Niobium (Columbium) and Titanium at Magnet Cove and Potash Sulphur Springs, Arkansas

---

GEOLOGICAL SURVEY BULLETIN 1015-B

DEPARTMENT OF THE INTERIOR
March 3, 1849

Niobium (Columbium) and Titanium at Magnet Cove and Potash Sulphur Springs, Arkansas

By V. C. FRYKLUND, Jr., R. S. HARNER, *and* E. P. KAISER

A CONTRIBUTION TO ECONOMIC GEOLOGY

GEOLOGICAL SURVEY BULLETIN 1015-B

Description of deposits and results of analyses

DEPARTMENT OF THE INTERIOR
March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1954

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 35 cents (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

A CONTRIBUTION TO ECONOMIC GEOLOGY

NIOBIUM (COLUMBIUM) AND TITANIUM AT MAGNET COVE AND POTASH SULPHUR SPRINGS, ARKANSAS

By V. C. Fryklund, Jr., R. S. Harner, and E. P. Kaiser

ABSTRACT

Niobium (columbium) and titanium occur in several minerals and rocks of the Magnet Cove and Potash Sulphur Springs areas. Niobium is in demand for use in high-temperature and noncreep steels; titanium metal is becoming an important structural material.

The Magnet Cove and Potash Sulphur Springs areas are in central Arkansas between the communities of Malvern and Hot Springs. They are underlain by similar alkalic igneous complexes consisting of nepheline syenite, more basic alkalic rocks, and calcite rock or carbonatite. The igneous rocks transect sedimentary rocks of Paleozoic age and were truncated by erosion of Late Cretaceous age.

At Magnet Cove, deposits of rutile (TiO_2) occur within the igneous complex, and deposits of brookite (TiO_2) occur in quartzite of the Arkansas novaculite of Devonian and Mississippian age near the margin of the complex. Perovskite ($CaTiO_3$) occurs in several places in the igneous complex.

Analyses of drill core and channel samples show that the larger titanium deposits contain 3 to 6 percent TiO_2 in recoverable form. The Nb/TiO_2 ratios in these samples are sufficiently constant to allow a fairly accurate calculation of the percentage of niobium from the percentage of titania. Concentrates of rutile and brookite average 1.2 and 2.0 percent niobium respectively. Single crystals of these minerals are surprisingly variable in their content of niobium. Brookite crystals contain from 0.8 to 9.6 percent niobium; rutile crystals contain from 0.0 to 1.7 percent niobium. The vanadium content varies greatly, both in core and channel samples and in individual crystals of titanium minerals, and shows no correlation with the niobium content.

Drill cores of perovskite-bearing magnetite-pyroxene rocks at the Mo-Ti Corp. property contain 0.03 to 0.04 percent niobium.

The Kimsey calcite quarry area was mapped, and channel samples were analyzed and found to contain about 0.01 percent niobium. The niobium content of single crystals of perovskite from this area ranges from 5.1 to 8.8 percent. Rare earths of the lanthanum group occur in the apatite and calcite of the area.

Analyses of channel samples from the trenches in the Wilson prospect at Potash Sulphur Springs show 0.1 to 0.9 percent niobium.

INTRODUCTION

LOCATION AND GENERAL GEOLOGIC FEATURES

Magnet Cove is a shallow topographic basin about 3 miles in diameter near the center of Arkansas in Hot Spring County (see fig. 2). It is 12 miles east of Hot Springs and 7 miles northwest of Malvern. U. S. Highway 270 passes through the center of the cove. The Hot Springs branch of the Chicago, Rock Island, and Pacific Railroad skirts the southern edge of the cove. The Potash Sulphur Springs area is about 6 miles west of Magnet Cove.

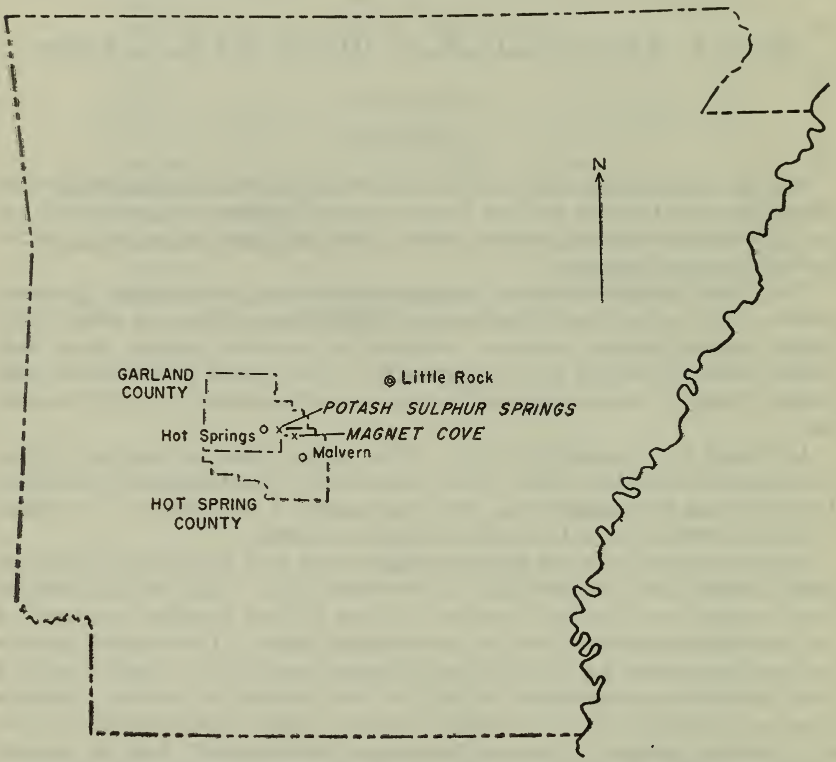


FIGURE 2.—Map showing location of Magnet Cove and Potash Sulphur Springs, Ark.

The Magnet Cove and Potash Sulphur Springs areas are underlain by igneous rocks which have intruded folded sedimentary rocks of Paleozoic age, ranging from Silurian to Mississippian. The sedimentary and igneous rocks were truncated by erosion of Late Cretaceous age and then covered in Late Cretaceous and Tertiary time by sediments of the Coastal Plain. The Coastal Plain sedimentary rocks crop out a few miles to the south of Magnet Cove.

The igneous rocks are unusually rich in sodium and titanium; they are part of an alkalic igneous province extending from the syenites in the vicinity of Little Rock and Bauxite, Ark., to Magnet Cove and Potash Sulphur Springs. The diamond-bearing peridotites and associated rocks of Pike County, Ark., which are relatively rich in titanium, are part of this province.

The Magnet Cove rocks, and those of the smaller complex at Potash Sulphur Springs, consist chiefly of varieties of nepheline syenite and related rocks. They also include rocks of doubtful origin that consist chiefly of calcite; rocks of this type are sometimes called carbonatites. The Magnet Cove and Potash Sulphur Springs rocks thus are similar to the rocks in several other alkalic complexes that also contain nepheline-bearing rocks in association with calcite rock or carbonatite, as in Colorado, Norway, Germany, South Africa, and other places. Abundant titanium is a common feature of these complexes; relatively abundant niobium is characteristic of many of them. The calcite rocks associated with these complexes have been interpreted as blocks of sedimentary carbonate, but in the last few years they have more commonly been described as material introduced by either hydrothermal or intrusive action.

Associated with the Magnet Cove complex are deposits of rutile and brookite, which contain not only titanium but also niobium. Rocks containing niobium and uranium have been found at Potash Sulphur Springs, but little is known of the occurrence of these elements in that area.

The element niobium (columbium) is in demand for use in high-temperature and noncreep steels. It is commonly referred to as columbium in commerce and in older American technical literature, and as niobium in foreign and recent American technical literature. Titanium is in demand for use as TiO_2 in pigments, and as titanium metal in structural forms. Rutile (TiO_2) is used in welding-rod coatings.

PREVIOUS WORK

The Magnet Cove and Potash Sulphur Springs areas were first described in detail by Williams (1891) whose monograph on the igneous rocks of Arkansas still remains a classic of geologic literature. Additional petrographic data were contributed by Washington (1900, 1901) and more recently by Landes (1931) and Ross (1941). Williams described the various rare and unusual rocks and minerals in detail and presented chemical analyses. The presence of niobium in perovskite (dysanalite) was first reported by Mar (1890, p. 403).

Little geologic work was done on the rutile and brookite deposits until the work of Holbrook (1947) and Fryklund and Holbrook (1950), which depended in part on data made available by test pitting and by Bureau of Mines drilling (Reed, 1949a, b). This work has established the nature and approximate grade of the rutile and brookite deposits.

PRESENT WORK

As part of the U. S. Geological Survey's program of studying niobium resources, the rutile, brookite, and perovskite areas at Magnet Cove were studied, sampled, and in part mapped, in order to determine the approximate abundance and habit of the niobium. The Wilson prospect at Potash Sulphur Springs was also mapped and sampled. This work was done during February and March 1952, by V. C. Fryklund, Jr., H. L. Sobel, and E. P. Kaiser. Splits of samples from drill cores were obtained from the U. S. Bureau of Mines station at Rolla, Mo.; splits of channel samples from pits were obtained from the Division of Geology, Arkansas Resources and Development Commission. Spectrographic analyses were made by R. S. Harner, K. J. Murata, and R. G. Havens.

ACKNOWLEDGMENTS

The writers are indebted to the U. S. Bureau of Mines for a number of drill-hole samples of the Magnet Cove Titanium Corp. area and the Christy brookite property; to N. F. Williams, director of the Division of Geology, Arkansas Resources and Development Commission, for splits of samples taken by Fryklund on the Kilpatrick brookite property, for the use of a power auger, and for many other courtesies; and to Wynne Christy for samples from the Christy brookite property. It is a pleasure also to acknowledge the help of J. W. Kimsey and Lawton Kimsey of Magnet Cove. Part of the cost of this investigation was supported by funds for the columbium program from the Defense Minerals Procurement Agency.

METHODS OF SPECTROGRAPHIC ANALYSIS

The spectrographic analyses were made under the following conditions:

Excitation:	Ballasted d-c arc of 250 volts, run at 15.5 amperes. Arc gap maintained at 3.5 mm throughout the burning period. Arc image focussed on the collimator lens which was diaphragmed to permit only light from the central 2 mm of the arc column to pass through the prism. A rotating sector, set at 20 percent transmission, was used to reduce light intensity.
Spectrograph:	A large quartz prism instrument of the Littrow type. The region from 2520 to 3575 A was photographed.
Electrodes:	High-purity graphite rod, ¼-in. diameter, with thin-walled cavity as described by Myers (1951), used as the anode; a ⅛-in. high-purity graphite rod used as the cathode.
Plate:	Eastman III–0, developed at 20° C for 5 minutes in DK–50 developer.

Plate calibration: Method of Dieke and Crosswhite (1943). Iron lines present in spectra of a quartz-microcline mixture containing 1 percent Fe_2O_3 were used.

Microphotometer: Projection comparator-microphotometer employing a scanning slit at the plate.

Analysis lines	*Limit of detection in weight percent*	
	Element	*Oxide*
Nb 3163.40	0.01	----------
Nb 3194.98	.01	----------
Ti 3088.03	.001	0.002
Ti 3261.61	.05	.09
Ti 3299.41	.1	.2
V 3183.41	.002	.004
V 3183.98	.001	.002
La 3245.12	.02	----------
La 3337.49	.01	----------
La 4333.73	.003	----------
Y 3327.88	.002	----------

The line pair Nb 3163.40/Th 3124.39 was used for determining niobium in the single crystals of titanium minerals reported in tables 4, 6, and 9.

The analytical curves for the various elements were established by means of two sets of standards prepared by successive dilutions to contain 1.00, 0.464, 0.215, 0.100, 0.0464, 0.0215, . . . , 0.00100 percent niobium, vanadium, lanthanum, and yttrium. The titanium percentage was tenfold higher than that of the other elements in each step of the standards. The first set was prepared with a pure calcite matrix and was used in the analysis of samples from calcite veins. The second set was prepared in a pegmatite-base matrix consisting of 60 parts of quartz, 40 parts of microcline, and 1 part of Fe_2O_3, and was used for analyzing all other samples.

The samples were prepared by crushing, quartering, and grinding in agate mortars to pass 150-mesh silk bolting cloth. Single crystals were picked out of one quarter of the original sample and weighed before grinding.

The samples from calcite veins were arced without further preparation. All other samples, excepting the single crystals of titanium minerals, were diluted with equal weights of pegmatite base, and 25-milligram portions were arced to completion. The spectra of a few steps of the appropriate standard were put on each plate to correct for any shifts in the analytical curves.

If a sample was found in the initial analysis to contain a high concentration of any of the elements it was further diluted with calcite or pegmatite base and reanalyzed. This dilution made the composition of the sample approach that of the standard used in its analysis and improved the accuracy of the determination.

A separate pegmatite base containing 2 percent thorium (incorporated as ThO_2) was prepared for determining niobium in the single crystals of titanium minerals. The single crystals were diluted with 5 parts of this thorium pegmatite base and 4 parts of thorium-free pegmatite base so that the thorium was 1 percent of the sample. An internal standard was needed for the single crystal determinations because the crystals were frequently so small that 25-milligram portions were not available for analysis. Thorium was chosen for the internal standard element because it does not occur in appreciable percentages in the rocks and minerals analyzed and moving-plate studies showed that it has a volatilization rate similar to niobium.

Since the work reported in U. S. Geological Survey Circular 225 (Fleischer and others, 1952), additional checks on the spectrographic determination of niobium have been obtained by means of X-ray fluorescence analyses. These checks are listed below.

Mineral	*Sample no.*	*Analyses*	
		Spectrographic	*X-ray fluorescence*
Rutile	52–813a	2. 2	1. 70
Do	52–813b	1. 2	1. 16
Do	52–813c	1. 1	. 91
Brookite	52–718e	1. 9	2. 03
Bauxite	52–383	. 098	. 097
Do	52–390	. 072	. 084
Do	52–397	. 030	. 040
Do	52–409	. 020	. 014
Ilmenite	53–149	. 23	. 25
Do	53–151	. 14	. 17
Do	53–156	. 16	. 16
Do	53–157	. 11	. 12

It has not been possible to obtain checks on vanadium, lanthanum, and yttrium.

The analytical results for niobium, lanthanum, and yttrium are given as weight percentages of the elements. The analytical results for titanium and vanadium in many of the samples had previously been given as weight percentages of the oxides (Fryklund and Holbrook, 1950) so this mode of reporting has been retained for these two elements in order to facilitate comparison with previous results. The only exception is in table 11, where the semiquantitative results for titanium are reported in terms of the element.

MAGNET COVE AREA

DESCRIPTION OF TITANIUM-NIOBIUM DEPOSITS

GENERAL

Niobium and titanium occur together at Magnet Cove, and in fact all the niobium of possible economic interest occurs as part of the crystal structure of titanium minerals. The two elements are, therefore, described together.

The titanium-niobium deposits of Magnet Cove (pl. 6) consists chiefly of rutile and brookite deposits. The only known large deposit of rutile is on the property of the Magnet Cove Titanium Corp., which also includes unexplored areas where rutile is locally abundant in the soil. The major brookite deposits are on the Christy property and the Kilpatrick property. Other areas of rutile and brookite float are shown on plate 6.

Rutile-brookite-feldspar veins and molybdenite veins cut perovskite-bearing magnetite-pyroxene rock on the Mo-Ti Corp. property. Although none of these rocks crop out, they were studied in drill core. Because some of the perovskite in Magnet Cove contains as much as 8.8 percent niobium, the perovskite-bearing calcite rock and perovskite syenites are of interest and were studied during the current work.

MAGNET COVE TITANIUM CORPORATION RUTILE DEPOSIT

Location and extent.—The Magnet Cove Titanium Corp. deposit, the only major rutile deposit known in the area, is mainly in the east-central part of sec. 18, T. 3 S., R. 17 W., about three-quarters of a mile north of U. S. Highway 270 (pl. 6). The property was controlled by C. H. Scott of Denver, Colo. in 1952. About 5,188 short tons of rutile concentrates were recovered from this property between 1931 and 1944. The mill has since been dismantled.

The deposit has been described by Ross (1941) and Fryklund and Holbrook (1950). U. S. Bureau of Mines drilling projects have been described by Spencer (1946) and Reed (1949a). The main deposit (fig. 3) has been partly exposed in two shallow open pits. Information from outcrops and drill holes indicates that the known deposit has a long axis striking east and is about 2500 feet long and up to 800 feet wide. The deposit has been proved to a depth of 188 feet by drilling. In an area about one-half mile southwest of the open pits, old shallow workings can be seen, and rutile is locally abundant in the soil.

Former mining operations utilized the weathered material in which some residual concentration had occurred. Most of this material has been removed. All drilling has been done in the vicinity of the open pits (fig. 3). The U. S. Bureau of Mines sank 16 churn-drill holes in 1945 and 27 core-drill holes in 1948. For the results of sampling and analyses see pages 32 and 33.

Character of the deposit.—The bedrock consists of igneous rock, chiefly nepheline syenite of several types, cut by veins and irregular bodies of feldspar-carbonate rock. The most common igneous rock is aegirine-nepheline syenite porphyry, which contains scattered inclusions of various igneous and metamorphic rocks. Inclusions of igneous breccia are described by Fryklund and Holbrook (1950, p. 22) and are similar to those in Conway and Perry Counties, Ark., described by

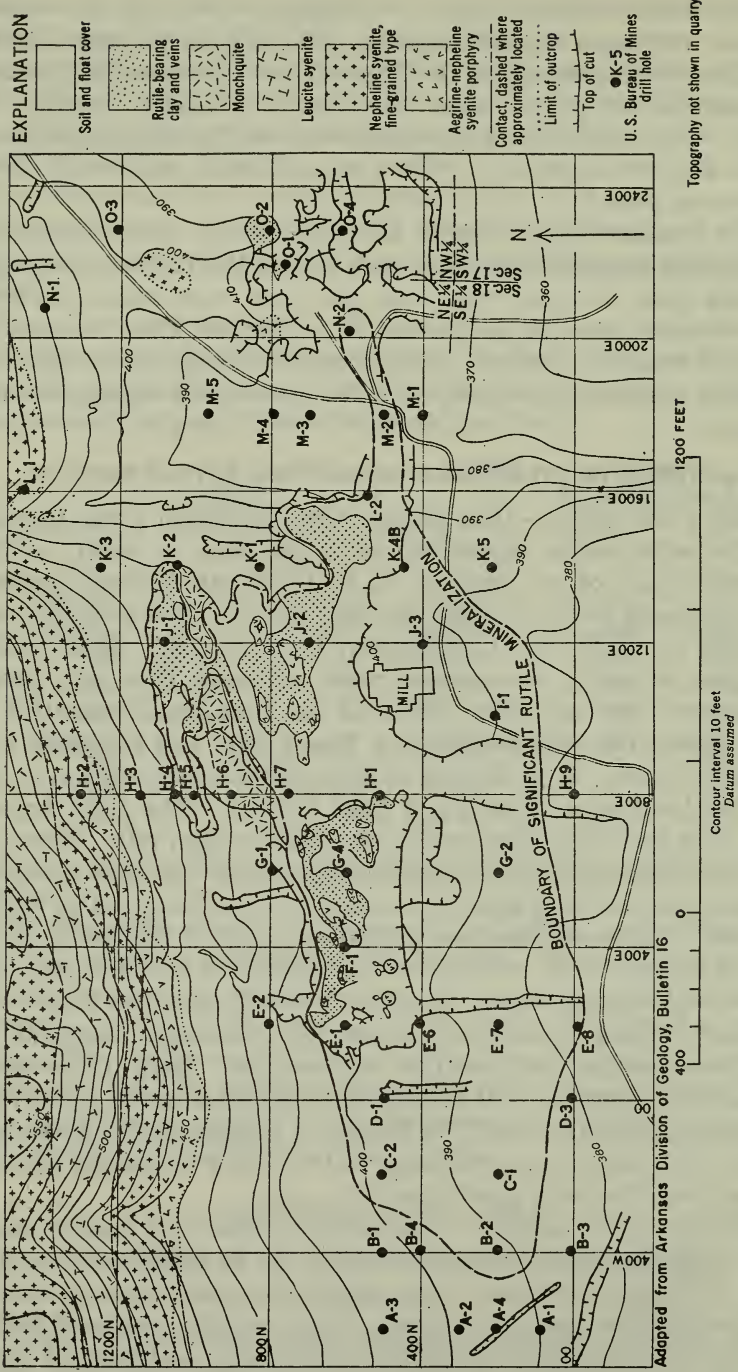


FIGURE 3.—Geologic and topographic map of the Magnet Cove Titanium Corp. deposit, Hot Spring County, showing the location of the U. S. Bureau of Mines drill holes.

Croneis (1930, p. 155–161). The igneous rocks and their characteristic minerals are listed in table 1.

TABLE 1.—*Characteristic minerals of the igneous rocks, Magnet Cove Titanium Corp., Magnet Cove, Ark.*

[For descriptions of rock types see Fryklund and Holbrook, 1950, p. 16–25]

Rock type	Minerals		
	Feldspar	Feldspathoid	Ferromagnesian
Aegirine-nepheline syenite porphyry.	Orthoclase	Nepheline	Aegirine.
Nepheline syenite (fine-grained type).	do	Nepheline, cancrinite	Diopside, aegirine.
Nepheline syenite (Diamond Jo type).	do	do	Do.
Leucite-nepheline syenite	do	Nepheline	Aegirine.
Nepheline tinguaite dikes	do	do	Do.
Monchiquite dikes	Plagioclase	Analcime(?)	Titanaugite, barkevikite, biotite, olivine(?).
Fourchite dikes		do	Titanaugite.
Amphibole fourchite dikes		do	Titanaugite, barkevikite.

In the main deposit the rutile occurs in feldspar-carbonate veins of several types that cut the igneous rocks and constitute 50–75 percent of the deposit. For a detailed description the reader is referred to Fryklund and Holbrook (1950, p. 26–35). The veins are tabulated according to constituents and rutile content in table 2.

TABLE 2.—*Primary constituents of veins in the Magnet Cove Titanium Corp. deposit*

Vein name	Constituents	Average grain size (millimeters)	Rutile content
Coarse-grained biotite-apatite-calcite.	Coarse calcite, apatite, green biotite	2–12	Absent.
Sugary-textured albite-dolomite.	Euhedral albite, euhedral dolomite, pyrite, apatite, molybdenite.	0.5 .5	Up to 5 percent.
Microcline-calcite	Microcline, calcite, albite, apatite, sphene, pyrite.	.04 .5–1.0 5–20	1–2 percent.
Albite-ankerite	Albite, ankerite, pyrite	1 1	Very abundant, large masses.
Coarse-grained albite-perthite-carbonate.	Albite, microcline, perthite, carbonate (leached) quartz.	2 2 2	Less than 1 percent.
Calcite-rutile	Calcite, albite	5 .5	Very abundant, disseminated in calcite.

The rutile occurs as single grains, aggregates of acicular grains, and as veins. The maximum length of acicular rutile crystals is 0.5 millimeter; the average length is 0.1 millimeter, but some are barely visible at 360 diameters magnification. Probably 15 to 20 percent of the TiO_2 in the carbonate veins is in the form of leucoxene.

Sampling and analysis.—The location of drill holes in the vicinity of the open pits is shown on figure 3. The results of analyses of the cores for TiO_2 and V_2O_5 by the U. S. Bureau of Mines are discussed and tabulated in Fryklund and Holbrook (1950, p. 39–40, 82–130). Splits of 38 samples of cores from 18 drill holes were obtained in 1952 from the U. S. Bureau of Mines at Rolla, Mo. These splits were analyzed spectrographically for niobium, TiO_2, V_2O_5, yttrium, and lanthanum (table 3).

TABLE 3.—*Analyses of samples from the Magnet Cove Titanium Corp. property, Magnet Cove, Ark.*

[Spectrographic analyses by K. J. Murata; chemical analyses by Bureau of Mines (Reed, 1949b). Rock type, Fryklund and Holbrook (1950). Leaders indicate item not looked for; zero indicates item looked for but not found at limit of sensitivity (Nb, 0.01; Y, 0.002; La, 0.003)]

Drill hole no. (fig. 3)	Depth (feet)	Laboratory no.	Sample no.	Nb	TiO_2		V_2O_5		Y	La	Rock type
					Spectrographic	Chemical	Spectrographic	Chemical			
B-2	91-95	52-782SW	1333	0.039	4.3	4.95	0.065	0.11	0.008	0.009	Albite-dolomite vein.
B-2	110-115	52-783SW	1337	.028	1.1	1.70	.042	.19	.025	.15	Calcite-rutile vein.
B-3	27-34	52-784SW	1758	.036	2.4	2.65	.086	----------	.014	.054	Albite-dolomite vein.
B-3	73-79	52-785SW	1765	.021	1.2	1.05	.025	----------	.008	.029	Calcite and feldspar-carbonate veins.
BCC-1	54-60	52-789SW	1557	.009	1.1	----------	.028	----------	.020	.070	Microcline-calcite vein.
BCC-2	30-36	52-786SW	1553	.022	2.6	----------	.098	----------	.006	.012	Syenite porphyry.
BCC-2	73-80	52-787SW	1560	.12	9.5	----------	.091	----------	.013	.008	Albite-dolomite vein.
BCC-2	80-86	52-788SW	1561	.026	1.7	----------	.032	----------	.011	.006	Do.
D-1	21-24	52-770SW	1633	.021	3.2	2.50	.13	.11	0	.029	Do.
E-7	48-49.8	52-790SW	1396	.041	2.7	3.20	.13	.05	.013	.033	Feldspar-carbonate vein.
E-7	49.8-52	52-791SW	1397	.039	2.0	2.70	.072	.10	.010	.030	Do.
E-7	73-76.5	52-792SW	1405	.015	1.2	1.35	.070	.18	.004	.031	Do.
E-7	108.2-111.4	52-793SW	1418	.021	1.3	2.30	.048	.08	.004	.027	Microcline-calcite vein.
F-1	10.7-19.4	52-794SW	1716	.020	1.3	1.10	.030	----------	.014	.039	Albite-dolomite vein.
F-1	110.4-120.1	52-795SW	1727	.023	1.5	1.55	.021	----------	.016	.020	Microcline-calcite vein.
G-2	53-56	52-798SW	1218	.014	1.4	1.73	.071	.05	.022	.078	Albite-dolomite vein.
G-2	56-58	52-796SW	1219	.042	2.4	2.90	.066	.07	.011	.068	Do.
G-2	115-118	52-797SW	1234	.022	2.6	2.30	.085	.05	.012	.042	Do.
G-4	135.8-145	52-799SW	1816	.037	4.1	3.78	.052	.08	.014	.055	Do.
I-1	20-26	52-800SW	1189	.013	1.2	.88	.098	.07	.006	.11	Do.
I-1	36-40	52-801SW	1192	.012	1.3	2.35	.033	.05	.010	.006	Do.
I-1	67-72	52-802SW	1200	.014	1.0	1.15	.022	.05	.004	.005	Do.
J-1	32.5-35.9	52-803SW	1911	.026	3.3	3.14	.14	.09	.008	.009	Syenite porphyry.
J-2	31.8-39.4	52-804SW	1846	.026	2.1	2.38	.024	.07	.017	.068	Albite-dolomite vein
J-3	33-39	52-805SW	1865	.012	1.2	1.00	.030	.08	.006	.018	Do.
J-3	75-82	52-806SW	1872	.019	2.9	2.62	.11	.08	.008	.013	Syenite porphyry.
J-3	96-103	52-807SW	1875	.016	1.7	1.82	.064	.09	.011	.51	Albite-dolomite vein.
J-3	103-109	52-808SW	1876	.029	2.7	3.04	.10	.09	.008	.047	Syenite porphyry.
K-5	24-29	52-809SW	1491	.016	2.4	2.40	.18	.15	.008	.016	Do.
K-5	57.5-67	52-810SW	1496	0	.02	.25	.005	.07	.004	.006	Biotite-calcite vein.
L-2	14-21	52-811SW	1965	.062	2.6	3.08	.039	.08	.007	.11	Albite-dolomite vein.
L-2	21-28	52-761SW	1966	.075	3.7	3.56	.057	.07	.009	.18	Do.
M-5	54-61	52-762SW	1885	.009	.51	.49	.012	.08	.31	.041	Do.
O-2	9.5-11.7	52-763SW	1289	.020	2.9	3.26	.47	.19	.010	.014	Microcline-calcite vein.
O-2	27.1-29.1	52-764SW	1296	.071	4.2	5.35	.030	.07	.014	.029	Do.
O-2	29.1-34.1	52-765SW	1297	.048	2.9	2.67	.025	.05	.020	.064	Do.
O-2	49.1-52.3	52-766SW	1301	.040	3.0	3.25	.031	.15	.012	.011	Do.
O-3	23-26.5	52-767SW	1347	.025	.64	.70	.063	.11	0	.005	Diamond Jo type nepheline syenite.
O-3	34.3-35.2	52-768SW	1352	.026	1.2	.95	.013	.09	0	0	Albite-perthite-carbonate vein.
O-3	59.5-64.5	52-769SW	1365	.034	.97	1.15	.053	.05	0	.011	Fine-grained nepheline syenite.

The original core samples were divided according to the length of core pulled, rather than according to lithology, partly to permit correlation of core and sludge analyses. The igneous rocks contain from 2 to 5 percent TiO_2 in rutile, ilmenite, and silicates, probably unrecoverable by milling. In the common case, therefore, where a sample includes both igneous rock and vein, the analysis cannot be interpreted directly and quantitatively. Adjustment of analytical figures on the basis of type of material indicates that in the main deposit about 3 percent TiO_2 is present in recoverable form. Calculation of average grade of niobium likewise cannot be done directly, but a similar adjustment indicates that the deposit contains about 0.04 percent niobium in recoverable form.

The relation between niobium and titania in the samples is shown graphically in figure 4. The scattering of the points may be due partly to the mixed material analyzed. A more important reason is indicated in table 4, which shows the results of the analyses of rutile concentrates and single crystals. The single crystals of rutile from the west pit range from 0.4 to 1.7 percent niobium; those from the float area one-half mile southwest of the pits range from 0.00 to 1.4 percent niobium. This variation is probably sufficient to explain the scattering shown in figure 4. Table 4 also contains analyses of two composite samples of rutile, 814–e and 815–f, and analyses of rutile concentrates. These analyses indicate that the average niobium content of rutile concentrates is about 1.2±0.2 percent niobium.

TABLE 4.—*Spectrographic analyses of rutile crystals and rutile concentrates from the Magnet Cove Titanium Corp. property, Magnet Cove, Ark.*

[R. S. Harner, analyst, except where noted. Leaders indicate item not looked for; zero indicates item looked for but not found at limit of sensitivity (Nb, 0.01; Y, 0.002; La, 0.003)]

Laboratory no.	Description	Nb	V_2O_5	Y	La
52–814SM	Rutile crystals from west pit:				
	Single-crystal samples:				
a	52 mg	1.3	0.52	--------	--------
b	20 mg	.4	.071	--------	--------
c	12 mg	1.7	.30	--------	--------
d	8 mg	1.7	.30	--------	--------
e	Composite sample, several grams	1.4	.54	0	0
52–815SM	Rutile crystals from surface, ½ mile southwest of west pit:				
	Single-crystal samples:				
a	40 mg	1.2	.71	--------	--------
b	27 mg	1.4	.071	--------	--------
c	21 mg	1.4	.071	--------	--------
d	11 mg	0	.073	--------	--------
e	8 mg	1.2	.41	--------	--------
f	Composite sample, several grams	1.0	.80	0	0
[1] 51-1385S	Rutile concentrate from old mill	1.3	--------	--------	--------
52–813SM	Rutile concentrate from old mill, separated on Frantz separator:				
a	Most magnetic fraction	2.2	1.5	0	0
b	Intermediate fraction	1.2	.29	0	0
c	Least magnetic fraction	1.1	.17	0	0
d	Dust from sample	1.6	.43	0	0

---

[1] H. J. Rose, Jr., analyst.

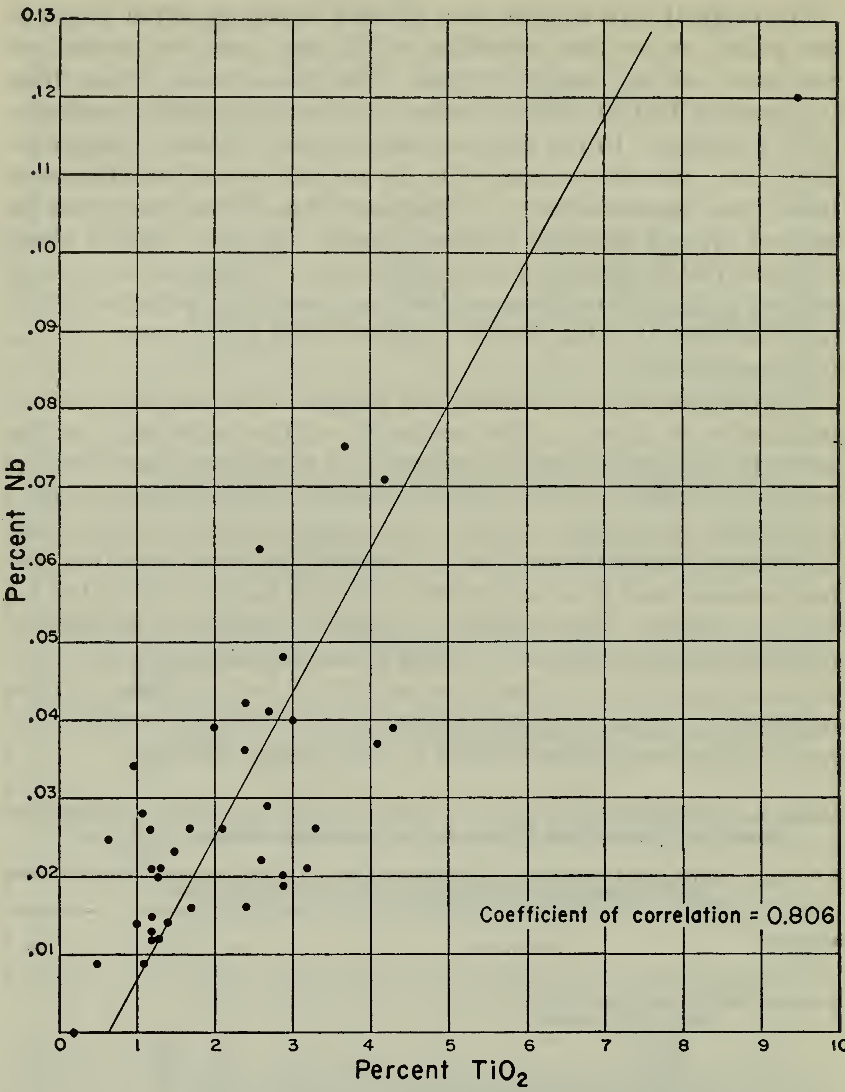


FIGURE 4.—Correlation of niobium and TiO_2, Magnet Titanium Corp. property, Magnet Cove.

Vanadium content in the single crystals ranges from 0.071 to 0.71 percent and it is not surprising that the vanadium content of the drill-core samples is also erratic. The lanthanum and yttrium are probably in the apatite.

CHRISTY BROOKITE DEPOSIT

Location, geology, and extent.—The Christy deposit is near the eastern margin of Magnet Cove. It is about one-half mile north of the town of Magnet, in the SW¼SW¼ sec. 16, T. 3 S., R. 17 W. (pl. 6). The property was owned in 1952 by the Malvern Lumber Co. of Malvern, Ark., and has been described by Holbrook (1947), Reed (1949b), and Fryklund and Holbrook (1950).

The deposit (fig. 5) contains primary brookite-bearing rock and enriched residual material. The primary deposit is in quartzite of the Arkansas novaculite of Devonian and Mississippian age. The primary deposit extends about 420 feet north-south and about 900 feet east-west, and has been proved to a depth of 130 feet by drilling. Residual material has crept downslope from the primary deposit and forms a deposit about 900 feet long and at least 550 feet wide. The maximum thickness of the residual material is about 20 feet.

Character of the deposit.—The primary material, as seen in drill core, is composed of brookite-bearing dark quartzite, separated by clay layers containing little or no brookite. The brookite grains average less than 0.5 millimeter in diameter and are rarely visible megascopically. In thin sections the quartz grains range from 0.05 millimeter to slightly more than 1 millimeter in diameter. The dark color of the rock is due to the brookite, to abundant very fine-grained acicular rutile needles, and to altered taeniolite, a rare magnesian lithium mica containing a small proportion of titanium as an essential constituent (Miser and Stevens, 1938). Rutile inclusions in brookite show that the rutile formed earlier. In thin sections brookite occurs in quantities ranging from a few grains to 10 percent.

The residual material consists of porous quartzite fragments, quartz crystals, brookite crystals, and sand-sized material in a matrix of red clay. The dark quartzite forms at least one-third of the residual material. The largest brookite crystals of the deposit, some of which reach a diameter of 6 or 7 millimeters, are within or attached to quartz crystals.

No production from this deposit has been recorded. Exploration work has consisted of test pits financed by the Reconstruction Finance Corp. in 1944 and of 21 core- and bucket-drill holes put down by the U. S. Bureau of Mines in 1948.

Sampling and analysis.—The location of drill holes and test pits is shown in figure 4. The results of analyses by the U. S. Bureau of Mines of drill-core samples are discussed and tabulated in Fryklund and Holbrook (1950, p. 63, 131–151).

Splits of 5 samples from drill cores, and 29 samples of residual material from test pits, were analyzed for niobium, TiO_2, V_2O_5, and yttrium; the results are shown in table 5.

Calculations on the basis of the Bureau of Mines figures give an average grade of 5.9 percent TiO_2. Part of this is present in fine-grained rutile, leucoxene, and taeniolite, and therefore is probably not recoverable.

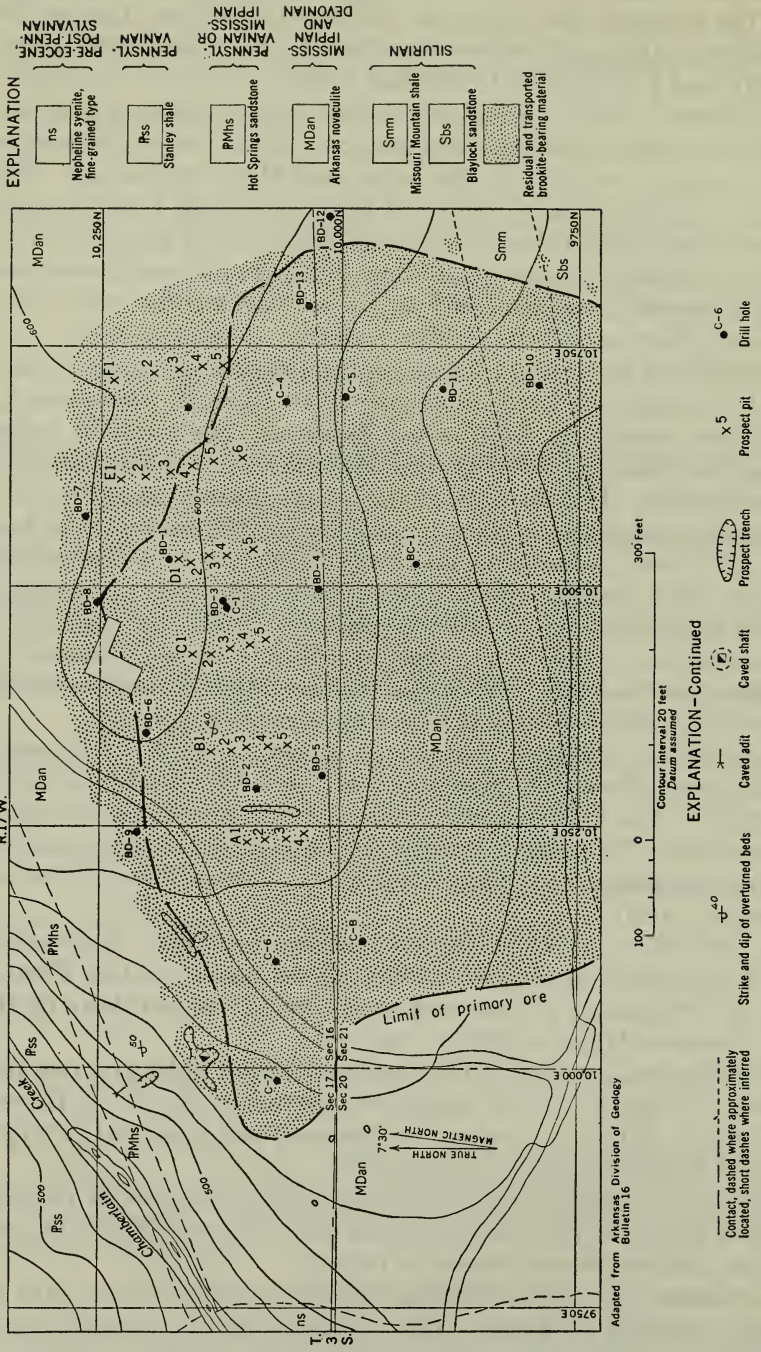


FIGURE 5.—Geologic and topographic map of the Christy brookite deposits, Hot Spring County, showing the location of drill holes and pits.

TABLE 5.—*Analyses of samples from the Christy property, Magnet Cove, Ark.*

[Spectrographic analyses by R. S. Harner; chemical analyses by Bureau of Mines (Reed, 1949a). Zero indicates element looked for but not found at limit of sensitivity (Nb, 0.01; Y, 0.002). Lanthanum content less than 0.005 percent in all samples]

Pit no. (fig. 5)	Laboratory no.	Nb	TiO_2	V_2O_5	Y
Pit Samples					
A-1	52-694SW	0.32	13	0.55	0
A-2	52-695SW	.060	8.0	.29	0
A-3	52-696SW	.15	9.7	1.8	.016
A-4	52-719SW	.072	6.3	.50	.016
B-1	52-697SW	.032	2.1	.079	.014
B-2	52-698SW	.042	11	.29	.028
B-3	52-699SW	.096	7.2	.40	0
B-4	52-700SW	.086	6.7	.54	0
B-5	52-720SW	.040	5.0	.34	0
C-1	52-701SW	.058	7.7	.54	0
C-2	52-703SW	.20	12	1.0	.012
C-3	52-702SW	.080	7.3	.43	0
C-4	52-704SW	.050	5.7	.36	0
C-5	52-705SW	.15	12	1.3	0
D-1	52-706SW	.026	6.3	.82	0
D-2	52-707SW	.086	8.0	.43	.011
D-3	52-708SW	.042	9.7	.43	.016
D-4	52-709SW	.092	7.7	.29	.016
D-5	52-710SW	.028	4.0	.28	.022
E-2	52-711SW	.20	12	.15	.016
E-3	52-712SW	.086	9.7	.21	.015
E-4	52-713SW	.24	10	.55	.013
E-5	52-714SW	.40	18	.89	.018
E-6	52-721SW	.072	9.7	.36	.013
F-1	52-715SW	.20	9.7	.26	0
F-2	52-722SW	.21	12	.85	.014
F-3	52-723SW	.086	6.3	.21	.016
F-4	52-716SW	.030	3.3	.32	.019
F-5	52-717SW	0	2.0	.33	.026

Drill Samples

Drill hole no. (fig. 5)	Depth (feet)	Laboratory no.	Sample no.	Nb	TiO_2		V_2O_5		Y
					Spectrographic	Chemical	Spectrographic	Chemical	
C-4	77.5-80.5	52-727SW	419	0.18	10	10.70	0.53	0.81	0.040
C-4	103-106	52-728SW	427	.20	11	6.72	.20	.31	.14
C-8	63.5-66	52-724SW	1012	.088	4.4	3.83	.38	.52	.024
C-8	85-86.5	52-725SW	1018	.45	23	26.30	.25	.38	0
C-8	100.5-102.5	52-726SW	1025	.33	11	12.25	.30	.42	0

The correlation of niobium and TiO_2 is shown graphically in figure 6. The lack of good correlation is explained at least in part by the data given in table 6. The single crystals range from 0.80 to 9.6 percent niobium. The analyses of composite brookite samples indicate that the average niobium content of brookite concentrates is about 2 percent niobium.

The lanthanum and yttrium are probably in the apatite. The vanadium content varies greatly. The following analysis shows that at least part of the vanadium is present in brookite:

Analysis of brookite crystal from Christy property

[Lee C. Peck, analyst, Rock Analysis Laboratory, University of Minnesota]

Constituent	*Percent*
Fe_2O_3	1.13
TiO_2	98.25
V_2O_5	.41
Total	99.79

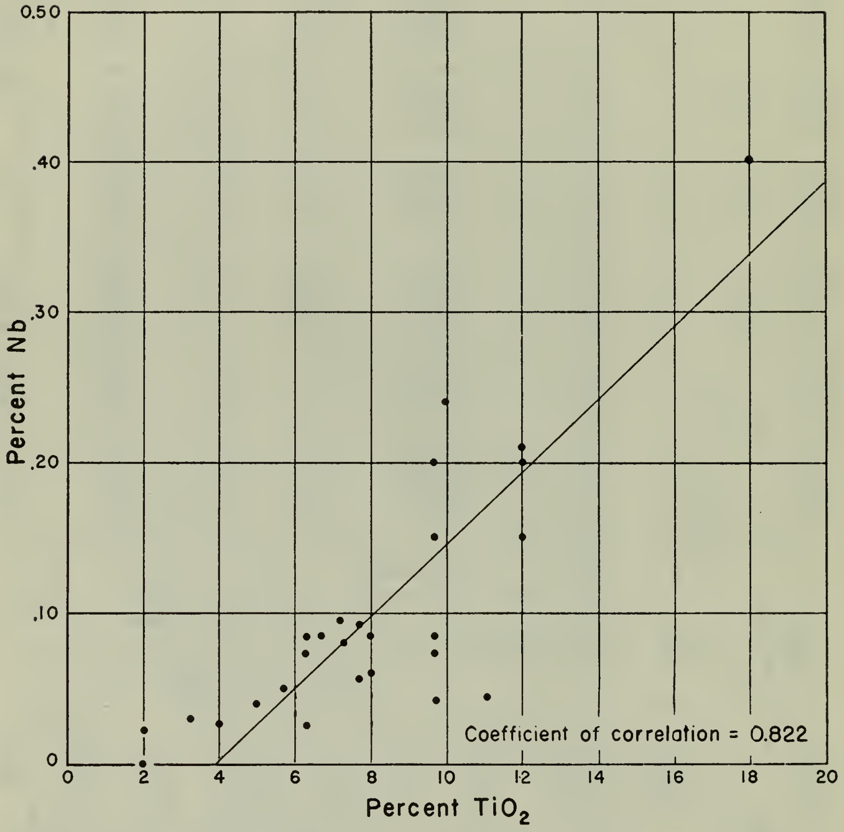


FIGURE 6.—Correlation of niobium and TiO_2, Christy brookite property, Magnet Cove.

KILPATRICK BROOKITE DEPOSITS

General.—The Kilpatrick deposits are in secs. 16 and 17, T. 3 S., R. 17 W., 1 mile north of the town of Magnet (pl. 6). The deposits have been described by Ross (1941) and Fryklund and Holbrook (1950). They have been known in the literature as the Hardy-Walsh deposits, but in 1952 they were owned by the estate of William Kilpatrick.

TABLE 6.—*Analyses of brookite crystals and composite samples of brookite from the Christy property, Magnet Cove, Ark.*

[Spectrographic analyses by R. S. Harner, except where noted. Leaders indicate item not looked for; zero indicates item looked for but not found at limit of sensitivity (La, 0.003)]

Laboratory no.	Description	Nb	V_2O_5	Y	La
52-718SM	Small brookite crystals from surface:				
a	Single crystal	0.80	--------	--------	--------
b	do	2.3	--------	--------	--------
c	do	4.4	--------	--------	--------
d	do	9.6	--------	--------	--------
e	Composite sample	1.9	0.58	0.002	0
IWS-254	Composite sample of brookite:				
	Spectrographic analysis[1]	2.4±0.3	--------	--------	--------
	Colorimetric analysis[2]	2.7	--------	--------	--------

[1] By K. J. Murata and E. L. Hufschmidt.
[2] By J. I. Dinnin.

The deposits are exposed on a ridge of Arkansas novaculite of Devonian and Mississippian age, at the eastern edge of the cove. Igneous rocks of several types crop out a few hundred feet north of the deposit. The ridge consists of several knobs and saddles (fig. 7). The knobs consist of novaculite with small quantities of brookite, chiefly exposed in shallow trenches. The saddles are underlain by residual material whose depth is not known. The eastern saddle contains the largest residual deposit, which is at least 450 feet long and 200–300 feet wide. The primary deposit is in quartzite of the Arkansas novaculite. The material of the primary and residual deposits is similar to that in the Christy deposit.

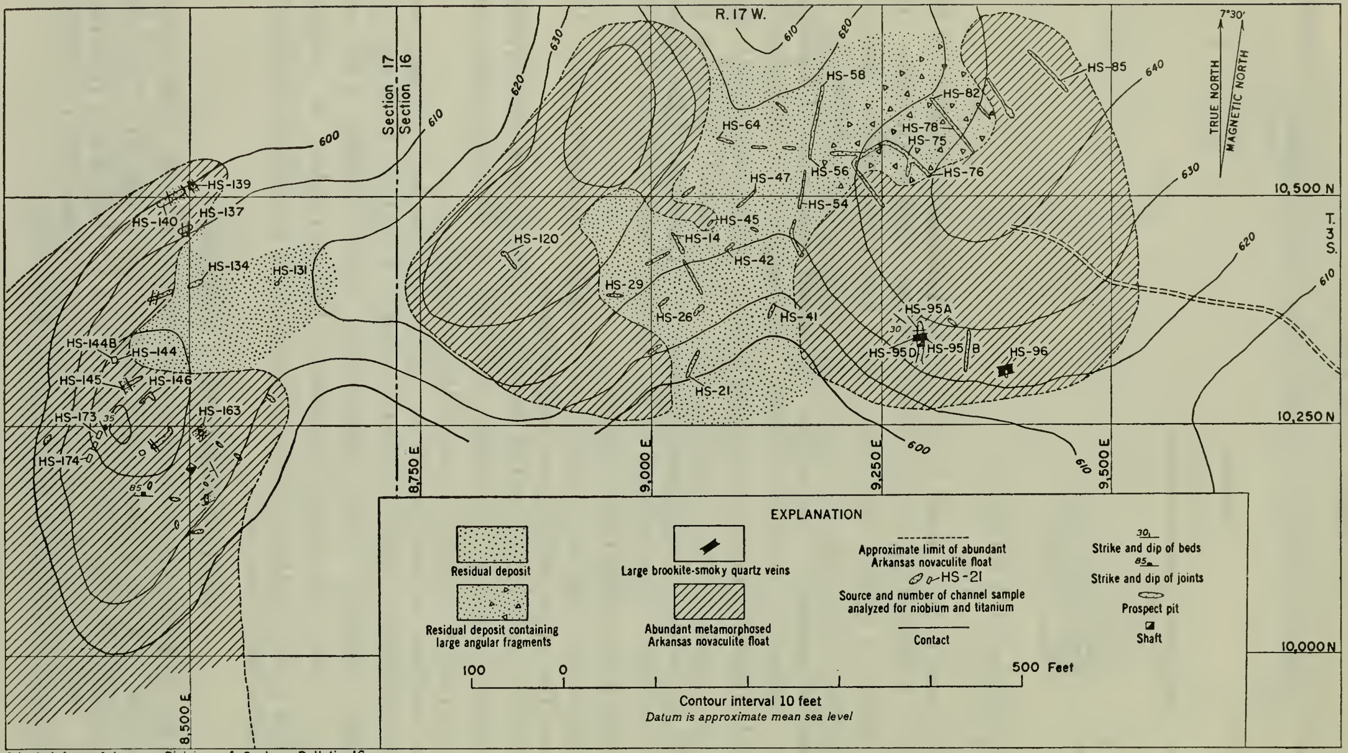
Exploration work has consisted of test pits and auger holes. The results of the auger drilling are not available.

Sampling and analysis.—The locations of test pits and the results of analyses by the U. S. Bureau of Mines of channel samples are shown on plate 4 of Fryklund and Holbrook (1950).

The locations of test pits from which samples for niobium were taken are shown in figure 5, and the results of analyses of 33 samples are given in table 7. The average grade of the samples is 5.9 percent TiO_2 and 0.06 percent niobium. The correlation of niobium and TiO_2 is shown graphically in figure 8. No analysis of crystals or concentrate have been made.

MO-TI CORPORATION PROPERTY

The Mo-Ti Corp. prospect pit is in sec. 17, T. 3 S., R. 17 W., on the south bank of Cove Creek within Magnet Cove (pl. 6). The area has been described by Holbrook (1948) and Fryklund and Holbrook (1950). The pit was flooded in 1952, but drill-core obtained during a drilling program in 1947 was studied in Fryklund.



Adopted from Arkansas Division of Geology, Bulletin 16

FIGURE 7.—Geologic and topographic map of the Kilpatrick brookite deposits, showing sources of samples analyzed for niobium.

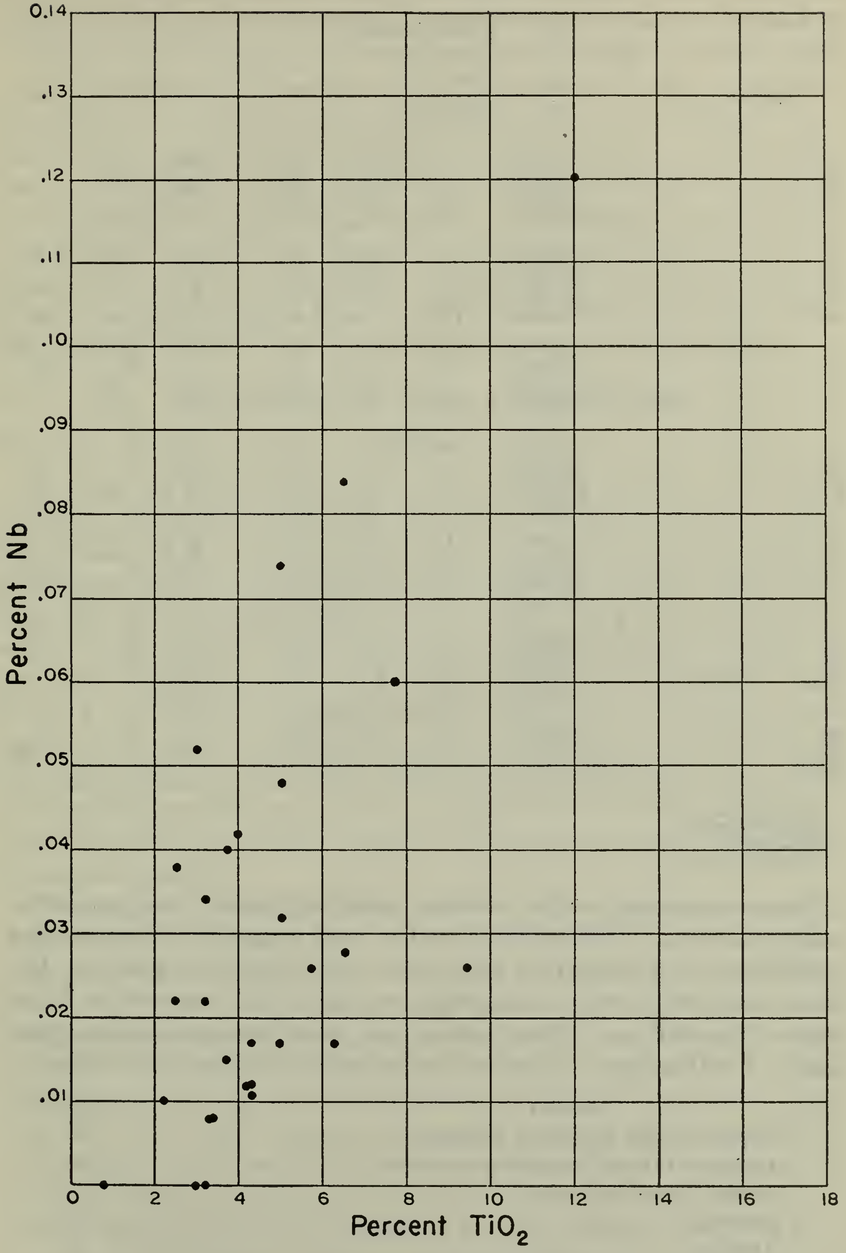


FIGURE 8.—Correlation of niobium and TiO_2, Kilpatrick property, Magnet Cove.

TABLE 7.—*Spectrographic analyses of samples from the Kilpatrick property, Magnet Cove, Ark.*

[R. S. Harner, analyst. Zero indicates element looked for but not found at limit of sensitivity (Nb, 0.01; Y, 0.002, La, 0.003)]

Location (fig. 7)	Laboratory no.	Length of channel (feet)	Nb	TiO_2	V_2O_5	Y	La
14	52–757SW	5.0	0.008	3.3	0.092	0	0.009
21	52–729SW	1.7	.028	6.5	.15	0.009	0
26	52–762SW	10.0	.017	6.3	.015	0	.026
29	52–730SW	5.0	.017	4.3	.14	0	0
41	52–731SW	14.0	.032	5.0	.13	.007	0
42	52–732SW	7.0	.026	5.7	.15	.004	0
45	52–733SW	(1)	.052	3.0	.21	0	0
47	52–758SW	7.0	.048	5.0	.21	0	0
54	52–759SW	8.0	.011	4.3	.14	0	.040
56	52–734SW	14.0	.026	9.4	.17	.004	0
58	52–735SW	9.0	.008	3.3	.053	0	.028
64	52–736SW	3.0	.012	4.3	.14	0	0
75	52–737SW	7.0	.040	3.7	.39	.017	0
76	52–760SW	4.0	.012	4.3	.21	.034	.076
78	52–738SW	6.0	.20	14	.27	0	0
82	52–761SW	5.0	.27	9.0	.16	0	.040
85	52–739SW	(2)	0	.082	.034	0	0
95A	52–740SW	6.5	.084	6.5	.21	0	0
95B	52–741SW	6.0	.074	5.0	.23	.030	0
95D	52–742SW	(3)	.12	12.0	.39	0	0
96	52–743SW	4.0	.022	3.2	.39	0	.019
120	52–744SW	3.0	.060	7.7	.29	.026	0
131	52–746SW	4.0	.12	37	.34	0	0
134	52–747SW	3.0	.042	4.0	.61	.011	.003
137	52–748SW	3.0	.010	2.2	.32	0	.003
139	52–749SW	6.0	.022	2.5	.20	0	0
140	52–750SW	4.0	.017	5.0	.36	0	.004
144	52–751SW	5.0	.46	20	.27	0	0
144B	52–752SW	6.0	0	3.2	.082	0	.004
145	52–753SW	6.0	.034	3.2	.25	0	.003
146	52–754SW	10.0	.32	12.0	.32	0	0
163	52–755SW	7.0	0	3.0	.19	0	.004
173–174	52–756SW	[4] 12.0	.038	2.5	.39	0	.003

[1] Grab sample.
[2] Quartzite sample.
[3] Chip sample.
[4] Composite sample.

Veins containing rutile, brookite, and molybdenite cut pyroxene-magnetite rock. The results of earlier work suggest that mineralized and altered rock underlie a large area now covered by gravels. Pyroxene-magnetite rock containing nepheline and perovskite forms most of the drill core. The rock is dark green with a maximum grain size of 4 millimeters. The mode of one thin section is as follows:

Mineral	*Percent*
Nepheline and alteration products	7
Diopside (?) and alteration products	58
Biotite, mainly primary	6
Magnetite	16
Apatite	4
Perovskite	8
Others, mainly garnet and sphene	1
Total	100

The pyroxene is light yellow in color and pleochroic; $X\wedge c=52^\circ$; the extinction is anomalous and similar to the titanaugite of the area. In other thin sections the perovskite content ranges from 5 to 8 percent.

According to Johannsen's classification the rock is a perovskite melteigite, 3125P (Johannsen, 1938, v. 4, p. 327). It was included in the "eleolite syenite" group by Williams (1891, p. 188–189).

Perovskite-pyroxene-magnetite rock has been seen in drill cores from this property, but no outcrops were found. In three thin sections the perovskite content ranged from 5 to 8 percent. Material for analysis was drilled from one grain of perovskite in a thin section; it contained 0.56 percent niobium. Assuming that this is an average figure, the rock contains 0.03 to 0.04 percent niobium in perovskite. No analyses of brookite or rutile-bearing material have been made.

DESCRIPTION OF CALCITE ROCK BODIES

GENERAL

At several places in the cove the bedrock consists of coarse-grained calcite with scattered accessory minerals. The accessory minerals include perovskite that contains as much as 8.8 percent niobium. Rocks of this type and of doubtful sedimentary origin have been called "carbonatite" (Daly, 1933, p. 564) and have been found to contain appreciable concentrations of niobium in other localities.

Plate 6 shows the location of known bodies and the probable location of other bodies of coarse-grained calcite rock at Magnet Cove. Rock of this type is especially well exposed in and near the Kimsey quarry, which is on the west side of Cove Creek and on the north side of Highway 270 (see pl. 6). To the north of the Kimsey quarry, coarse-grained calcite rock crops out in two areas along Cove Creek, as shown in plate 6.

Power-auger drilling showed that the hill north of the quarry and west of Cove Creek (labelled "west tufa hill" on plate 6) is underlain by residual clay to the level of the surrounding gentle slopes. The surface of the hill is littered with boulders of cellular iron-stained apatite-rich material which was called "tufa" by Williams (1891, p. 183). Gradation from "tufaceous" material to calcite rock, which can be seen in the outcrop at the northwest corner of the quarry, indicates that the "tufa" is derived from the calcite rock by weathering. The "tufa" can, therefore, be used as evidence for the occurrence of coarse calcite in underlying bedrock. On this basis the hill west of Cove Creek and the hill north of the church, labelled "east tufa hill" on plate 6, are inferred to be underlain at least partly by coarse calcite rock. On "east tufa hill" the "tufa" float is not abundant and is accompanied by boulders of bleached igneous rock. A power-auger hole at the crest of the hill penetrated 40 feet of clay, to the limit of available drill pipe. The hill is only about 40 feet above the surrounding flat.

The hill labelled "middle tufa hill" on plate 6 has relatively few float boulders; most of them are igneous rock and quartzite, and a few are "tufa". On the flat south of the hill the soil contains abundant magnetite and some apatite and perovskite. A power auger struck rock at 20 feet and brought up fragments of apatite. The bedrock is probably at least partly calcite rock.

Calcite rock crops out near the Baptist Church about 3500 feet southeast of the Kimsey quarry (pl. 6). According to J. W. Kimsey, a well near the church penetrated about 50 feet of calcite rock. In the field on the southern side of the highway, south of the calcite quarry, abundant perovskite in the soil indicates that calcite rock forms part or all of the underlying bedrock. This area is called "perovskite hill" in the older reports and on plate 6.

In addition to the areas just described, the southwestern part of the area near the pits on the Magnet Cove Titanium Corp. property (pl. 6) is underlain in considerable part by calcite rock. One drill hole penetrated calcite rock to a depth of 161 feet. A water well, said to be about 90 feet deep, in the northwest corner of sec. 19 (pl. 6), penetrated calcite rock. There is no outcrop in the vicinity, but rutile is locally abundant in the soil. These data indicate that the total area underlain by calcite rock is very large.

KIMSEY CALCITE QUARRY AREA

General geology.—The Kimsey quarry area was mapped and studied in detail because of the presence of niobium-bearing perovskite, and because it is the only good exposure of the calcite rock. The calcite rock has been described by Williams (1891) and Landes (1931). The calcite body (figs. 9 and 10) trends roughly east and has a maximum exposed length of about 360 feet; the maximum north-south dimension is about 300 feet. Other calcite bodies are present to the north and south but are poorly exposed. One such body is in the southeast corner of the mapped area (fig. 9). The body exposed in the quarry is in contact with syenite porphyry on the northern and southern sides. Cover prevents determination of its extension to the east and west. An attempt to drill auger holes in the flat east of Cove Creek failed because the auger could not penetrate the coarse gravels.

The calcite rock has little obvious structure but locally does have a faint layered appearance produced by color differences in the calcite, by differences in concentration of apatite and monticellite, and by local concentrations of pyrite and molybdenite (figs 9 and 10). Accessory minerals, in approximate order of abundance and also in approximate order of decreasing age, are apatite, monticellite, biotite, magnetite, pyrite, and perovskite. Zones containing abundant pyrite and those containing molybdenite are only locally present. Pyrrhotite is associated with magnetite and occurs only at contacts of calcite rock and syenite.

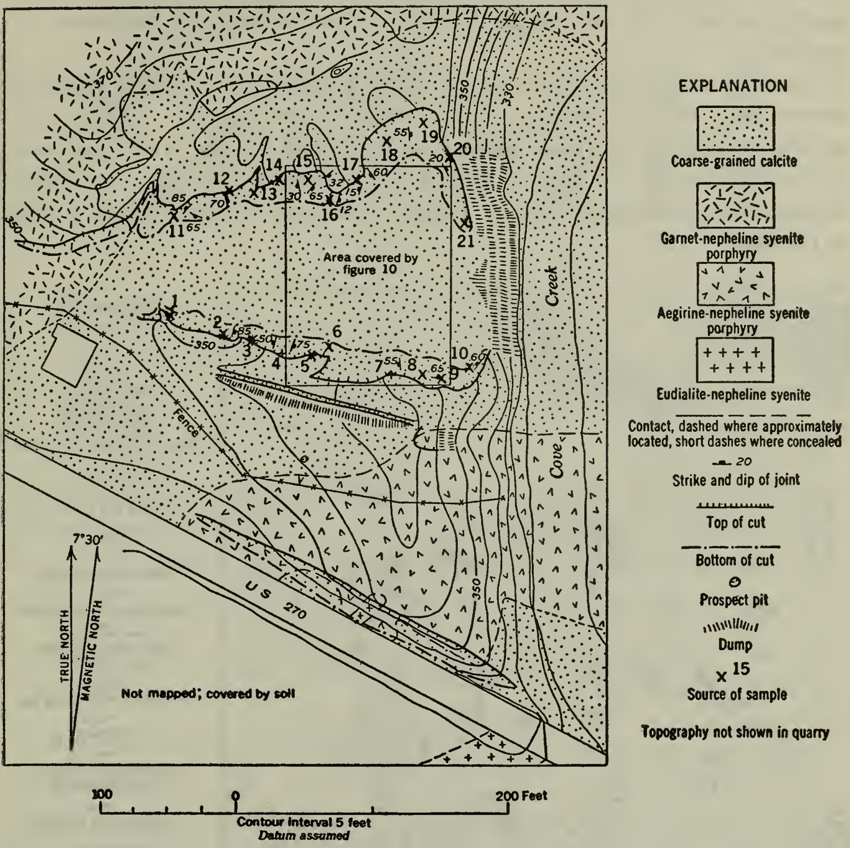


FIGURE 9.—Geologic and topographic map of the Kimsey calcite quarry, Hot Spring County.

Inclusions in the calcite rock.—The calcite body contains inclusions of several rock types, ranging in size from fragments a few inches long to angular blocks 6 to 7 feet long. Small aggregations of green biotite may represent digested or replaced inclusions. Reaction rims of varying thickness are present around the larger inclusions. Some inclusions have only a small remnant of the original rock at the center; others have a reaction rim only 1 to 2 inches wide. A typical reaction rim consists of the following zones:

1. A narrow outer zone, usually less than 1 inch wide, of magnetite and pyrrhotite lying in a medium-grained calcite matrix.

2. An intermediate zone rich in green biotite. Some biotite grains may reach 1 centimeter in diameter.
3. A fine-grained idocrase-rich inner zone of variable width, in some cases including the whole block. A few large idocrase crystals, reaching 3 to 4 centimeters in length, are present in these zones.

In thin section the altered rock shows total replacement of pyroxene by epidote, muscovite, and idocrase; and brown garnet is bleached and partly replaced by idocrase. Only a minor amount of carbonate is present.

Channel samples and average grade.—Twenty-one channel samples were taken from the sloping walls of the Kimsey quarry. The channels were cut along lines normal to the trend of the walls and are located as shown on figures 9 and 10. Quantitative spectographic analyses for niobium, TiO_2, V_2O_5, yttrium, and lanthanum are given in table 8.

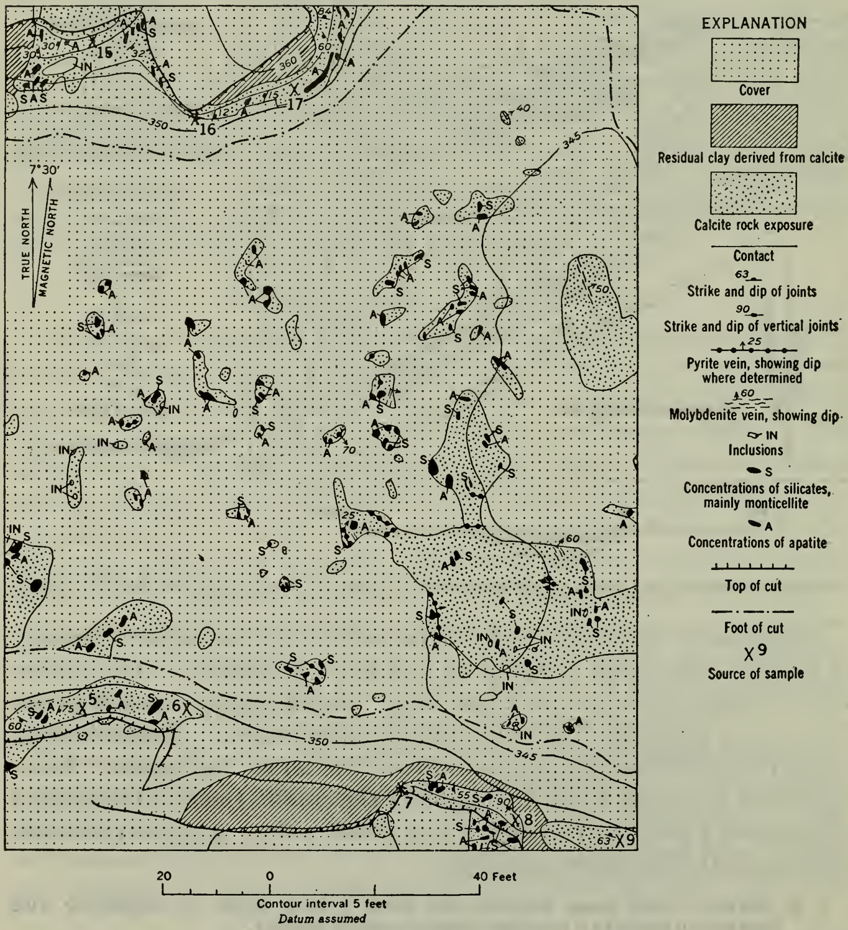


FIGURE 10.—Eastern part of the Kimsey calcite quarry, Hot Spring County, showing the occurrence of accessory minerals in the calcite rock.

Table 8.—*Spectrographic analyses of channel samples from the Kimsey calcite quarry, Magnet Cove, Ark.*

[R. S. Harner, analyst. Zero indicates element looked for but not found at the limit of sensitivity (Nb, 0.01)]

Channel No.	Channel Length (feet)	Laboratory no.	Nb	TiO_2	V_2O_5	Y	La
1	2.3	52-665SW	0	0.031	0.009	0.003	0.022
2	1.5	52-666SW	0	.020	.015	.006	.037
3	2.1	52-667SW	0	.14	.022	.015	.049
4	2.4	52-668SW	0	.053	.009	.003	.019
5	7.5	52-669SW	0	.10	.017	.006	.038
6	2.0	52-670SW	.028	.20	.013	.006	.034
7	1.9	52-671SW	0	.075	.012	.003	.024
8	4.5	52-672SW	0	.022	.014	.003	.024
9	3.8	52-673SW	0	.029	.008	.003	.022
10	2.0	52-674SW	0	.019	.007	.008	.014
11	3.2	52-675SW	0	.075	.011	.003	.022
12	2.7	52-676SW	0	.019	.016	.008	.033
13	3.1	52-677SW	0	.099	.009	.009	.029
14	2.5	52-678SW	.025	.40	.031	.007	.029
15	7.7	52-679SW	.022	.22	.023	.007	.035
16	1.9	52-680SW	.048	.91	.022	.007	.046
17	7.0	52-681SW	.053	.67	.023	.009	.050
18	4.4	52-682SW	0	.080	.016	.007	.026
19	2.4	52-683SW	0	.050	.011	.006	.010
20	1.8	52-684SW	.070	.97	.045	.015	.062
21	2.1	52-685SW	0	.13	.010	.007	.018

Niobium was detected in only six of the samples. The analyses confirmed the visual impression that perovskite, apatite, and monticellite tend to be concentrated in the same zones. The graph of figure 11

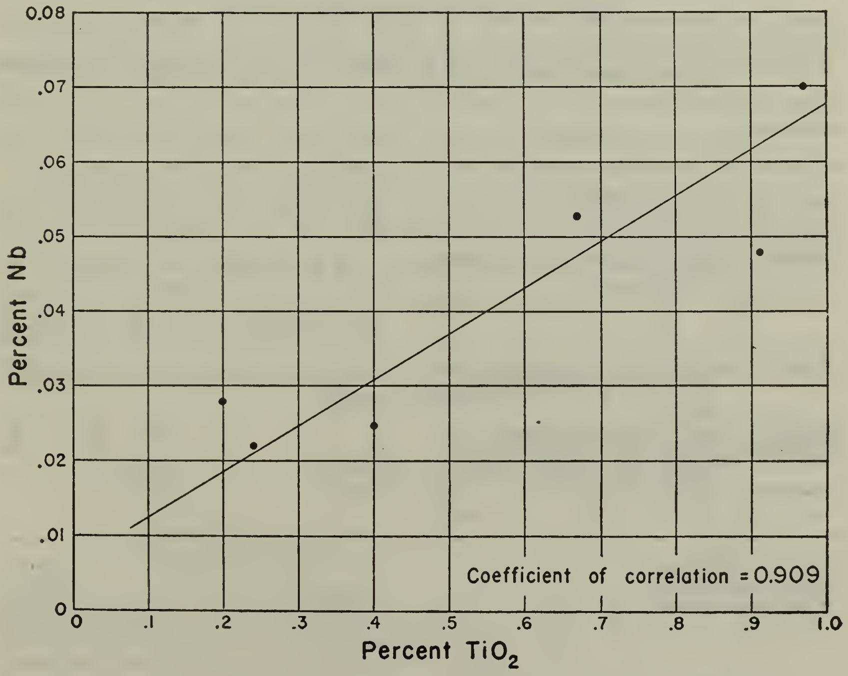


Figure 11.—Correlation of niobium and TiO_2, Kimsey calcite quarry, Magnet Cove.

shows moderately good correlation between niobium and TiO_2 analyses.

The average grade of the channel samples is 0.011 percent niobium. The average content of the calcite body is probably about 0.01 percent niobium.

Analyses of perovskite, apatite, and calcite.—Niobium in Magnet Cove perovskite has been reported by several workers, beginning with Mar (1890, p. 403). Available analyses, including those made during the present study, are given in table 9. All values are given as niobium, rather than as Nb_2O_5. Presumably the samples of Mar (1890) and of Rankama (1948) came from the Kimsey quarry-"perovskite hill" area, as this has been the only collecting ground for loose perovskite crystals. For comparison, an analysis of perovskite from the pyroxene-rich rock at the Mo-Ti Corp. pit is also given.

The analyses of previous workers range from 3.1 to 3.3 percent niobium; those of the Geological Survey range from 5.1 to 8.8 percent niobium. Mar's very early analysis for niobium by chemical methods may be in error. The high percentage of tantalum (4.2 percent) reported by him has not been confirmed by later workers.

Analyses of apatite and calcite from the Kimsey quarry are also given in table 9. Magnet Cove apatite contains rare earths of the lanthanum group and is probably the source of most of the lanthanum-group rare earths in the samples from the rutile and brookite deposits.

TABLE 9.—*Spectrographic analyses of single crystals from Magnet Cove, Ark.*

[R. S. Harner, analyst, except where noted. Leaders indicate item not looked for; zero indicates item looked for but not found at limit of sensitivity (Nb, 0.01; TiO_2, 0.05; V_2O_5, 0.002)]

Laboratory no.	Description	Nb	Ta	TiO_2	V_2O_5	Y	La
(1)	Perovskite, Magnet Cove, Ark	3.1	4.2	--------	--------	--------	--------
(2)	do	3.3	.02	--------	--------	--------	--------
IWS-202	Perovskite crystal, from Kimsey calcite quarry.[3]	5.6±0.3	[4] 0	--------	--------	0.1	1.2
52-686SM	Perovskite crystals from soil, "perovskite hill:"						
a	Single crystal	8.8	--------	--------	--------	--------	--------
b	do	6.8	--------	--------	--------	--------	--------
c	do	8.4	--------	--------	--------	--------	--------
d	do	5.6	--------	--------	--------	--------	--------
e	do	6.4	--------	--------	--------	--------	--------
52-942SW	Material drilled from perovskite grain in thin section of perovskite melteigite from drill core, Mo-Ti Corp. property.	.56	--------	--------	--------	--------	--------
52-1407SW	Apatite, Kimsey calcite quarry	0	--------	0	0.57	0	.38
52-1408SW	Calcite, Kimsey calcite quarry	0	--------	0	0	0	.008
52-687SM	Eudialyte from eudialyte syenite near Kimsey calcite quarry.	.28	--------	1.3	--------	--------	--------
52-688SM	do	.30	--------	1.2	--------	--------	--------
	do						

[1] From Mar, 1890.
[2] From Rankama, 1948.
[3] K. J. Murata, analyst.
[4] Less than 0.2 percent.

ORIGIN OF THE CALCITE ROCKS

Bodies of calcite rock or carbonatite associated with and included in alkaline igneous complexes have generally been described as sedimentary inclusions, whose assimilation may have been a factor in the origin of the alkaline rocks (Landes, 1931; Daly, 1933, p. 508–509, 564–565; Shand, 1947, p. 303–328). Recent descriptions however, have emphasized evidence that some calcite bodies of this type are introduced material, formed either as magmatic carbonate intrusives or by hydrothermal replacement (Bowen, 1924; Von Eckermann, 1948; Strauss and Truter, 1951).

Two lines of evidence indicate that the coarse calcite rock at Magnet Cove is introduced into the igneous rocks. The inclusions of syenite, rimmed by reaction products and veined by calcite, testify that the calcite material was both mobile and reactive after the formation of the igneous rocks, and most likely was introduced later than the igneous rocks. Also, coarse calcite bodies and veins cut the igneous rocks in drill cores from the Magnet Cove Titanium Corp. deposit, and it is apparent that widespread introduction of calcite has taken place here probably by hydrothermal action. The question of magmatic intrusion versus hydrothermal replacement has not been answered for the Magnet Cove calcite rocks, but the available evidence favors hydrothermal replacement.

ECONOMIC FACTORS

RUTILE AND BROOKITE DEPOSITS

The drilling on the Magnet Cove Titanium Corp. property and the Christy property has been sufficient to indicate the presence of considerable resources of rutile and brookite. It is probable that rutile and brookite deposits at Magnet Cove will be mined eventually.

The present work was done in order to determine the distribution and average grade of niobium in the titanium deposits and associated rocks. In addition the past work of the U. S. Bureau of Mines and of Fryklund and Holbrook has been summarized, and average grades for TiO_2 and V_2O_5 have been calculated for the deposits. This information is listed in table 10.

TABLE 10.—*Summary of analytical data from the principal titanium deposits at Magnet Cove, Ark.*

Locality	Mineral of possible value	Estimated average recoverable grade of known material			Estimated average grade of titanium concentrates		
		TiO_2	Nb	V_2O_5	TiO_2	Nb	V_2O_5
Magnet Cove Titanium Corp. property.	Rutile	3	0.04	0.09	92	1.2	0.5
Christy property	Brookite	5.9	.07	.35	92	2	.5
Kilpatrick property	do	5.9	.06	.21	92	2	.5(?)
Mo-Ti Corp. property	Rutile	--------	--------	--------	--------	--------	--------
Do	Perovskite	--------	.03	--------	--------	--------	--------
Kimsey calcite quarry area	do	.20	.01	--------	--------	6	--------

The Bureau of Mines has made milling tests on rutile and brookite material from Magnet Cove (Fine and others, 1949; Fine and Frommer, 1952). These tests gave low recovery—46 percent for rutile, 55 to 60 percent for brookite—but produced high-grade concentrates of about 92 percent TiO_2 in rutile and brookite. As shown in table 10, the rutile and brookite concentrates contain about 1.2 percent and 2 percent niobium respectively.

The chief factor in the low recovery is the occurrence of TiO_2 in several forms. In the rutile deposits, for example, nonrecoverable TiO_2 occurs in ilmenite, leucoxene, and silicates. In addition, the rutile occurs in grains of widely varying size and shape and the finer acicular grains are easily broken down into clay sizes that are recoverable only with difficulty. In the brookite deposits, TiO_2 occurs not only in brookite of widely varying sizes but also in very fine-grained acicular rutile grains and in taeniolite.

The vanadium content of samples from the rutile and brookite deposits varies widely, and the ratio of concentration of vanadium in rutile or brookite concentrates is much lower than that for TiO_2 and niobium. This relation indicates that part of the vanadium is in minerals other than rutile or brookite. The recoverable vanadium is, however, of possible economic value. Extensive bulk sampling and mill testing under operating conditions will be necessary to determine accurately the recoverable grade of the deposits.

The data indicate the niobium is a constant companion of the titanium, and its average grade can be predicted within rather close limits.

It is probable that processes for making metallic titanium from the rutile and brookite concentrates will allow separation and recovery of niobium and vanadium. However, if the rutile and brookite are used for welding-rod coatings, the niobium and vanadium will be lost.

OTHER POSSIBLE SOURCES OF TITANIUM AND NIOBIUM

Perovskite-bearing rocks in other areas have been considered as possible sources of titanium alone and of both titanium and niobium. The perovskite-bearing calcite rock exposed in the Kimsey quarry has been studied and sampled as described in this report, and the analytical data are summarized in table 10. Unless the perovskite can be recovered easily as a byproduct of other operations, the TiO_2 and niobium content of this material is probably too low to be of economic interest.

Two localities where perovskite-bearing silicate rock occurs are known: the Mo-Ti Corp. locality described in this report, and an area about 1000 feet east of the magnetite quarry on the north side of

Highway 270 (pl. 6). The quantity of perovskite-bearing rock in these localities is not known.

POTASH SULPHUR SPRINGS AREA

LOCATION AND PREVIOUS WORK

The Potash Sulphur Springs area is about 6 miles west of Magnet Cove (fig. 2). The area underlain by igneous rocks is on the north side of U. S. Highway 270 and is about one-half mile in diameter. The Potash Sulphur Springs area is more rugged than Magnet Cove and is cut by several deep valleys draining southward to the Ouachita River. About one-half mile north of the highway, near the head of the deepest valley, are the hot springs that give the area its name. The Wilson prospect described in this report (fig. 12) is on the hillside east of the hot springs, above the Wilson residence.

No natural outcrop is present in the vicinity of the prospect. Several bulldozer trenches up to 10 feet deep expose only heavily weathered rock (saprolite). On the surface are several residual boulders, somewhat similar to the "tufa" boulders near the Kimsey quarry at Magnet Cove. One of these boulders is unusually radioactive and a grab sample analyzed in December 1950, by T. W. Carney, chemist of the Arkansas Division of Geology, was found to contain a notable quantity of niobium. Later analyses by the U. S. Geological Survey and the University of Arkansas have confirmed the presence of niobium and uranium. The bulldozer trenches were dug in 1951 for B. G. Wilson, the owner of the property. Shortly thereafter a churn-drill hole about 75 feet deep was drilled in one of the cuts.

GEOLOGIC RELATIONS

The Potash Sulphur Springs area, like Magnet Cove, is underlain by alkalic igneous rocks that have intruded sedimentary rocks of Paleozoic age. The geology of the area was described by Williams (1891, p. 344–366), and Purdue and Miser (1923). The scant outcrops and float material indicate that the rocks, like those at Magnet Cove, are syenite and more basic alkalic rocks. Calcite rock is exposed in the valley near the hot springs. Perovskite, rutile, and brookite have not been reported from the area.

At the Wilson prospect, which is on the eastern contact of the igneous complex, the trenches expose heavily weathered syenite and quartzite. The quartzite, probably part of the Arkansas novaculite of Devonian and Mississippian age, is exposed in the eastern part of the long east-west trench shown on figure 12. Elsewhere in the trenches heavily weathered syenitic rock is exposed. The presence of dikes of syenite in the quartzite, and of quartzite inclusions in the

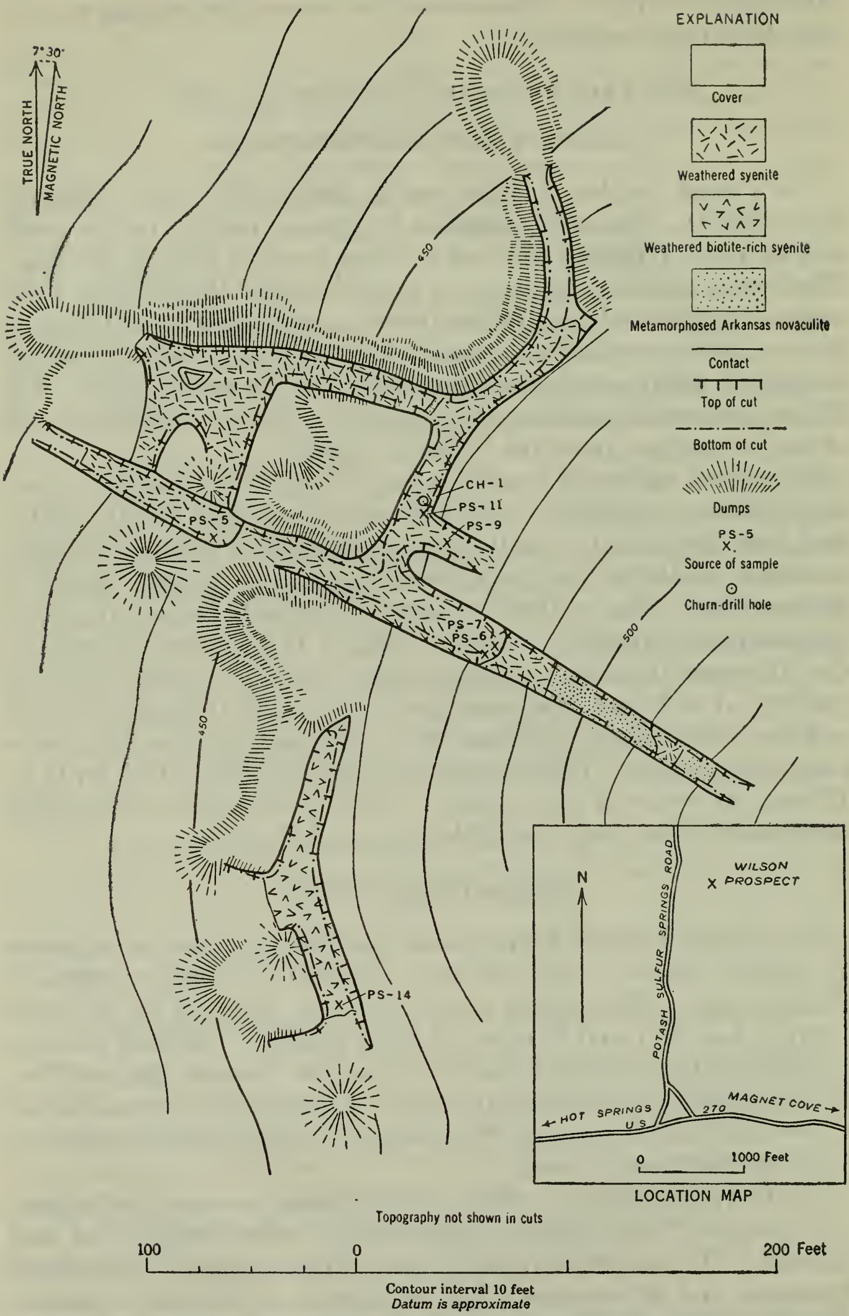


FIGURE 12.—Geologic and topographic map of the Wilson prospect, Potash Sulphur Springs, Garland County.

syenite, indicates that the syenite is intrusive. The syenite is almost completely altered to brown, white, and green clay. Irregularly shaped blocks of clay are separated by stringers and veins of iron oxide and clay. Some of the rock may have been a breccia before weathering, or may have developed this structure during weathering and joint-filling.

In hand specimens the least altered material is cream-colored. Orthoclase and microcline phenocrysts up to 2 millimeters in diameter are common. In the southern trench biotite brooks up to 2 inches in diameter are abundant. In the northern trenches the rock is finer grained and biotite is rare or absent. In a thin section of the weathered syenite the groundmass consists of feldspar grains (averaging 0.1 millimeter in diameter) and very fine-grained yellowish material, presumably composed of clay minerals. The feldspar contains abundant large apatite inclusions. The rock also contains a few grains of zircon and 1 or 2 percent opaque minerals. Ferromagnesian minerals, if originally present, have been altered to clay minerals. The rock was originally a syenite but cannot be identified further in its weathered condition.

SAMPLING AND ANALYSIS

A split of the original sample collected by the Arkansas Division of Geology was obtained and analyzed by the Geological Survey. In addition, 3 channel samples, 3 grab samples, and 5 samples of churn-drill cuttings were taken during the present work. The locations where samples were taken are shown on figure 12, and the results of analyses are given in tables 11 and 12.

TABLE 11.—*Quantitative and semiquantitative spectrographic analyses of samples from the Wilson prospect, Potash Sulphur Springs, Ark.*

[R. G. Havens, analyst, except where noted. eU (equivalent uranium), the quantity of uranium in equilibrium with its daughter products that would produce the observed radioactivity. X, a figure other than zero: X indicates a value between 1 and 9 percent, 0.X indicates a value between 0.1 and 0.9 percent, and so on. Leaders indicate element not looked for; zero indicates element looked for but not found at limit of sensitivity. Elements looked for but not found in any sample: Ag, As, Au, B, Bi, Cd, Co, Ge, In, Ir, Hf, Hg, Li, Mo, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Th, Tl, W, and Zn]

Field no.	Laboratory no.	Description	Nb	Ti	Y	La	eU	U
1143-B [1]	51-10745	Grab sample of "discovery boulder"; iron-stained, siliceous material.	1.6±0.3	------	0.05	0.05	------	------
VF-PS-5	D-67153	9-foot channel sample	.0X	X	.00X	.0X	0.011	0.008
VF-PS-6	D-67154	4.5-foot channel sample	.X	X	.00X	.0X	.009	.005
VF-PS-7	D-67155	Grab sample	.X	X	.0X	.X	.007	.005
VF-PS-9	D-67156	1.5-foot channel sample	.X	X	.00X	.0X	.004	.005
VF-PS-11	D-67157	Grab sample	X	X	.0X	.X	.13	.15
VF-PS-14	D-67158	do	.0X	.X	.00X	.00X	.005	.002

[1] K. J. Murata, analyst.

TABLE 11.—*Quantitative and semiquantitative spectrographic analyses of samples from the Wilson prospect, Potash Sulphur Springs, Ark.*—Continued

Field no.	Si	Al	Fe	Mn	P	Ca	Mg	Na
1143-B								
VF-PS-5	XX	XX	X	0.00X	0. X	0. X	0. X	0. X
VF-PS-6	XX	X	X	.00X	0	.X	.X	.X
VF-PS-7	XX	X	X	.00X	.X	.X	.X	.X
VF-PS-9	XX	X	X	.00X	.X	.X	.X	.X
VF-PS-11	X	X	X	.0X	X	X	.0X	.X
VF-PS-14	XX	X	X	.0X	0	.X	.X	X

Field no.	K	Ba	Be	Ce	Cr	Cu	Ga
1143-B							
VF-PS-5	X	0. X	Tr.	0.0X	0.0X	0.00X	0.00X
VF-PS-6	X	.X	0.000X	.0X	.0X	.00X	.0X
VF-PS-7	X	.X	.000X	.X	.0X	.00X	.0X
VF-PS-9	X	.X	.000X	.0X	.00X	.00X	.0X
VF-PS-11	X	.X	.000X	.X	.00X	.00X	.00X
VF-PS-14	X	.X	Tr.	0	.00X	.00X	.00X

Field no.	Nd	Ni	Pb	Sc	Sr	Zr	V
1143-B							
VF-PS-5	0.0X	0	0	0.00X	0. X	0.0X	0. X
VF-PS-6	.0X	0	0.00X	.00X	.X	.0X	.X
VF-PS-7	.0X	0	.00X	.0X	.X	.0X	.X
VF-PS-9	.0X	0	.00X	.00X	.0X	.0X	X
VF-PS-11	.0X	0.00X	.00X	.00X	.X	.X	.X
VF-PS-14	0	0	0	.000X	.0X	.0X	.0X

TABLE 12.—*Analyses of samples of cuttings from churn-drill hole CH-1, Wilson prospect, Potash Sulphur Springs, Ark.*

[Quantitative chemical analyses by A. P. Marranzino]

Field no.	*Depth of cuttings (feet)*	*Nb (percent)*
5AR53K	6½–8	0.20
6AR53K	53	.11
7AR53K	58½	.11
8AR53K	±65	.05
9AR53K	75	.06

Radioactivity is irregularly distributed in the weathered rock exposed in the cuts. Because of the irregularity, no systematic radiometric work was done. Sample No. VF-PS-11 was taken at one of the places where the rock is highly radioactive; it contained a notable quantity of niobium and uranium. Churn-drill hole CH-1 was drilled at this point. Samples of cuttings were taken from the cutting trough about a year after the hole was drilled. The only feature noted visually was the presence of abundant pyrite in cuttings from below 40 feet. The results of analyses, given in table 12, show that niobium is present but in smaller quantities than in the saprolite exposed near the collar of the drill hole.

CONCLUSIONS

The lack of outcrops and the limited exposures in the trenches preclude definite geologic interpretation of this occurrence. Material of this type—high in niobium and uranium, and relatively low in titanium—is not known to occur at Magnet Cove, and therefore no analogies with that area can be drawn.

The results of sampling suggest that material high in both niobium and uranium is not abundant, but that material relatively high (0.1 to 0.9 percent) in niobium may be abundant in the trenched area. It is possible that certain elements, including niobium and uranium, may have been relatively enriched by weathering processes in the saprolite, as compared to the unweathered rock. Another possibility is that the zones high in niobium and uranium represent weathered pegmatites that contained minerals such as samarskite.

Estimates of quantity of material present cannot be made with the information now available. Further work should include diamond drilling to test the presence of similar material below the surface and to reach unaltered rock.

LITERATURE CITED

Bowen, N. L., 1924, The Fen area in Telemark, Norway: Am. Jour. Sci., 5th ser., v. 8, p. 1–11.

Croneis, C. G., 1930, Geology of the Arkansas Paleozoic area: Arkansas Geol. Survey Bull. 3, 457 p.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill Book Co., Inc., 598 p.

Dieke, G. H., and Crosswhite, H. M., 1943, The use of iron lines as intensity standards: Optical Soc. America Jour., v. 33, p. 425–434.

Eckermann, Harry von, 1948, The alkaline district of Alnö Island: Sveriges Geol. Undersökning, ser. CA, no. 36, p. 13–163.

Fine, M. M., Kenworthy, H., Fisher, R. B., and Knickerbocker, R. G., 1949, Titanium investigations: The laboratory development of mineral-dressing methods for Arkansas rutile: Mining Eng., v. 1, p. 447–452.

Fine, M. M., and Frommer, D. W., 1952, Mineral dressing investigation of titanium ore from the Christy property, Hot Spring County, Arkansas: U. S. Bur. Mines Rept. Inv. 4851, 7 p.

Fleischer, Michael, Murata, K. J., Fletcher, J. D., and Narten, P. E., 1952, Geochemical association of niobium (columbium) and titanium and its geological and economic significance: U. S. Geol. Survey Circ. 225, 13 p.

Fryklund, V. C., Jr., and Holbrook, D. F., 1950, Titanium ore deposits of Hot Spring County, Ark.: Arkansas Res. Devel. Comm., Div. Geology, Bull 16, 173 p.

Holbrook, D. F., 1947, A brookite deposit in Hot Spring County, Ark.: Arkansas Res. Devel. Comm., Div. Geology, Bull. 11, 21 p.

——— 1948, Molybdenum in Magnet Cove, Ark.: Arkansas Res. Devel. Comm., Div. Geology, Bull. 12, 16 p.

Johannsen, Albert, 1938, A descriptive petrography of the igneous rocks: Chicago, Univ. of Chicago Press, v. 4, 523 p.

Landes, K. K., 1931, A paragenetic classification of the Magnet Cove minerals: Am. Mineralogist, v. 16, p. 313–326.

Mar, F. W., 1890, On the so-called perofskite from Magnet Cove, Ark.; Am. Jour. Sci., 3d ser., v. 40, p. 403–405.

Miser, H. D., and Stevens, R. E., 1938, Taeniolite from Magnet Cove, Ark.: Am. Mineralogist, v. 23, p. 104–110.

Myers, A. T., 1951, Improved cutting tool for spectroscopic electrodes: Anal. Chemistry, v. 23, p. 209–210.

Purdue, A. H., and Miser, H. D., 1923, Description of the Hot Springs quadrangle, Arkansas; U. S. Geol. Survey Geol. Atlas, folio 215.

Rankama, Kalervo, 1948, On the geochemistry of niobium: Annales Acad. Sci. Fennicae, ser. A, pt. 3, no. 13, 57 p.

Reed, D. F., 1949a, Investigation of Christy titanium deposit, Hot Spring County, Ark.: U. S. Bur. Mines Rept. Inv. 4592, 10 p.

——— 1949b, Investigation of Magnet Cove rutile deposit, Hot Spring County, Ark.: U. S. Bur. Mines Rept. Inv. 4593, 9 p.

Ross, C. S., 1941, Occurrence and origin of the titanium deposits of Nelson and Amherst Counties, Va.: U. S. Geol. Survey Prof. Paper 198, 59 p.

Shand, S. J., 1947, Eruptive rocks, 3d ed.: London, Thomas Murby and Co., 488 p.

Spencer, R. V., 1946, Exploration of the Magnet Cove Rutile Co. property, Magnet Cove area, Hot Spring County, Ark.: U. S. Bur. Mines Rept. Inv. 3900, 23 p.

Strauss, C. A., and Truter, F. C., 1951, The alkali complex at Spitskop, Sekukuniland, eastern Transvaal: Geol. Soc. South Africa Trans., v. 53, p. 81–130.

Washington, H. S., 1900, Igneous complex of Magnet Cove, Ark.: Geol. Soc. America Bull., v. 11, p. 389–416.

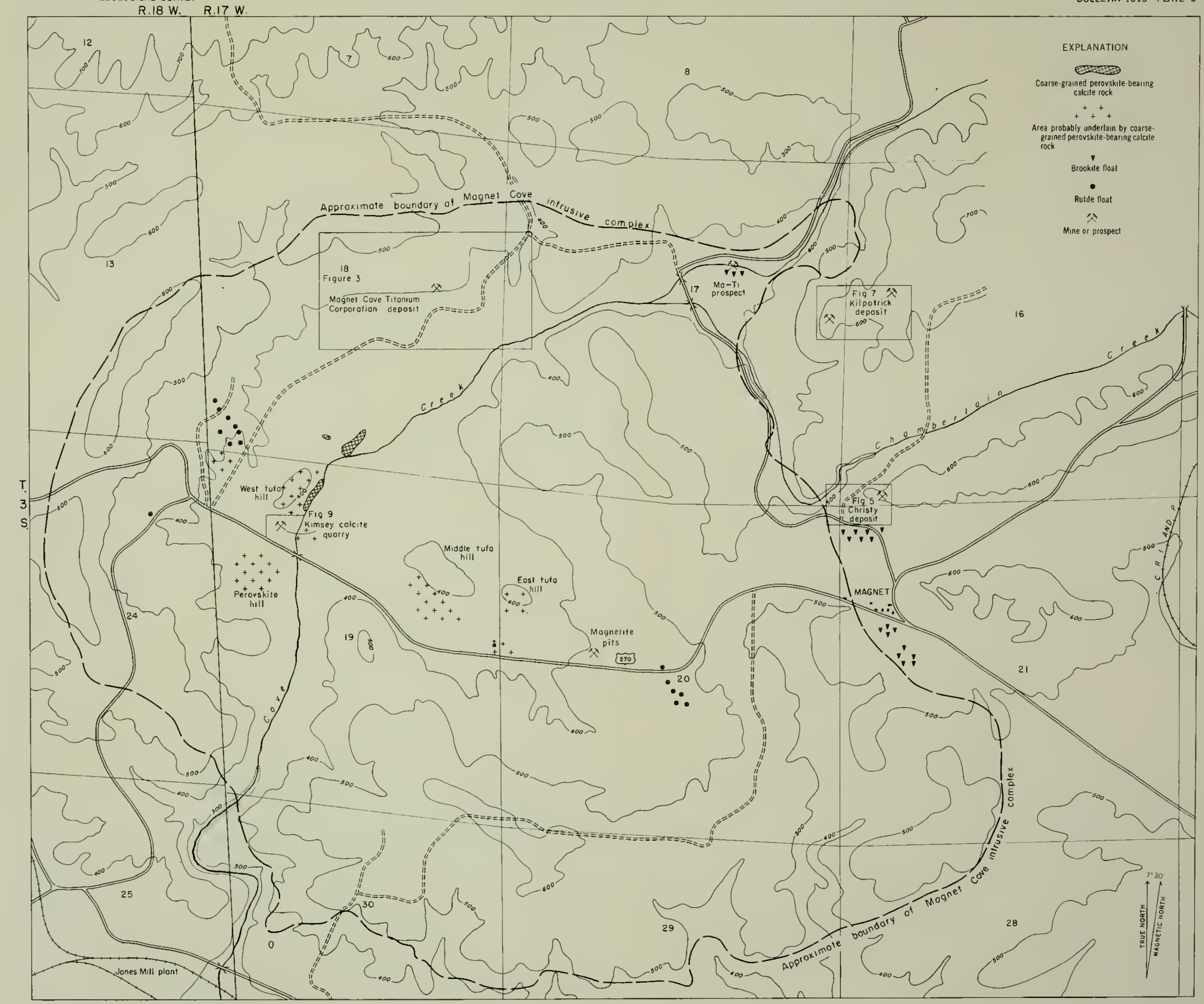
——— 1901, The foyaite-ijolite series of Magnet Cove: Jour. Geology, v. 9, p. 607–622, 645–670.

Williams, J. F., 1891, The igneous rocks of Arkansas: Arkansas Geol. Survey Ann. Rept., 1890, v. 2, 457 p.

INDEX

U. S. GOVERNMENT PRINTING OFFICE: 1954

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



Topography from Malvern quadrangle map, U S. Geological Survey
Adopted from Arkansas Division of Geology, Bulletin 16

TOPOGRAPHIC MAP OF MAGNET COVE, HOT SPRINGS COUNTY ARKANSAS, SHOWING THE LOCATION OF KNOWN DEPOSITS OF RUTILE AND BROOKITE

2000 0 6000 Feet

Contour interval 100 feet
Datum is mean sea level

302324 O - 54 (In pocket)