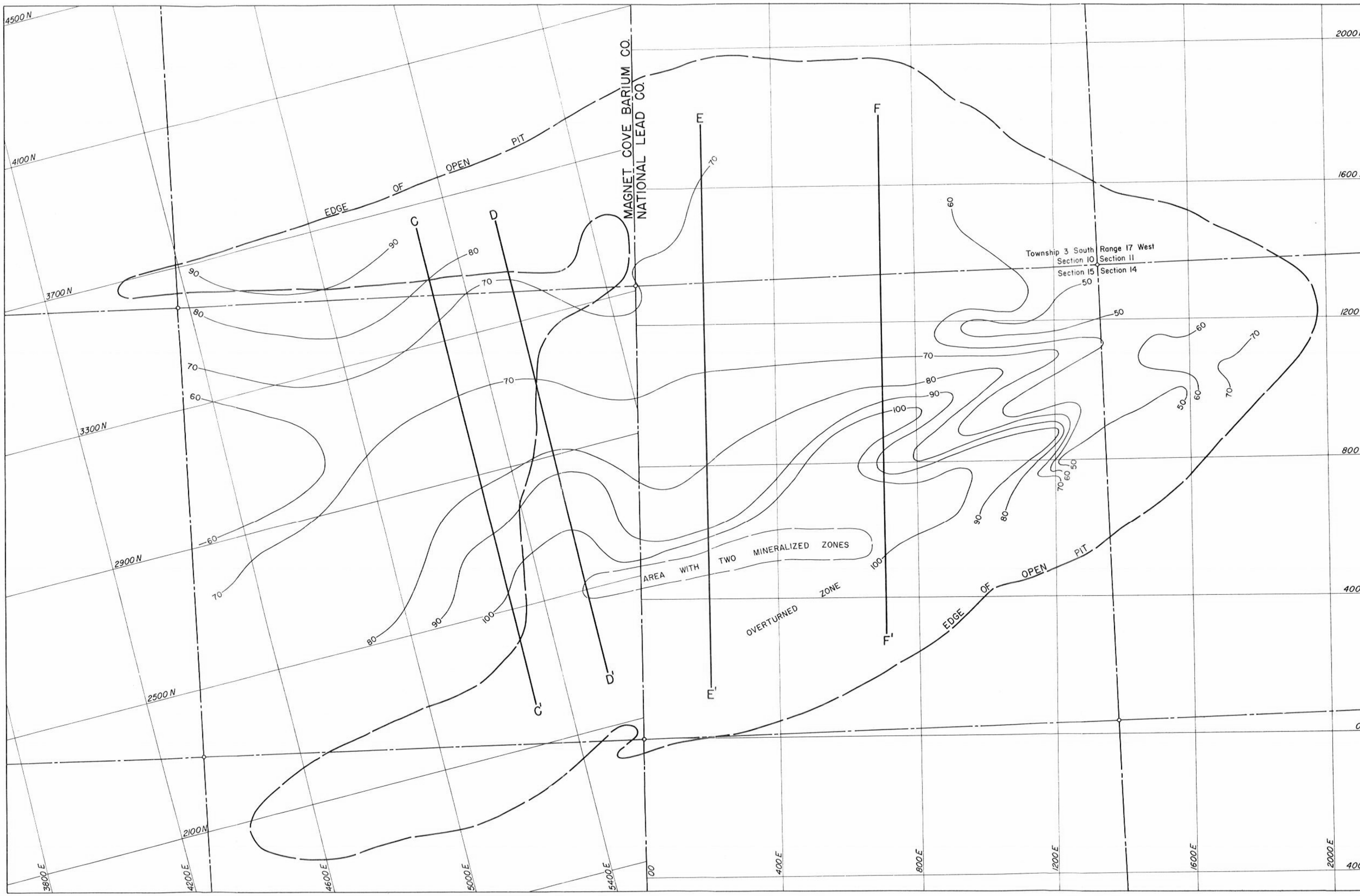
(B) Photomicrograph of the black shale at the base of the Stanley formation in the Chamberlain Creek syncline. Plane polarized light; X 13.

(C) Photomicrograph of crumpled shales at apex of V-fold, underground workings, Magnet Cove district. Plane polarized light; X 13.



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

AFTER B. J. SCULL 1956



THICKNESS MAP OF THE MINERALIZED ZONE, CHAMBERLAIN CREEK BARITE DEPOSIT
MAGNET COVE BARITE DISTRICT, ARKANSAS

SCALE IN FEET
0 500 1000 1500 2000

about two miles. From near the northwest corner of sec. 14 to near the center of the southeast quarter of sec. 11, the axial trend is a few degrees north of east. Although the surface trace of the stratigraphic units within this syncline is roughly symmetrical, structurally the syncline is decidedly asymmetrical, with the southeast limb being steeper and locally overturned (Plates 26, 30).

There are a great number of faults cutting the sediments in this syncline with displacements ranging from a fraction of an inch to two feet. Both pre- and post-mineralization faults occur. Nearly all of the post-mineralization faults, both underground and surface, seem to be the result of rock adjustments to the mining operations.

In the rock exposures made available by the underground mining operations, many more local structures can be seen than anywhere in the district. In the open pit workings the blasting operations have destroyed much of the continuity of the rock surface, making it difficult to distinguish between structures formed by tectonic forces and those formed by the blasting operations. Underground, minor structures in the form of V and chevron folds, rollovers, and normal and reverse faults are common (Plate 27C). The displacement along the faults is ordinarily only a few inches. These local structures have no appreciable effect on the concentration of the barite, although there is a slight increase in the grade of the ore along the axes of some of the folds.

Stratigraphic relations. In this deposit the Arkansas novaculite forms the floor of the mineralization. In the anticlines flanking the Chamberlain Creek syncline the lower and middle divisions are typical—the lower division is massive, and the middle division is thin bedded. The character of the upper division which is not everywhere present is somewhat different in this area than in other parts of the Ouachita Mountains. The upper division consists of alternating layers of dense, cryptocrystalline novaculite, mostly white or pink, and light gray, medium-grained quartzite, (Plate 27A). These two lithologies are present in beds ranging in thickness from 2 to 8 feet.

Everywhere in the Chamberlain Creek syncline where mining operations or core drilling enable the stratigraphic sequence to be studied, the novaculite is overlain by a black shale, ranging in thickness from 2 to 22 feet (Plate 27B). This black shale is considered part of the mineralized zone. At the base of the black shale is a zone containing small pebbles which is ordinarily a fraction of inch thick but does range up to a thickness of four inches. The pebbles are chiefly novaculite, but iron-stained clay pebbles are present.

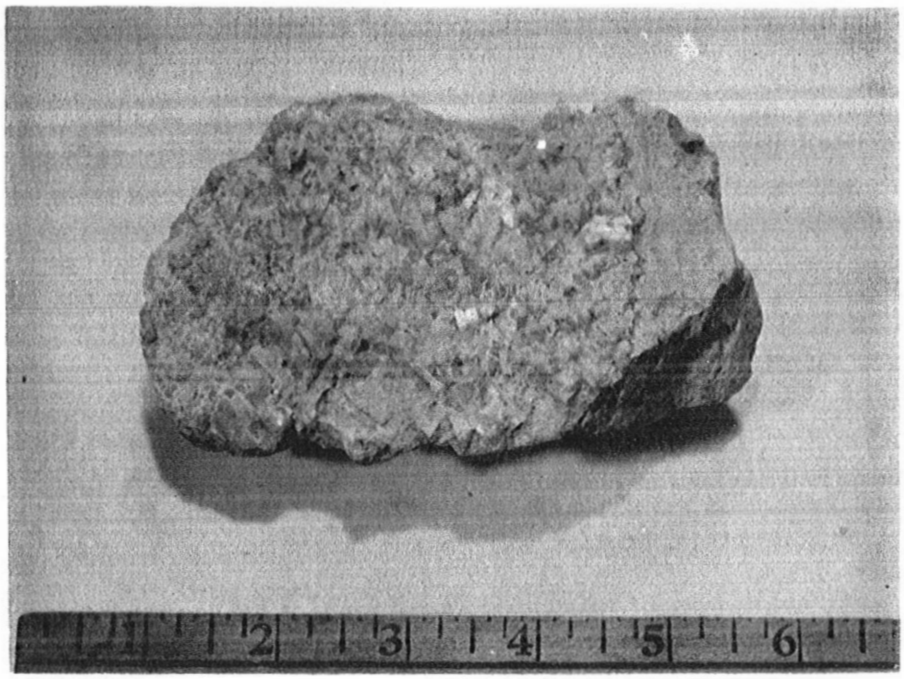
At other places in the district, the novaculite is overlain by a quartzitic sandstone at the base of the Stanley. This quartzitic sandstone cannot readily, microscopically or megascopically, be separated from the quartzites of the novaculite. Exposures in a cut along the Chicago-Rock Island and Pacific Railroad near the east end of the center line in sec. 27, T. 3 S., R. 17 W., were the only ones seen by the writer in which the basal quartzitic sandstone of the Stanley was separated by an interval of Stanley shale from the quartzites of the novaculite, which indicates that all the quartzite does not belong to the novaculite formation. This quartzitic sandstone unit and some of the quartzite of the novaculite were mapped as the Hot Springs sandstone by Parks (1932). As discussed under regional stratigraphy, the writer does not believe the term Hot Springs is applicable to this area.

In the area of the mine workings there is a maximum of 600 feet of Stanley shale, sandstone, and siltstone overlying the black shale unit. This formation is probably about 2,000 feet thick near the contact with the Magnet Cove intrusion. Elsewhere in the district, the thickness of the formation could not be determined because of the intricate crumpling of the beds and the deep weathering, which obscured any marker beds if such were present.

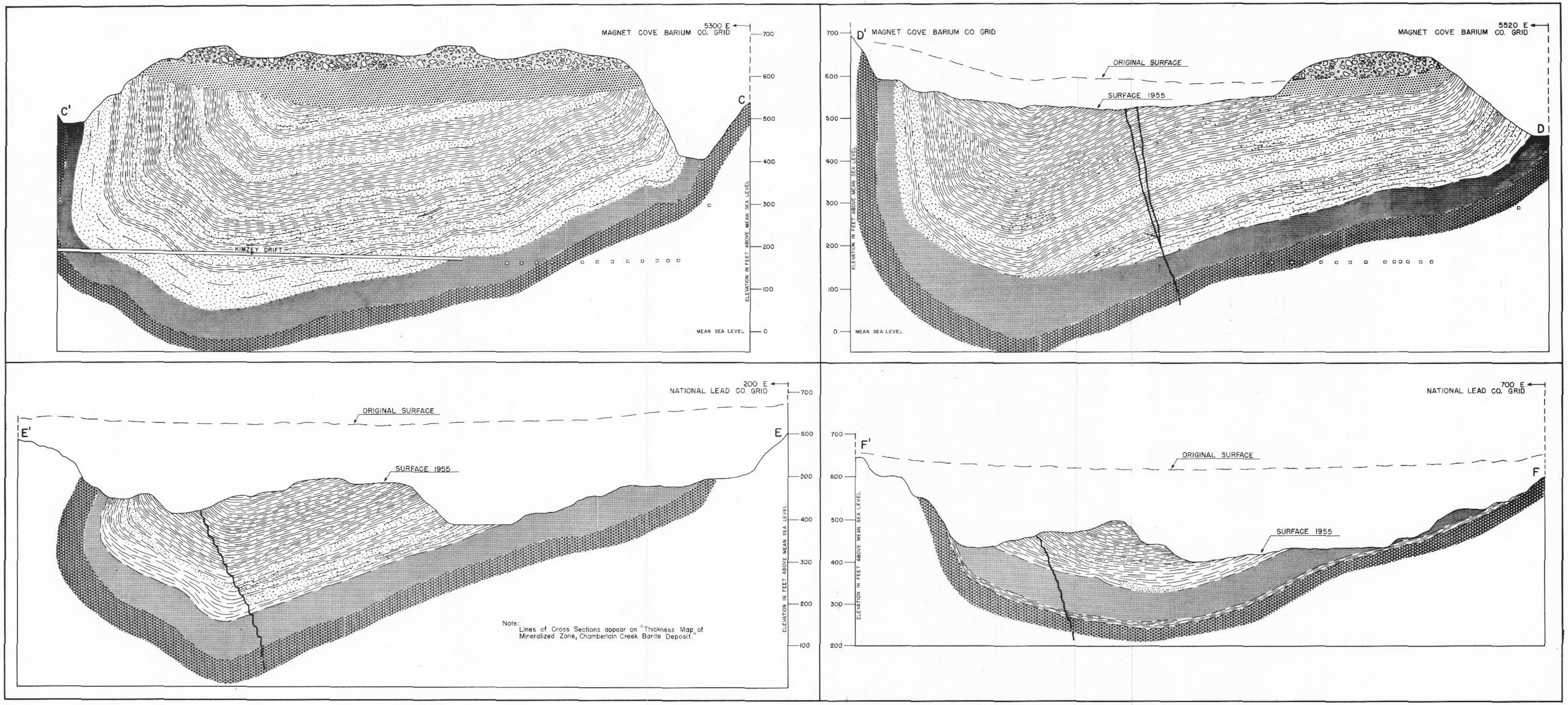
The ore bodies. The barite deposit in the Chamberlain Creek syncline is located in the northeastern part of the structure (Plate 28). It has a maximum length of 3,200 feet and apparently is restricted to that portion of the syncline in which the axial trend is nearly eastward. The maximum width of the ore body (1,800 feet) occurs at the west end of the deposit. Because of natural truncation, the width diminishes eastward. The ore body has been completely eroded away at the eastern tip of the structure (Plate 29). The average thickness of the mineralized zone is about 300 feet and the average thickness of commercial concentration is about 60 feet. The maximum thickness of commercial ore occurs just north of the axis of the syncline where it has a thickness of 80 to 100 feet.

The available drill hole information and the exposures in the surface and underground mine workings show that in this thicker portion the mineralized zone is split into two bodies sep-

PLATE 31



Photograph of crystalline barite along fracture face in Stanley shale. West end, Baroid pit, Magnet Cove district.



E X P L A N A T I O N

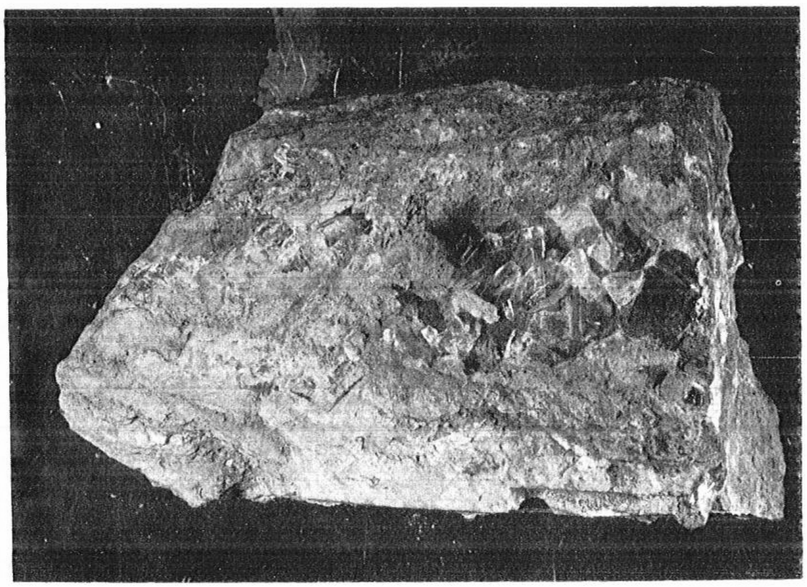
Shale	Overburden
Sand	Ouachitite Dike
Mine Waste	Arkansas Novaculite
Barite Ore	Magnet Cove Barium Co Drift

CROSS SECTIONS OF THE CHAMBERLAIN CREEK SYNCLINE
MAGNET COVE BARITE DISTRICT, ARKANSAS

HORIZONTAL SCALE IN FEET

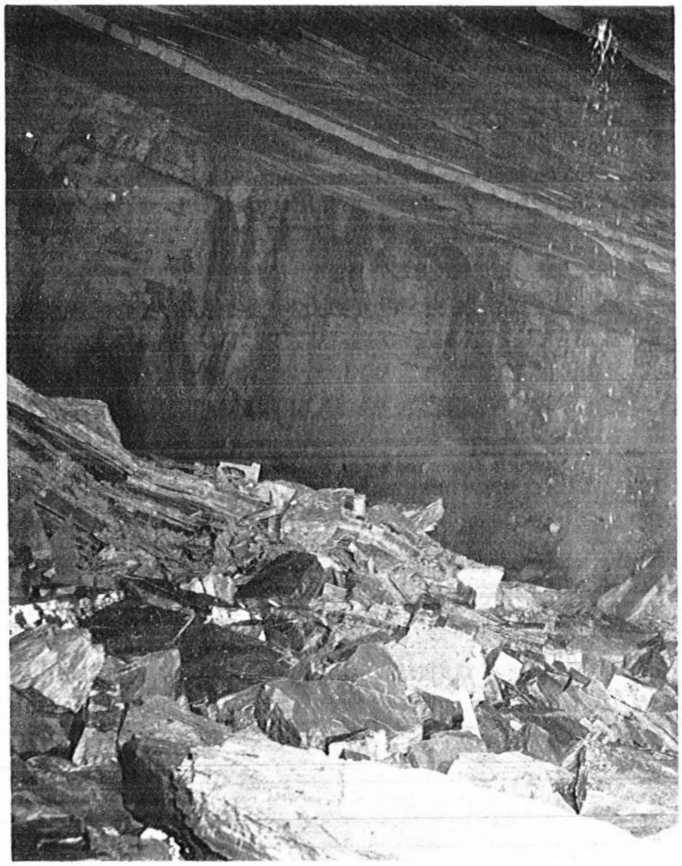
100 50 0 100 200 300 400 500 600 700 800 900 1000

PLATE 32



Photograph of transparent barite crystals in a vug in the Stanley shale 60 feet above the replacement zone in the Baroid strip mine, Magnet Cove district. (Photographer, Harry Smith, Jr.)

PLATE 33



Photograph of dark gray massive barite, "top slice," Magcobar mine, Magnet Cove district. (Photographer, Fred A. Burnett.)

arated by an essentially barren shale lens 5 to 15 feet thick. This is the only place in the commercial ore zone where a persistent barren or non-productive unit occurs. There is considerable variation of grade in the ore of the commercial zone, as well as considerable variation in the hardness or resistance to grinding which affects the desirability of the ore with respect to mining costs and adjustments in the milling program.

Character of the ore. The barite ore in this deposit is discussed, in a general way, in the section on types of ore. All four of the varieties discussed under Replacement Type Deposits are to be found in this zone. The nodular type ore makes up from 3 to 30 percent of the ore body, depending on the section measured. It appears to be more prevalent on the flanks of the syncline, perhaps because of the effects of weathering. Coarsely crystalline barite is rare in this deposit (Plates 31, 32). Most of the ore is of the gray or dark gray dense variety. Much of it has, superficially, a close resemblance to a dense limestone (Plate 33) which has led some observers to postulate that the barite replaced a limestone. The petrographic evidence will not support this interpretation.

Reyburn Creek Syncline

The barite deposit in the Reyburn Creek syncline occurs on the north limb of the structure. This limb is overturned and the dip at the contact of the Stanley shale with the Arkansas novaculite is 45° to the north, with the amount of overturning diminishing to the vertical near the axis of the fan-folded anticline bounding the syncline on the north.

Lenses of barite occur stratigraphically above and topographically below the Arkansas novaculite in the NE¼ SW¼ sec. 18, T. 3 S., R. 16 W., and the SE¼ SE¼ sec. 13, T. 3 S., R. 17 W. The thickest mineralized zone determined was 25 feet, of which a maximum of 12 feet would be commercial ore. The various lenses range in length from 40 to 900 feet. In the spring of 1955 the Magnet Cove Barium Corporation stripped the overburden from the topographic face of this deposit without disclosing significant reserves.

Cove Creek Syncline

The Cove Creek syncline is the downfolded structure immediately northwest of the Chamberlain Creek syncline. The Lucinda Creek syncline is a prong of the Cove Creek syncline along its southeastern margin (Plate 25). The Lucinda Creek prong is separated from the main part of the structure by a narrow elongate anticline projecting southwestward into the Cove Creek structure.

A zone of barite extends along the southeast limb of the Lucinda Creek syncline. Abundant novaculite float and the deeply weathered condition of the Stanley shale prevented any extensive tracing of this barite zone. From a road cut in the NW¼ SW¼ sec. 10 T. 3 S., R. 17 W., discontinuous exposures of this horizon, which is approximately 35 feet above the novaculite-Stanley contact, were traced about one-fourth of a mile to the southwest and about 2¼ miles to the northeast.

The barite as seen was mostly of the nodular type, although some massive and crystalline material was observed. The maximum thickness noted was about 15 feet. The poor quality of the exposures prohibits making any estimates as to maximum or average thickness of the mineralized zone.

Assays of samples from this zone made in the chemical laboratories of the Arkansas Geological Survey show a barite content of 2 to 84 percent in various samples. A well-planned trenching program would be necessary to evaluate this mineralized zone.

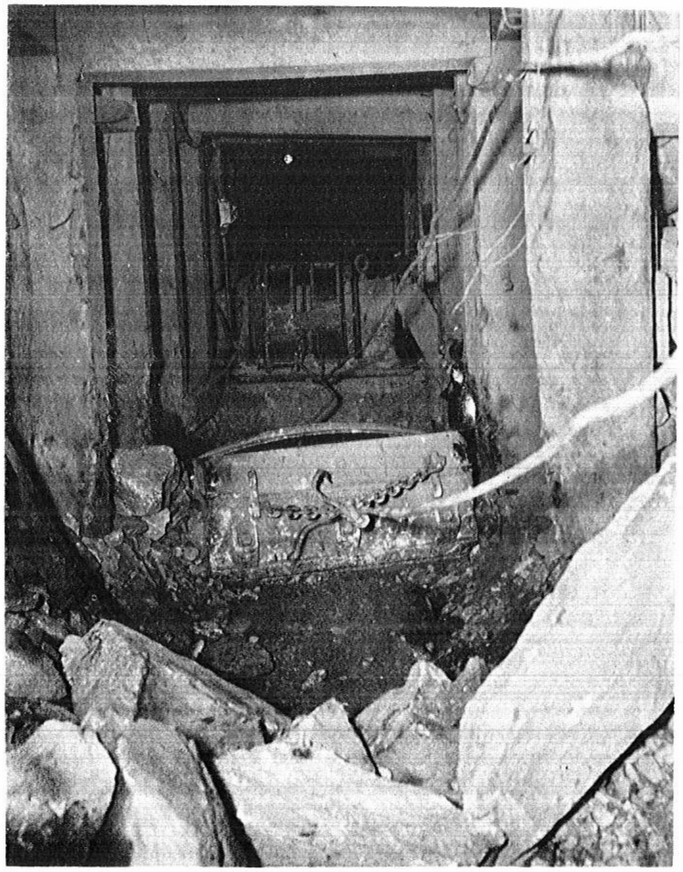
In the NW¼ sec. 2 and the SE¼ sec. 3, T. 3 S., R. 17 W., on the north limb of the anticline projecting into the Cove Creek syncline, massive crystalline and nodular barite was observed in the float from 20 to 150 feet above the Stanley-novaculite contact. In this case, and in all others where a reference is made to the Stanley-novaculite contact, unless specifically stated otherwise, "above the contact" means stratigraphically above and topographically below.

A drill hole of the U. S. Bureau of Mines drilled near the closure of the Cove Creek syncline in the SE¼ SE¼ sec. 35, T. 2 S., R. 17 W., in Garland County, drilled through 360 feet of the Stanley shale and bottomed in the Arkansas novaculite without encountering any barite. Calcite seams and pyrite were reported from the shale just above the novaculite contact (McElwaine, 1946 A, p. 20).

Trap Mountains

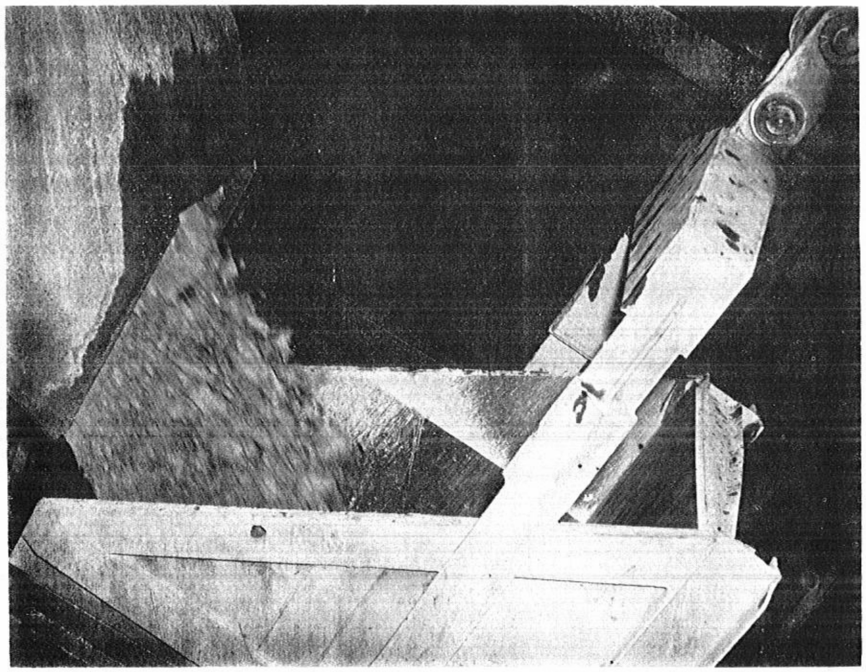
In the northern part of the Trap Mountains in the southern part of the district, small lenses and pods of barite were noted in numerous places. The mineralization, as seen, lacks the continuity to be called a zone or horizon. A sample of Stanley shale collected from a cut on the Chicago-Rock Island-Pacific Railroad in the northern part of sec. 33, T. 3 S., R. 17 W., was submitted to the laboratory for an analy-

PLATE 34



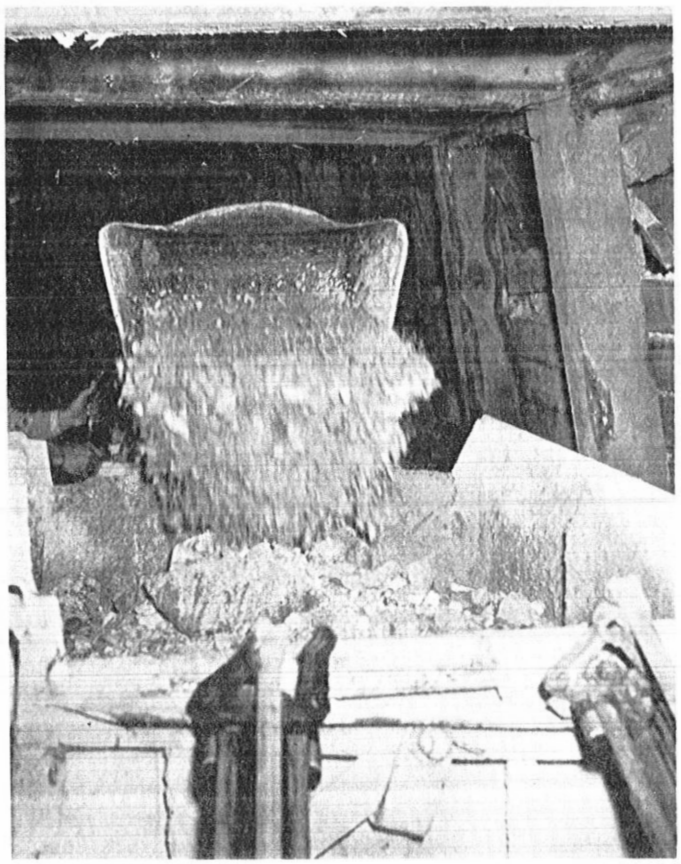
Photograph showing operations in a scraper drift, Magcobar underground mine, Magnet Cove district. (Photographer, Fred A. Burnett)

PLATE 35



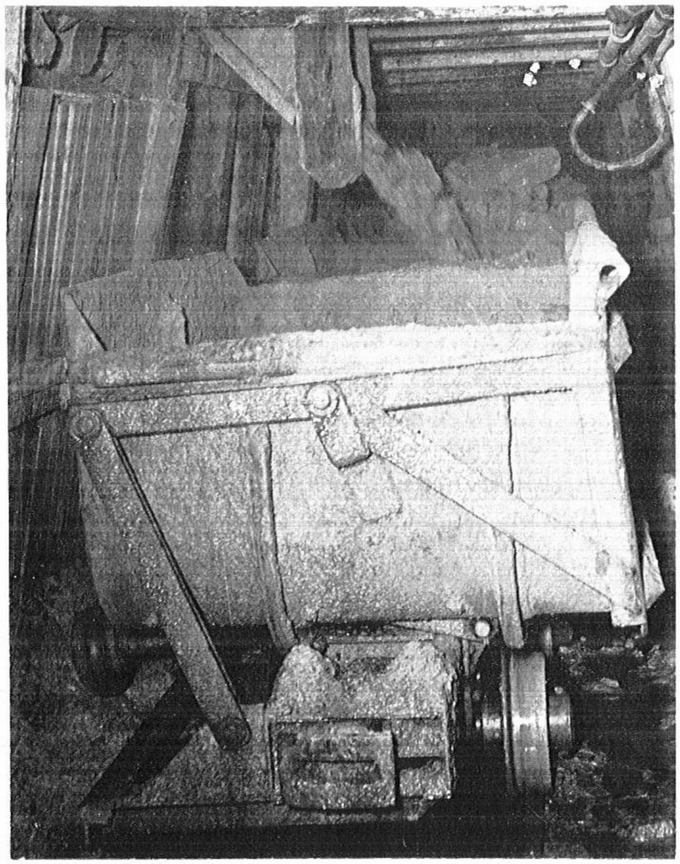
Photograph of skip loading at ore pocket, Magcobar mine. The ore is pulled up the inclined shaft and dumped into railroad cars at the surface. (Photographer, Fred A. Burnett)

PLATE 36



Photograph showing mucking machine loading ore cars in haulage drift, Magcobar mine. (Photographer, Fred A. Burnett)

PLATE 37



Photograph of ore cars being loaded at ore shoot from raise, Magcobar mine. Water removal is an almost constant problem in the mine. (Photographer, Fred A. Burnett)

sis which was to represent the chemical makeup of unaltered, unmineralized Stanley shale. Analysis shows that this shale contained 5.5 percent barium sulfate.

The greatest concentration of observed barite mineralization in the Trap Mountains was noted near the center of sec. 31, T. 3 S., R. 17 W. Several pods of barite a few inches thick and only a few feet long and assaying as much as 87 percent barium sulfate were observed in this area. A rather dense vegetation cover and the weathered condition of the rocks made it impossible to determine the amount of barite that could possibly be present in this area. The veinlets and pods are mostly earthy or shaly-appearing in the weathered state. Where fresh samples could be obtained the barite resembled closely the massive barite in the Chamberlain Creek syncline in that it had an appearance similar to that of a dense crystalline limestone.

Mazarn Basin

West of the Magnet Cove intrusions in the Mazarn Basin, the Stanley is for the most part deeply weathered. All of the roads, stream valleys, and utility line rights of way were worked rather closely in order to find fresh samples of the Stanley formation. Fifteen such samples from scattered localities were analyzed and each contained less than one percent barium sulfate, from one-half to two percent pyrite, and from a trace to five percent carbonate, substantiating, to some degree, the idea that the mineralization of the replacement deposits is restricted to that part of the formation immediately overlying the Arkansas novaculite.

Mining Operations

The Baroid Division of the National Lead Company is mining the eastern half of the deposit, and the Magnet Cove Barium Corporation is mining the western half. In the portion of the deposit controlled by the National Lead Company, the ore is recovered entirely by stripping operations. The engineers of this company (Chaney, 1954) plan underground operations where the overburden is too thick to make the stripping economical.

The Magnet Cove Barium Corporation in their initial operation strip-mined along the limbs of the syncline. After a few years of operation the excessive overburden in this deeper part of the syncline necessitated conversion to underground operations. The company sank an inclined shaft on the north limb of the syncline and to date has opened two levels underground. The company has driven one drift completely across the syncline, the geology of which is shown by the cross section on Plate 30.

The open pit mining operations of the National Lead Company are governed by the requirements of the mill, the structure of the ore body, and the character of the ore. The general procedure is to mine along the flanks and east end of the structure toward the center of the syncline in order to minimize the amount of waste removal and to utilize the existing haulage ramps without making major alterations. The waste is dumped in areas adjoining the mine and the ore is hauled to a mill located on the property.

The Magnet Cove Barium Corporation, in the underground workings, has used a great variety of mining methods, with scraper drifts and stopes being the most common (Plates 34-37). Local areas of bad ground require some deviation from standard mining methods. The ore recovered from this mine is shipped by rail to Malvern, where the company's mill is located.

Pigeon Roost District

Discovery and Description

The Pigeon Roost barite district is located at the western end of Pigeon Roost Mountain, in the southern part of Montgomery County. The barite occurs as lenticular bodies in sec. 25, T. 4 S., R 24 W., and sec. 30, T. 4 S., R. 23 W. According to Jones (1948, p. 5) the barite of this district was first discovered in November, 1946, when a bulldozer used in constructing logging roads uncovered several barite boulders. Under the direction of Jones, trenches were dug to determine the extent of the deposits. The trenches were shallow, and caving of the walls and vegetation have destroyed the exposures available to Jones' studies. However, the Baroid Division of the National Lead Company stripped the zones adjacent to the trenches dug by Jones and found that the mineralization did not extend beyond the lenses mapped by him (Schoenike, 1955). Jones' descriptions are given below:

> In each of the barite bodies in the Pigeon Roost Mountain area, barite has apparently replaced beds of shale and sandstone in the Stanley shale formation. The nearest observed outcrop of novaculite in the vicinity of the deposits is 250 feet south of trench I in the southwestern deposit. It is probably part of one of the many synclinal structures of the Mazarn synclinorium that are mostly hidden by the overlying Stanley shale.
>
> The southwestern deposit is lenticular, measuring 800 feet along the strike, with a maximum thickness of 29 feet near the center of the lens. The general strike is N. 60° E., but on the northeastern and southwestern extremities of the lens, the strike is N.

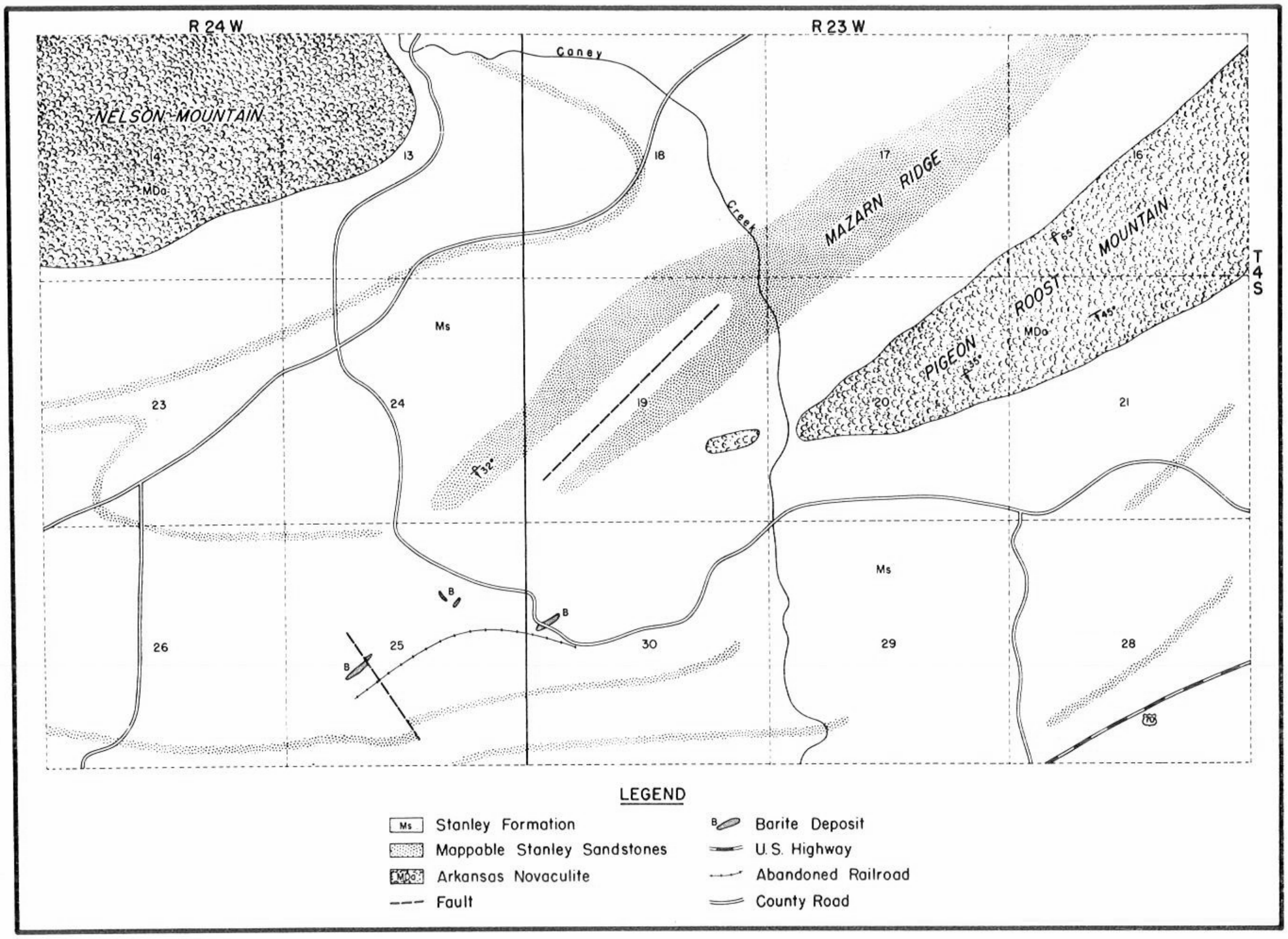


Figure 3—Sketch map showing geology of the Pigeon Roost barite district.

70° E. and N. 80° E., respectively. The dip varies from 66° in the center of the body to 60° and 50° on the northeastern and southwestern ends of the body. At each of the places where measurements were taken, the dip was to the northwest. Approximately 200 feet from the northeastern end of the lens, the ore has apparently been faulted along a plane bearing N. 12° W., with a resultant displacement of 30 feet to the southeast.

On either end of the body, the barite-bearing beds grade rapidly into shales having practically no barium sulfate content.

Four types of ore are in the southwestern deposit. One type is white crystalline barite disseminated in a porous, greenish-gray sandstone member of the Stanley formation. The barium sulfate content is directly proportional to the porosity of the sandstone which varies considerably within the lens. In trench G (fig. 3), the sandstone has a barium sulfate content of 62.1 percent, whereas in trenches E and H, 200 and 300 feet on either side of trench G, the barium sulfate content of the sandstone is 74.0 percent.

A second type of ore is that in which barium sulfate has permeated the bluish-black Stanley shale. Within the lens, the shale member has an average barium sulfate content of 75 percent. This type of ore occurs in thin beds, usually not more than 3 inches thick, interbedded with the greenish-gray sandstone member. Some of the shale beds have a barium sulfate content as low as 30 percent, and it is difficult to differentiate in the field between the beds of high and low barium sulfate content.

Barite also occurs in dark-gray rocks of dense, fine-grained texture, similar in apperance to weathered novaculite. Some of these beds have a cellular honey-comb structure that is commonly filled with iron-stained clay and silica grains. Because of the cellular structure, the material is locally termed "rotten rock." This third type of ore has an average barium sulfate content of 73 percent.

A fourth type of ore is in a whitish-gray shale, stained with limonite and containing veinlets of white crystalline barite. Although this shale often averages 69 percent barium sulfate, some parts have a content of only 38 percent and it is difficult to differentiate in the field between the beds having a high or low barium sulfate content.

Each of the four types of ore is of the fetid variety, in that a strong odor of hydrogen sulfide is released when the rocks are struck with a hammer.

The central deposit of the Pigeon Roost Mountain barite deposits consists of a small lens that appears to be on the nose of a small anticline. That part of the lens striking N. 80° and dipping 75° to the southeast has a strike length of 100 feet and is revealed in trenches F and S (fig. 3). The other part of the lens

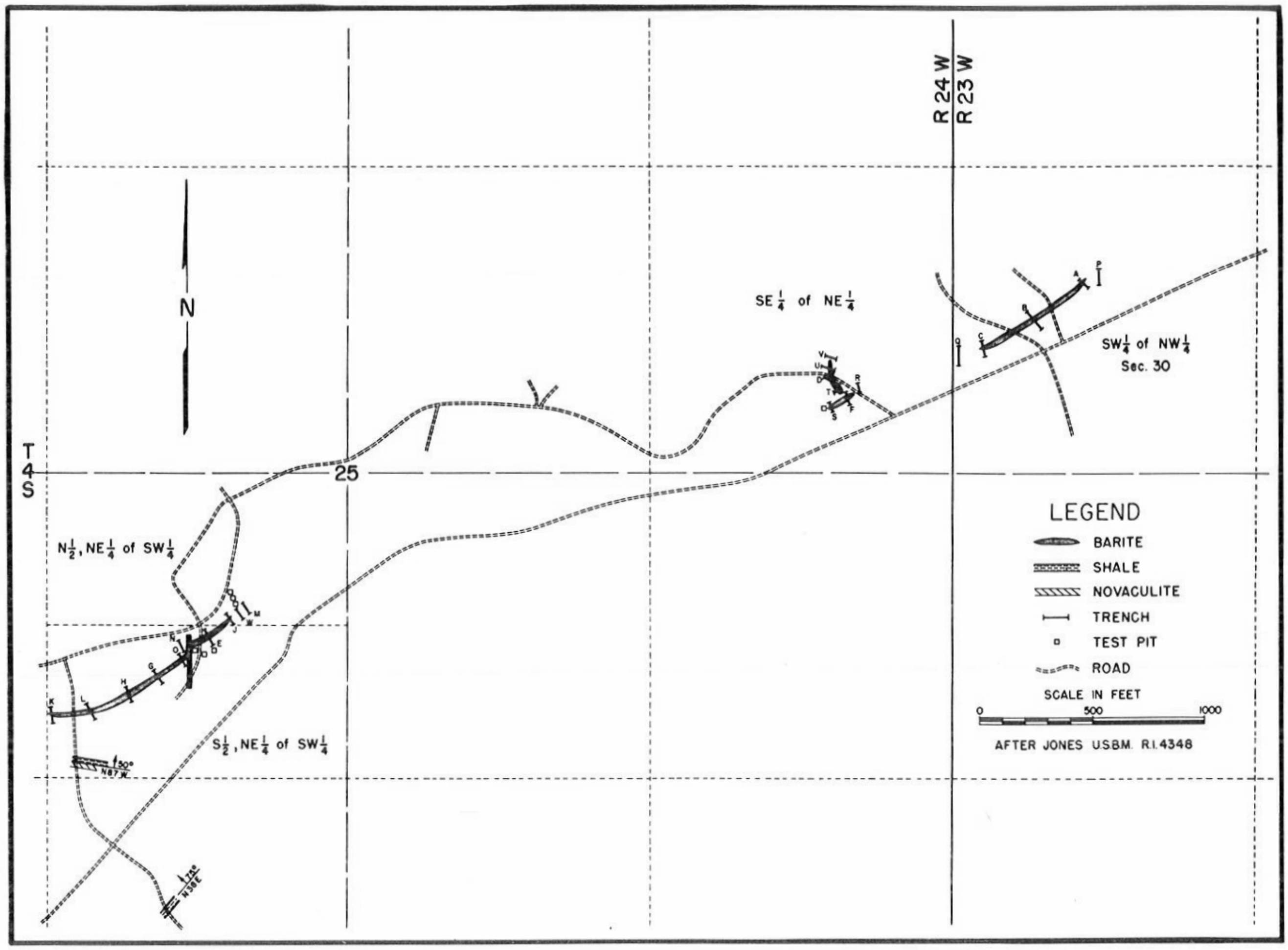


Figure 4—Location map of the barite lenses Pigeon Roost district.

strikes N. 5° W., and dips 60° to the southwest; it has a strike length of 100 feet and is revealed in trenches D, T, and U. The ore in the lens is of the whitish-gray shale variety and has a maximum thickness of 7 feet, with an average barium sulfate content of 56 percent.

On the northeastern end of the Pigeon Roost Mountain barite area is a lenticular body of barite measuring 500 feet along the strike. The general strike of the lens is N. 55° E. with a dip of 75° to the southeast. The four types of barite found in the southwestern deposits are also in this body; but the beds are few in number and are interbedded with shale beds of equal thickness that have practically no barium sulfate content. The maximum thickness of the zone in which mineralization occurs is 16 feet, as revealed in trench C (fig. 3), but the total thickness of ore beds is only 3 feet.

Samples were collected from each trench that could readily be cleaned enough to determine the contact of the wall rock and the barite. Petrographic studies of these samples show that they are almost identical with those occurring in the Magnet Cove and Fancy Hill districts. The barite cemented sandstone, however, is rare in these other districts.

Geologic Setting

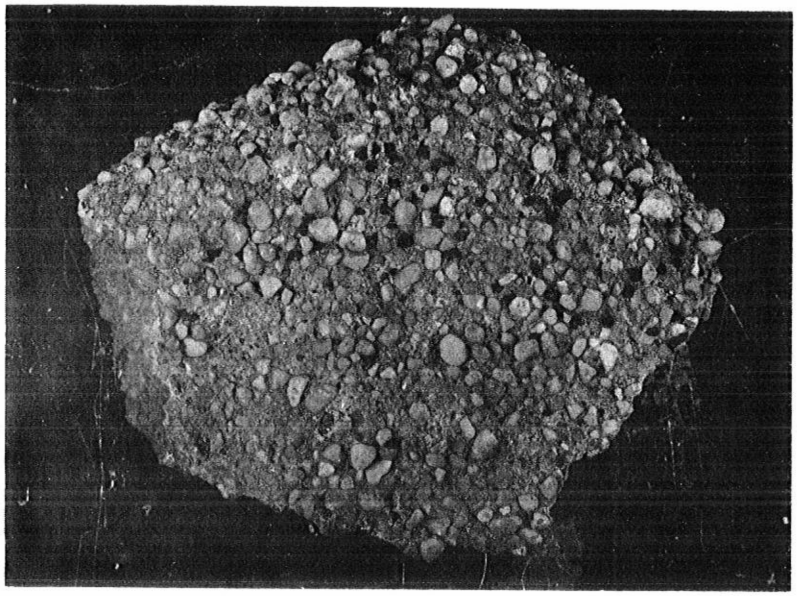
In order to ascertain the stratigraphic and structural picture in the vicinity of the barite bodies the area was traversed as systematically as possible using aerial photographs with a scale of 1″ = 500′ for orientation. The dense undergrowth and thick humus soil made it impossible to determine the exact stratigraphic and structural relationships of the barite zones. Although the exact corrugations of the Stanley formation were not determined, the general structural and stratigraphic features were established.

An intermittent zone of novaculite float a mile to two miles south of, and roughly paralleling Pigeon Roost Mountain, may mark the southern flank of the syncline containing the Pigeon Roost barite deposits. Exposures along Caney Creek in the southwest part of T. 4 S., R. 23 W., were the only ones with any continuity south of Pigeon Roost Mountain. Although these beds are highly corrugated, their atti-

PLATE 38

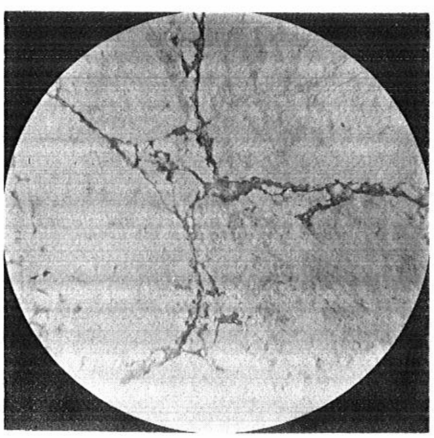
Aerial photograph showing westward plunging core of novaculite of Pigeon Roost Mountain. Caney Creek transverses left part of photograph. Scale about 1″ = 1000′. (Original photographer, D. F. Holbrook; reduction, Jay Simmons)

PLATE 39

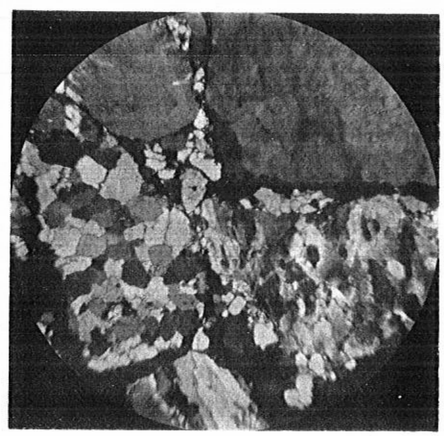


(A)

(A) Photograph of pebbly Stanley sandstone from Mazarn Ridge in the Pigeon Roost district, Montgomery County.



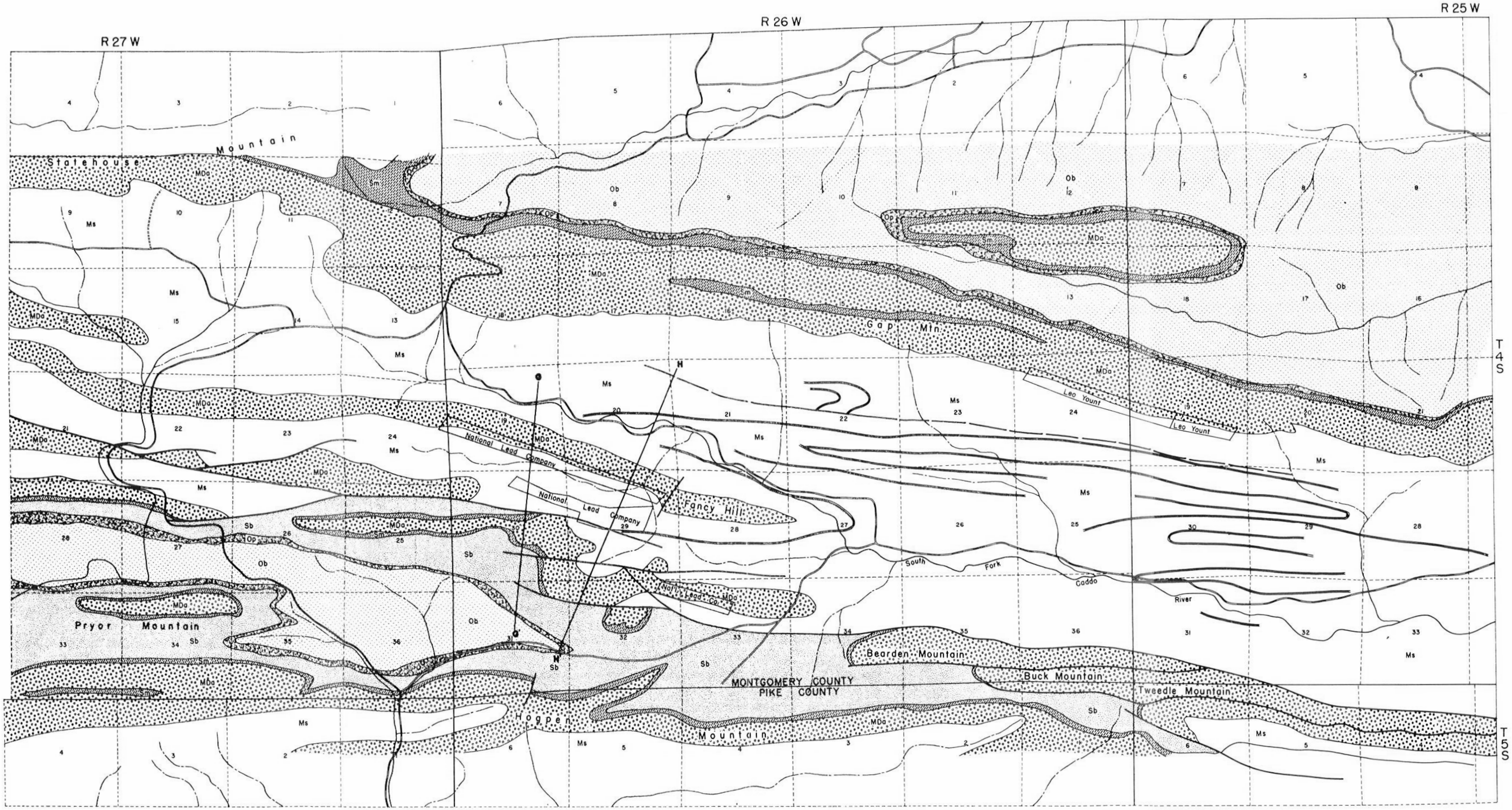
(B)



(C)

(B) Photomicrograph to show the nature of the pebbles in the sandstone shown above. Plane polarized light; X 13.

(C) Same view as (B) with nicols crossed.



EXPLANATION

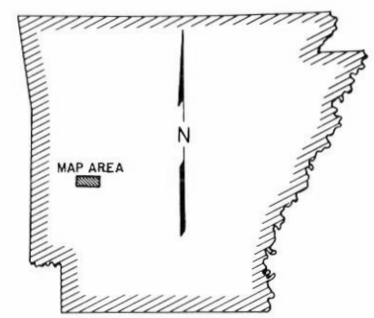
- Ms — Stanley Formation
- Mappable Stanley Sandstone
- MDa — Arkansas Novaculite
- Sm — Missouri Mountain Shale
- Sb — Blaylock Sandstone
- Op — Polk Creek Shale
- Ob — Big Fork Chert
- Lead Co — Barite Bearing Zones (Leased)
- Fault

GENERALIZED GEOLOGIC MAP OF THE FANCY HILL BARITE DISTRICT

SCALE IN MILES

1 0 2 3

Modified After Miser and Purdue, 1929



INDEX SHOWING MAP AREA

tudes tend to substantiate the idea that there is a larger syncline about two miles wide in this area. The dip patterns indicate that the barite deposits occur at the southwest end of this syncline, although the mineralization was governed by local lithology and structure.

The geologic setting of the barite deposits of the Pigeon Roost district is poorly known considering the amount of information available. The size of the deposit did not seem to warrant the time that would be required to map in detail the geology of the adjoining area; however, the older reports are in such conflict that reconnaissance traverses were made, using aerial photographs for orientation over a considerable part of the surrounding area. The conflict in the older literature centers around the structure of Pigeon Roost Mountain and the stratigraphy and structure of the Mazarn Ridge.

Pigeon Roost Mountain is an arcuate ridge of novaculite that extends about five miles northeast from the barite deposits. The Mazarn Ridge is held up by sandstones and extends from north of the barite deposits and north of Pigeon Roost Mountain some 14 miles to the northeast. Griswold (1892, pp. 364-66) considered these two ridges to be part of the same overturned anticline, with Pigeon Roost Mountain at the core of the anticline (Plate 38) and the south flank, including the sandstones, mostly removed by erosion. In both ridges the north flank is overturned to the south. Miser and Purdue (1929, Plate 3) show only the southwestern tip of the Mazarn Ridge, which they mapped as Jackfork sandstone overturned to the south. The state geologic map of Arkansas shows the Mazarn Ridge as being Jackfork sandstone and having a thrust fault to the north bounding its south side. Croneis (1930, pp. 347-50) considered that each ridge belonged to a separate overturned anticline and that the sandstone in the Mazarn Ridge is Stanley. Of all these interpretations, the writer believes that of Griswold to be the most accurate. Southwest and northeast of Pigeon Roost Mountain, the Mazarn Ridge shows anticlinal closure which is to be expected along a double plunging anticline.

None of these reports points out that the resistant sandstone in the Mazarn Ridge is actually a series of lenticular pebbly sandstones (Plate 39). Placing the sandstones of the Mazarn Ridge in the Jackfork formation creates numerous problems with no apparent answers. First and foremost of these is that the Stanley in this area between the "Jackfork" and the Arkansas novaculite in Nelson Mountain in the W$\frac{1}{2}$ sec. 13, T. 4 S., R. 24 E., would be less than 2000 feet thick. Second, placing a thrust fault on the south side of the Mazarn Ridge creates a very improbable structural configuration. Evidence of faulting was noted in several places along this ridge, but no more than would be expected in a tightly folded overturned structure in brittle beds. If the faulting is major it is similar to and perhaps is an eastward extension of the thrust faulting in the eastern part of the Cossatot Mountains, or possibly the thrusting of the Caddo Gap in the Caddo Mountains.

Fancy Hill District

General Discussion

Within the Fancy Hill district there are four barite deposits that occur in replacement zones in the basal parts of the Stanley shale: the Gap Mountain deposit (Yount) extending along the south side of Gap Mountain from the southeast part of sec. 19, T. 4 S., R. 25 W., to the northeastern part of sec. 23, T. 4 S., R. 26 W.; the Fancy Hill (Henderson) deposit extending along the south side of Fancy Hill from the northeastern part of sec. 29 to the southwestern part of sec. 19, T. 4 S., R. 26 W.; the Sulphur Mountain (McKnight) deposit extending along the north side of Sulphur Mountain in sec. 29, T. 4 S., R. 26 W.; and the Dempsey Cogburn deposit on the southeast side of Sulphur Mountain extending from the center of sec. 33 to the northeastern part of sec. 32, T. 4 S., R. 26 W. Assigned to this district are two barite deposits in which the mineral occurs as veins in the middle member of the Arkansas novaculite. The Boone Springs Creek deposit is in the SE$\frac{1}{4}$ sec. 24, T. 4 S., R. 27 W., and the Polk Creek Mountain deposit occurs in the SW$\frac{1}{4}$ sec. 12, T. 4 S., R. 27 W. McElwaine (1946 B) has described the replacement deposits, with the exception of the Dempsey Cogburn, and Jones (1948) described the veins in the Middle Arkansas novaculite.

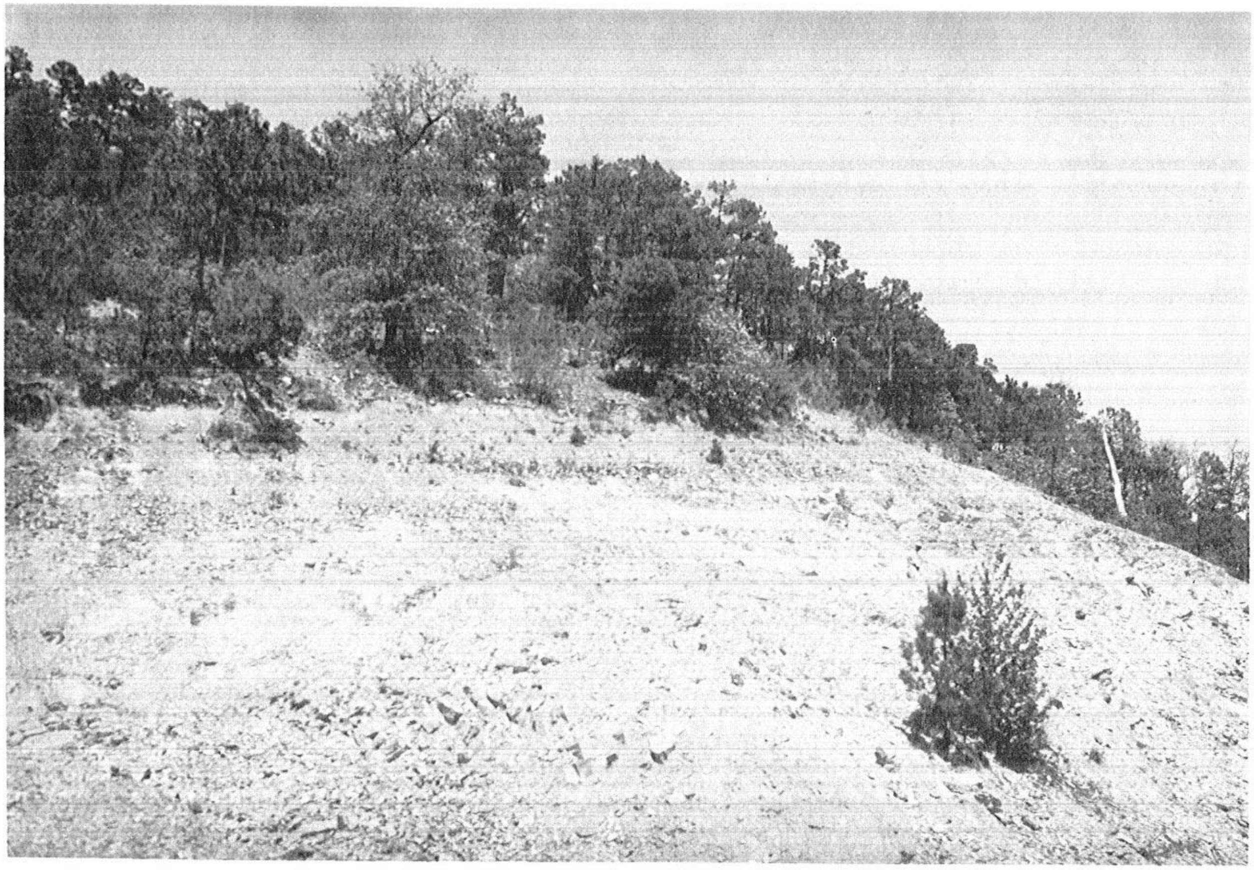
Gap Mountain Deposit (Yount)

History and description. The Gap Mountain barite deposit was discovered by Mr. Leo Yount in December, 1944 (1946 B, p. 4). Six mining claims were filed on public domain and leases totaling 140 acres on private land were obtained. The claims at the eastern end of the property have since been patented (Plate 41). After studying the general geology of the deposit and making detailed examinations of U. S. Bureau of Mines trenches and drill holes, McElwaine (*Idem.*, p. 6) reports:

PLATE 41

Aerial photograph showing location of patented claim on south flank of Gap Mountain. The Arkansas novaculite crops out north of the strip pit, and the Stanley formation crops out south of it. Scale about 1″ = 1000′. (Original photograph, D. F. Holbrook; reduction, Jay Simmons.)

PLATE 42



Photograph of strip pit on Gap Mountain shown on Plate 41. Novaculite-Stanley contact is at upper edge of pit. Figures in right middle distance indicate scale. (Photographer, N. F. Williams)

The barite occurrences consist of intermittent lenticular bodies occurring as replacement deposits in sedimentary beds near the stratigraphic base of the steeply dipping Stanley shale formation. The dip of the beds in which the barite occurs changes and travels westward along the strike from a steep north dip at the east end of the deposits to vertical near the center and then to a steep south dip at the west end. At depth, all of the beds must assume a south dip, but on the eastern part of the property drill holes indicate the dip to be still 86° to the north at a depth of 200 feet. The areas between the ends of the intermittent ore bodies contain considerable barite-bearing shale, but only thin lenses and scattered concretionary nodules of good barite are present. The latter type of material has been traced westward along the south side of Gap Mountain for a distance of 5 or 6 miles to the east side of R. 27 W. The important known deposits are four lenticular bodies of barite ranging from 300 to 1200 feet in length. The zone in which the barite is found is 20 to 30 feet thick and occurs near the base of the Stanley formation, about 70 to 90 feet from the massive novaculite. The actual point of the contact between the two formations can be observed only in a few places where the thin-bedded chalcedonic novaculite is exposed in ravines on the mountain side. At one point near trench L-1-D, west of claim 2, the contact is 30 feet from the barite zone. However, it is known to be considerably more than this on claims 1 and 2. The material occurring between the barite and the novaculite is a dense, light-gray shale and is of a very different appearance than normal Stanley shale. It is composed chiefly of illite with some quartz. The beds to the south of the barite are typical of the Stanley shale formation and contain considerable sandstone and sandy shale. At many places the ore beds show a flat dip to the north, but trenching revealed this to be a result of surface slump on the hillsides, and within a few feet of depth the dip becomes nearly vertical.

Local structure. Structurally, Gap Mountain is the common flank between the Caddo Mountains and the Mazarn Basin. Throughout its length the south flank of Gap Mountain is essentially vertical or slightly overturned to the south, but locally high south dips were noted. Readjustments of the Arkansas novaculite in response to deforming pressures produced a large number of north to north-northeast trending faults with displacements ranging from a few inches to a few feet. Only a few of these faults were of sufficient magnitude to affect the overlying Stanley shale. In each case where these faults could be demonstrated to be associated with an ore body, they marked the westward extremity of a mineralized zone. No evidence indicating major faulting could be found associated with these deposits. A major fault probably is present 1500 to 2000 feet south of the barite zone, but this could not be proven because of poor exposures. This leads to the tentative conclusion that the barite occurs on the north flank of an extremely steep-sided syncline having a length of about 12 miles and a width not exceeding one-half mile. The novaculite at the center of this syncline would have a cover of Stanley of not less than 1000 nor more than 4000 feet.

Stratigraphic relations. The shale overlying the novaculite is 10 to 30 feet thick. In texture and composition it closely resembles the black shale in the Chamberlain Creek deposit. It is not as dark, possibly because of weathering, and does not contain as much pyrite. It also contains lentils of conglomerate composed of novaculite pebbles and a siliceous matrix. Unlike its counterpart in the Magnet Cove district, the basal shale in the Gap Mountain deposit has not been mineralized. It forms the foot wall of the mineralized zone.

Because suitable exposures were not available it is not possible to determine accurately the thickness of the mineralized zone. It is between 100 and 150 feet thick. Unlike the Magnet Cove and Fancy Hill deposits, the commercial grade barite zones in the Gap Mountain deposit are not confined to a definite horizon. Lenticular bodies from 3 to 30 feet thick occur from 30 to 50 feet above the base of the mineralized zone.

Character of the ore. The individual bodies of barite contain at least two types of ore and ordinarily contain all four types, with the exception of those bodies made up of interbedded nodular ore and baritic shale. In these bodies, branching tubular barite concretions are associated with the nodular zones. These concretions have a maximum dimension of 3½ inches.

The barite bodies considered to be commercial (containing 65 percent or more barium sulfate) have a fairly uniform thickness and tenor except for the pinchout at the ends. The lower grade bodies are much more irregular. There is a distinct diminishing of amount of barium sulfate in the mineralized zone east to west. It could not be determined whether the thickness of the mineralized zone also diminished westward.

Fancy Hill Deposit (Henderson)

History. The presence of barite on the south flank of Fancy Hill has been known since the early 1900's. A formal claim was not filed until 1944 when Mr. Allen Cogburn, a resident of the area, staked claims to properties which lie within the confines of the Ouachita National Forest. Mr. Cogburn deeded his claims to Mr. J. E. Henderson, who, with his partners, leased the properties to the Baroid Division of the National Lead Company. The Company meets the annual assessment require-

PLATE 43

Photograph of east end of pit shown in Plate 42 showing mineralized Stanley dipping northward under novaculite. (Photographer, N. F. Williams.)

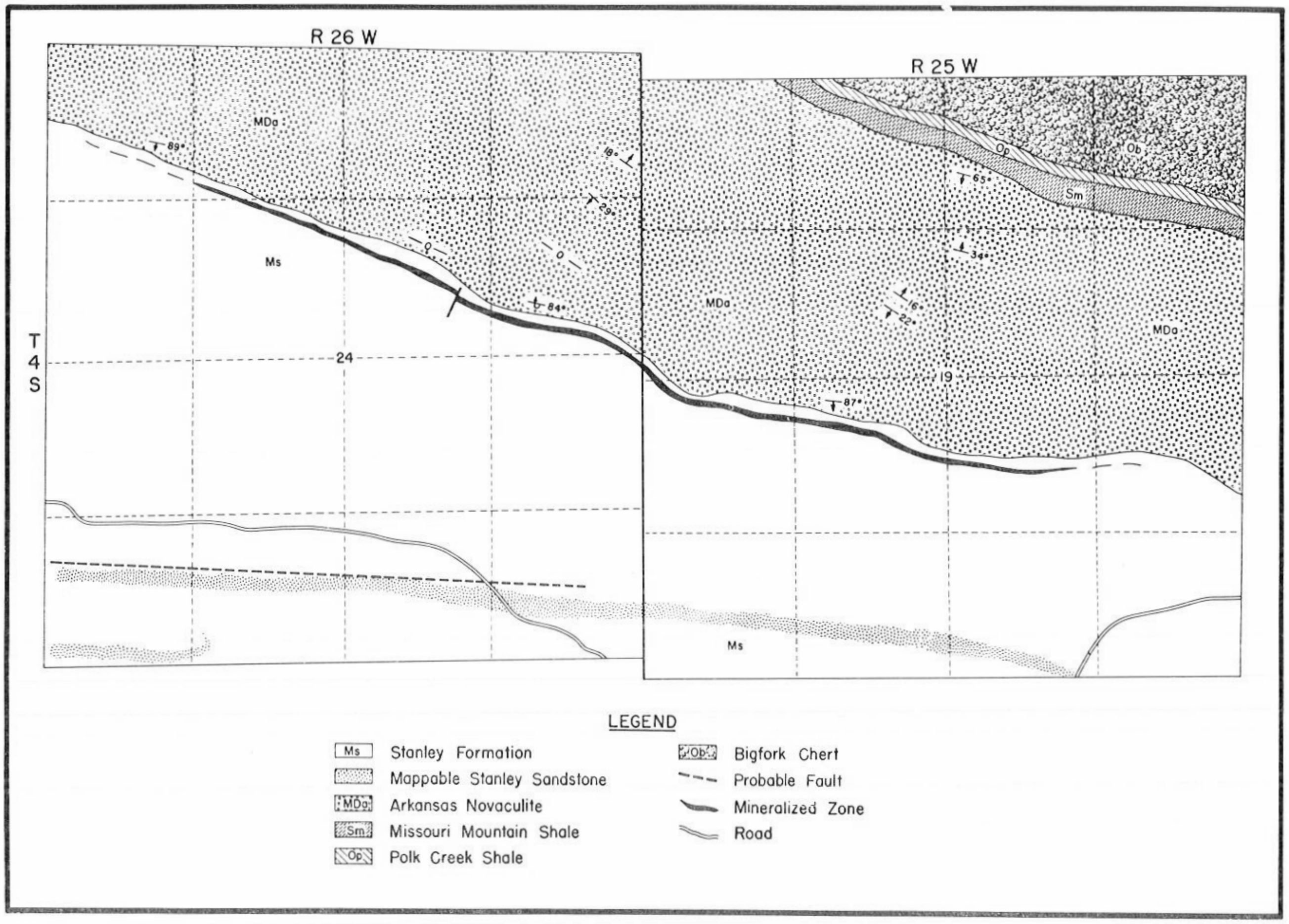


Figure 5—Geological map of Gap Mountain barite deposit, Fancy Hill district.

ment by doing exploration, evaluation and maintenance work.

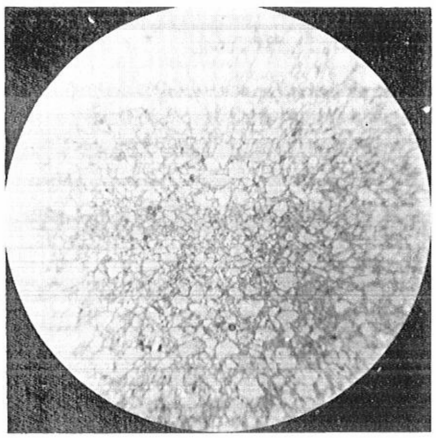
Local structure. Fancy Hill is an anticlinal mountain rising from the floor of the Mazarn Basin. The anticline is asymmetrical, the north flank having an average dip of about 50° to the north and the south flank having an average dip of 85° to the south; locally the beds are vertical or overturned. At places, erosional sapping has undermined the Arkansas novaculite resulting in slumpage and creep to give the beds an apparent northward dip of 45° or less. As in the Gap Mountain deposit the brittle novaculite has been shattered by deformational stresses so that joints, fractures, and small faults are extremely numerous in the formation. Only a small number of the faults were of sufficient magnitude to affect the overlying Stanley formation. These faults preceded and affected the course of mineralization. The available drill hole data show that the steep south dip continues at depth.

The Back Valley syncline is bordered on the north by the Fancy Hill anticline and on the south by the Sulphur Mountain anticline. The projection of the dips observable on the flanks and on the floor of this syncline indicates, unless unknown faulting is present, that the barite-bearing zone can have a depth no greater than 2000 feet at the center of this syncline.

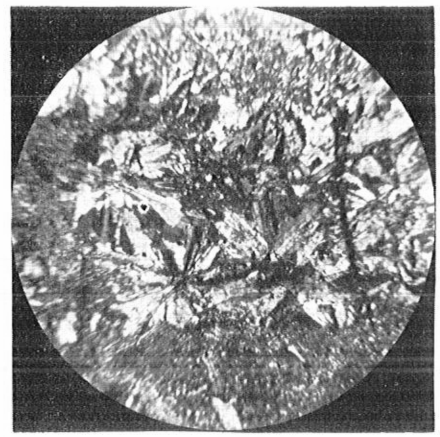
Stratigraphic relations. As in the previously discussed deposits, the barite mineralization occurs near the base of the Stanley formation. A black shale, 10 to 30 feet thick, forms the foot wall of the mineralized zone. The black shale overlies 40 to 70 feet of chalcedonic to punky upper Arkansas novaculite. Unlike the deposits previously discussed, the mineralized zone in Fancy Hill appears to have a definite hanging wall. A yellow to brown highly oxidized sandy shale or shaly sandstone, apparently impervious to the mineralizing solutions, forms the hanging wall (Plate 44A). This unit ranges in thickness from a few inches to 10 feet.

The mineralized zone ranges in thickness from 30 to 80 feet. In all of the assays of samples from this zone some barium sulfate was found to be present. The bodies of barite of potential commercial grade are lenticular and

PLATE 44



(A)



(B)

(A) Photomicrograph of sandy shale forming the hanging wall of the mineralized zone in the Fancy Hill district. Plane polarized light; X 13.

(B) Photomicrograph of radial barite nodules from a high-grade ore zone, Henderson property, Fancy Hill district. Crossed nicols; X 13.

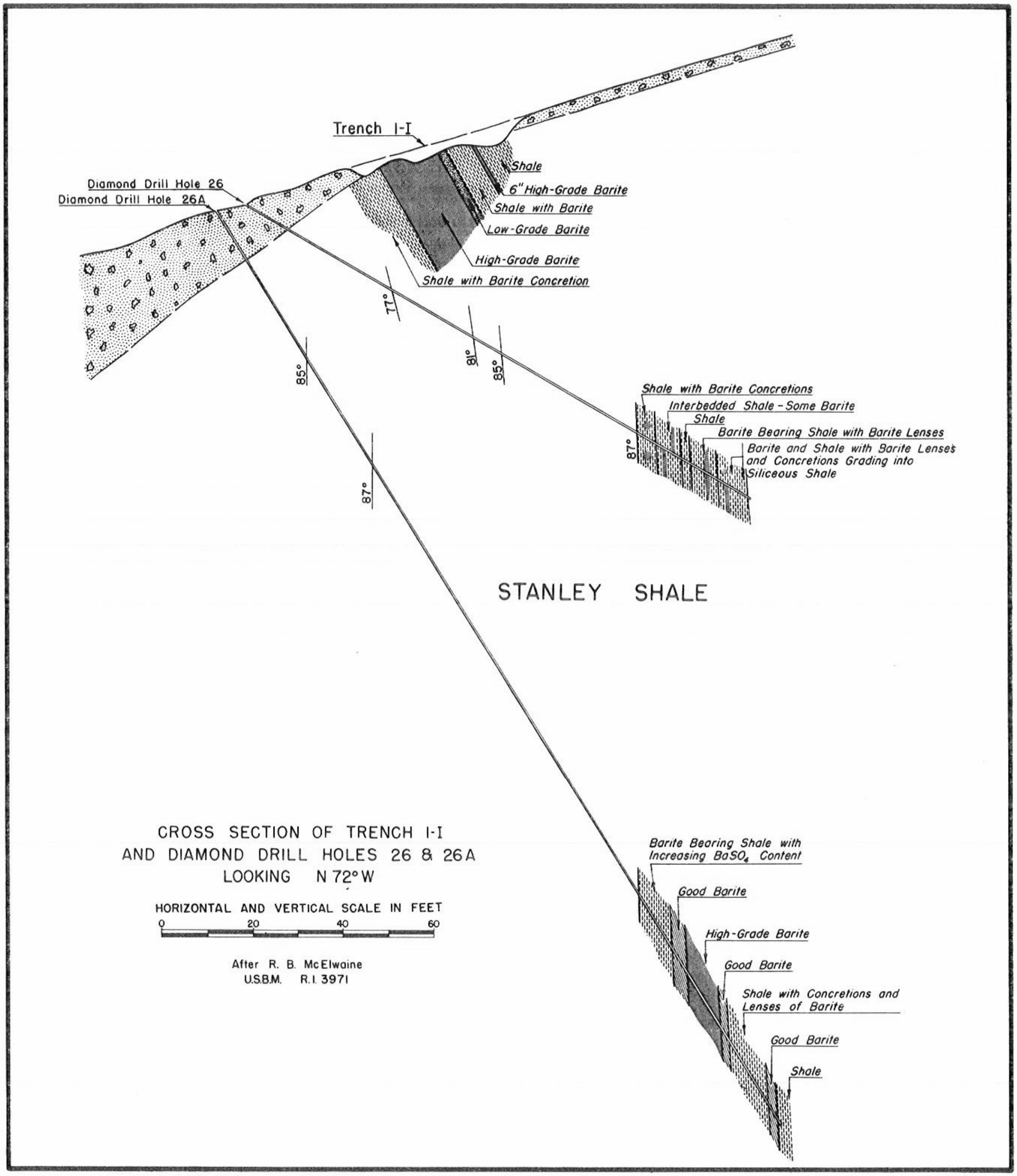


Figure 6—Cross section of Gap Mountain barite deposit, Fancy Hill district, Arkansas.

are not evenly distributed throughout the mineralized zone.

Character of the ore. There are six lenticular high-grade barite bodies in the mineralized zone ranging from 300 to 1800 feet in length. These bodies of high-grade barite are 15 to 40 feet thick, with the individual barite beds ranging from 1 to 18 inches in thickness. The ore occurs as the various types noted in all the other replacement deposits of the region. The chief type of ore is the dense gray material which superficially resembles the novaculite.

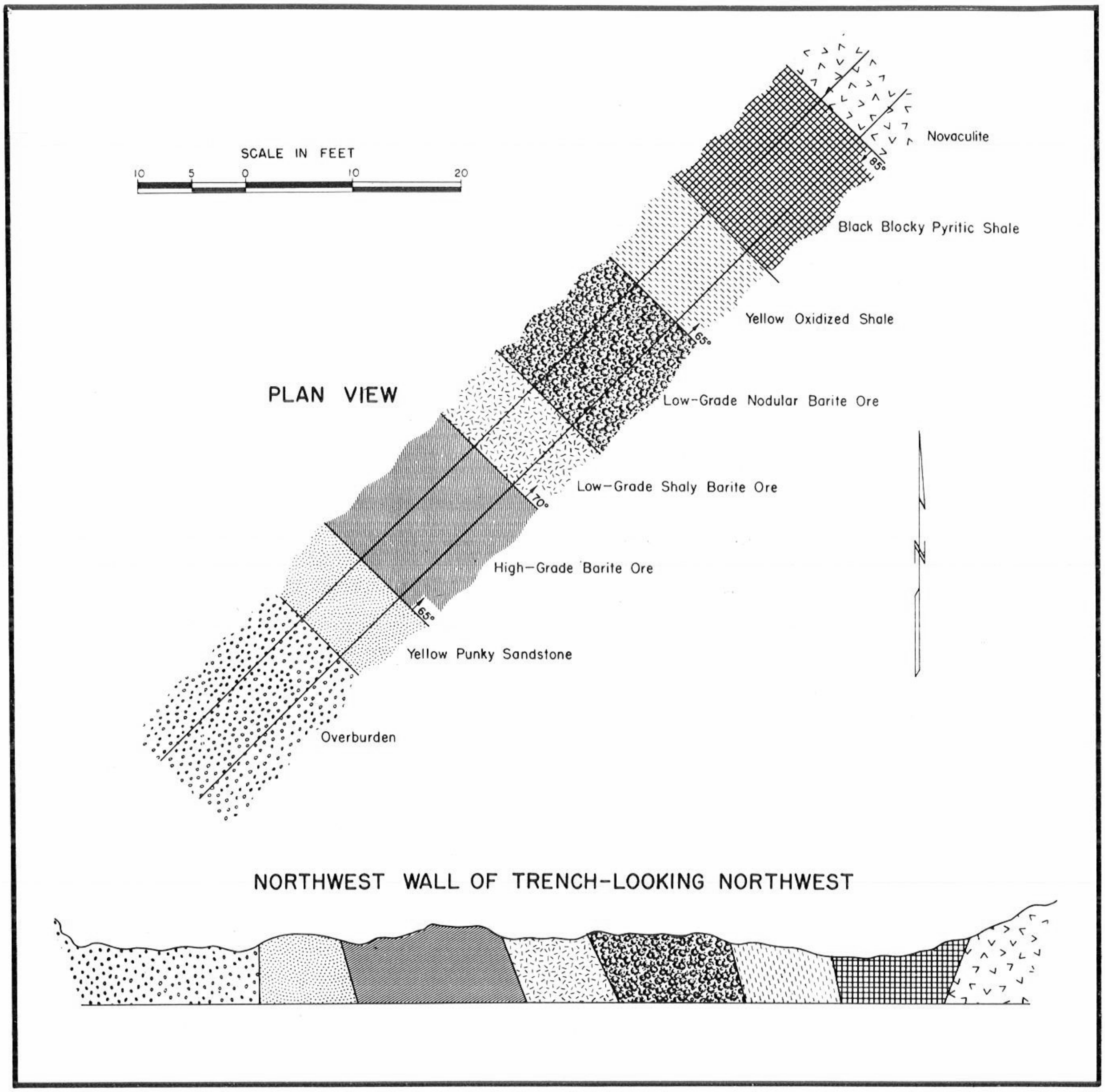


Figure 7—Plan and section of trench near southeast end of the Henderson barite deposit, Fancy Hill district, Arkansas. Arkansas.

Many such beds in this deposit can be recognized as barite only by scratching or hefting the material. The nodular type ore is much less conspicuous here than at Gap Mountain (Plate 44B). Locally the limestone-like barite is the most abundant. In this deposit as in all other replacement deposits in the region, the chief impurity in the ore is the silica of the clay minerals. The clay minerals as studied in thin section can be classified as illite or montmorillonite. Probably members of both groups are present, as reconstituted chemical analyses for the most part require the presence of two types of clay minerals.

Sulphur Mountain Deposit (McKnight)

History. McElwaine (1946 B, p. 5) reported that his attention was called to the Sulphur Spring Mountain barite deposit by Jerry Cogburn, a native of the district, and that H. R. McKnight, of Hot Springs, controlled the property. Since then the National Lead Company has acquired a lease on the property and holds it by doing annual assessment work. This deposit occurs on the opposite flank of the Back Valley syncline from the Fancy Hill deposit (Plate 45).

Description. The Sulphur Mountain barite deposit occurs in a highly deformed zone along the common limb of the Back Valley syncline and the Sulphur Mountain anticline. A major thrust fault with a strike slightly north of west and having a strike length of some 15 miles has its eastern terminus in the area of the Sulphur Mountain deposit. Associated with this major thrust are numerous cross folds and cross faults, the structural details of which could not be determined because of the lack of suitable exposures.

The apparent structural setting of the barite deposit is a small graben with the bounding faults striking slightly north of west. The ore body and the Stanley host rock dip to the south between novaculite beds. If the structure were simple the ore beds would dip to the north and the novaculite would occur only on the southern part. The stratigraphic relations show that the beds bearing the barite are not overturned where they are exposed. The foot wall shale and the hanging wall sandstone of the Fancy Hill deposit are readily recognized in this area. The writer's interpretation of the structural conditions existing in this deposit are shown in the cross sections on Plate 47.

As in the Fancy Hill deposit, the chief type of ore is the novaculite-appearing barite, although the limestone-appearing and the nodular barite are quite abundant.

Dempsey Cogburn Deposit

History. Mr. Dempsey Cogburn, a native of the district, staked claims on the deposit after the activity at Fancy Hill. The Mil-White Company obtained the leases and later turned them to the National Lead Company.

The barite zone can be studied only in the trenches and cuts made by the National Lead Company. The mineralized zone has an apparent thickness of about 50 feet and the high-grade lenses as seen in the trenches and cuts have a thickness ranging from 12 to 25 feet. The ore types are the same as in the other deposits of the district. It should be noted that this is the only deposit within the district where a major fault forms a boundary of the mineralized zone. As shown on the geologic map, the cross fault near the east line of section 32 apparently forms the western margin of the mineralized zone. The exposures as observed in the cuts and trenches show that the mineralized zone has a stratigraphic foot wall and hanging wall, probably identical to those of the Henderson and McKnight properties.

Boone Spring Creek Prospect

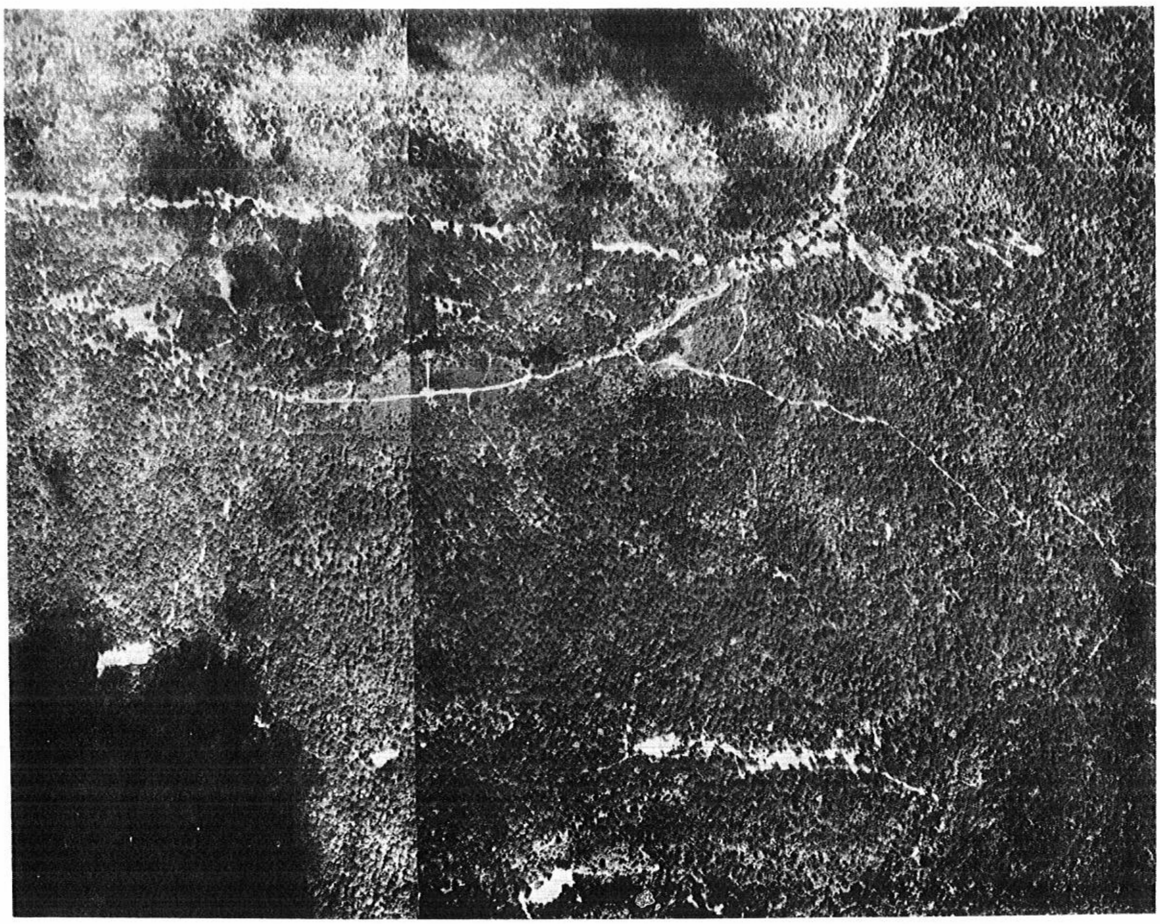
The Boone Spring Creek barite deposit occurs as a vein in the Middle Arkansas novaculite on the overturned south limb of the Fancy Hill anticline. The vein as exposed in prospect pits has a maximum thickness of one foot and a maximum length of 24 feet. Thick vegetation and overburden prevented tracing the barite away from the pits. Numerous other prospect pits in the vicinity did not expose any barite. The beds containing the barite strike north 45° west and dip 40° to the northeast. This anomalous attitude of the beds is the result of drag along the cross fault cutting across the Fancy Hill anticline.

Polk Creek Mountain Prospect

A comprehensive description of this deposit is given by Jones (1948, p. 6):

> A mineral claim, designated as the Polk Creek Mountain Claim No. 4, North Group, was owned by Mrs. Mabel G. Stenger of Norman, Arkansas. In 1945 the Mil-White Company of Houston, Texas, obtained an option to lease the property and dug the trenches described below.
>
> The work done on the prospect consisted of two cuts, made by a bulldozer, in the south side of Polk Creek Mountain, about 200 feet above the base of the mountain and at an elevation of 1300 feet above sea level. The largest cut, in which mineralization was exposed, paralleled the strike of the strata, bearing N. 70° W., and measured 25 feet wide, 16 feet deep, and 100 feet long. The other cut was barren. It was normal to the strike of the strata, was at the east end of the first cut, bore N. 20° E., and measured 25 feet wide, 16 feet deep, and 75 feet long.
>
> Examination shows the barite mineralization as sparsely disseminated nodular concretions of barite enclosed in shale beds of the middle division of the Arkansas novaculite formation. The concretions average 0.3 feet in diameter, and ranged in size from 0.1 to 1 foot in diameter.
>
> The nodules were found in the north wall and floor of the large cut in the zone 30 feet long in an east-west direction. The thickness normal to the dip was computed to be 24 feet. The depth to which mineralization extends is unknown. No concretions were found in the south wall of the cut, or in any part of the other cut.
>
> The shale beds containing the barite concretions have been metamorphosed to such an extent that they approach the hardness and texture of slate. The beds range in thickness from one inch to one foot, and are colored red, buff, brown, gray-green, and black. The shales above and below the ore zone were interbedded with thin beds of reddish-brown novaculite ranging from 1 to 3 inches in thickness. In the vicinity of the prospect, the strata strike N. 70° W. and 52° to the southwest.
>
> Channels were cut across the beds, normal to their strike, 2 feet wide and 6 inches deep, spaced at 10 foot intervals along the strike. All nodules encountered in each channel were collected and submitted

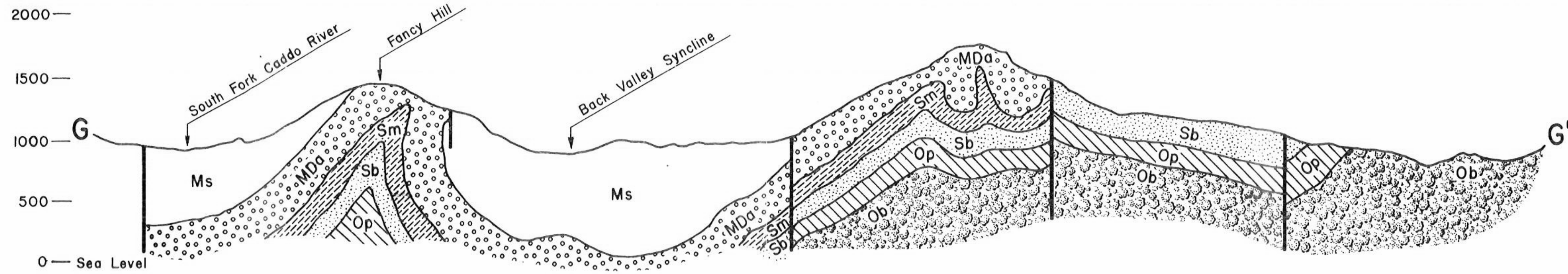
PLATE 45



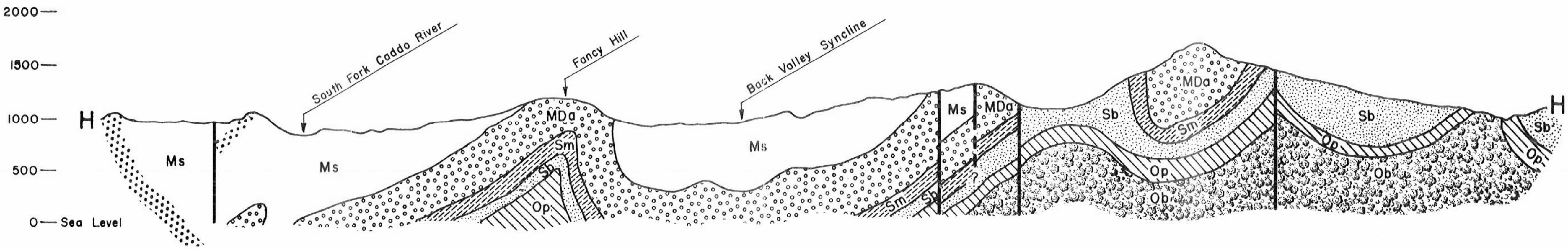
Overlapping aerial photographs to show position of exploration trenches, Henderson and McKnight properties, Fancy Hill district. Scale about 1" = 1000'. (Original photograph, D. F. Holbrook; reduction, Jay Simmons.)

Photographs showing the types of exploration trenches in the Fancy Hill district. (Photographer, H. G. Schoenike.)

NOTE: Lines of cross sections appear on "Geologic Map of the Fancy Hill Barite District."



CROSS SECTION G—G'



CROSS SECTION H—H'

EXPLANATION

Ms	Stanley Formation
	Stanley Sandstone
MDa	Arkansas Novaculite
Sm	Missouri Mountain Shale
Sb	Blaylock Sandstone
Op	Polk Creek Sandstone
Ob	Bigfork Chert
	Fault

CROSS SECTIONS ACROSS BACK VALLEY SYNCLINE FANCY HILL BARITE DISTRICT, ARKANSAS.

for analyses. The barium sulfate content of the nodules averaged 81.9 percent. It is estimated that the concretions occur in the ratio of one per cubic foot of host rock.

No ore had been shipped from this deposit at the time of the investigation.

This deposit lies on the south flank of one of the anticlines forming the southern border of the Caddo Mountain anticlinorium. The barite-bearing horizon was traced laterally from the east side of sec. 12 to the central part of sec. 11, T. 4 S., R. 27 W., and the adjoining ridges were checked in a general way. Crystalline barite, probably of the vein variety, was noted in a few of the numerous prospect pits, in the debris brought up by uprooted trees, and in the banks of a few ravines. No continuous zone could be established as it would require an extensive trenching and drilling program to evaluate this mineralized belt.

Hatfield District

General Statement

The barite deposits of the Hatfield district occur as vein material in the middle member of the Arkansas novaculite on the flanks of the anticlines at the west end of the Cossatot anticlinorium. As far as could be determined, these veins filled available fractures with a minimum amount of replacement or displacement of the wall material. Most of these veins were emplaced in open fissures but some are present as fracture filling and cement in brecciated zones. About 60 pits or prospects were examined during the course of the work in the Hatfield district. In nearly all cases it was necessary to enlist the aid of the local residents in order to find a given pit or prospect. The larger prospects have been described by Jones (1948, pp. 11-13).

Bee Mountain Prospect

The Bee Mountain prospect occurs in the SE¼ NE¼ Sec. 15, T. 3 S., R. 31 W., along the south flanks and near the west end of this anticlinal mountain. According to Jones a pit measuring 20 feet long, 10 feet wide, and 7 feet deep was dug on the outcrop, and an estimated 18 tons of barite removed from it. This pit is badly caved so that only at the ends and part of the middle could the vein be studied. The barite is dark gray and megascopically crystalline. The vein was emplaced along an opening formed by differential slippage and perhaps weathering of the contact between novaculite and shale in the middle member of the Arkansas novaculite.

Boar Tusk Mountain Prospects

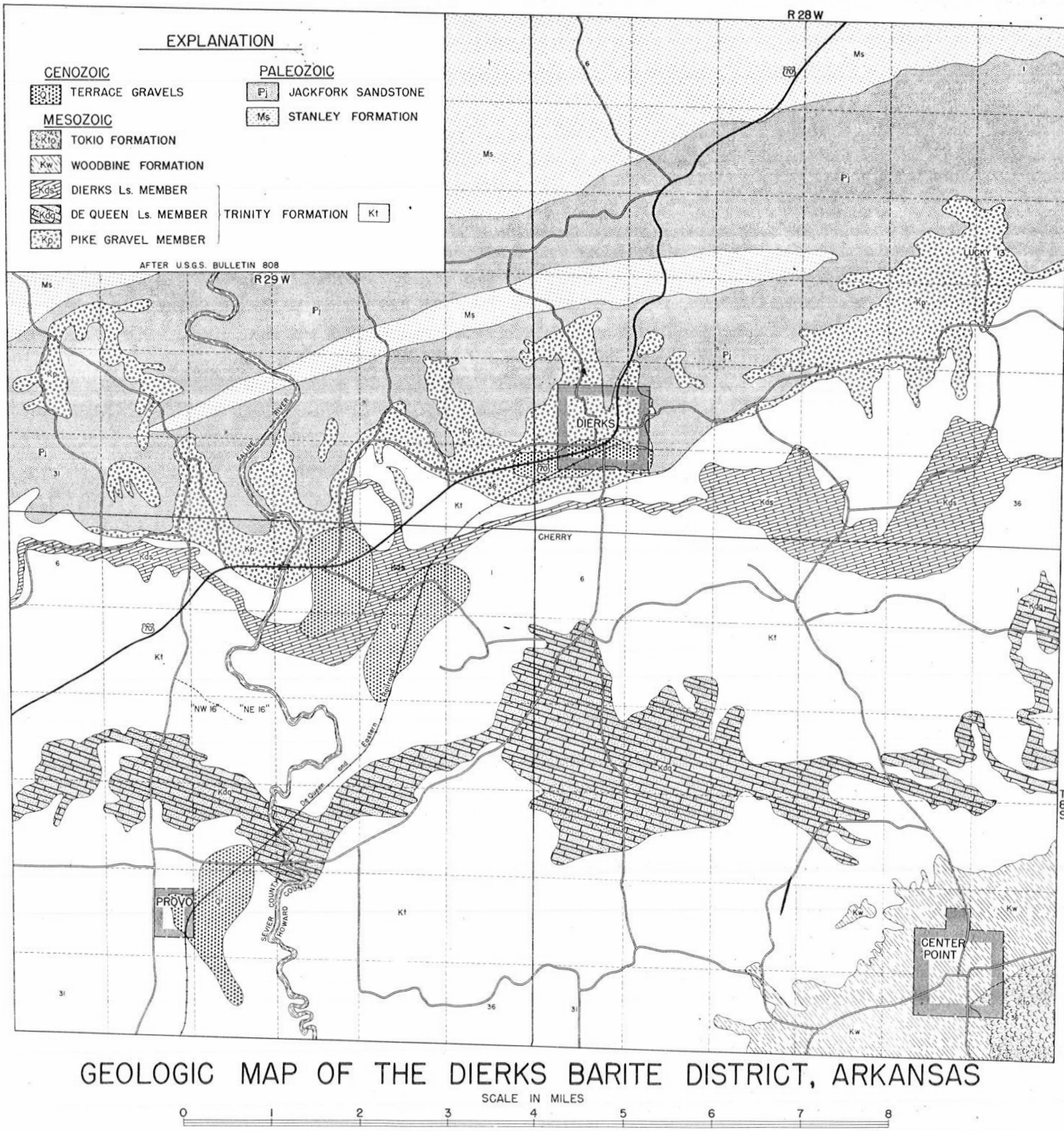
One Boar Tusk Mountain prospect is in the NW¼ NW¼ sec. 23, T. 3 S., R. 31 W. The mineralization occurs on the north flank near the west end of this anticlinal mountain. The barite occurs as fracture filling and breccia cement, and is disseminated to small extent into the wall rock. On the dump there are ellipsoidal and discoidal boulders with a maximum dimension of 30 inches. They were not found in place.

On the south flank of the mountain in the NE¼ SW¼ NE¼ sec. 22, T. 3 S., R. 31 W., a small vein of barite in the middle member of the Arkansas novaculite is exposed in a road cut. This deposit is of particular interest because the barite occurs stratigraphically below a manganese deposit. The manganese was deposited in a porous section of faulted upper novaculite. In nearly all other places in the region where manganese and barite are present in the same vicinity the barite occurs stratigraphically above the manganese.

Southeastward from this deposit along the strike of the middle member of the Arkansas novaculite on the south side of Boar Tusk Mountain are numerous prospect pits. In about one-fourth of these pits small lentils of barite are exposed. No individual lentil has a strike length greater than 20 feet and all of them observed have a thickness of less than one foot. This mineralized zone extends southeastward at least to the east side of Brushy Creek in the NE¼ sec. 33, T. 3 S., R. 30 W.

Two Mile Creek Prospects

Two other prospects of particular interest in the district were described briefly by Jones (1943, p. 12) as the Two Mile Creek prospects. The western prospect consists of several lenses of crystalline barite with a strike length ranging from 3 to 60 feet and the average thickness being less than one foot. These lenses occur in the middle member of the Arka. ɜas novaculite on the westward plunging nose of the most northwestern anticline of the Cossatot anticlinorium. These lenses are best exposed in the SE¼ SW¼ sec. 11, T. 3 S., R. 31 W., where Two Mile Creek has cut across the nose of the anticline. The mineralized zone can be traced eastward to a northwest plunging anticlinal spur in the NW¼ SW¼ sec. 13, T. 3 S., R. 31 W. There are several lenticular barite bodies ranging up to 50 feet in length and ordinarily less than a foot thick in the middle member of the Arkansas novaculite on the southwest flank of the anticlinal spur. The Two Mile Creek mineralized zone is about 40 feet thick, and the maximum aggregate thickness of barite would be on the order of 5½ feet. This zone apparently contains more barite than any other deposit visited by the writer in the district.



GEOLOGIC MAP OF THE DIERKS BARITE DISTRICT, ARKANSAS

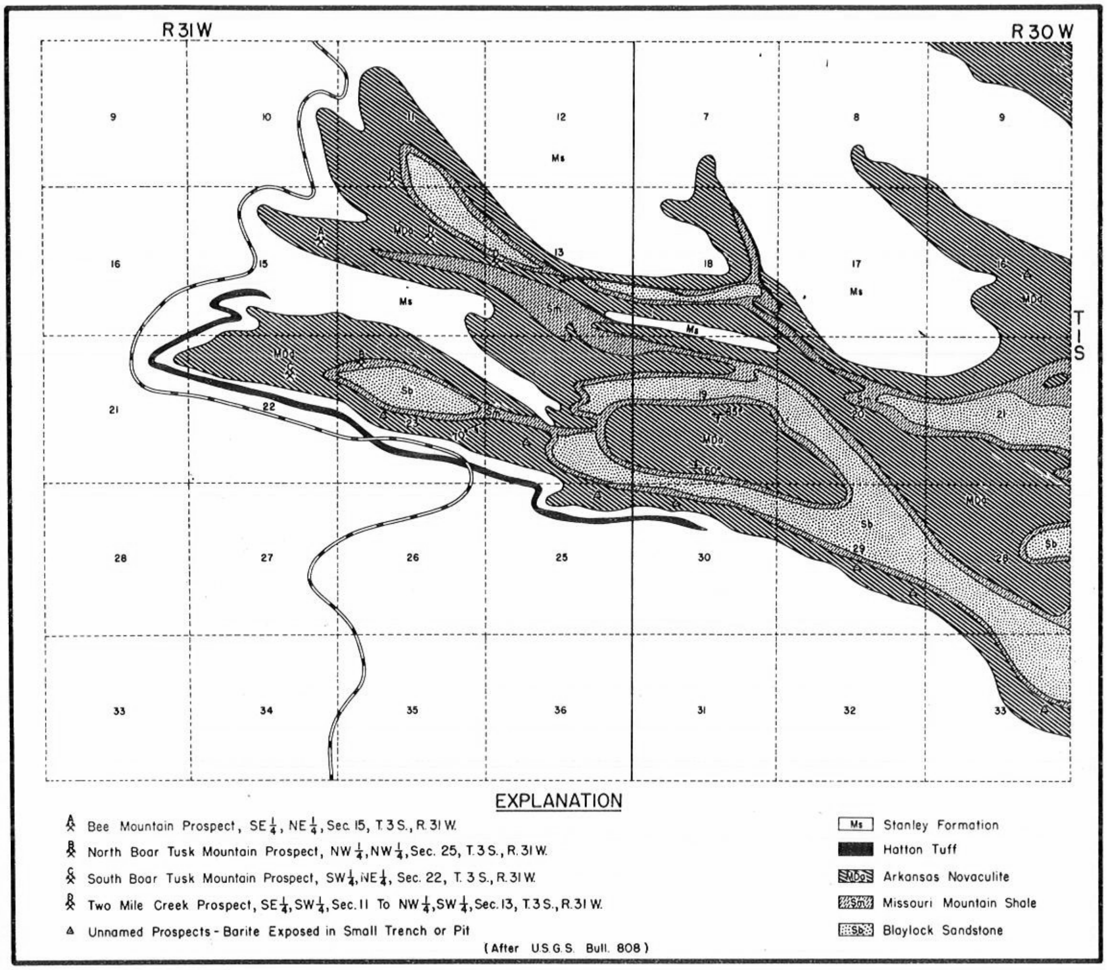


Figure 8—Sketch map showing geology of the Hatfield barite district, Arkansas.

Dierks District

General Statement

There are four known barite deposits in the Dierks district, the Northwest 16 and the Northeast 16, which occur in and adjacent to the NW¼ NW¼ and the NE¼ NE¼ respectively of sec. 16, T. 8 S., R. 29 W. A third deposit, the Cherry, occurs in the NW¼ sec. 6, T. 8 S., R. 28 W. The largest deposit is the Lucky 13 which occurs in the western parts of secs. 13 and 24, T. 7 S., R. 28 W. All these properties are on lands belonging to the Dierks Coal and Lumber Company, and are held by leases issued to Leo Yount and R. B. McElwaine. Each of these deposits occurs on a topographic high because the barite cemented sediments are more resistant to erosion.

Northwest 16

The Northwest 16 deposit trends diagonally across the NW¼ of the section (Figure 9). It has a maximum length of 1500 feet and a maximum width of 400 feet with the average width being about 250 feet. A small barite-bearing sandstone-capped knob in the SE¼ of section 8 is probably a continuation of this deposit. Here the barite cemented zone is about 175 feet long, and about 80 feet wide.

The Trinity sandstones in this area are for the most part uncemented and their true thickness could not be determined. The barite-bearing beds occur at least 50 feet above the Dierks limestone and at least 30 feet below the De Queen limestone. The barite was deposited in several lenticular sandstone units within a zone having a maximum thickness of 22 feet. The exact shape and size of these lenses could not be determined because they were exposed only in the exploratory trenches and pits on the property.

The cemented lenses have an average thickness of 8 to 10 inches with a thickness range from 1 to 16 inches. The maximum aggregate thickness observed in the trenches was 8 feet. The average is probably less than 5 feet. The assays of 16 samples collected at random from the trenches show the barite content to range from 0 to 45 percent, with an average barite content of slightly over 20 percent. The average content in selected samples of high-grade material was 32 percent.

PLATE 49

Photograph of barite "rosettes" developed in the weathered residual zone, Trinity sandstone, Dierks district.

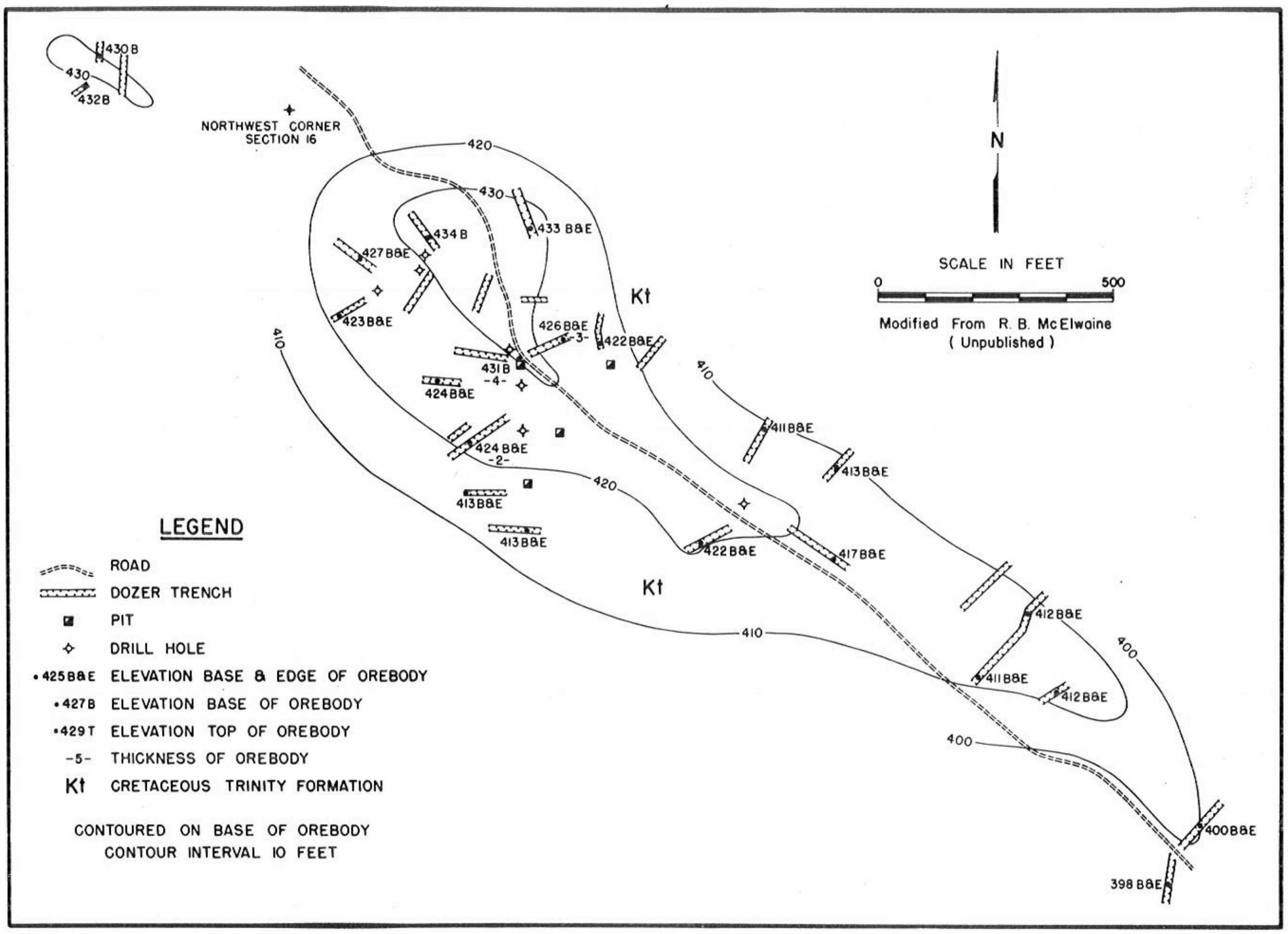


Figure 9—Sketch map of "NW 16" barite deposit, Dierks district, Arkansas.

At places along this deposit residual accumulations of rosettes form a mantle from 2 to 14 inches thick (Plate 49). These rosette accumulations are the highest grade of ore present in the deposit. The barium sulfate content is about 50 percent.

Northeast 16

The Northeast 16 barite deposit is dumbbell-shaped in plan (Figure 10). It trends northwest and has a length of about 1300 feet, with the width ranging from 200 to 500 feet. The northeast corner of section 16 is near the center of the deposit. The barite here, as is that in the Northwest 16, is present as a cement in sandstone lenses of the Trinity formation. It is highly probable that the mineralized zones in each of these deposits are stratigraphic equivalents, but this could not be proved. The maximum thickness of the mineralized zone is 30 feet, and the average is about 15 feet. The barite is present in units ranging from 1 to 14 inches in thickness, and the aggregate thickness of barite observed in any single trench is 6 feet. As in the companion deposit, the highest grade barite occurs in a residual zone of barite rosettes.

Cherry Deposit

The Cherry deposit consists of a roughly tadpole-shaped mineralized zone about 500 feet wide at the head or northeastern end, and tapering to a width of about 100 feet at the southwest end (Figure 11). The length of the deposit is about 1800 feet. About 700 feet south from this mineralized zone are two barite-capped hills, each with a maximum diameter of 200 feet. Undoubtedly these two mineralized areas were connected before erosion removed the intervening beds.

This deposit, like the two previously discussed, consists mostly of barite present as cement in sandstones; however, a few barite cemented gravels are present in the section. The mineralized zone has a maximum thickness of 25 feet and an average thickness of about 18 feet. The barite-bearing units have about the

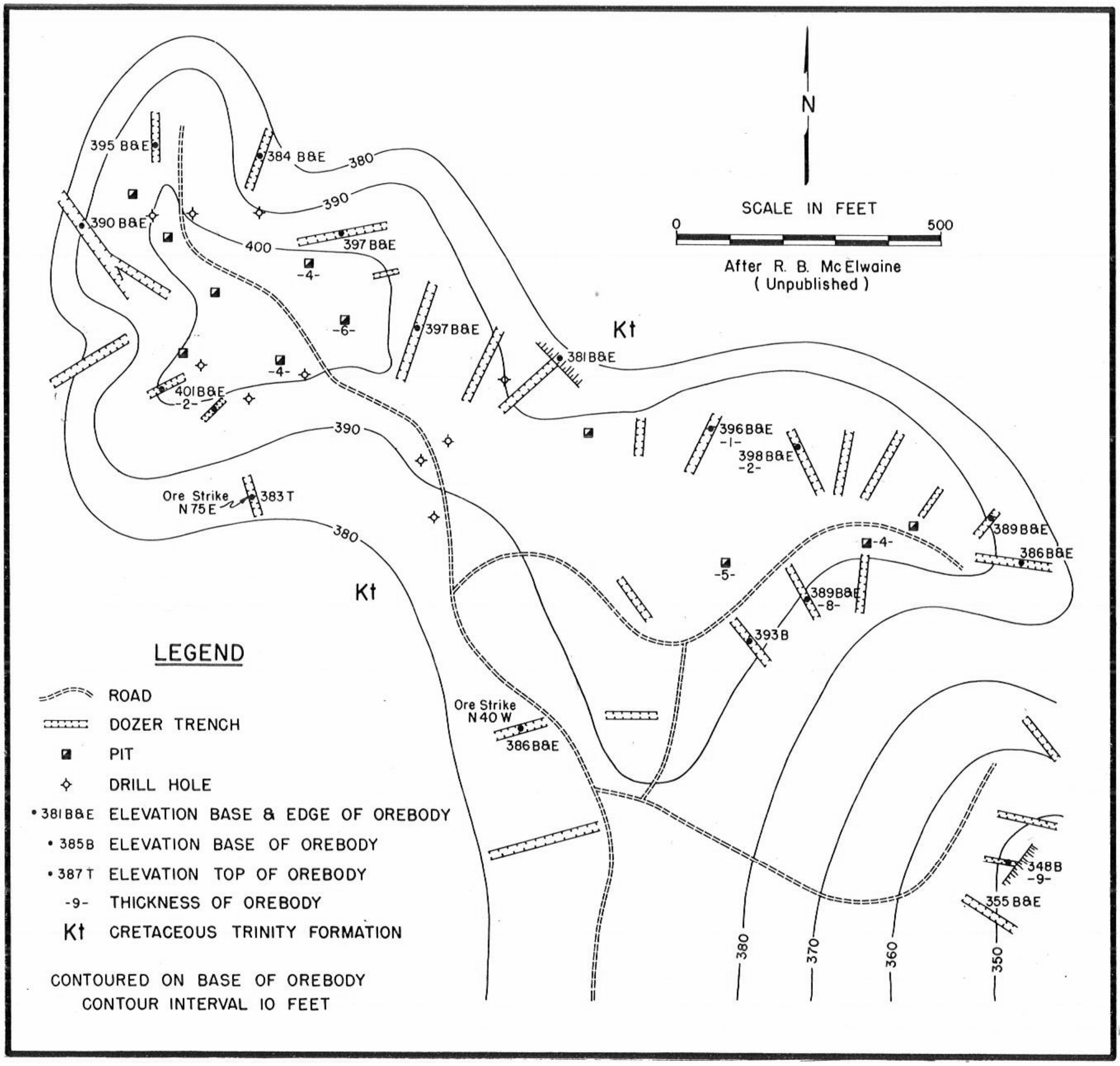


Figure 10—Sketch map of "NE 16" barite deposit, Dierks district, Arkansas.

same thickness range, 1 to 15 or 16 inches, as do those in the deposits in section 16, but here the units have a greater average thickness, on the order of 10 inches. Residual rosettes are fairly abundant along the flanks, but are not present in any quantity toward the center of the deposit. This deposit is about 20 feet above the Dierks limestone and about 100 feet below the De Queen limestone.

Lucky 13 Deposit

The Lucky 13 barite deposit has an irregular shape (Figure 12). Most of it lies along the western part of section 13, but the tongues or projections extend into sections 14 and 24. The total area of the deposit is approximately one-half mile square.

The barite occurs as cementing material in the lower Trinity sand and in the underlying Pike gravel. If an average could be taken it would probably show that about 50 percent of the barite is in the Pike gravel and 50 percent in the sandstones. Downward pinching veins of crystalline barite indicate that the barium sulfate solutions percolated along the sandstone and down into the gravel along fractures. In all of the pits, trenches and drill holes that penetrated the barite-bearing gravel, the barite was confined to the upper zone of

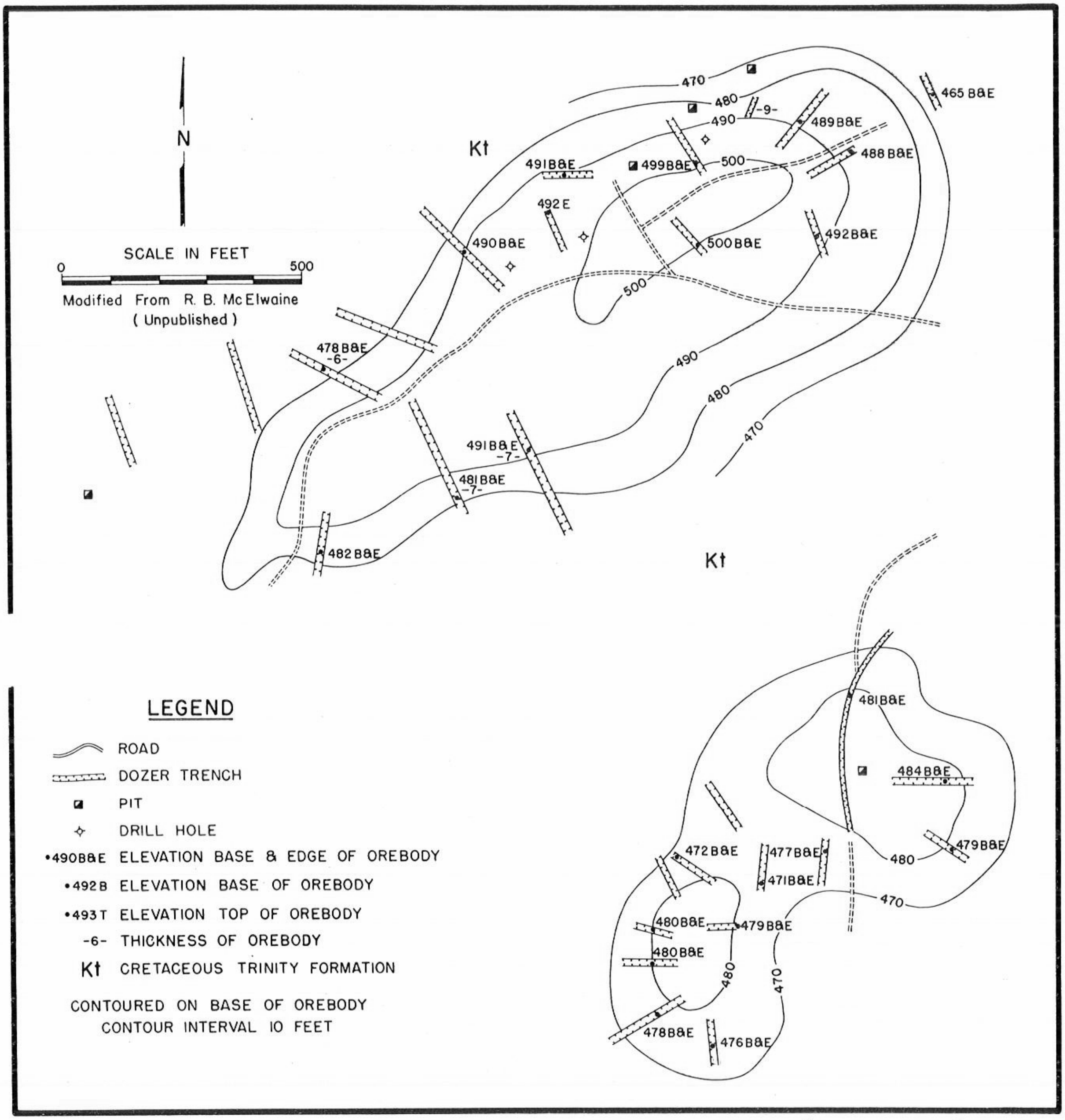


Figure 11—Sketch map of Cherry barite deposit, Dierks district, Arkansas.

the gravel with the lower zone being barren. The total thickness of the mineralized zone could not be determined, but it is no less than 12 feet in the gravel and no less than 18 feet in the overlying sandstones. Residual accumulations are common in the area, but rosettes are lacking or are poorly developed.

Petrographic studies of the sandstones indicate that the large barite crystals tend to have a parallel rather than a radial development in this deposit. On fresh fractures or bedding planes in some of the sandstones sheen surfaces up to six inches in diameter can be observed. Thin section examinations show that these surfaces are formed by barite crystals parallel to the bedding, and not by single crystals. The maximum observed length of an optically continuous crystal was 3½ inches.

The concentration of barite is greater in this deposit than in the others in the district. It is not known whether this is because of more favorable host characteristics in the beds or be-

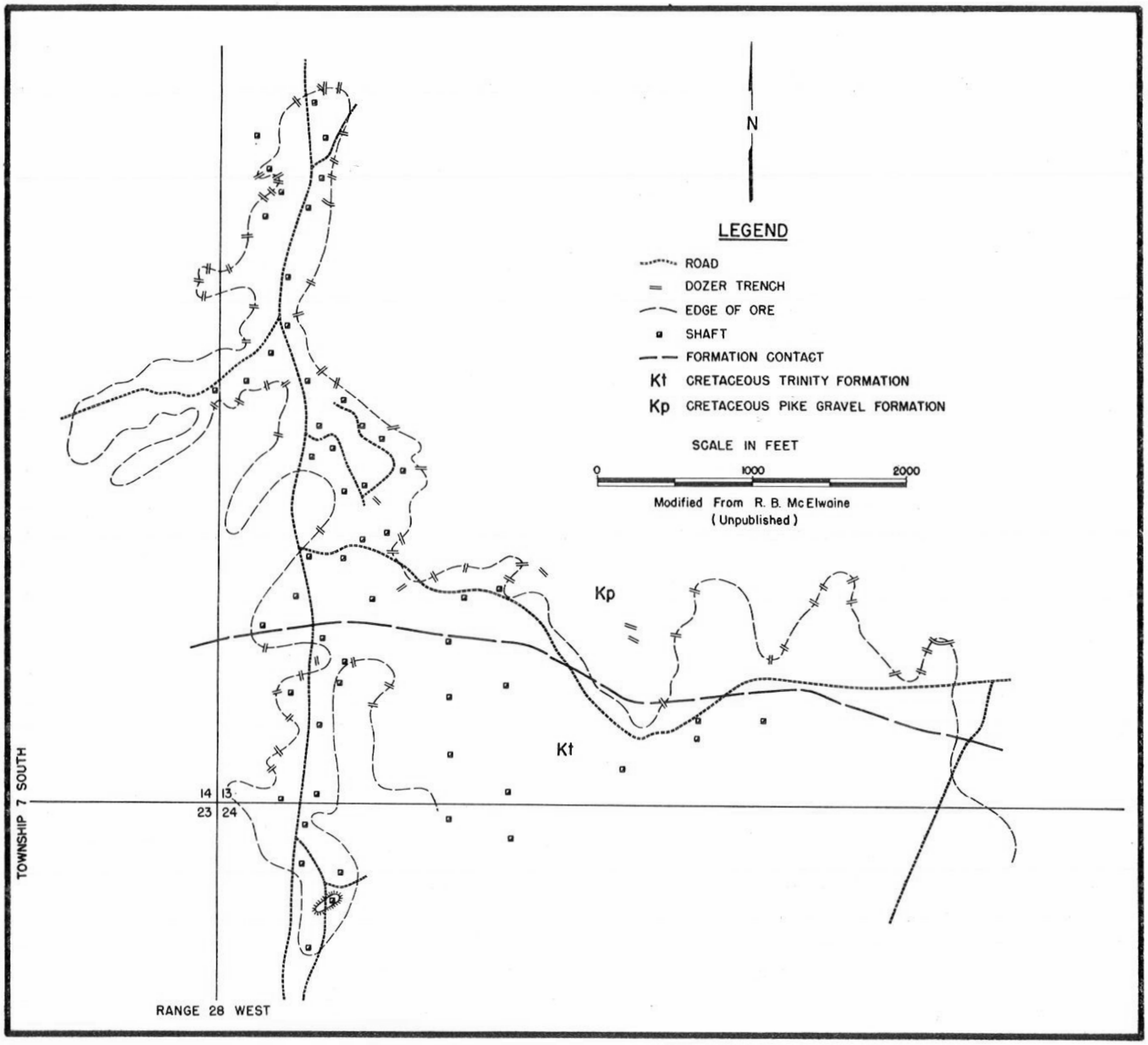


Figure 12—Sketch map of Lucky "13" barite deposit, Dierks district, Arkansas.

cause these stratigraphically lower beds have been less weathered and eroded. Probably both factors are responsible to some degree.

The barite zone of the Lucky 13 deposit is about 50 feet below the Dierks limestone.

The barite in the deposits of this district is present as cementing material. The highest grade of ore is over 50 percent (in the Pike gravel) and the average tenor (30 to 40 percent with selective mining) is considerably less than the tenor of the high-grade ore in the replacement deposits. The cementing barite can be freed from the enclosing rock much more readily than can the replacement-type barite. It is probable that the cost per ton of recovered barite, assuming suitable mining methods, would be about the same as that for the replacement deposits.

The economic value of the barite deposits in the Dierks district as well as those in the Pigeon Roost, Fancy Hill and Hatfield districts, is dependent upon (1) amount of reserves that can be established, (2) transportation costs, and (3) availability of a market.

Uses

The chief commercial uses of barite are as weighting material in drilling mud, as a source of barium chemicals and in lithopone. However, considerable amounts are used as filler in rubber and paper and in some types of glass. In recent years the uses of barite in cement for coating oil and gas lines in swampy areas and as a constituent of rubberized asphalt pavement has created new markets for the mineral. Over half of the domestic production, as well as much of the imported material is used to produce weighting material for drilling muds.

In the rotary drilling of oil wells a drilling bit is rotated by a hollow central shaft. A mud pumped down this hollow shaft removes the rock cuttings as they are formed and carries them up the annular space between the drill stem and the wall of the hole to the surface. In addition this fluid or mud lubricates and cools the bit and seals off the wall of the hole and develops sufficient head to withhold abnormal pressures encountered in the drilling. It is in the performance of this last function that barite is useful.

The oil fields in the Gulf Coast area have abnormally high pressures in the producing zones. When this pressure is greater than the hydrostatic head of the mud, the oil or gas will blow out of the well frequently with disastrous results. These pressures are controlled by increasing the gravity of the drilling fluid by the addition of finely-grained barite.

Production

The entire barite production in Arkansas to date has come from the Chamberlain Creek deposit in the Magnet Cove area of Hot Spring County. The Magnet Cove Barium Corporation and the Baroid Sales Division of the National Lead Company are the sole producers in the district. Table 5 shows the annual production of barite in the district from the beginning of mining operations to date.

TABLE 5

Production Statistics — Arkansas Barite

Year	Amount (short tons)	Estimated Value
1939	2,500	
1940	12,000	$ 67,250
1941	31,200	178,760
1942	53,500	321,180
1943	94,700	568,240
1944	159,700	1,038,050
1945	261,400	1,793,240
1946	288,900	2,144,100
1947	376,800	2,411,910
1948	362,400	2,681,780
1949	363,300	6,104,930
1950	343,100	5,973,370
1951	399,500	6,956,550
1952	422,400	7,603,740
1953	381,400	7,437,430
1954	370,600	3,488,480
1955	366,000	3,440,000
1956	481,668	4,335,012
1957	468,526	4,132,399

From files of Arkansas Geological and Conservation Commission

Prospecting for Barite

Paleozoic Areas

Barite occurs in three known modes within the Paleozoic rocks of the barite region; concordant veins in the Middle Arkansas novaculite, discordant veins in the cinnabar deposits, and replacement zones in the lower Stanley formation. Only those barite deposits in the Stanley are of sufficient size and grade to be commercial in the present economy. These replacement deposits occur immediately above the Arkansas novaculite and are, for the most part, restricted to synclinal structures. There is no evidence to indicate the emplacement was not effected in several adjoining close-folded structures.

The character of the known deposits suggests that the most successful prospecting should be in downfolded structures where the novaculite (ore base) can be found by coring at a reasonable depth below the surface. The economic factors that determine a "reasonable depth" are varied, complex and subject to change without notice. In an aggressive well-financed prospecting program, coring to depths of 2000-2500 feet could yield profitable information about paths of barium migration and possible host rock characteristics. In general, the writer does not recommend coring deeper than 500 feet unless barite is encountered.

The most favorable areas for prospecting for barite in Arkansas are along the flanks of the Mazarn basin. Most of the basin is outlined by anticlinal ridges of novaculite. Minor folds and wrinkles containing Stanley shale are plentiful along the flanks of these anticlinal ridges. Only along the north flank of the basin (Caddo Mountains), where the Stanley is missing, are the prospects unfavorable for finding barite. The intricate folding of the sediments within and around the Mazarn basin has not been mapped in sufficient detail to determine the aggregate dip of the novaculite away from the exposures in the anticlinal ridges. Dip and strike patterns suggest that the novaculite and therefore the favorable Stanley host rock is close enough to the surface to warrant prospecting in a zone about two miles wide on either side of the novaculite exposures. The folding is such that the whole of the Mazarn basin may be suitable for prospecting.

The best method of exploration for barite would be to map the structural configuration off the flanks of the bounding novaculite ridges and core drill the flanks and axes of the synclines. Lack of good exposures of the sediments make surface mapping difficult and inaccurate, so that except where barite can be found at the surface, other methods of mapping can be used. The writer has gained some degree of proficiency in determining structures from aerial photographs but does not claim to be an expert photogeologist. However the results obtained while mapping from aerial photographs in the Mazarn basin were good enough to show that an experienced photogeologist could accurately determine the position of 70 to 90 percent of the folds along the flanks of the basin and 60 to 85 percent of the folds of the interior of the basin and the adjoining Athens plateau. Photogeology would cost less and perhaps be more accurate than most geophysical methods.

The most common geophysical exploration tools are seismograph, magnetometer, gravimeter, electrical resistivity, and radiation counters. The Arkansas novaculite is a good datum for all of these methods but the structural complexity strongly limits the efficiency of most of them. On account of the close control required, rough terrain, and lack of roads, a seismograph crew, costing $16,000-20,000 per month, probably could not survey over 250 square miles per month. Magnetometer and gravimeter surveys would cost about a third as much and the other methods considerably less than that. A large scale geophysical exploration program does not seem practical considering the margin of profit in barite mining. In local areas any of the above methods may be used to good advantage.

In many areas of the world, uranium is found associated with barite, but this is not the case in Arkansas. There are radioactive "hot spots" in the Magnet Cove igneous complex, therefore the writer made a series of scintillometer traverses from the igneous exposures to the barite mine in the Chamberlain Creek syncline. The instrument was not calibrated so all readings were relative. Background variations were not large enough to affect materially the patterns obtained. The patterns were surprising and perhaps useful. The readings were highest in the igneous rocks and almost nil in the novaculite, as was expected. The readings from the Stanley shales were higher than those from the sandstones, also as expected. The black shale underlying the barite and the barite have a much lower radioactivity than the sandstones and only slightly greater than the novaculite. This was not expected. These conditions are also true of the Fancy Hill deposit in Montgomery County except no igneous rock is exposed. Mapping of radioactivity minimums may be an accurate, comparatively rapid, and economical method of prospecting for barite. Linear zones of radioactivity minimums would reflect the axial trace of anticlines in which the novaculite was not deeply buried. The intervening synclines of low radioactivity would be the most logical to core to test for barite. Aerial radiometric surveys with ground checks should be carefully considered in an exploration program in the Arkansas barite region.

Mesozoic Areas

Barite occurs as cementing material in the Trinity sands and the Pike gravel in the Dierks district. These deposits have not as yet proved to be in commercial concentrations, which dampens the enthusiasm for searching for similar deposits. The ease of ore concentration and the purity of the barite, as discussed in earlier sections, indicate that some commercial development is feasible. Exploration methods are limited to examining outcrops of the Pike gravel and the lower Trinity sands. Topographic highs should be checked for the resistant barite. A discovery of barite float must be evaluated by coring. The more favorable areas should be eastward from the Dierks district toward the known barite veins in the cinnabar district and in the peridotites near Murfreesboro.

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