BIXBYITE AND PSEUDOBROOKITE FROM THE TIN-BEARING RHYOLITE OF THE BLACK RANGE, NEW MEXICO*

CARL FRIES, JR., WALDEMAR T. SCHALLER, AND JEWELL J. GLASS,
Geological Survey, Washington, D. C.

ABSTRACT

Bixbyite, $(Mn, Fe)_2O_3$, has been found at five localities in the tin-bearing rhyolite in the Black Range in southwestern New Mexico. It occurs as small cubes implanted with specularite and cassiterite on fissure walls and in cavities and lithophysae with topaz, quartz, specularite, and opal. Two new forms, $u\{554\}$ and $t\{421\}$, were found. A review of chemical analyses reported for bixbyite and a new analysis of material from the Black Range substantiates the formula $(Mn''', Fe''')_2O_3$. This is the third verified occurrence for the mineral.

Pseudobrookite, $Fe_2O_3 \cdot TiO_2$, occurs in cavities widely distributed throughout the tin-bearing rhyolite. Crystals collected from one of the bixbyite localities show six new prism forms, $d\{560\}$, $f\{11.10.0\}$, $g\{650\}$, $i\{320\}$, $j\{830\}$, and $k\{410\}$. This is the third recorded occurrence in the United States.

A review of the occurrences for bixbyite and for pseudobrookite indicates that the minerals have not been found as pyrogenetic accessories. Their origin has been attributed only to fumarolic or pneumatolytic processes. It is reasonable to attribute the origin of these minerals in the tin-bearing rhyolite of the Black Range to vapors escaping from the cooling flows.

INTRODUCTION

Small glossy black cubes of bixbyite and tiny slightly radiating groups of crystals of pseudobrookite were found in the tin-bearing rhyolite of the Black Range in Sierra and Catron counties, New Mexico, during an investigation of the tin deposits under the Strategic Minerals Act in the fall of 1939 and in the summer and fall of 1940. The identity of the bixbyite was not suspected until fragments of the mineral were observed by one of the authors (J. J. G.) in heavy concentrates during laboratory studies at the Federal Geological Survey. More than 2000 crystals ranging in size from 0.5 mm. to about 6 mm. on the edge were collected. Specimens of pseudobrookite were collected from only one locality.

GEOLOGY

The tin-bearing rhyolite in the Black Range forms relatively undeformed flows of Tertiary age. It is in general coarsely porphyritic and contains from 20 to 40 per cent phenocrysts, which are largely soda-sanidine and quartz. Minor quantities of oligoclase and biotite are pres-

* Published by permission of the Director, Geological Survey, United States Department of the Interior, Washington, D. C.

ent. The groundmass is made up of microcrystalline quartz and feldspar and is slightly to very vesicular throughout the greater part of the areas where the rhyolite crops out. Minerals present in these vesicles in different parts of the region include magnetite, specularite, bixbyite, pseudobrookite, sphene, andradite garnet, topaz (high fluorine-low water type), quartz, sanidine, cristobalite, tridymite, chalcedony, opal, zeolites, fluorite, and calcite. The walls of some of the narrow irregular fissures in a dozen small areas in the rhyolite are incrusted largely with specularite and cassiterite, but all the minerals of the vesicles, except pseudobrookite, sphene, and topaz, have been found in one or more of the incrustations. A somewhat more detailed description of the geology is given by Fries.[1]

BIXBYITE, $(Mn, Fe)_2O_3$

Occurrence and association.—Bixbyite was first discovered in the Thomas Range in Utah and was described by Penfield and Foote[2] in 1897. The second discovery of the mineral was made in Valle de las Plumas, northern Patagonia, in 1923. A handwritten report, dated 1930, of a study made by Sarah Cortelezzi de Mouzo on 6 crystals from that locality is on file in the Museum of La Plata, Buenos Aires. Schiller[3] gave an abstract of her paper in 1931. A chemical study was made by Corti[4] in the same year. A more detailed crystallographic study was later made by Cortelezzi, Himmel, and Schroeder[5] on a collection of 50 crystals. Bixbyite is also mentioned, but with unconfirmed identity, in a list of minerals from a locality in Spain.[6]

The bixbyite from the Black Range does not occur throughout all the rhyolite but appears to be limited to small areas. It is present in and within 2 feet of a narrow fissure filled with specularite and cassiterite in a small prospect trench 300 yards southeast of the road from Beaverhead to Winston, in the center of the south half of section 22, T. 10 S., R. 11 W. The largest crystals found (see Fig. 1, a and b) are in lithophysae, together with specularite, quartz, and opal, in the rhyolite along-

[1] Fries, Carl, Jr., Tin deposits of the Black Range, Catron and Sierra Counties, New Mexico; a preliminary report: *U. S. Geol. Survey, Bull.* **922-M,** 360–365 (1940)

[2] Penfield, S. L., and Foote, H. W., On bixbyite, a new mineral, and notes on the associated topaz: *Am. Jour. Sci.*, 4th ser., **4,** 105–110 (1897).

[3] Schiller, W., Abstr. La Existencia de la Bixbyita en la Patagonia, by Sarah Cortelezzi de Muzzo, 20 handwritten pages: *Neues Jahrb. Min.*, Referate **1,** 133–135 (1931).

[4] Corti, Hércules, Datos sobre una nueva variedad de bixbyita hallade en el Chubut: *Anal. Asoc. Quim. Argentina,* **19,** 109–116 (1931).

[5] Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert, Bixbyit von Patagonien: *Centralbl. Mineral., Geol., u. Paleon.*, Ab. A, 129–135 (**1934**).

[6] Tomás, Llorenç, Els minerals de Catalunya: *Treballs Inst. Catalana Hist. Nat.*, 246, vol. for **1919–1920.**

side the incrusted fissure walls. Other crystals, such as those shown in Fig. 1, c, are intergrown with specularite and cassiterite in the incrustation, or implanted with specularite, quartz, and sanidine on the walls of cross fissures. The pseudobrookite that is described is present in lithophysae about 50 feet west of the incrustation.

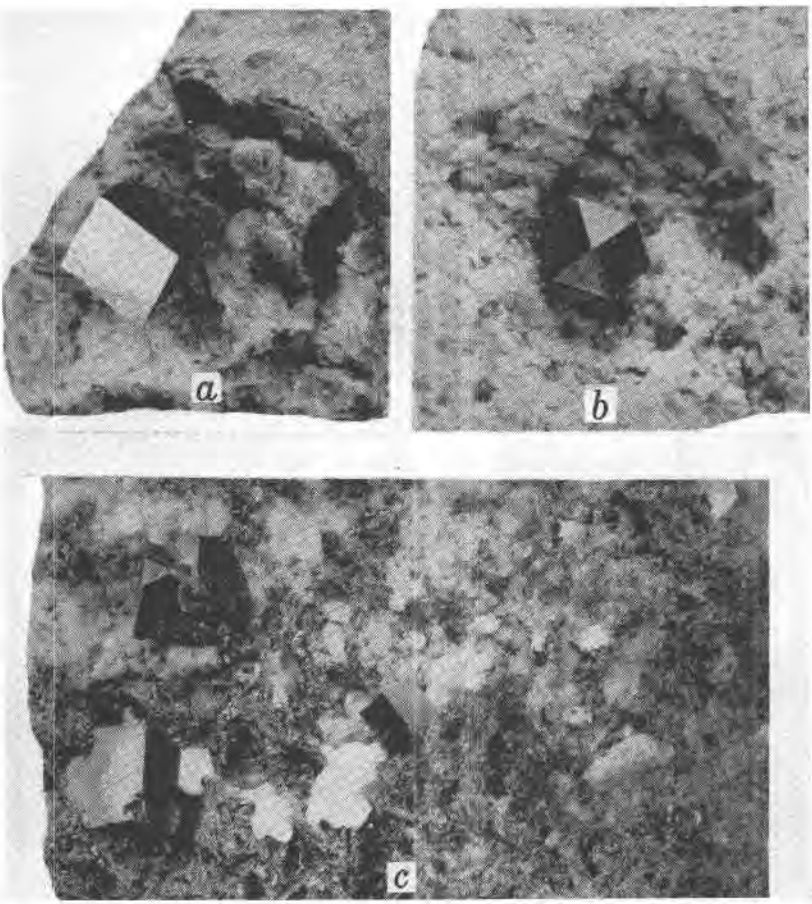

FIG. 1

a. Cube of bixbyite in lithophysa. The shell-like cavity also contains many tiny clear crystals of quarts. × 2

b. Crystal of bixbyite showing combination of cube and octahedron in a vesicle with quartz and hyaline opal. ×2

c. Cubes of bixbyite on wall of fissure. Clusters of small crystals of cassiterite are attached to the sides and edges of the bixbyite. Thin black plates are specularite; white crystals are sanidine; and glassy transparent crystals are quartz. × 2

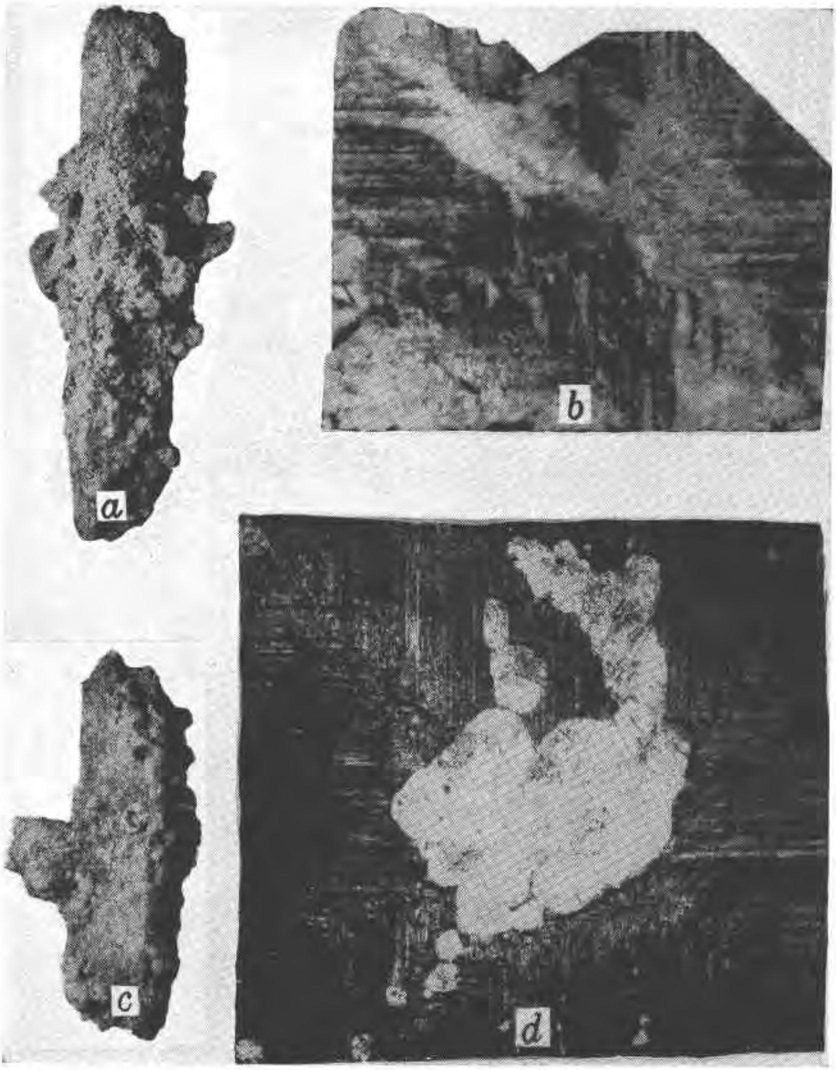

Fig. 2

a and c. Crystals of topaz incrusted with quartz, specularite, and bixbyite. × 2

b. Cube face of bixbyite crystal showing pattern of markings present on many crystals. × 20

d. Similar to b, except that markings are finer. Light patch near center is unstriated. × 33

A few crystals of bixbyite were found in a small shaft sunk on a veinlet of specularite and cassiterite 200 yards north of Hardcastle Creek, in the NW$\frac{1}{2}$ of the NE$\frac{1}{4}$ of section 4, T. 10 S., R. 10 W. They are intergrown with specularite in the veinlet.

The larger part of the bixbyite was collected from a small prospect pit 200 yards northeast of Scales Creek, in the NW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 31, T. 10 S., R. 10 W. The highly friable white rhyolite within one foot of a small veinlet of specularite carries an abundance of small, nearly perfect cubes and clusters of as many as 6 interpenetrating cubes. Recovery of the bixbyite is possible by disintegrating and panning the friable rock. Some of the crystals are intergrown with specularite in the veinlet. Bixbyite is implanted with specularite and quartz on the walls of a narrow fissure in a small prospect pit 400 yards north of this and 400 yards northeast of Scales Creek, in the SW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 30, T. 10 S., R. 10 W.

A fourth locality is at the west base of Round Mountain, also known as Maverick Mountain, 1300 yards north of Main Diamond Creek, in section 30, T. 11 S., R. 10 W. The rhyolite at this place contains numerous cavities, in some of which occur crystals of topaz up to an inch in length. Tiny crystals of bixbyite, specularite, and quartz incrust the large crystals of topaz, as illustrated by Fig. 2, a and b. No definite orientation of the bixbyite was noted, such as that described by Pabst[7] on material from Utah. The bixbyite crystals range from half a millimeter to 2 or 3 mm. in diameter. A thin film of hyaline opal covers parts of some of these aggregates.

Heavy mineral concentrates of rhyolite taken from a prospect adit driven in 1939 by the Federal Bureau of Mines, in the NW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 2, T. 11 S., R. 12 W., contain broken fragments of bixbyite, though the mineral was not recognized in hand specimen. The rhyolite at this place is porous and friable and is cut by numerous fissures, the walls of some of which are incrusted with specularite and cassiterite.

There seems little doubt but that detailed search of the tin-bearing rhyolite in the region would lead to the discovery of additional areas in which bixbyite is present.

A summary of the occurrences of bixbyite and the associated minerals in the 3 localities known, New Mexico, Utah, and Patagonia, is given in Table 1.

[7] Pabst, Adolph, Orientation of bixbyite on topaz: *Am. Mineral.*, **23**, 342–347 (1938).

TABLE 1. OCCURRENCES OF BIXBYITE AND ASSOCIATED MINERALS

Locality	1. New Mexico	2. Utah	3. Patagonia
Enclosing rock	Rhyolite	Rhyolite	Trachyte?
Where present	In cavities and incrustations	In cavities	In veins?
Minerals found in contact with bixbyite	Specularite Topaz Cassiterite Quartz	Specularite Topaz Spessartite? Garnet Quartz	Quartz ?
Minerals not found in contact with bixbyite, but present in cavities; association inferred	Pseudobrookite Magnetite Andradite garnet Sphene Sanidine Cristobalite Tridymite Chalcedony Opal Zeolites Fluorite Calcite	Pseudobrookite Beryl Fluorite Calcite	?

1. Tin-bearing rhyolite of the Black Range, New Mexico.
2. The Thomas Range, Utah. See Montgomery, Arthur, A recent find of bixbyite and associated minerals in the Thomas Range, Utah: *Am. Mineral.*, 19, 82–87 (1934). See also Palache, Charles, Minerals from Topaz Mt., Utah: *Am. Mineral.*, **19**, 14–15 (1934).
3. Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert: *op. cit.*, p. 29.

The similarity of the occurrences in New Mexico and in Utah is apparent. The presence of bixbyite in the cassiterite-bearing incrustations in New Mexico may be significant in interpreting the environment in which the tin was deposited. The shorter list of associated minerals in the Utah occurrence may be due to a less complete study of the rhyolite, as at least one or more of the other silica minerals would be expected in the vesicles. The bixbyite from Patagonia is reported to be in a brecciated quartz vein which cuts a trachyte with well developed flow structure. The trachyte has a fine-grained or glassy groundmass and phenocrysts of quartz, plagioclase, orthoclase, biotite, ilmenite, and hematite. Quartz is the only mineral mentioned that is associated with bixbyite. Flows of rhyolite are near the bixbyite occurrence, it is said.

Crystallography.—The forms[8] present are $a\{100\}$, $d\{110\}$, $o\{111\}$, $n\{211\}$, $u\{554\}$, and $t\{421\}$, the last two forms being new for bixbyite.

Out of about 2000 crystals examined, 57 or about 3 per cent show the combination $a\{100\}$, $o\{111\}$, and 36 or about 2 per cent show the combination *a*, *o*, $n\{211\}$. Six crystals were selected and carefully measured. Crystal no. 4 showed one very small face of $d\{011\}$, first noted on crystals from Patagonia, and two faces of the new form $u\{554\}$, as well as *a*, *o*, and *n*. On crystal no. 6, with *a* and *o*, 13 faces of the new form $t\{421\}$ were measured. No faces of $n\{211\}$ were seen on this crystal. No faces of $x\{321\}$ were observed on any of the crystals from New Mexico, although this form is present on 10 of the 50 crystals from Patagonia, described by Cortelezzi, Himmel, and Schroeder.

TABLE 2. MEASUREMENTS OF $u\{554\}$ ON BIXBYITE FROM NEW MEXICO

Angle	ϕ	ρ
Measured	44°56′ 45°09′	60°32′ 60°24′
Calculated	45°00′	60°30′

TABLE 3. MEASUREMENTS OF $t\{421\}$ ON BIXBYITE FROM NEW MEXICO

Face	(142)		(214)		(241)	
Angle	ϕ	ρ	ϕ	ρ	ϕ	ρ
Measured	13°38′	63°29′	27°38′	28°54′	26°37′	77°29′
	13 37	63 48	26 57	29 08	26 31	77 17
	14 13	64 06	26 12	29 02	26 45	76 04
	13 38	64 05	26 34	30 16	27 45	75 07
			27 51	29 57		
Average	13 47	63 52	27 00	29 27	26 55	76 29
Calculated	14 02	64 07	26 34	29 12	26 34	77 23

Only a single very small face of $d\{011\}$ was observed. It measured: ϕ—0°31′, ρ—45°03′.

[8] In their description of the crystals from Patagonia, Cortelezzi, Himmel, and Schroeder use the letters advocated by Goldschmidt, namely *c* for $\{100\}$, *p* for $\{111\}$, *q* for $\{121\}$, and *x* for $\{321\}$. The letters used by Dana are used in this paper, except for $\{321\}$ where priority of discovery extends them the privilege of assigning their choice. Penfield used *a* for $\{100\}$ and *n* for $\{211\}$, and Montgomery used *o* for $\{111\}$.

The two measurements of the new form *u*{554} are given in table 2. The first face of {554} was small but as large as the small faces of {111}, whereas the second face of {554} was very small. Both faces gave poor reflections.

The faces of the new form *t*{421} were all small and somewhat striated. The crystal on which they occur has large faces of *a*{100}, with medium-sized faces of *o*{111}, much broken up. The measurements of *t*{421} are given in Table 3.

Table 4. First Described Occurrence of Crystal Forms of Bixbyite

Forms	First described occurrence			Combinations			
	Utah	Patagonia	New Mexico	Utah		Patagonia	New Mexico
				P. & F.	M.		
a{100}	P. & F., 1897	—	—	*a*	*a*	*a*	*a*
d{110}	—	C., 1931	—	—	—	*d*	*d*
o{111}	—	C., 1931	—	—	*o*	*o*	*o*
n{211}	P. & F., 1897	—	—	*n*	*n*	*n*	*n*
u{554}	—	—	P.p.	—	—	—	*u*
x{321}	—	C.H. & S., 1934	—	—	—	*x*	—
t{421}	—	—	P.p.	—	—	—	*t*

P. & F., 1897. Penfield, S. L., and Foote, H. W.: *Op. cit.*, p. 105.

C., 1931. Corti, Hércules: *Op. cit.*, p. 111. Corti presents a drawing indicating also the forms {221} and {265} but gives no measurements.

C.H. & S., 1934. Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert: *Op. cit.*, pp. 129–135.

P.p. Present paper.

M. Montgomery, Arthur: *Op. cit.*, p. 83.

Most of the crystals from both Utah and New Mexico are simple cubes. Penfield and Foote described bixbyite from Utah as crystallizing "usually in cubes," and Montgomery says: "Practically all the crystals are simple cubes. . . ." About 95 per cent of the 2000 crystals from New Mexico likewise are simple cubes. All the 50 measured crystals from Patagonia show *a* and *n*, and 60 per cent of the crystals also have *d*{110}; 20 per cent have *x*{321}, and 4 per cent have *o*{111}.

The faces of the cube on the crystals from New Mexico are usually striated, as already described on crystals from Patagonia by Cortelezzi, Himmel, and Schroeder,[9] and many are uneven and irregular. (See Fig. 2, b and d.) On the most deeply furrowed crystals the two parts in one

[9] Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert: *Op. cit.*, pp. 129–135.

zone are inclined from 11° to 12° to the cube face, the striations approaching the form {150} (with ϕ angle of 11° 19′). On other crystals the striations are inclined only about 7° to the cube.

The relative size of the faces of *o*{111} and *n*{211} varies greatly, even on the same crystal. The faces of *o* on some crystals are relatively large, whereas those of *n* are very narrow; on other crystals the faces of both forms are about equally developed; and on still other crystals the faces of *n* are relatively large, whereas those of *o* are mere points. There is a marked tendency for narrow faces of *o* to occur along the intersection edges of the faces of *n* as oscillatory combinations.

The mineral is isotropic in reflected polarized light (on polished faces parallel to the cube) and shows no indication of twinning. Treatment with dilute HCl did not produce any structures on the polished surfaces.

Physical properties.—No cleavage could be detected when several crystals were broken, although Cortelezzi, Himmel, and Schroeder have reported cubic cleavage in the bixbyite from Patagonia. The imperfect octahedral cleavage noted by Penfield is developed on polished surfaces. The fracture is uneven to conchoidal; the color is brilliant black, with metallic luster; the streak is black; hardness is 6 to 6.5; and the specific gravity as determined on the Berman microbalance is 5.05. Penfield and Foote[10] clearly state that 4.945, the specific gravity generally given for bixbyite, is "the specific gravity of the material used for the quantitative analysis. . . ." If this be corrected for 4½ per cent of included topaz,[11] the specific gravity of the bixbyite from Utah becomes 5.01. The correct specific gravity of bixbyite probably lies in the range of 5.0 to 5.1.

Fragments of bixbyite fuse with difficulty to a black magnetic slag before the blowpipe flame. Under the microscope the finely-crushed fragments transmit a dark smoky-brown color and are completely isotropic. The mineral is too nearly opaque to permit a satisfactory determination of the index of refraction.

Chemical composition.—Most of the reported chemical analyses of bixbyite, including an analysis of the new material from New Mexico, are given in Table 5.

The analyses given in Table 5 are restated in Table 6 to express all the oxides in the form of R_2O_3. In this way a direct comparison of the variability of the ratio of manganese to iron can be better shown.

The molecular ratios and molecular percentages calculated from these figures are shown in Table 7, rearranged in the order of decreasing amounts of Mn_2O_3.

[10] Penfield, S. L., and Foote, H. W.: *op. cit.*, p. 105.

[11] The percentage calculated on the basis of the alumina in the analysis. See Penfield and Foote, p. 106.

TABLE 5. COMPILATION OF CHEMICAL ANALYSES OF BIXBYITE

	1	2	3					4
			a	b	c	d	e	
SiO_2[a]	1.21	2.42	1.04	1.18	4.77	2.78	—	—
Al_2O_3[a]	2.53	—	—	3.89	3.27	4.24	—	0.47
FeO	—	44.85	52.41	50.99	47.61	48.68	53.21	—
Fe_2O_3	47.98	—	—	—	—	—	—	42.54
TiO_2	1.70	2.05	3.48	2.04	2.35	2.56	3.48	—
Ti_2O_3	—	—	—	—	—	—	—	1.57
MnO	42.05	—	—	—	—	—	—	—
MnO_2	—	50.71	42.37	41.51	42.44	42.03	42.79	—
Mn_2O_3	—	—	—	—	—	—	—	51.92
Avail. O	4.38	—	—	—	—	—	—	—
MgO	0.10	0.51	—	0.35	—	—	—	trace
CaO	—	—	—	—	—	—	—	none
Insoluble	—	—	—	—	—	—	—	2.21
	99.95	100.54	99.30	99.96	100.44	100.29	99.48	98.71

[a] Silica and alumina are regarded as impurities.

1. Thomas Range, Utah; H. W. Foote, analyst.
2. Valle de las Plumas, Patagonia; W. Schiller, analyst.
3. Valle de las Plumas, Patagonia; H. Corti, analyst (analyses were made of 5 different groups of crystals).
4. Black Range, New Mexico; W. T. Schaller, analyst (analysis was made on a quarter of a gram and is only approximate). A spectrographic analysis made by George Steiger shows small quantities of tin, copper, and zinc.

Although the values in Table 7 indicate that the ratio of Mn_2O_3 to Fe_2O_3 approaches 1:1, only the original analysis of bixbyite from Utah approaches it closely; manganese dominates in the bixbyite from New

TABLE 6. ANALYSES OF BIXBYITE, WITH OXIDES EXPRESSED AS R_2O_3

	1	2	3					4
			a	b	c	d	e	
Mn_2O_3	46.79	46.04	38.47	37.69	38.53	38.16	38.85	51.92
Fe_2O_3	47.98	49.84	58.25	56.67	52.91	54.10	59.13	42.54
Ti_2O_3	1.53	1.85	3.13	1.84	2.12	2.30	3.13	1.57
Others	3.84	2.93	1.04	5.42	8.04	7.02	—	2.68
	100.14	100.66	100.89	101.62	101.60	101.58	101.11	98.71

Mexico, whereas iron dominates in the bixbyite from Patagonia. The validity of the formula of bixbyite as (Mn''', Fe''')$_2$O$_3$, as given by Zachariasen[12] and later verified by Pauling and Shappell,[13] is therefore

TABLE 7. MOLECULAR RATIOS AND MOLECULAR PERCENTAGES, REARRANGED IN THE ORDER OF DECREASING AMOUNTS OF Mn_2O_3

	Molecular ratios							
	N. Mex.	Utah	Patagonia					
	4	1	2	3c	3d	3a	3e	3b
Mn_2O_3	.329	.296	.292	.244	.242	.244	.246	.239
Fe_2O_3	.266	.301	.312	.331	.339	.365	.370	.355
Ti_2O_3	.011	.011	.013	.015	.016	.022	.022	.013
	Molecular percentages							
	N. Mex.	Utah	Patagonia					
	4	1	2	3c	3d	3a	3e	3b
Mn_2O_3	54	49	47	41	40	39	39	39
Fe_2O_3	44	49	51	56	57	58	58	59
Ti_2O_3	2	2	2	3	3	3	3	2
	100	100	100	100	100	100	100	100

substantiated. The analyses suggest that Ti''' may also substitute in small quantity for Fe''' and Mn'''.

In other words, bixbyite is a solid solution of Mn_2O_3 and Fe_2O_3, with a close approach in the analyses from 3 localities to a 1:1 ratio. In this connection it may be noted that the length of the unit cell of artificial Mn_2O_3 (9.43, 9.41) is very close to that of bixbyite (9.36)[14], whereas that of cubic Fe_2O_3 ($\gamma-Fe_2O_3$) is much smaller (8.30, 8.40).

PSEUDOBROOKITE, $Fe_2O_3 \cdot TiO_2$

Occurrence and association.—Pseudobrookite was first discovered at

[12] Zachariasen, William, Ueber die Kristallstruktur von Bixbyit, sowie vom künstlichen Mn_2O_3: *Zeits. Krist.*, **67**, 455–471 (1928).

[13] Pauling, Linus, and Shappell, M.D., The crystal structure of bixbyite and the C-modification of the sesquioxides: *Zeits. Krist.*, **75**, 128–142 (1930).

[14] Powder pictures of Mn_2O_3 and of bixbyite taken by Dr. W. E. Richmond are identical.

Aranyer Berg, Transylvania, and described by Koch[15] in 1878. Subsequent discoveries have been made at Jumilla, Spain; Mont Dore, France; Havredal, Norway; Katzenbuckel, Baden; Mt. Vesuvius, Italy; Castello Branco, Azores; Berge Hadis, Caucasus; Puy de Dome, France; Crater Lake, Oregon; Hessenbrücker Hammers, Hesse; and in the Thomas Range, Utah. Crystals of artificial pseudobrookite formed by sublimation in a furnace were described by Doss[16] in 1892. A somewhat more complete summary of the history of the mineral is given by Palache.[17]

The discovery of pseudobrookite in the tin-bearing rhyolite in the Black Range in New Mexico is the third recorded occurrence in the United States. The mineral is also widely distributed in vesicles in the rhyolite in the tin-bearing area in northern Lander county, Nevada, examined by one of the authors (C. F.)[18] in the late summer of 1940. It was also found in some of the tin-bearing rhyolites in the states of Guanajuato, Zacatecas, and Durango, Republic of Mexico, by Dr. W. F. Foshag of the National Museum and one of the authors (C. F.) in the early spring of 1941. The mineral is probably widespread in its occurrence but overlooked because of its minute size or its resemblance to some types of amphibole.

Hand specimens of pseudobrookite from the Black Range were collected only from one of the bixbyite localities, as the crystals in the lithophysae there are fairly large and well formed. Fragments of the mineral are present in many of the heavy concentrates made from crushed specimens of the tin-bearing rhyolite. As all the fragments have good crystal faces on unbroken edges and termination on one end, it is assumed that all the pseudobrookite is present in cavities in the rhyolite. Minerals observed in the same cavities with the pseudobrookite are specularite, quartz, and opal. Pseudobrookite is more widely distributed in the tin-bearing rhyolite of the Black Range than is bixbyite.

A resume of the occurrences of pseudobrookite is given in Table 8. The associated minerals are not completely listed, except for the New Mexico and Nevada occurrences.

Crystallography.—The shining black prismatic crystals of pseudobrookite from New Mexico reach a length of about a millimeter and

[15] Koch, A., Neue minerale aus dem Andesit des Aranyer Berges in Siebenbürgen: *Tschermak's mineral. u. petrogr. Mittheil.*, new ser., **1**, 331–361 (1878).

[16] Doss, Bruno, Ueber eine zufällige Bildung von Pseudobrookit, Hämatit und Anhydrit als Sublimationsprodukte, und über die systematische Stellung des ersteren: *Zeits. Kryst.*, **20**, 569–584 (1892).

[17] Palache, Charles, Pseudobrookite: *Am. Mineral.*, **19**, 16–20 (1934). Also, Additional notes on pseudobrookite: *Am. Mineral.*, **20**, 660–663 (1935).

[18] Fries, Carl, Jr., Tin deposits of northern Lander county, Nevada: *U. S. Geol. Survey*, Bull. **931**, in press.

TABLE 8. OCCURRENCES OF PSEUDOBROOKITE AND ASSOCIATED MINERALS

Locality	Enclosing rock	Where present	Associated minerals
1. Aranyer Berg, Transylvania	Augite-andesite	In cavities and on fissure walls	Specularite Hypersthene (szaboite) Tridymite Garnet Amphibole Sphene Biotite
2. Jumilla, Spain	Volcanic rocks	?	Specularite Apatite (spargelstein)
3. Mont Dore, France	Augite-andesite	In cavities	Specularite Hypersthene (szaboite) Tridymite
4. Havredal, Norway	?	In veins	Quartz Apatite Feldspar Wagnerite (kjerulfine) Ilmenite?
5. Katzenbuckel, Baden	Nephelinite	In highly altered zone	Apatite Ilmenite
6. Mt. Vesuvius, Italy	Trachyte	In cavities	Mica Hematite Wagnerite? (crifiolite) Sellaite (belonesite) Gypsum Anhydrite
7. Castello Branco, Azores	Trachyte	In cavities	Hypersthene (szaboite)
8. Royat, Puy de Dome, France	Basalt	In cavities and on fissure walls	Specularite Pyroxene Feldspar (sanidine?) Magnetite Apatite Biotite
9. Berge Hadis, Caucasus	Augite-andesite	On fissure walls	Hypersthene (szaboite) Specularite
10. Crater Lake, Oregon	Basalt	In cavities	Hypersthene Apatite Tridymite?

TABLE 8. (*Continued*)

Locality	Enclosing rock	Where present	Associated minerals
11. Hessenbrücker Hammers, Hesse	Basalt	In highly altered zone	Magnetite
12. Thomas Range, Utah	Rhyolite	In cavities	Specularite Bixbyite Topaz Beryl Quartz Garnet Fluorite Calcite
13. Black Range, New Mexico	Rhyolite	In cavities and on fissure walls	Magnetite Bixbyite Specularite Sphene Topaz Garnet Cassiterite Sanidine Quartz Cristobalite Tridymite Chalcedony Opal Zeolites Fluorite Calcite
14. Lander county, Nevada	Rhyolite	In cavities and on fissure walls	Specularite Topaz Garnet Cassiterite Quartz Cristobalite Tridymite Chalcedony Opal Fluorite
15. Guanajuato, Zacatecas, and Durango, in Republic of Mexico	Rhyolitic lavas	In cavities and on fissure walls	Specularite Topaz Cassiterite Quartz Tridymite Chalcedony Opal Fluorite Zeolites

1. Koch, A.: *Op. cit.*
   Traube, H., Ueber den Pseudobrookit vom Aranyer Berge in Siebenbürgen: *Zeits. Kryst.*, **20,** 331 (1892).
2. Lewis, W. J., Krystallographische Notizen, (1) Pseudobrookit: *Zeits. Kryst.*, **7,** 181–182 (1883).
3. Von Lasaulx, A., Mineralogische Notizen, (2) Szaboit von Riveau grand im Mont Dore: *Zeits. Kryst.*, **3,** 293–294 (1879).
   ———, Pseudobrookit und Tridymit von Riveau grand im Mont Dore: *Sitz. ber. d. schles. Ges. f. vaterl. Cult.*, p. 19, Nov. 1879. (Abstr. in *Zeits. Kryst.*, **6,** 203, 1882.)
4. Cederström, Anders, Pseudobrookit in grossen Krystallen von Havredal, Bamle, Norwegen: *Zeits. Kryst.*, **17,** 133–136 (1890).
5. Lattermann, Georg, Untersuchungen über den Pseudobrookit: *Tschermak's mineral. u. petrogr. Mittheil.*, new ser., **9,** 47–54 (1887).
6. Krenner, J. A., Ueber den Pseudobrookit vom Vesuv: *Földtani Közlöny*, **18,** 153–157 (1888). (Abstr. in *Zeits. Kryst.*, **17,** 517–518, 1890.)
7. Mügge, O., Petrographische Untersuchungen an Gestenen von den Azoren: *Neues Jahrb. f. Min., Geolog., u. s. w.*, **2,** 194–196 (1883).
8. Lacroix, A. and Gautier, P., Sur les minéraux des fumerolles basaltiques de Royat (Puy de Dome): *Compt. Rend.*, **126,** 1529–1532 (1898).
9. Dannenberg, A., Beiträge zur Petrographie der Kaukasuslander, (2) Schluss: *Tschermak's mineral. u. petrogr. Mittheil.*, new ser., **23,** 26–29 (1904).
10. Diller, J. S. and Patton, H. B., The geology and petrology of Crater Lake National Park: *U. S. Geol. Survey, P.P.* **3,** 146–148 (1907).
11. Von Ramdohr, Paul, Ein neues Vorkommen von Pseudobrookit: *Notizblatt des Vereins f. Erdkunde u. der Hess. Geol. Landesanstalt zu Darmstadt*, ser. 5, pt. **5,** 191–193, 1920 (published 1923).
12. Palache, Charles, Minerals from Topaz Mt., Utah: *Op. cit.*
    Montgomery, Arthur: *Op. cit.*
13. Present paper.
14. Fries, Carl, Jr., Tin deposits of northern Lander county, Nevada: *Op. cit.*
15. Found by Dr. W. F. Foshag of the National Museum and one of the authors (C.F.) during a reconnaissance of the tin deposits of Mexico. (List of associated minerals is not complete.)

are about half to a fifth as wide. They are slightly flattened parallel to the front pinacoid, and in the prism zone the faces are strongly striated. In general habit they resemble the crystal from Topaz Mountain, Utah, shown by Palache.[19]

Three crystals were measured. Two of these (nos. 2 and 3) were attached to each other at a small angle, with a third, smaller and more needle-like crystal, not measured, projecting out from the two larger crystals. In most of these occurrences of pseudobrookite there is a marked tendency for several crystals to form slightly radiating groups. The forms present are given in Table 9.

The averages of the measured angles are given in Table 10.

The 6 new forms were all narrow prism faces. The measurements are given in Table 11.

[19] Palache, Charles, Pseudobrookite: *Op. cit.*, p. 19.

TABLE 9. FORMS ON THREE PSEUDOBROOKITE CRYSTALS FROM NEW MEXICO

Known forms	*a*{100} *l*{301}	*b*{010} *s*{121}	*h*{340} *p*{131}	*m*{110}	*μ*{210}	*e*{101}
New forms	*d*{560}	*g*{650}	*f*{11.10.0}	*i*{320}	*j*{830}	*k*{410}

The faces of *f*{11.10.0}, *i*{320}, and *j*{830} are all line faces, whereas some faces of *k*{410}, *g*{650}, and *d*{560} are as broad as some faces of *μ*{210}.

TABLE 10. AVERAGE MEASURED AND CALCULATED ANGLES OF PSEUDOBROOKITE FROM NEW MEXICO

a:*b*:*c*—0.9777:1:0.3727 (Palache 1934)

Forms	No. crystals	No. faces	Measured		Calculated	
			ϕ	ρ	ϕ	ρ
b{010}	1	1	0°00′	90°00′	0°00′	90°00′
a{100}	3	4	90 16	89 54	90 00	90 00
h{340}	1	1	36 44	90 00	37 30	90 00
**d*{560}	2	6	40 20	89 47	40 27	90 00
m{110}	1	1	46 51	90 25	45 39	90 00
**f*{11.10.0}	3	4	48 19	90 16	48 22	90 00
**g*{650}	2	3	50 40	89 57	50 50	90 00
**i*{320}	3	3	56 52	90 06	56 54	90 00
μ{210}	3	6	63 58	89 55	63 57	90 00
**j*{830}	3	6	69 23	89 43	69 52	90 00
**k*{410}	3	6	76 44	89 44	76 15	90 00
e{101}	1	2	89 57	21 18	90 00	20 52
l{301}	3	5	89 33	48 58	90 00	48 50
s{121}	3	7	27 45	40 26	27 05	39 56
p{131}	3	10	18 51	49 31	18 50	49 45

* New forms.

The dominant terminal form is *l*{301}, with the faces of *p*{131} much smaller. The unit front dome *e*{101} was observed on only one crystal as extremely narrow line faces. The faces of *s*{121} are mostly very small; some faces reflected mere points of light without signal. No faces of the unit pyramid *q*{111} were observed on any of the crystals.

Only one face of *b*{010} is present. Some faces of *a*{100} are replaced by a set of alternating striations or occur with other prisms as a continuous set of strongly striated narrow faces. On the rear side of crystal

TABLE 11. MEASUREMENTS OF SIX NEW PRISM FORMS ON PSEUDOBROOKITE FROM NEW MEXICO

Form	Crystal no.	Measured ϕ	Measured ρ	Form	Crystal no.	Measured ϕ	Measured ρ
d{560}	1	40°48′	89°20′	*i*{320}	1	57°03′	90°05′
	1	39 16	88 33		2	55 47	90 25
	1	40 51	90 00		2	57 06	89 52
	2	40 19	90 00		3	57 30	90 00
	2	39 51	90 25			(Calculated)	
	2	40 55	90 25			56 54	90 00
		(Calculated)		*j*{830}	1	70 34	88 33
		40 27	90 00		2	69 59	90 36
f{11.10.0}	1	47 29	90 14		2	69 20	89 14
	2	48 57	90 25		2	68 39	89 52
	2	48 51	90 25		3	68 32	90 00
	3	47 57	90 00		3	69 15	90 00
		(Calculated)				(Calculated)	
		48 22	90 00			69 52	90 00
g{650}	1	51 36	89 20	*k*{410}	1	75 30	89 59
	1	50 06	90 05		1	77 14	89 59
	2	50 18	90 25		2	77 09	90 00
		(Calculated)			2	76 28	89 14
		50 50	90 00		2	76 47	89 13
					3	77 16	90 00
						(Calculated)	
						76 15	90 00

no. 1, the broad face is $(\bar{2}10)$ with line faces of $(\bar{1}\bar{1}.10.0)$, $(\bar{6}50)$, $(\bar{3}20)$, $(\bar{4}10)$, and $(\bar{5}\bar{6}0)$ and narrow faces, much broader than line faces, of $(\bar{1}00)$, $(\bar{4}\bar{1}0)$, $(\bar{2}\bar{1}0)$, and $(\bar{6}\bar{5}0)$, the striated zone extending from $(\bar{1}\bar{1}.10.0)$ through $(\bar{2}10)$ to $(\bar{5}\bar{6}0)$. The faces of *m*{110} are likewise replaced by sets of striations containing the forms *d*{560}, *f*{11.10.0}, *g*{650}, and *i*{320}. Only one face gave a reading close to the ϕ value of *m*{110}.

ORIGIN

Bixbyite has been found in rhyolite and in trachyte; pseudobrookite occurs in rocks that vary in composition from rhyolite to basalt. In all the occurrences, except two of those for pseudobrookite (nos. 4 and 5 in Table 8), the enclosing rock is a lava flow or an associated pyroclastic bed. In each occurrence the bixbyite and the pseudobrookite formed later than the enclosing rock, either in cavities, on fissure walls, or in veins; neither mineral has been found as a pyrogenetic accessory.

It is clear that pseudobrookite may form by sublimation, for it has been found in the flues of furnaces in a soda factory.[20] At Mt. Vesuvius it was found in cavities in lavas less than 16 years after they were extruded. Earlier writers have attributed its origin to vapors escaping from bodies of cooling lava, in some places as fumaroles. The similarity in the occurrences for bixbyite and pseudobrookite suggests that they are formed by similar processes. It is reasonable to attribute the origin of the bixbyite and the pseudobrookite in the tin-bearing rhyolite of the Black Range to vapors escaping from the cooling flows.

[20] Doss, Bruno: *Op. cit.*