BRANNERITE FROM SAN BERNARDINO COUNTY, CALIFORNIA*

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Abstract

Brannerite has been found in the San Bernardino Mountains, San Bernardino County, California. It occurs typically as lenticular or roughly spherical nodules in a probable Precambrian light-gray granite gneiss. The nodules have been found in two distinct modes of occurrence. Some lie along the foliation of the gneiss and in several places, for short distances, they are concentrated along a definite lamina; others lie in thin, tabular shear zones. In general, the smaller nodules (from 1 to 20 grams) are found along the foliation and seem to consist entirely of brannerite surrounded by a thin layer of biotite; the larger nodules (up to 200 grams) are found in the tabular shear zones and contain brannerite and grains of rutile. The larger nodules not only are surrounded by biotite but contain small plates and sheaves of that mineral. In the larger nodules it appears that the brannerite has replaced the biotite.

Introduction

In January 1955, B. W. Blankenship of Reseda, California, and W. P. Sykes of North Hollywood, California, brought to D. F. Hewett specimens of a highly radioactive mineral that they had found in prospecting for uranium in the low hills along the north slope of the San Bernardino Mountains, San Bernardino County, Calif. Blowpipe tests followed by a spectroscopic analysis by the Smith-Emery Company of Los Angeles, indicated that the principal mineral was brannerite. This determination was subsequently confirmed by work in the laboratories of the U. S. Geological Survey.

As the occurrence has many interesting features, Blankenship and Sykes have continued to explore the area and it has been visited four times by D. F. Hewett. The interpretation of the local geology, nature of the rocks, and relations of the minerals to geologic features are based upon work by D. F. Hewett. Laboratory work on the minerals has been done by Jerome Stone (preparation of materials and microscopic work), by George Ashby, Evelyn Cisney, Daphne D. Riska (*x*-ray analyses), by Katherine E. Valentine (spectroscopic analyses), and by Harry Levine (chemical analyses), all of the U.S. Geological Survey.

Location and Accessibility

Brannerite and several other uncommon minerals have been found on the steep eastward slope of a ridge that extends generally north from the San Bernardino Mountains, the largest and highest range in southern

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California. Even though the higher parts of the range, culminating in San Gorgonio Peak, 11,485 feet above sea level, are relatively smooth surfaces, the northern and southern slopes are trenched by rugged steep canyons. The brannerite locality is in one of these canyons, at an altitude of about 4,000 feet, where it merges into one of the broad basins north of the mountains. Projecting the land net into the canyon area, the brannerite locality lies near the center of sec. 22, T. 3 N., R. 3 E., San Bernardino Meridian. The area lies within the Old Woman quadrangle which is the northeast quarter of the San Gorgonio quadrangle. (See Fig. 1.)

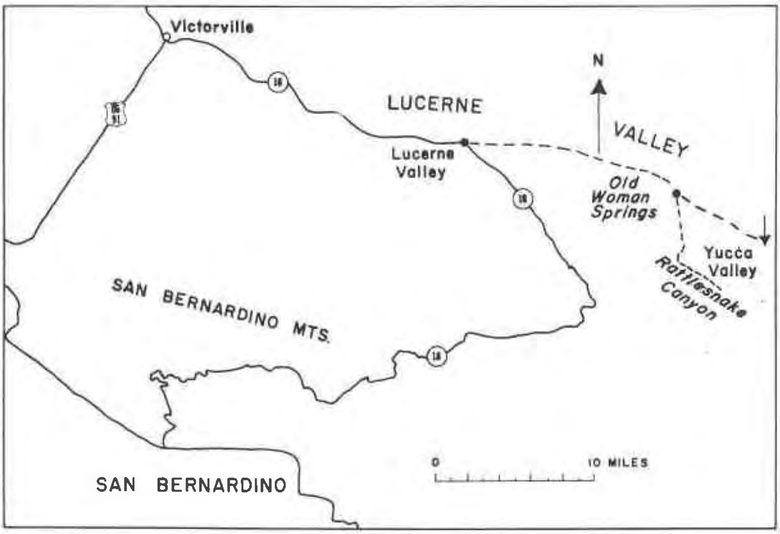

FIG. 1. Index map of Old Woman Springs area, San Bernardino County, California.

The area is most readily accessible by a road that extends eastward from Victorville to Lucerne Valley Post Office, 22.7 miles east of Victorville, and to the Old Woman spring and ranch which are 15.1 miles east of Lucerne Valley. A few hundred feet east of the ranch, the road divides; the right fork leads south to Rattlesnake Canyon and the left fork eastward to Yucca Valley. At a point on the left fork or main road, 4.0 miles east of Old Woman Ranch, a new dirt road extends southwest 1.3 miles to several low hills, beyond which is it impossible for cars with two-wheel drive to travel. Cars with four-wheel drive can divert eastward to a wash and ascend it southward about 1.45 miles. From there, a rugged trail extends eastward about one mile to another wash; the brannerite area is about 1,500 feet up the wash. Thus far, all of the brannerite specimens have been found in an area about 100 feet in diameter along the steep west slope of the valley.

Local Geology

The brannerite area lies within the San Gorgonio quadrangle, the geologic features of which were studied during 1915–1917 by Vaughan (1922). A part of the San Gorgonio quadrangle, near Blackhawk Canyon, was later studied by Woodford and Harris (1928), but the brannerite area lies just east of its eastern border. All the rocks of the area here under review are included in the "undifferentiated schists" of Vaughan, and Woodford and Harris. They are regarded as the oldest rocks of the region and are probably Precambrian. These "undifferentiated schists" are intruded by the Cactus granite of Vaughan (1922) and other "plutonic rocks," probably Mesozoic in age.

Field work by D. F. Hewett during recent years indicates that large plates and small blocks of foliated schists and gneisses form a belt that extends along the north slope of the San Bernardino Mountains from Blackhawk Canyon eastward about 20 miles to the Rock Corral area. These plates and blocks either abut against or rest upon relatively unfoliated intrusive rocks of granitic or monzonitic type. As Woodford and Harris (1928) have shown, Vaughan's (1922) Cactus granite of the type locality, Cactus Flat, south of Lucerne Valley, is quartz monzonite.

The most widespread foliated rock of the area, and the host of all of the brannerite that has been found thus far, is a light-gray granite gneiss with persistent fine texture; it underlies at least 20 acres on the north end of the ridge that extends north from the San Bernardino Mountains. A fresh specimen collected 50 feet distant from any known brannerite shows 50 per cent quartz, 20 per cent orthoclase, 20 per cent microcline, 5 per cent sodic plagioclase, 2 per cent biotite, with traces of sericite, chlorite, magnetite, zircon, monazite, and xenotime. Most of the grains range from 1 mm. to 2 mm. in diameter. Probably most of the gneiss of the area contains much more feldspar and less quartz than the examined section. The foliation of the gneiss is indicated by thin layers of biotite. In detail, the rock shows widespread plication, but in larger aspect the trend of the major foliation is northwest and the dip steeply northeast. From place to place, there is jointing that also trends northwest and dips northeast.

Most exposures of the gray gneiss exhibit large and small angular blocks of an older dark schist, persistently thinly laminated owing to the presence of considerable biotite. The areal source of this dark schist is not known.

Several hundred feet south of the brannerite locality, the gray gneiss is intruded by a pale reddish granite gneiss that shows slight but persistent foliation. A similar rock forms small lenticular sills in the gray gneiss north of the brannerite area. Boulders of a coarse quartz monzonite occur in the wash, but this rock does not crop out within half a mile south of the brannerite area.

The presence of persistent foliation in each of the three rock units described above, the biotite schist, gray granite gneiss, and reddish granite gneiss, and the general absence of foliation in the Vaughan's Cactus granite of this region, indicate that the local rocks are much older than the so-called Cactus granite and probably Precambrian.

As a result of recent work in the Rock Corral area, about 10 miles east of the brannerite area, Moxham, Walker, and Baumgardner (1955) recognize two varieties of quartz monzonite. The older variety contains abundant coarse tabular crystals of orthoclase in a finer matrix made up of oligoclase and calcic andesine, quartz, and biotite with small amounts of magnetite, allanite, apatite, muscovite, zircon, and fluorite. The younger monzonite is uniformly coarse grained and contains orthoclase, andesine, quartz, and minor amounts of biotite, magnetite, chlorite, muscovite, zircon, apatite, sphene, and allanite; it is considered the equivalent of the Cactus granite of Vaughan (1922).

An analysis of euxenite from the Pomona Tile pegmatite body in the so-called Cactus granite near Rock Corral, indicates that the age is 150 million years, or middle Jurassic (Hewett and Glass, 1953).

No bodies of rock that would commonly be called "pegmatite" have been seen in the brannerite area. At several places in the gray granite gneiss, however, there are thin lenses made up of white orthoclase which show terminated crystals in open cavities. The largest of these lenses is an inch wide and 15 inches long.

At the brannerite locality there are sparse poorly defined patches within which the normal feldspathic gray granite gneiss is wholly altered to sericite with sufficient chlorite to give it a pale-greenish color. Within the altered rock, there are small irregularly shaped masses of granular cordierite surrounded by muscovite and phlogopite. The cordierite is highly fractured and sericitized; it has not been found in the unaltered granite gneiss. Some quartz and traces of sillimanite, biotite, magnetite, zircon, and feldspar are present. One thin section of sericitized granite gneiss shows a few needles of sillimanite embedded in cordierite. During the early months of exploration, brannerite was found only in the sericitized gneiss, but as work progressed the mineral was found in unaltered gneiss. There seems to be no relation between the occurrence of brannerite and the sericitic alteration of the gneiss.

A little euxenite occurs both as small granular masses within the brannerite nodules and as small grains dispersed in the biotite-rich parts of the granite gneiss. These masses range from 1 to 4 mm. in greatest dimension, are wax-brown, and are made up of many very small grains; no crystals have been found. Thus far, the quantity of euxenite seems to be no more than several per cent of that of brannerite. Also, at several places within the brannerite locality, small masses of granular rutile have been found in biotite-rich lenses in the granite gneiss; the color is reddish brown, about that of much almandite garnet.

Brannerite

Occurrence. Thus far, all the brannerite recovered forms lenticular or roughly spherical nodules in the gray granite gneiss. The largest nodule is nearly 2 by 2 inches and weighs about 200 grams; most of the nodules range from one-half to 1 inch in largest diameter and weigh from 5 to 50 grams. The owners estimate that after six months of intermittent exploration about 25 pounds of nodules have been recovered.

Nodules have been found in two distinct modes of occurrence. Some lie along the foliation of the gneiss and in several places, for short distances, they are concentrated along a definite lamina; others lie in thin tabular shear zones filled with biotite or chlorite that definitely cut across the foliation. Most of the nodules found along the foliation planes are embedded in the feldspathic gneiss and are surrounded by a thin layer of biotite; most of these nodules range in weight from 1 to 20 grams. The nodules found in the discordant shear zones are embedded in larger nodules of fresh or altered biotite; most of these range in weight from 20 to 50 grams, but a few weigh from 100 to 200 grams.

In general, the smaller nodules seem to be wholly brannerite; the larger nodules found in the shear zones contain grains of rutile as large as grains of rice. The larger nodules not only are surrounded by biotite but contain small plates and sheaves of that mineral; in these, it appears that the brannerite has replaced the biotite. A polished section (Fig. 2) of a large nodule of brannerite reveals that the brannerite is surrounded and transected by biotite. Sodic plagioclase and rutile are present in some of the nodules of brannerite. The sodic plagioclase is present as (1) large anhedral crystals which are transected by biotite and (2) as small crystals intimately associated with biotite, which fills the numerous fractures in brannerite and rutile. The rutile is present as roughly ellipsoidal crystalline masses and as very small crystals within the brannerite. A thin section reveals that the partings of the large crystals of plagioclase are filled with sericite. The smaller crystals of plagioclase are in places almost completely sericitized.

Physical Properties. Examined by reflected light, polished sections of the nodules show that the brannerite ranges in color from black nearly metallic to dark yellowish brown; examined by transmitted light, finely crushed brannerite is transparent and ranges from pale brown to pale green. All specimens have a conchoidal fracture and a hardness of 5. The physical properties and chemical analysis recorded below are those

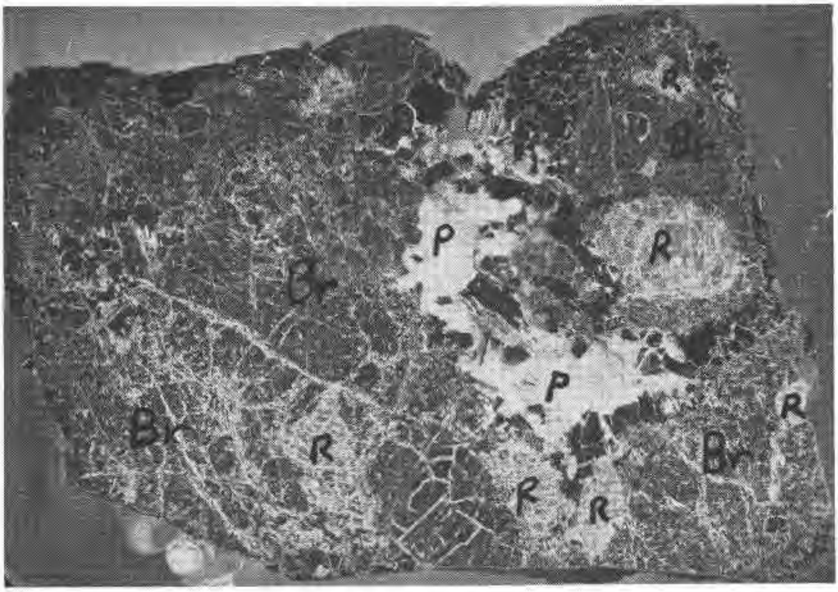

FIG. 2. Polished section of brannerite nodule. Rutile (*R*) and sodic plagioclase (*P*) are present as inclusions in the brannerite (*Br*). Biotite (*B*) surrounds and transects brannerite. The numerous fractures are filled with biotite and plagioclase. Photograph by U. S. Geological Survey.

of one of the largest nodules thus far found. It weighs about 125 grams and is nearly black by reflected light. Figure 2 shows a photograph of a highly polished section of this nodule. In order to determine any appreciable differences in composition of brown and black nodules, spectrographic analyses were made as follows:

Per cent	*Nodule, black by reflected light*	*Nodule, brown by reflected light*
Over 10	—Ti	—Ti
5–10	—U	—U, Th
1–5	—Th, Y	—Si, Fe
0.5–1.0	—Fe, Si, Mg	—Ca, Y, Nb
0.1–0.5	—Ca, Yb, Lu	—Gd, Al, Mn, Mg

The brannerite is isotropic, metamict, and has an index of refraction that ranges from 2.2 to 2.3. After heating the material for one hour at 900° C. in air, a pattern which matched that of brannerite was produced. By using a Frantz isodynamic separator at vertical and horizontal setting at 11°, brannerite is concentrated in the magnetic fraction at 0.5 ampere.

Chemical analysis. A chemical analysis of brannerite is shown in Table 1. A small part of the iron oxide, magnesia, alumina and silica in this

TABLE 1. CHEMICAL ANALYSES, IN PER CENT, OF BRANNERITE FROM CALIFORNIA AND IDAHO

	San Bernardino County, Calif.[1]	Custer County, Idaho[2]	Mono County, Calif.[3]	
TiO_2	39.60	39.	32.9	
UO_3	26.74	33.5	32.0	
UO_2	Trace	10.3	8.2	
ThO_2	9.15	4.1	5.0	} =87.0 R_2O_3
RE_2O_3[4]	9.75	3.9	6.5	
FeO	1.28	Trace	2.4	
Fe_2O_3	2.73	—	—	
CaO	2.70	2.9	2.8	
MgO	0.82	—	—	(Mn, Mg)=0.X
PbO	1.75	—	—	
SiO_2	2.25	0.6	0.5	
Al_2O_3	1.24	—	—	
H_2O^-	0.05 }	2.0 }	2.6	
H_2O^+	2.35 }			
Total	100.41	96.3		
Specific gravity	4.76	5.42	5.43	

[1] Analysis by Harry Levine, U. S. Geological Survey.

[2] Hess and Wells (1920), analysis by R. C. Wells.

[3] Analysis by J. J. Rowe (Pabst, 1954). The total R_2O_3 was determined as 92.3 per cent. The difference between 87.0 and 92.3 in R_2O_3 is stated as being probably due to Pb, Nb, Ni, Bi, Zr, Ta which were found by spectrographic analysis.

[4] RE_2O_3 is the total of the rare-earth oxides.

analysis may be due to contamination by biotite. Although an *x*-ray diffraction pattern did not reveal any biotite in the brannerite, an electron micrograph of a grain of brannerite did reveal the presence of biotite.

Rutile probably consituted about 1–2 per cent of the brannerite in the analysis, as estimated by *x*-ray diffractometer studies made by George Ashby of the U. S. Geological Survey. The estimate was made by adding a weighed amount of rutile to the metamict brannerite and measuring the change in intensity of a rutile line. UO_2 is not present in the sample. It seems that any UO_2 that may have been present has been oxidized by Fe_2O_3 to UO_3. Also in Table 1 are two previous analyses of brannerite reported by Hess and Wells (1920) and Pabst (1954) that show the presence of $UO_2 = 10.3$ per cent, $FeO = $ Trace; and $UO_2 = 8.2$ per cent, $FeO = 2.4$ per cent, respectively.

In addition, a semiquantitative spectrographic analysis by Katherine E. Valentine of the U. S. Geological Survey shows the following constituents not determined in the chemical analysis:

Per cent	
0.01–0.05	Mn B Nb
0.005–0.01	Ba Zr
0.0005–0.001	Cr
0.0001–0.0005	Ag Be

The individual rare-earth metals are as follows:

Per cent	
1–5	Y
0.05–0.1	Yb Gd Er Dy
0.01–0.05	Lu Tm Ce
0.005–0.01	Ho La

Paragenesis

Brannerite and biotite are in very close association. Biotite commonly surrounds the brannerite in nodules, transects the brannerite, and is found within brannerite as macroscopic, microscopic, and submicroscopic crystals. Electron micrographs made by Malcolm Ross of the U. S. Geological Survey show that even an apparently homogeneous fragment of brannerite contains crystals of biotite.

This suggests that the biotite crystallized first and brannerite followed, possibly as a replacement.

However, since biotite also cuts across the brannerite and fills many of the fractures in brannerite, a second generation of biotite is indicated. Rutile is present as submicroscopic and macroscopic crystals in the brannerite and probably represents an excess of titania in the brannerite solutions.

Modes of Occurrence of Brannerite

Where it was first discovered in Kelly Gulch, Custer County, Idaho, brannerite formed grains in alluvial sands and the source has not been determined (Hess and Wells, 1920). Brannerite from the Deans mine, along Walker River, Mono County, Calif., formed "lustrous, black crystals firmly embedded in quartz" from a quartz vein (Pabst, 1954). According to Bateman (1955), brannerite and pitchblende "form discrete mineral particles . . . rarely seen by the naked eye" in the matrix between the quartz pebbles that form a bed of conglomerate near the base of the Huronian in the Blind River area, Ontario.

In contrast with these occurrences, the brannerite from the north slope of the San Bernardino Mountains, San Bernardino County, Calif., forms lenticular nodules from one-half to 2 inches in largest dimension that are (1) dispersed along the foliation of a Precambrian(?) granite gneiss and (2) lie along thin zones of biotite that cut across the foliation. It would seem that the brannerite from San Bernardino County has formed at great depth under conditions of high pressure and temperature.

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