STATE OF ARKANSAS

ARKANSAS RESOURCES
And
DEVELOPMENT COMMISSION

HENDRIX LACKEY
Executive Director

BULLETIN 11

A BROOKITE DEPOSIT IN HOT SPRING COUNTY ARKANSAS

By
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DIVISION OF GEOLOGY

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LITTLE ROCK
1947

LETTER OF TRANSMITTAL

Division of Geology

Little Rock, Arkansas
March 1, 1947

Colonel Hendrix Lackey
Executive Director
Arkansas Resources and
Development Commission
Little Rock, Arkansas

Dear Sir:

I have the honor to transmit, herewith, a report entitled, "A Brookite Deposit in Hot Spring County, Arkansas," by Drew F. Holbrook.

Brookite is a titanium mineral identical to rutile in its chemical composition and, therefore, has applications both as a welding rod coating and as a source of titanium for certain alloys. The increased demand for rutile, particularly for welding rod coatings, has placed it in the strategic class and the Federal government is now purchasing rutile under the "Strategic and Critical Materials Stockpiling Act," approved July 23, 1946.

This project constitutes a valuable contribution to the geology, origin and nature of this brookite deposit, and was undertaken to stimulate and encourage its economic development.

It is recommended that the report be published as Bulletin 11, in order to follow the publication sequence of the former Arkansas Geological Survey.

Respectfully submitted,

Harold B. Foxhall
Director

A BROOKITE DEPOSIT
IN HOT SPRING COUNTY, ARKANSAS

Introduction

The occurrence of brookite at Magnet Cove, in northeastern Hot Spring County, Arkansas, has been known for a number of years. J. F. Williams[1] in 1890 wrote the first detailed account of the occurrence and origin of the rutile and brookite from this locality. Magnet Cove is a basinlike area about two miles in diameter surrounded by a roughly circular ridge. Although the soils of the Cove commonly contain rutile and brookite, concentrations are limited to two general areas: the alluvial and residual rutile deposits of the northern part of the Cove interior, and the brookite-quartz area along the northeastern edge of the Cove. The Christy brookite deposit, located in the SW 1-4 SW 1-4 Sec. 16, Twp. 3S, Rge. 17W, is a portion of this latter area.

[1] Williams, J. F.: The igneous rocks of Arkansas. Ark. Geol. Surv. Ann. Rept. Vol. 2: 163-343, 1890.

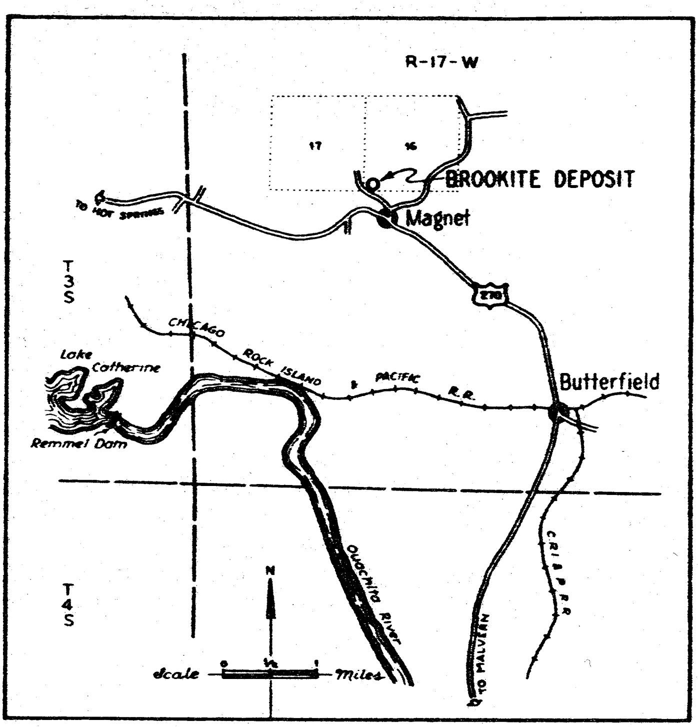


Fig. 1

Development work was first attempted on the present Christy property in 1913 when H. E. Perkins had a tunnel driven into the brookite-bearing quartz rock of Chamberlain Creek gorge just west of the property. No report is available on the results of this work, and it is believed that the project ceased due to the lack of demand for titanium at that time. The property was successively obtained and relinquished by various operators until 1941, due largely to difficulties encountered in ore dressing. Mr. Wynn O. Christy, who obtained a lease on the property in 1941, developed a substantial tonnage of ore by test pitting the deposit. Ore dressing tests were run on the test pit material, the results of which indicated that a major portion of the titania was recoverable in a marketable concentrate composed chiefly of brookite.

It should be noted here that all the past production of rutile from Arkansas has come solely from the rutile deposits within the Cove. The Christy brookite deposit is situated on the edge of the Cove, is a different type of deposit from the Cove rutile deposits and has as yet produced no titania for other than metallurgical test purposes.

Stratigraphy

The exposed sedimentary rocks with the exception of the Recent alluvial sands and gravels in the creek valleys in the area immediately adjacent to the brookite deposit are all of Paleozoic age. Less than two miles to the southeast, however, Tertiary sediments of the Gulf Coastal Plain are exposed. The following is a generalized geologic section of the Paleozoic formations adjacent to Magnet Cove:

System	Series	Formation	Thickness[2] in Feet
Carboniferous	Mississippian	Stanley Shale	300 (+)
		Hot Springs Sandstone	50 (+)
			(—)
Devonian		Arkansas Novaculite	700 (+)
Silurian			(—)
		Missouri Mountain Shale	50 - 100
		Blaylock Sandstone	0 - 500

Since the Blaylock Sandstone formation occurs primarily in the anticlinal valleys of the region, the outcrops are somewhat limited. The formation is predominantly a fine-grained, thin-bedded sandstone varying from buff to gray in color. The formation is thoroughly jointed, its presence usually being indicated by an abundance of angular sandstone fragments on the surface. Many of the joints are filled with veins of milky quartz. Though the formation is known in other localities to contain interbedded shale, none was observed in the area immediately adjacent to Magnet Cove.

The Missouri Mountain shale formation does not outcrop very extensively in this region, due largely to its thinness and susceptibility to weathering. It is composed primarily of a thin-bedded, slaty, black, clay shale, and may

[2] Parks, B.: A barite deposit in Hot Spring County, Arkansas. Ark. Geol. Surv. Info. Circ. 1: 1932.

be distinguished by interbedded, thin layers of coarse-grained quartzite. The shaly phases weather to buff, red, and gray-green clays. The red and green slaty phases common to the formation farther west in the Ouachita Mountains are absent in the Magnet Cove region.

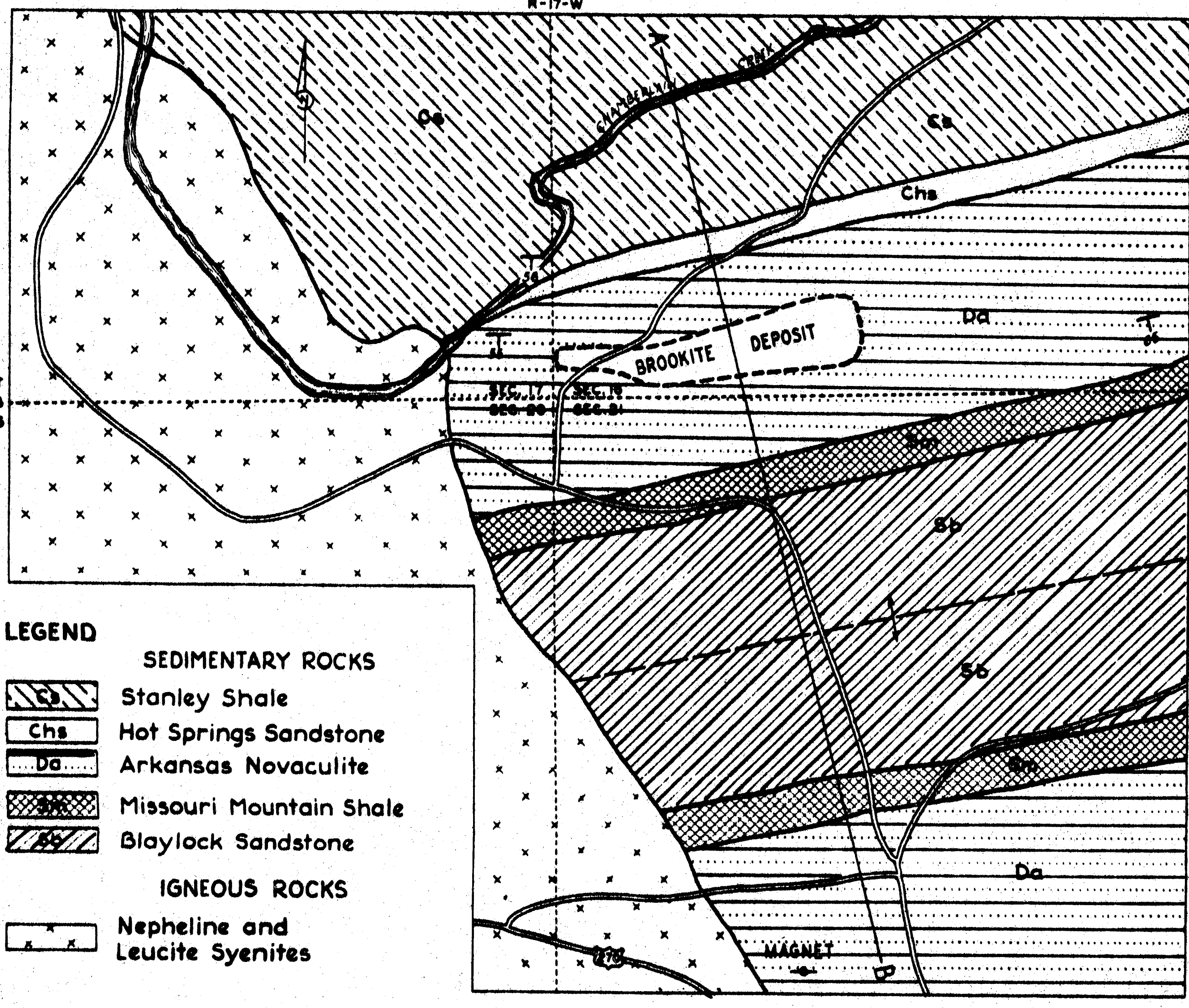
Only the middle and lower divisions of the Arkansas Novaculite formation are exposed in this locality. The novaculite itself is a very hard, dense, siliceous rock, with a conchoidal to subconchoidal fracture, probably a variety of chert. Red, green, brown, and black novaculite are known, but the predominant color is white.

The lower division of the Novaculite formation has an average thickness of about 225 feet, and is characteristically composed of massive white novaculite in beds from two to ten feet thick. The resistance to erosion of this lower division has resulted in numerous outcrops in the form of a series of east-west ridges, both the younger and older beds forming the adjacent valleys.

The middle division of the formation consists primarily of thin-bedded dark novaculite and black shale and ranges in thickness from ten to about 350 feet. Its susceptibility to weathering does not afford many outcrops.

The Hot Springs Sandstone formation forms low ridges in some places, but conspicuous outcrops are lacking particularly near the brookite deposit. It is composed primarily of a fine to medium-grained gray quartzitic sandstone. In many exposures, the sandstone is finely laminated paralled to the bedding. The formation is characteristically thin and lenticular, and locally contains a basal conglomerate. This conglomerate is not in evidence however in the outcrops of the formation near the brookite deposit.

In the Magnet Cove region the Stanley Shale formation is present principally in the synclinal valleys. It is for the most part, a black, fine-grained clay shale formation. Interbedded quartzitic sandstone layers are common near the base of the formation so that the contact with the underlying Hot Springs Sandstone formation is difficult to determine. The entire formation is so complexly jointed that the bedding is obscure. Shaly phases of the formation commonly weather to red, brown, and buff colored clays.



GEOLOGIC MAP
OF THE
CHRISTY BROOKITE DEPOSIT

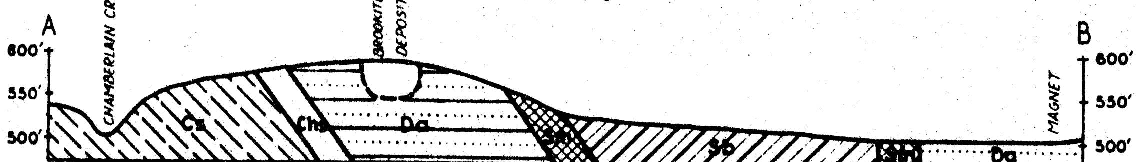
BY DREW F. HOLBROOK

ARKANSAS RESOURCES AND DEVELOPMENT COMMISSION

DIVISION OF GEOLOGY

SCALE 0 200 400 600 800 1000 FEET

1 9 4 6



VERTICAL SCALE EXAGGERATED

SECTION ALONG LINE A - B

PLATE NO. I

Igneous Rocks

The Magnet Cove igneous complex is an elliptical mass of alkalic igneous intrusives enveloping smaller masses of metamorphosed sediments. The mechanism of intrusion of the complex has long been a subject of controversy. Williams[3] believed that the igneous rocks were injected during three distinct periods of igneous activity. H. S. Washington[4] later suggested a single laccolithic intrusion followed by differentiation into two distinct groups of rocks; the central basic ijolitic rocks, and the peripheral, less basic, syenites. The monchiquitic and tinguaitic dikes were attributed to contemporaneous and subsequent injection of the above differentiates. More recently, Landes[5] has suggested the intrusion of a central and a peripheral magma, the peripheral magma being an acid differentiate of the central mass.

That part of the igneous complex which is most closely related to the brookite deposit is the garnet nepheline syenite intrusive which occurs along the eastern border of the complex in contact with the invaded Paleozoic sediments. The syenite exhibits no flow layers or lineation, the only evident structural feature being the jointing. In the vicinity of the brookite deposit the contact between the syenite and Paleozoic sediments is not visible. A very sharp contact is exposed at the southern boundary of the Cove in the Diamond Jo quarry where the syenite intrusive has thrust up the adjacent Stanley Shale formation. Thus, the age relationships at the Cove itself indicate that the intrusion was post-Stanley, though it has been more definitely assigned to the mid-Cretaceous.[6] The syenite mass is fairly uniform in color and texture throughout its outcrops. The fresh rock is dark gray in color and has a medium-grained. granitoid texture. Weathered surfaces of the syenite are a

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[3] Williams, J. F.: op. cit.

[4] Washington, H. S.: The igneous complex of Magnet Cove, Arkansas. Geol. Soc. Am. Bull. Vol. 21: 389-416, 1900.

[5] Landes, K. K.: A paragenetic classification of the Magnet Cove minerals. Amer. Mineral. Vol. 16, No. 8: 313-326, 1931.

[6] Miser, H. D.: New areas of diamond-bearing peridotite in Ark. U. S. Geol. Surv. Bull. 540: 534-546, 1912.

somewhat lighter gray than the fresh rock. Several outcrops show the rock to be deeply weathered, and examples of spheroidal weathering are common.

Dikes of igneous rock are common in the area, particularly within the igneous complex itself. Several however, may be noted in the adjacent Paleozoic sediments. Two dikes of fine-grained, dark igneous rock are well exposed in the Stanley Shale formation in the bed of Chamberlain Creek some 400 feet north of the brookite deposit.

Contact Metamorphism

Pronounced changes were effected by the igneous intrusive on the invaded sediments. The shaly phases of the Stanley formation were baked into a hornfelsic rock whose resistance to erosion resulted in the development of the gorge along Chamberlain Creek. The sandy layers of the Stanley formation and the Hot Springs sandstone formation become increasingly quartzitic as the igneous contact is approached. Of particular interest, however, are the changes in the Novaculite formation. Through contact action, shaly layers become hornfelsic while the novaculite itself becomes a rather loosely consolidated saccharoidal mass of quartz grains. Generally speaking, the size of these quartz grains increases as the contact is approached. Quartz veins as well as porous masses of smoky quartz crystals are common in this sugary textured rock. It is in these porous masses of smoky quartz crystals that the brookite occurs. Contact action on the Missouri Mountain and Blaylock formations was indeterminable as the contacts were obscured by soil and vegetation.

Structure

The regional structure is a group of tightly folded Paleozoic sediments intruded by the Cretaceous igneous rocks of Magnet Cove. A series of parallel anticlines and synclines trend roughly northeast-southwest and plunge to the southwest. The folds are well outlined by a series of ridges which are an expression of the resistance of the Arkansas Novaculite formation and constitute a portion of the Zigzag Mountains. Locally, the Magnet Cove intrusives have truncated one of these plunging anticlines. This truncated anticline is overturned to the north, and ore deposition has taken place in the north limb. The formations in the north limb of the anticline trend S.75° W. dipping about 65° SE. Within a few hundred feet of the intrusive, however, they gradually shallow in dip and approach an east-west strike.

From the field evidence available it is doubtful that the structure played a primary role in ore localization. No brookite ore has been observed in place in a fracture or system of fractures, however, smoky quartz veins have been found in the altered novaculite in the road cut at Magnet. The fact that the known ore lies within the Novaculite formation is an indication of stratigraphic control.

The Brookite Deposit

The developed brookite deposit lies within the Arkansas Novaculite formation and consists of a loosely consolidated, red, clayey material with fragments of porous clusters of quartz crystals and coarse-grained metamorphosed novaculite. Dark red clays compose the major portion of the deposit from the surface to a depth of about ten feet, however, below that depth, lenses of a very fine-grained white to blue-white clay are encountered. These lenses vary in thickness from several inches up to three feet and their orientation does not seem to correspond to the surrounding structural trends. Ross[7] has described similar clays in a brookite deposit one-half mile north of the Christy deposit and has stated that the latter clays are altered volcanic ash.

Titanium is present in the deposit principally as subhedral brookite crystals and as crystal fragments. The brookite crystals occur in the porous, metamorphosed novaculite, in quartz veins and disseminated with the crystal fragments in clay. Individual brookite crystals vary from several millimeters to over a centimeter in length. Williams[8] has noted that pseudobrookite (rutile after brookite) is also present. Microscopic study of the ore (see Fig. 2, be-

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[7] Ross, C. S.: Titanium deposits of Nelson and Amherst Counties, Virginia, U. S. Geol. Surv. Prof. Pap. 198: 23-26, 1941.

[8] Williams, J. F.: op. cit.

low) has revealed that a small percentage of the titanium is present in the form of minute needles of rutile in quartz. Occasionally dusty leucoxene may be seen included in the quartz grains.

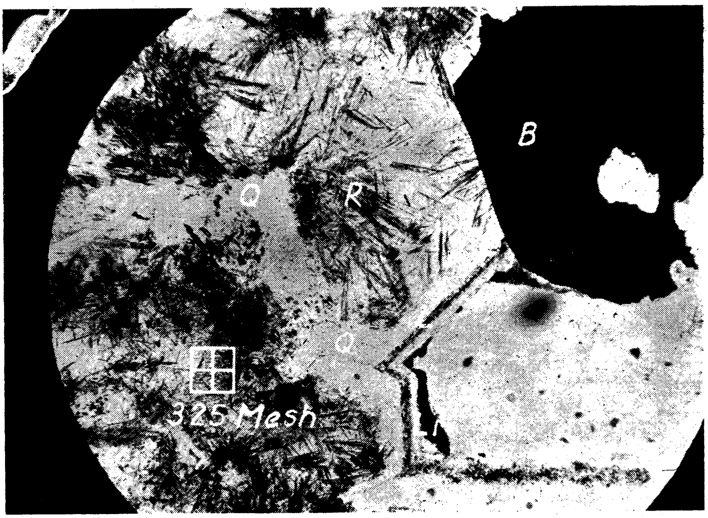


Fig. 2

Photomicrograph of brookite ore showing needles of rutile (R), a large brookite crystal (B), and a fringe of leucoxene (L), all included in quartz (Q). A cavity between several quartz crystals appearing at lower right is coated with limonite (Li). Plain light. x75

Limonite and hematite are abundant in the ore as a cement in the porous novaculite and also as constituents of the clay. Quartz is common in the ore as crystal fragments, euhedral crystals and irregular grains. It is, of course, the chief constituent of the metamorphosed novaculite and the quartz veins. Both the clear and smoky varieties of quartz are common.

A composite sample of ore representing grab-sample material from all of the test pits was analyzed[9] with the following results:

	Per Cent
SiO_2	66.26
P	0.119
S	0.011
Fe_2O_3	14.9
Al_2O_3	6.54
ZrO_2	0.04
TiO_2	7.56
CaO	0.014
BaO	Nil
MgO	Trace
Li_2O	Nil
K_2O	0.13
Na_2O	0.06
Ign. Loss	4.40
Total	100.034

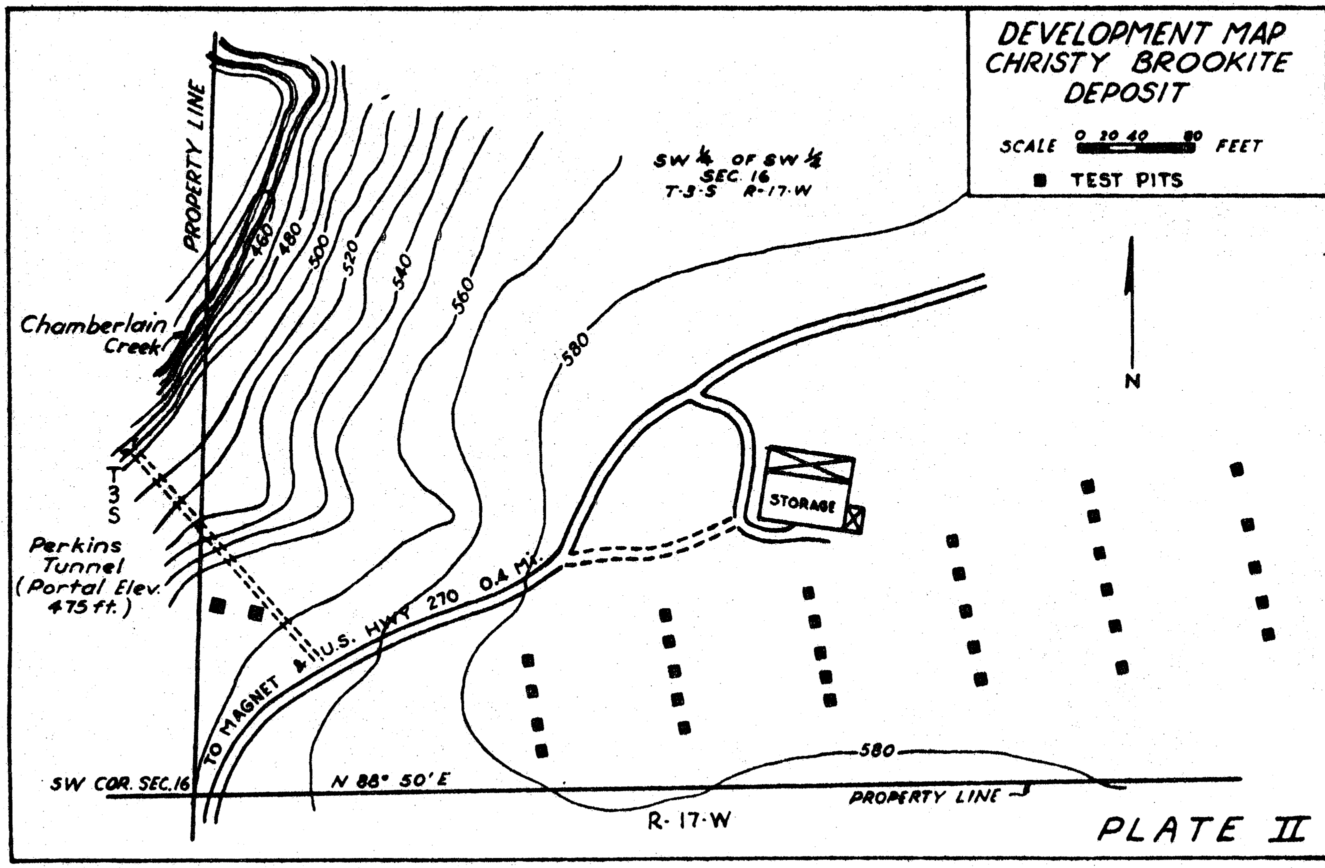
The analysis was made primarily to detect the presence of undesirable elements, and therefore, the value for titania is not intended to represent the average value for the entire deposit. Lithium[10] and barium[11] were investigated because of their known occurrence in the area.

It should be noted that the recent test pitting has not disclosed any ore in place in solid rock, all the developed ore being detrital material in clay. The outline of the brookite deposit, shown by a dashed line on Plate I, represents only the proved ore body developed by test pitting. It is lenticular in plan, about 760 feet long and 120 feet wide. Thirty-two test pits were sunk, all of which were begun in ore and twenty-six of which were bottomed in ore (see Plate II). The pits were variable in depth, the maximum being forty-five feet. It can readily be seen, therefore, that the test pitting did not fully delimit the ore body. Although

9 Analysis by T. W. Carney, Chief Chemist, Ark. Resources and Development Commission, Little Rock, Ark.

10 Miser, H. D. and Stevens, R. E.: Taeniolite from Magnet Cove, Ark. Am. Mineral. Vol. 23: 104-110, 1938.

11 Parks, B.: op. cit.


DEVELOPMENT MAP
CHRISTY BROOKITE
DEPOSIT
SCALE 0 20 40 80 FEET
TEST PITS
N
SW 1/4 OF SW 1/4
SEC. 16
T·3·S R·17·W
PROPERTY LINE
Chamberlain
Creek
460
480
500
520
540
560
580
T
3
S
Perkins
Tunnel
(Portal Elev.
475 ft.)
TO MAGNET & U.S. HWY 270 0.4 MI.
STORAGE
SW COR. SEC.16
N 88° 50' E
PROPERTY LINE
R·17·W
PLATE II

there are soil concentrations of brookite for a distance of several hundred feet in all directions from the boundary of the developed deposit, in most cases they are shallow and overlie barren rock. Surface exposures indicate that the best possibilities for horizontal extensions of the proved ore are in a westerly direction toward the syenite contact and in the shallow soil concentrations previously discussed. The possibility of vertical extension of the ore is encouraging since the material from the dump of the Perkins tunnel indicates that brookite was encountered in quartz veins in metamorphosed novaculite some 100 feet below the top of the orebody (See Plate II).

Since the Magnet Cove igneous complex was injected into tightly-folded Paleozoic sediments, the syenites composing this complex are in contact with the Novaculite formation at points other than the Christy brookite deposit. Two such Novaculite-syenite contacts were examined in the field and both exhibit evidence of brookite mineralization. One of these contacts is exposed in the highway drainage ditch at Magnet post office (See Plate I) about one-half mile southeast of the Christy deposit. Here brookite crystals occur in quartz veins in metamorphosed novaculite. On a hill about one-quarter of a mile southeast of Magnet post office along this same contact, fragments of float composed largely of brookite and quartz crystals may be found. About one-half mile northwest of the Christy deposit is the second Novaculite-syenite contact referred to. Adjacent to this contact is a brookite deposit known as the Hardy prospect. Exposures here are rare, but trenching has revealed brookite both as crystals in quartz and as crystal fragments disseminated in clay.

The existence of brookite mineralization in the vicinity of these other two Novaculite-syenite contacts indicates that the titania-bearing solutions were not restricted to the Christy deposit.

Origin

Titanium-bearing minerals are common as accessory minerals in the igneous rocks at Magnet Cove. Leucoxene, titanite, ilmenite, schorlomite, and rutile are among those that have been identified. It is reasonable to assume, therefore, that the magma from which the Magnet Cove intrusives were derived was also the source of the titanium in the brookite deposits. A magma, however, that yields subsilicic igneous rocks is unlikely to afford an excess of silica for deposition as vein quartz. Probably, as Landes[12] and Ross[13] have pointed out the silica was derived from the novaculite by an active solution. Microscopic examination of the porous, brookite-bearing quartz masses reveals that leucoxene and quartz have been alternately deposited in crystallographic continuity in the formation of euhedral quartz crystals (Fig. 2), thus, indicating an essentially simultaneous deposition of titania and silica.

Summarizing then, it may be said that the brookite-quartz mineralization was probably accomplished by an active titania-bearing solution that was related to the Magnet Cove intrusive magma.

Economic Aspects of the Brookite Deposit

The average TiO_2 content of the samples obtained by channelling the thirty-two test pits was 10.2 per cent. This test pitting was preliminary and did not delimit the deposit either vertically or horizontally.

The fact that the ore is relatively unconsolidated and extends from the surface downward to a known depth of forty-five feet renders it suitable for open pit mining operations utilizing a scraper, dragline or bulldozer.

Beneficiation tests on the brookite ore were conducted by the Rolla Division, Metallurgical Branch, U. S. Bureau of Mines, the ore dressing laboratory of the American Cyanamid Company, the Allis-Chalmers Company, and the Deister Concentrator Company. The American Cyanamid Company was able to effect a recovery of 65 per cent of the titania (TiO_2), while the U. S. Bureau of Mines' laboratory reported a recovery of 71 per cent of the titania in a marketable 92 per cent concentrate. It should be noted that a complete recovery of all the titania content of the ore

[12] Landes, K. K.: op. cit.
[13] Ross, C. S.: op. cit.

would not be economically possible, due to the titania that is present in extremely fine rutile and leucoxene. (See Fig. 2). The following general procedure[14] was found by the Cyanamid laboratory to provide effective beneficiation of the ore:

1. Agitation (i.e. log washing or its equivalent) of the coarse ore followed by desliming for removal of slimes released from the ore.

2. Fine grinding of the washed ore to approximately minus 150 mesh.

3. Desliming of the washed and ground ore for removal of secondary slimes produced during grinding.

4. Conditioning of the ground and deslimed ore with reagents at high solids (70 to 80 per cent).

5. Rougher flotation of the conditioned feed.

6. Cleaning of the rougher concentrate at least four times.

On the basis of the results obtained by the American Cyanamid Company's laboratory, the Allis-Chalmers Company drew up a preliminary mill layout. The daily capacity of the mill would be 140 tons of ore per 24-hour day with a daily yield of ten tons of brookite concentrates analyzing 92 per cent TiO_2.

The problem of water supply can be solved by impounding water in Chamberlain Creek gorge nearby. Railroad facilities, natural gas lines and electric power lines all are available a short distance from the deposit.

Though the chemical analysis of the ore has indicated small percentages of phosphorus and sulfur, it is very probable that these elements are associated with limonite and would probably be practically eliminated in the beneficiation processes. There is, however, a possibility that pyrite may be encountered below the water table. This is indicated

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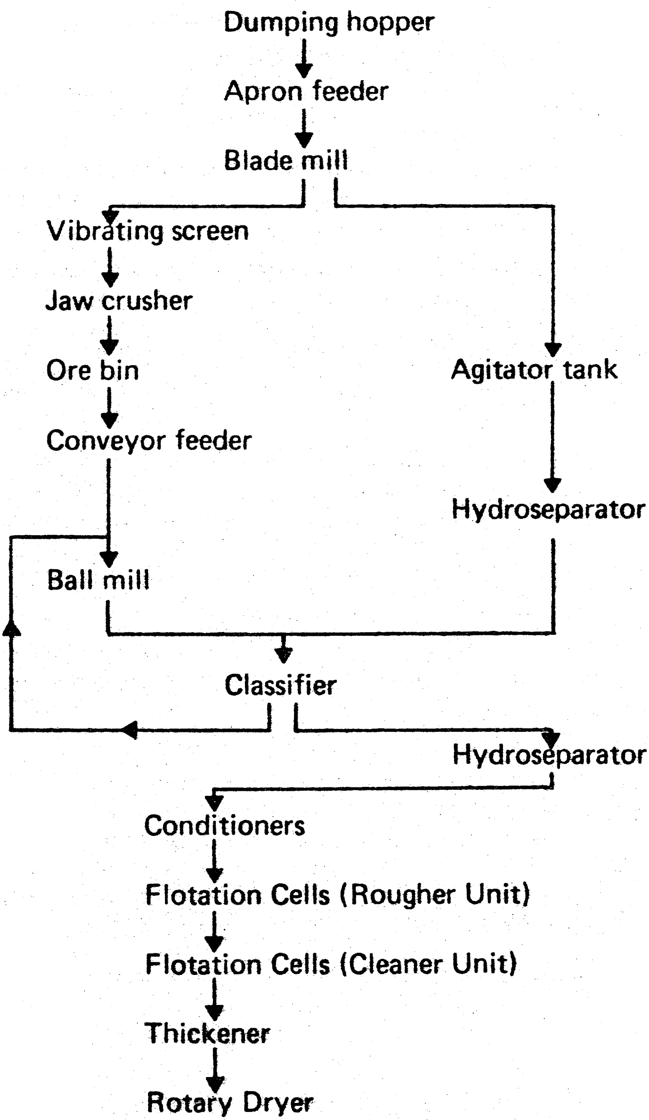
[14] Falconer, S. A. and Crawford, B. D.: Froth flotation of some nonsulfide minerals of strategic importance. Am. Inst. of Min. Eng. Tech. Publ. No. 1754: 8-10, 1944.

FLOW SHEET OF PROPOSED MILL



by the abundance of iron oxides associated with the developed ore, and the fact that pyrite was found at depth in the rutile mining operations within the Cove.

Brookite, since it differs from rutile, only in its physical properties, would undoubtedly be marketed as rutile. The bulk of the present rutile consumption is being used in the manufacture of welding rod coatings; other applications are in the manufacture of titanium alloys and carbide, and ceramic uses. By far the largest tonnage of titanium consumed is in the maufacture of paint pigment. The mineral ilmenite, however, is the source of supply for this purpose due to its lower cost and the fact that it is less stable chemically and, thus, easier to process. Pure titanium metal was produced experimentally for the first time during 1945 and has a promising future as a structural material.

Rutile statistics[15] for 1944 and 1945 according to the U. S. Bureau of Mines in short tons gross weight are as follows:

	1944	1945
Production	6,922	7,179
Mine Shipments	6,770	6,837
Imports	10,019	10,602
Consumption	14,813	9,876
Stocks at End	7,004	10,130

Domestic rutile production in 1945 was limited to two localities; the Florida beach sand deposits and the nelsonite deposits in Virginia. Over 90 per cent of the rutile imports came from the Australian beach sand deposits, the remainder being from Brazil.

The following statement on the postwar outlook for titanium ores is taken from the U. S. Bureau of Mines Minerals Yearbook for 1944:

> "The astonishing rate of growth in the overall use of titanium in the past two decades probably will exist for several years..... As a constructional material titanium has become nearly indispensable as a welding

[15] E. and M. J. Metal & Min. Markets. Vol. 17, No. 24, June 13, 1946.

rod coating..... Progress in the use of welding has been so great during the war that much of the gain will be translated to peacetime uses. Consumption of titanium in welding rods is likely, therefore, to fall off considerably but to remain well above the prewar level."

In summarizing the market situation, it may be said that a substantial market should exist for rutile ores in welding rod coatings for several years. The controlling factor in the market situation would seem to be the imports, particularly those from Australia. An important factor, however, in the rutile market situation is the recent passage by Congress of a war reserve stockpile bill. Under the provisions of this act, rutile is now being purchased and stockpiled by the Federal government.

SUMMARY

The occurrence of brookite at Magnet Cove, Arkansas has been known since 1846. Various attempts have been made since 1913 to develop a brookite deposit, but a substantial deposit had not been outlined until 1941. Beneficiation tests on the developed ore have shown that a marketable concentrate of titanium ore can be produced. The ore as developed so far is an unconsolidated mass of clay, metamorphosed novaculite fragments, and coarse quartz crystals all containing crystals or crystal fragments of brookite and is situated near the contact of a syenite intrusive and the Arkansas Novaculite formation. The brookite ore should find a ready market, particularly as a raw material for coating welding rods.