

SEVEN NEW BARIUM MINERALS FROM EASTERN  
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## ABSTRACT

Seven new barium-bearing silicate minerals have been found in eastern Fresno County, California. The minerals occur in sanbornite-bearing metamorphic rocks which out crop in a narrow zone  $2\frac{1}{2}$  miles long near a granodiorite contact.

Macdonaldite ( $\text{BaCa}_4\text{Si}_{15}\text{O}_{35}\cdot 11\text{H}_2\text{O}$ ) is biaxial (- or +),  $2V=90^\circ$ ,  $\alpha=1.518$ ,  $\beta=1.524$ ,  $\gamma=1.530$ , colorless,  $X=c$ ,  $Y=b$ ,  $Z=a$ ,  $G(\text{meas.})=2.27$ . It is orthorhombic,  $Bmmb$ ,  $B2mb$  or  $Bm2b$ ,  $a=14.06$ ,  $b=23.52$ ,  $c=13.08$ ,  $Z=4$ .

Krauskopfite ( $\text{BaSi}_2\text{O}_5\cdot 3\text{H}_2\text{O}$ ) is biaxial (-),  $2V=88^\circ$ ,  $\alpha=1.574$ ,  $\beta=1.587$ ,  $\gamma=1.599$ , colorless,  $X=b$ ,  $Y\Delta a=6^\circ$ ,  $Z\Delta c=10\frac{1}{2}^\circ$ ,  $a\Delta c=94^\circ 32'$ ,  $G(\text{meas.})=3.14$ . It is monoclinic,  $P2_1/a$ ,  $a=8.460$ ,  $b=10.622$ ,  $c=7.837$ ,  $\beta=94^\circ 32'$ ,  $Z=4$ .

Walstromite ( $\text{BaCa}_2\text{Si}_3\text{O}_9$ ) is biaxial (-),  $2V=30^\circ$ ,  $\alpha=1.668$ ,  $\beta=.1.684$ ,  $\gamma=1.685$ , colorless,  $G(\text{meas.})=3.67$ . It is triclinic,  $P\bar{1}$  or  $P1$ ,  $a=6.743$ ,  $b=9.607$ ,  $c=6.687$ ,  $\alpha=69^\circ 51'$ ,  $\beta=102^\circ 14'$ ,  $\gamma=97^\circ 6\frac{1}{2}'$ ,  $Z=2$ .

Fresnoite ( $\text{Ba}_2\text{TiSi}_2\text{O}_8$ ) is uniaxial (-),  $\omega=1.775$ ,  $\epsilon=1.765$ ,  $O=\text{colorless}$ ,  $E=\text{yellow}$ ,  $G(\text{meas.})=4.43$ . It is tetragonal,  $P4/mbm$ ,  $P4bm$ , or  $P\bar{4}b2$ ,  $a=8.52$ ,  $c=5.210$ ,  $Z=2$ .

Verplanckite ( $\text{Ba}_2(\text{Mn}, \text{Fe}, \text{Ti})\text{Si}_2\text{O}_6(\text{O}, \text{OH}, \text{Cl})_2\cdot 3\text{H}_2\text{O}$ ) is uniaxial (-),  $\omega=1.683$ ,  $\epsilon=1.672$ ,  $O=\text{orange-yellow}$ ,  $E=\text{colorless}$ ,  $G(\text{meas.})=3.52$ . It is hexagonal,  $P6/mmm$ ,  $P\bar{6}2m$ ,  $P\bar{6}m2$ ,  $P6mm$  or  $P622$ ,  $a=16.35$ ,  $c=7.17$ ,  $Z=6$ .

Muirite ( $\text{Ba}_{10}\text{Ca}_2\text{MnTiSi}_{10}\text{O}_{30}(\text{OH}, \text{Cl})_{10}$ ) is uniaxial (+),  $\omega=1.697$ ,  $\epsilon=1.704$ ,  $O=\text{orange}$ ,  $E=\text{colorless}$ ,  $G(\text{meas.})=3.86$ . It is tetragonal,  $P4/mmm$ ,  $P4mm$ ,  $P422$ ,  $P\bar{4}m2$  or  $P\bar{4}2m$ ,  $a=13.942$ ,  $c=5.590$ ,  $Z=1$ .

Traskite ( $\text{Ba}_5\text{FeTiSi}_6\text{O}_{18}(\text{OH})_4$ ) is uniaxial (-),  $\omega=1.714$ ,  $\epsilon=1.702$ ,  $O=\text{brownish-red}$ ,  $E=\text{colorless}$ ,  $G(\text{meas.})=3.71$ . It is hexagonal,  $P6/mmm$ ,  $P\bar{6}2m$ ,  $P\bar{6}m2$ ,  $P6mm$  or  $P622$ ,  $a=17.88$ ,  $c=12.30$ ,  $Z=6$ .

## INTRODUCTION

A number of new barium-bearing silicate minerals have been found during the course of a geological study of the sanbornite deposits of eastern Fresno County, California. Seven of the new minerals are described in this report; they are: macdonaldite, a hydrous barium calcium silicate ( $\text{BaCa}_4\text{Si}_{15}\text{O}_{35}\cdot 11\text{H}_2\text{O}$ ); krauskopfite, a hydrous barium silicate ( $\text{BaSi}_2\text{O}_5\cdot 3\text{H}_2\text{O}$ ); walstromite, a barium calcium silicate ( $\text{BaCa}_2\text{Si}_3\text{O}_9$ ); fresnoite, a barium titanium silicate ( $\text{Ba}_2\text{TiSi}_2\text{O}_8$ ); verplanckite, essentially a basic barium manganese silicate ( $\text{Ba}_2(\text{Mn}, \text{Fe}, \text{Ti})\text{Si}_2\text{O}_6(\text{O}, \text{OH}, \text{Cl})_2\cdot 3\text{H}_2\text{O}$ ); muirite, essentially a basic barium calcium manganese titanium silicate ( $\text{Ba}_{10}\text{Ca}_2\text{MnTiSi}_{10}\text{O}_{30}(\text{OH}, \text{Cl})_{10}$ ); and traskite, essentially a basic barium iron titanium silicate ( $\text{Ba}_5\text{FeTiSi}_6\text{O}_{18}(\text{OH})_4$ ). Specimens of the new minerals are preserved at the San Francisco office of the California Division of Mines and Geology.

The names have been approved by the Commission on New Minerals and Mineral Names of the International Mineralogical Association.

Several other unidentified and possibly new barium-bearing mineral are associated with the minerals herein described and they are now under study. The following barium minerals are associated with the new and unidentified minerals: sanbornite, taramellite, gillespite, celsian, witherite, barite and benitoite. The only previously known California locality for sanbornite, gillespite, celsian, and taramellite is north of Incline, Mariposa County.

Rogers (1932) described the then new mineral, sanbornite, and identified gillespite and celsian at the Incline locality. Rogers also noted a brown mineral in the Incline material; recently this brown mineral was identified as taramellite (R. M. Thompson, Univ. of British Columbia, written comm., 1962). A third California occurrence of taramellite has since been found in Santa Cruz County (E. B. Gross, Calif. Div. of Mines and Geology, pers. comm., 1963). Benitoite had been previously known to occur in outcrop in California only at the type locality, the Dallas Gem mine, San Benito County.

The occurrence of sanbornite and gillespite along Big Creek in eastern Fresno County was first brought to the attention of the California Division of Mines and Geology in 1957 when a sample containing gillespite and sanbornite was submitted by George M. Landers of North Fork, California, to the Division's public service laboratory for identification. In 1960 another sample containing sanbornite, this time from Rush Creek about 2½ miles north of Landers' Big Creek locality, was submitted by Robert E. Walstrom of Fresno, California, for identification. Shortly thereafter a field study of the sanbornite deposits of eastern Fresno County was begun by the Division to determine the geologic setting and potential commercial value of the deposits. A report on the geology of the sanbornite deposits is in preparation by Matthews and Alfors and it will include a discussion of the geochemistry and paragenesis of the new minerals. A brief description of the Rush Creek sanbornite deposits has been published (Matthews and Alfors, 1962) as has a brief note on eight new barium-bearing silicates (Stinson and Alfors, 1963). Six of the eight minerals are described in the present paper. Work on the other two minerals is in progress. Colored photographs of the seven new minerals herein described have been published along with a brief description (Stinson and Alfors, 1964; Alfors and Stinson, 1965).

The sanbornite deposits consist of gneissic metamorphic rocks which are composed mainly of variable amounts of sanbornite and quartz and minor amounts of pyrrhotite and diopside. The sanbornite-quartz rock forms conformable tabular bodies up to 40 feet thick within foliated

quartzite in a migmatite zone at or within a few hundred feet of the contact with a large granodiorite pluton. The trend of the outcrop of the sanbornite-bearing quartzite is sub-parallel to the granodiorite contact. The quartzite is conformably interbedded with steeply dipping mica schists, amphibole schists, and wollastonite-bearing quartzites. Sanbornite-quartz rock crops out sporadically in a north-trending zone  $2\frac{1}{2}$  miles long in sections 16, 17, 22, and 27, T. 11 S., R. 25 E., Mount Diablo Meridian (Fig. 2). The area, which is about 33 miles northeast of Fresno (Fig. 1), has been mapped in reconnaissance by Gordon A. Macdonald (1941) and Konrad B. Krauskopf (1953).

Pabst made the single crystal  $x$ -ray studies, using precession, Weissenberg, and oscillation techniques. He also indexed the powder patterns, related the optical orientations to the lattice directions, made some morphological observations, and carried out two syntheses. Work on the chemical compositions has been carried out by the staff of the California Division of Mines and Geology.

In 1962, the largest of the sanbornite outcrops in section 16 (Rush Creek deposits) was core drilled as a cooperative project with the U. S. Bureau of Mines. A report (Weiler *et al.*, 1963) on the results of the diamond drilling and beneficiation tests on the sanbornite-bearing core is on open file at the San Francisco offices of the U. S. Bureau of Mines and the California Division of Mines and Geology.

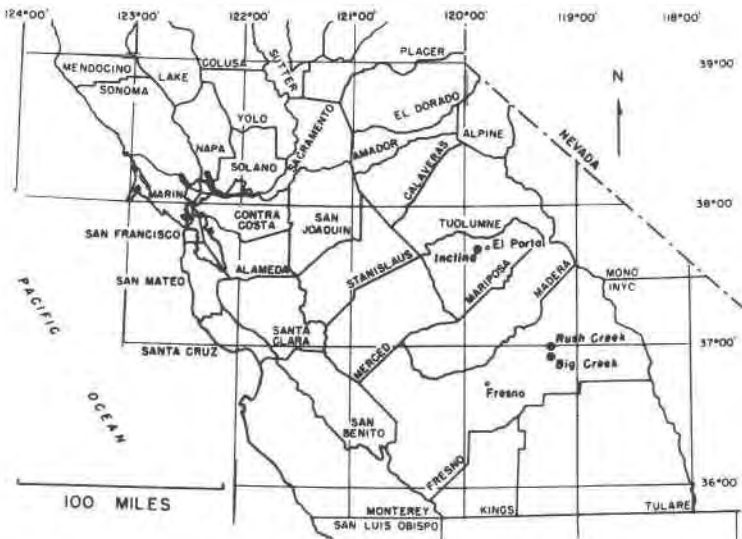


FIG. 1. Index map showing sanbornite localities in California.

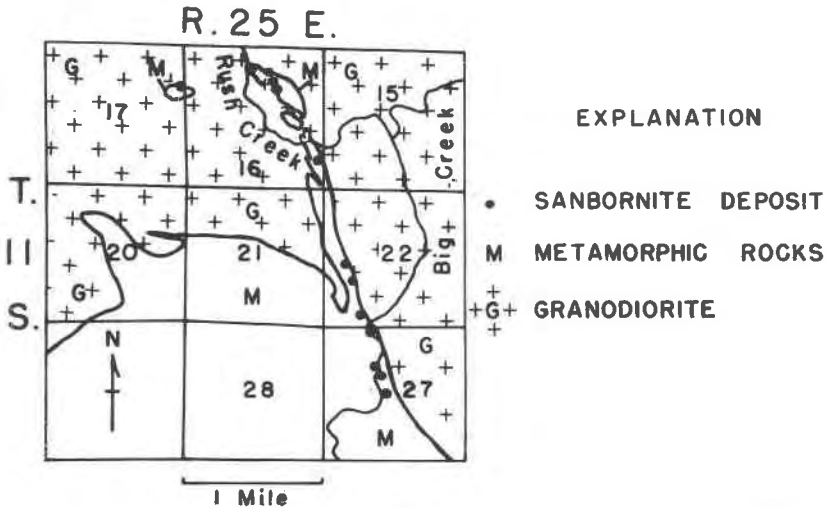


FIG. 2. Sketch geologic map showing the location of the sanbornite deposits of eastern Fresno County, California.

All of the larger sanbornite outcrops on U. S. Forest Service land are under mining claim. The principal claim owners are Robert E. Walstrom and associates in sections 16 and 27, and James and Loren Montgomery in section 22. Sanbornite-bearing rock also crops out on private land held by John van Leeuwen in section 16, J. A. Reiss in section 17, and Ted Forbes in section 16.

Macdonaldite is named for Gordon A. Macdonald, Senior Professor of Geology at the University of Hawaii. Krauskopfite is named for Konrad B. Krauskopf, Professor of Geochemistry at Stanford University. Walstromite is named for Robert E. Walstrom, mineral collector from Fresno, who discovered the mineral. Fresnoite is named for the county in which the mineral was found. Verplanckite is named for William E. Ver Planck (1916–1963), former Associate Geologist of the California Division of Mines and Geology. Muirite is named for John Muir (1838–1914) an American mountaineer, conservationist, and naturalist who made important observations in geology and glaciology in the Sierra Nevada. Traskite is named for John B. Trask (1824–1879) first State Geologist (1853–1856) of California.

#### OCCURRENCE

All of the new barium-bearing silicate minerals are found within or closely associated with sanbornite-quartz rock. Macdonaldite and krauskopfite are typically vein-forming minerals; the others occur sporadically

disseminated in sanbornite-quartz rock and they appear to have formed during the same period of metamorphism that produced the sanbornite.

Macdonaldite was first noted in March 1962 in samples of sanbornite-quartz rock collected by the authors from the NE $\frac{1}{4}$  sec. 16. It was subsequently recognized in nearly all outcrops of sanbornite-quartz rock in the Big Creek-Rush Creek area of eastern Fresno County, and in specimens collected from the type sanbornite locality north of Incline, Mariposa County, California. Macdonaldite forms small radiating crystal aggregates up to 12 mm in diameter and individual fibers as much as 6 mm long; more commonly the fibers are only about 1 mm long. Macdonaldite locally crystallizes along cleavage surfaces of sanbornite and coats joints and fractures as well as forming discrete veinlets. It has been found 30 feet below the ground surface as minute needle-shaped crystals lining a fracture in a drill core of sanbornite rock.

Krauskopfite was found in March 1962, during search for additional samples of macdonaldite in NE $\frac{1}{4}$  sec. 16; it has not been found elsewhere. Krauskopfite is typically a vein-forming mineral and is commonly associated with macdonaldite, opal, and witherite. The opal and witherite generally form the margin of the veinlets. Veinlets containing krauskopfite have been noted especially in weathered sanbornite-quartz rock where the sanbornite has altered to a white, opaque opaline substance and pyrrhotite has altered to limonite. Krauskopfite has also been found in relatively fresh rock. For example a diamond drill core taken from 70 feet below the ground surface contained a small veinlet of krauskopfite and opal. In addition to forming veinlets, krauskopfite also occurs as a replacement of sanbornite. Krauskopfite forms equidimensional to short prismatic grains up to 6 mm long, but more commonly the grains are 3 mm or less in length.

Walstromite was brought to our attention in August 1962 by Robert E. Walstrom, who recognized the distinctive character of the mineral even though it somewhat resembles sanbornite; later he was the first to notice the pink fluorescence, which has proved to be a great aid in the recognition of the mineral in the field. The original samples of walstromite came from blocks of sanbornite-bearing rock that had been blasted across Big Creek during construction of the U. S. Forest Service road near Landers' sanbornite and gillespite locality in sec. 27. Walstromite was later found in place in secs. 16, 22, and 27.

Walstromite occurs as individual grains disseminated in sanbornite-quartz rock, especially where the quartz content is high. It is sporadically distributed throughout nearly an entire 117 foot length of drill core taken from sec. 16. Walstromite is concentrated in layers or beds up to 6 mm thick in sec. 27 in rock rich in sanbornite. The layers of walstromite ap-

pear to represent original compositional differences in the pre-metamorphic sedimentary rocks. Walstromite occurs in sec. 22 in wollastonite-bearing quartzite that contains little or no sanbornite. It is one of the coarsest-grained and the most abundant of the new minerals, although it is not as widely distributed as macdonaldite or fresnoite. Grains as large as 12 mm long, 6 mm wide and 6 mm thick are not uncommon, but, nearly all of the grains contain tiny rounded inclusions of celsian or quartz that cause difficulty in isolating pure samples of the mineral. Walstromite is associated with sanbornite, quartz, wollastonite, celsian, taramellite, pyrrhotite, pyrite, witherite, fresnoite and an unidentified blue iron-barium silicate mineral.

Fresnoite was first noted in April 1960 during preliminary examination of the Rush Creek sanbornite outcrops, but at that time it was assumed to be idocrase. In 1962 when detailed mapping of the Rush Creek sanbornite deposits was in progress, an *x*-ray powder diffraction pattern of the mineral was made that proved the mineral was not idocrase. It has subsequently been observed in nearly all outcrops of sanbornite-bearing rock, and is one of the most widespread of the new minerals. Fresnoite is found in gneissic sanbornite-quartz rock and in quartzite that is poor or lacking in sanbornite. Locally it is concentrated in thin layers in quartzite associated with celsian, taramellite, diopside, and pyrrhotite. The individual grains are generally less than 1 mm long and sparsely distributed so that it is difficult to isolate a large amount of the pure mineral.

Verplanckite was brought to our attention in September 1962 by Dr. Stewart Agrell of Cambridge University during a field trip conducted by one of the authors to the Fresno County sanbornite deposits. The mineral was first noted in pieces of rock that had been blasted into Big Creek from the gillespite locality in sec. 27. Verplanckite occurs as radial masses of brownish-orange prismatic crystals up to 3 mm long and as disseminated grains, locally concentrated in thin layers, in sanbornite-quartz rock. Although the mineral probably occurs in all the outcrops of sanbornite-quartz rock in Fresno County, it is exceedingly rare. It occurs sporadically in the drill core from sec. 16. Associated minerals include: quartz, sanbornite, celsian, diopside, taramellite, pyrrhotite, pyrite, fresnoite, muirite and traskite.

Muirite was recognized to be a distinct mineral by Pabst in January 1963. After some preliminary work on a few grains of verplanckite in October 1962, Pabst asked for more material and in December 1962, some intense orange grains, which were thought to be verplanckite were provided. The intense orange grains proved to be tetragonal rather than hexagonal and thus distinct from verplanckite. The original grains of

muirite came from the same piece of float as did verplanckite; later the mineral was found in outcrop in secs. 16, 22, and 27. Although verplanckite and muirite are commonly associated, one or the other is more abundant in any one hand specimen. The grains are generally 1 mm or less in diameter and sparsely distributed.

Traskite was found in October 1962 in the same piece of float from sec. 27 which had yielded verplanckite and muirite. A brownish-red mineral, which later proved to be traskite, was previously noted in the Rush Creek sanbornite deposits; but when first noticed, the mineral was thought to be a variety of taramellite. Traskite occurs as tiny grains, generally less than 1 mm in diameter, sporadically distributed in the same rocks as verplanckite and muirite; but it also is present in quartz-sanbornite rock in which verplanckite and muirite are lacking. Traskite has been found in several outcrops in secs. 16, 22, and 27. It is probably the rarest of the minerals herein described.

#### SEPARATION AND PURIFICATION

The general procedure for separating fresnoite, verplanckite, muirite and traskite for chemical analysis involved crushing and sieving the rock and passing the material retained on the 120 and 230 mesh sieves through a Franz isodynamic separator. Fresnoite is concentrated in the non-magnetic fraction along with sanbornite, celsian, and quartz. Verplanckite comes out in the magnetic fraction with an electromagnet field current of 0.8 amperes, a tilt of 15 degrees, and a slope of 25 degrees. Taramellite and diopside come out in the magnetic fraction with verplanckite. Similarly, traskite is concentrated with a current of 1 ampere and muirite with a current of 1.5 amperes.

Fresnoite was further concentrated in heavy media. The final separation for all minerals was made by hand-picking under a binocular microscope. The purified concentrates were checked in oils under a petrographic microscope and grains which contained inclusions were discarded.

Because of the relatively large grain size of macdonaldite, krauskopfite and walstromite, it was possible to dig out individual grains of these minerals without crushing the rocks.

#### ANALYTICAL PROCEDURE

George W. Putman of the California Division of Mines and Geology analyzed the minerals by d-c arc emission spectrograph methods utilizing a borate fusion technique described by Joensuu and Suhr (1962). The minerals were fused in 5 parts by weight of lithium tetraborate and one part lithium tetraborate which contained approximately 7 per cent  $\text{Co}_3\text{O}_4$  as an internal standard. The resulting borate beads were crushed

and mixed with two parts of graphite. Two  $\frac{1}{8}$  inch diameter graphite electrodes were each loaded with a charge that included the equivalent of about 3 mg of mineral and were burned to completion with a Stallwood jet in carbon dioxide.

The results of replicate analyses indicate that the level of precision is comparable to that obtained by Joensuu and Suhr (1962). A check on the accuracy was obtained by analyzing sanbornite, celsian, and gillespite together with the new minerals. The spectrographic analyses of the known minerals compared favorably with reported analyses and theoretical compositions. In addition Matti Tavela, California Division of Mines and Geology, analyzed 100 mg samples of macdonaldite and sanbornite by conventional wet chemical methods. The wet chemical analyses are similar to the spectrographic results. The wet chemical and spectrographic analyses are not strictly comparable because they were not made on splits of the same sample. Each sample contained very small but somewhat different amounts of impurity. A dehydration study of krauskopfite and syntheses of walstromite and fresnoite (described later in the paper) provided an additional check on the accuracy of the chemical analyses of these minerals.

All of the spectrographic analyses have been calculated from the instrumental data to yield a total as near 100 per cent as is consistent with the analytical precision. For example the two analyses of walstromite (Table 2, analyses 6 and 7) which were made on different samples with different internal standard concentrations, gave instrumental totals of 103.5 per cent and 91.5 per cent respectively. Calculated to 100 per cent the analyses yield similar results. The difference in the instrumental totals is due simply to errors in weighing out equal amounts of sample and internal standard. As long as a complete analysis is made no errors are introduced by this calculation. No change in the ratio of the spectrographically determined constituents is involved and no constituent is deleted. Most instrumental totals fell in the range between 95 per cent and 104 per cent. The weight per cent of water, chlorine, and potassium was not changed in the calculation to 100 per cent.

Two separate samples each of macdonaldite, krauskopfite, walstromite, fresnoite and verplanckite were analyzed. For the first analyses (except for verplanckite) the borate fusions were ground in a diamonite mortar, which resulted in an excessive aluminum contamination; for the second analyses a boron carbide mortar, which was kindly provided by George M. Gordon of the University of California, was used and resulted in no detectable contamination. Muirite and traskite were analyzed once on samples ground in the boron carbide mortar.

About 10 mg of macdonaldite, krauskopfite, walstromite, fresnoite and



verplanckite were picked for each analysis, but only about 6 mg each of muirite and traskite were used.

Sodium and potassium were not detected in the emission spectrographic analyses. The limit of detection for sodium was about 0.5 per cent and for potassium about 1.5 per cent. Krauskopfite, walstromite, fresnoite, verplanckite, muirite and traskite were analyzed for potassium by x-ray spectrochemical methods and all contained 0.1 per cent or less.

The water contents of 100 mg of macdonaldite and krauskopfite, 60 mg of verplanckite and 10 mg of muirite were determined by ignition loss. The water content of 21 mg of traskite was determined by a modification of the Penfield method. The modification consisted of fusing the samples in a flux of anhydrous sodium tungstate and collecting the water on filter paper that was chilled by a jacket of dry ice.

The chlorine was determined by x-ray spectrochemical methods. The maximum error of the chlorine analyses is estimated to be  $\pm 0.5\%$ .

#### MACDONALDITE

*Physical Properties.* Macdonaldite is white to colorless with a satiny to vitreous luster and white streak. The mineral does not fluoresce under ultraviolet light. Tiny needle-like crystals exhibit the forms  $\{010\}$ ,  $\{001\}$ , and  $\{100\}$  and are elongate parallel to the  $a$  axis. The  $\{010\}$  form is the

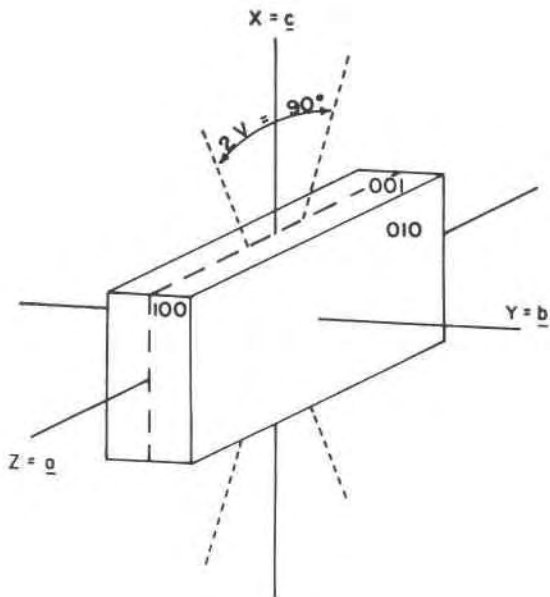


FIG. 3. Typical habit and optical orientation of macdonaldite.

TABLE 1. OPTICAL PROPERTIES OF THE SEVEN NEW BARIUM MINERALS FROM EASTERN FRESNO COUNTY, CALIFORNIA

	Macdonaldite	Krauskopfite	Walstromite
$\alpha$	orthorhombic 1.518 ± .002	monoclinic 1.574 ± .002	triclinic 1.668 ± .002
$\beta$	1.524 ± .002	1.587 ± .002	1.684 ± .002
$\gamma$	1.530 ± .002	1.599 ± .002	1.685 ± .002
2V (U-stage)	90° ± 5°	88° ± 5°	30°
2V (calc)	90°	87° 42'	28°
Sign	biaxial (- or +)	biaxial (-)	biaxial (-)
Dispersion	inconspicuous	r > v, distinct	weak
Orientation	X = c Y = b Z = a	X = b Y ∧ a = 6° Z ∧ c = 10½° a ∧ c = 94° 32' ± 8'	see Fig. 6
X = Y = Z =	colorless	colorless	colorless

	Fresnoite	Verplanckite	Muirite	Traskite
$\omega$	tetragonal 1.775 ± .003	hexagonal 1.683 ± .002	tetragonal 1.697 ± .001	hexagonal 1.714 ± .003
$\epsilon$	1.765 ± .003	1.672 ± .002	1.704 ± .002	1.702 ± .003
O	colorless	orange-yellow	orange	brownish red
E	yellow	colorless	colorless	colorless or straw yellow
Sign	uniaxial (-)	uniaxial (-)	uniaxial (+)	uniaxial (-)

largest. It is about twice the size of the {001} form and ten times the size of the {100} form. The mineral has two cleavages at 90° and possibly a third, also at 90°: (010) is perfect, (001) is good, and (100) is poor or a fracture. The intersection of (010) and (001) cleavages accentuates the fibrous habit of the mineral. The grains range from less than 1 mm in length to 6 mm, with the average length about 1 to 2 mm. The hardness is 3½ to 4 on Mohs scale. The specific gravity of 2.27 ± .02 gm/cm<sup>3</sup> was determined on a Berman balance using a weighted average of four grains totaling 41.48 mg. The density was determined at 22° C. All other measured densities were determined under similar conditions.

*Optical Data.* Macdonaldite is colorless in all orientations in transmitted light. The optical properties are given in Table 1. The cleavage fragments are straight extinguishing, and nearly always lie on the perfect (010) cleavage.

The typical habit and optical orientation of macdonaldite are shown in Fig. 3.

*Chemical Properties.* Three separate chemical analyses of macdonaldite have been made; two by d-c arc emission spectrograph and one by standard wet chemical methods. The results of these analyses are presented in Tables 2 and 3. The ideal formula is  $\text{BaCa}_4\text{Si}_{15}\text{O}_{35} \cdot 11\text{H}_2\text{O}$ . Samples of macdonaldite picked for the analyses were washed in dilute hydrochloric acid to eliminate witherite contamination. They probably contained less than one per cent limonite and opal impurities.

Macdonaldite is insoluble in cold acids and bases, but it is decomposed by boiling 1:1 hydrochloric acid. After boiling in hydrochloric acid, a transparent platy silica residue remains which is biaxial with a large 2V and somewhat lower birefringence than macdonaldite. The refractive indices of the leached material are variable ranging from 1.440 to 1.460. The leached material is straight extinguishing, length slow, and gives a weak x-ray powder diffraction pattern.

Macdonaldite gives off water in a closed tube test and fuses at about  $5\frac{1}{2}$ . A thermogravimetric analysis was made by Robert Langston of the University of California, Fig. 4. A 101.1 mg sample of macdonaldite was subjected to a temperature rise of  $4^\circ \text{C}$ . per minute over a range extending from  $30^\circ$  to  $851^\circ \text{C}$ . The mineral begins to lose weight at  $80^\circ \text{C}$ . and the weight loss is continuous up to  $851^\circ \text{C}$ . One break occurs in the curve between  $220^\circ$  and  $270^\circ \text{C}$ . indicating a sudden weight loss of 2.1 per cent. The thermogravimetric curve resembles those of mesolite and scolecite (Fedoseyev and Korytkova, 1963).

Heated in an electric furnace, the mineral shows no significant change in appearance until  $1200^\circ \text{C}$ . when it turns opaque white and the weight loss has totaled 13.7 per cent. At  $1300^\circ \text{C}$ . macdonaldite shows no further change but the grain tested adhered to the plate on which it was heated, and it may have been near its melting point.

*X-ray Data.* The crystallographic data for the seven new barium-bearing silicate minerals are given in Table 4, together with the calculated and measured densities. The powder patterns of the seven new barium minerals have been tabulated together in Table 5 and have been indexed from the single crystal data in Table 4. Calculated spacings are given only for observed lines to conserve space. Indexing has been determined by checking against indexed single crystal patterns.

#### KRAUSKOPFITE

*Physical Properties.* Krauskopfite is white to colorless and has a white streak. The luster is subvitreous, but is pearly on cleavage plates. The mineral does not fluoresce under ultraviolet light. No crystals of krauskopfite with well-formed faces have been observed. The mineral has two

TABLE 2. ANALYSES OF THE SEVEN NEW MINERALS FROM EASTERN FRESNO COUNTY, CALIFORNIA

Oxides in Wt. %	Macdonaldite		Krauskopffite	Walstromite		Fresnoite		Verplanckite		Muirite	Traskite		
	1	2		3	4	5	6	7	8			9	10
SiO <sub>2</sub>	61.1	62.1	61.2	35.2	35.95	39.6	38.8	21.8	23.8	20.3	20.6	21.6	28.2
Al <sub>2</sub> O <sub>3</sub>	0.06	—	—	0.05	—	0.07	—	0.12	—	0.33	0.68	0.70	0.47
TiO <sub>2</sub>	0.01	0.03	0.96	0.01	0.03	<0.01	0.03	17.2	15.2	2.05	1.73	4.2	5.9
FeO <sup>1</sup>	<0.01	0.1	—	<0.01	0.1	<0.02	<0.1	1.0	0.77	0.8	1.9	0.4	4.6
MnO	0.004	<0.01	—	<0.002	<0.01	0.33	0.18	0.027	0.074	8.8	8.7	2.06	1.4
MgO	<0.05	0.10	—	<0.05	0.10	<0.05	<0.1	<0.05	0.19	0.25	0.15	0.11	0.33
CaO	14.8	14.95	15.3	0.11	0.41	26.1	26.2	0.14	0.55	0.25	0.19	4.7	0.92
K <sub>2</sub> O <sup>2</sup>	—	—	—	<0.1	<0.1	<0.05	<0.05	nil	nil	<0.05	<0.05	0.1	<0.05
BaO	10.2	9.0	9.3	47.7	46.6	33.3	34.5	59.4	59.4	53.8	52.7	60.1	55.2
SrO	<0.05	—	—	<0.05	—	0.53	—	0.28	—	0.07	—	0.13	0.36
H <sub>2</sub> O <sup>3</sup>	13.7	13.7	13.7	16.7	16.7	nil	nil	nil	nil	10.6	10.6	2.4	2.6
Cl <sup>4</sup>	—	—	—	—	—	—	—	—	—	3.5	3.5	4.5	—
—(O≡Cl)	—	—	—	—	—	—	—	—	—	-0.8	-0.8	-1.0	—
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

M. Tavela made analysis 3 by wet chemical means. The sample used for analysis 3 was oxidized during analysis so that any iron and manganese would have been converted to Fe<sub>2</sub>O<sub>3</sub> and Mn<sub>2</sub>O<sub>3</sub>.

G. W. Putman made all other analyses by d-c arc emission spectrograph methods. The spectrographic analyses have been calculated to 100% from instrumental totals. All spectrographic analytical results reported are the mean of duplicate determinations. Each reported analysis was made on a separate sample and was not a split of material used for any other reported analysis.

<sup>1</sup> Iron was determined as Fe<sup>2+</sup> in the spectrographic analyses, but is reported as FeO.

<sup>2</sup> K<sub>2</sub>O was determined by x-ray spectrochemical methods.

<sup>3</sup> Water in analyses 1, 2, 3, 4, 5, 10, 11 and 12 was determined by ignition loss, in analysis 13 by a modification of the Penfield Method.

<sup>4</sup> Chlorine was determined by x-ray spectrochemical methods.

Samples 1, 2, 3, 4, 5, and 8 are from Sec. 16, T. 11 S., R. 25 E.; other samples are from Sec. 27, T. 11 S., R. 25 E.

perfect cleavages (010) and (001) at 90° and a third poor cleavage or fracture at a high angle to the other two. The intersection of the two perfect cleavages results in elongation in the direction of the *a* axis. The grain size ranges from less than 1 mm to 6 mm and averages about 2 mm. The mineral has a hardness of about 4. A density of  $3.14 \pm 0.02$  gm/cm<sub>3</sub> was determined from a weighted average of 4 grains totaling 22.40 mg. The grains used for the density determination contained a small amount of witherite and for this reason the measured density is higher than the calculated density (Table 4).

*Optical Data.* Krauskopfite is colorless in transmitted light. The optical properties are given in Table 1. The intersection of the perfect cleavages (010) and (001) results in fragments elongated nearly parallel to Y, thus the cleavage fragments can be either length fast or length slow. The optic

TABLE 3. NUMBER OF IONS IN UNIT CELLS OF THE SEVEN NEW BARIUM MINERALS FROM EASTERN FRESNO COUNTY, CALIFORNIA

	Macdonaldite 1 <sup>1</sup>	Krauskopfite 4	Walstromite 6	Fresnoite 9	Verplanckite 11	Muirite 12	Traskite 13
Si	60.14	7.78	5.78	4.00	12.07	9.08	35.72
Al	0.07	0.01	—	—	0.47	0.35	0.70
Ti	0.01	—	—	1.92	0.76	1.33	5.59
Fe	0.01	—	—	0.10	0.93	0.14	4.87
Mn	—	—	0.04	0.01	4.32	0.73	1.50
Mg	0.07	0.02	0.01	0.05	0.14	0.07	0.62
Ca	15.61	0.03	4.08	0.10	0.12	2.12	1.25
K	—	0.03	0.01	—	0.04	0.05	0.08
Ba	3.93	4.13	1.91	3.90	12.10	9.90	27.39
Sr	0.03	0.01	0.04	—	—	0.03	0.26
H	89.95	24.62	—	—	41.42	6.73	21.96
Cl	—	—	—	—	3.47	3.21	—
O	185.03	32.09	17.65	16.00	62.91	36.15	130.60

<sup>1</sup> Specimen numbers correspond to those of Table 2. Values are significant only to first decimal place.

- $4 [Ba_{0.98}Sr_{0.01}]_{0.99}(Ca_{3.90}Mg_{0.02})_{2.92}(Si_{15.03}Al_{0.02})_{15.05}O_{35.01} \cdot 11.24H_2O]$
- $4 [(Ba_{1.03}K_{0.01}Ca_{0.01})_{1.05}Si_{1.95}O_{4.95} \cdot 3.08H_2O]$
- $2 [(Ba_{0.96}Sr_{0.02})_{0.98}(Ca_{2.04}Mn_{0.02})_{2.06}Si_{2.89}O_{8.83}]$
- $2 [Ba_{1.95}Ca_{0.05}]_{2.00}(Ti_{0.96}Mn_{0.01}Mg_{0.02}Fe_{0.05})_{1.04}Si_{2.00}O_{8.00}]$
- $6 [(Ba_{2.02}Ca_{0.02})_{2.04}(Mn_{0.72}Fe_{0.15}Ti_{0.13}Mg_{0.02})_{1.02}(Si_{2.01}Al_{0.08})_{2.09}O_{6.19}(O_{0.25}OH_{1.17}Cl_{0.58})_{2.00} \cdot 2.87H_2O]$
- $[(Ba_{9.90}Sr_{0.03}K_{0.06})_{9.98}Ca_{2.12}(Mn_{0.73}Fe_{0.14}Mg_{0.07})_{0.94}Ti_{1.33}(Si_{9.08}Al_{0.36})_{9.43}O_{29.42}(OH_{6.73}Cl_{3.21})_{9.94}]$
- $6 [(Ba_{4.57}Ca_{0.21}Sr_{0.04}K_{0.01})_{4.83}(Fe_{0.81}Mn_{0.25}Mg_{0.10})_{1.16}(Ti_{0.93}Al_{0.07})_{1.00}(Si_{5.95}Al_{0.05})_{6.00}O_{18.11}(OH)_{3.66}]$

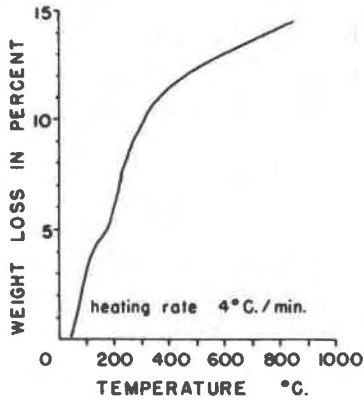


FIG. 4. Thermogravimetric curve of macdonaldite. The sample run contained some opal. Thermogravimetric analysis by Robert B. Langston, University of California, Berkeley.

plane is nearly normal to the elongation of the cleavage fragments. The optic orientation is shown in Fig. 5.

*Chemical Properties.* Two separate chemical analyses of krauskopfite have been made by d-c arc emission spectrograph. The water content was determined by ignition loss at 450° C on a separate 100 mg sample. The material analyzed spectrographically contained less than 5 per cent, probably less than 2 per cent, witherite and macdonaldite. The material used for the ignition loss determination contained  $6 \pm 1$  per cent witherite by volume, measured by point count after heating. This volume per cent corresponds to  $8 \pm 1$  per cent witherite by weight. None of the weight loss can be attributed to witherite because it decomposes at 810° C. Thus the measured weight loss of 15.4 per cent corresponds to an actual loss of

TABLE 4. CRYSTALLOGRAPHIC DATA FOR THE SEVEN NEW BARIUM MINERALS FROM EASTERN FRESNO COUNTY, CALIFORNIA

	Macdonaldite	Krauskopfite	Walstromite
System	orthorhombic	monoclinic	triclinic
Space Group	<i>Bmmb</i> , <i>Bm2b</i> , or <i>B2mb</i>	<i>C2h</i> - <i>P2<sub>1</sub>/a</i>	<i>P</i> $\bar{1}$ or <i>P1</i>
<i>a</i>	14.06 $\pm$ 0.01 Å	8.460 $\pm$ 0.005 Å	6.743 $\pm$ 0.005 Å
<i>b</i>	23.52 $\pm$ 0.02	10.622 $\pm$ 0.066	9.607 $\pm$ 0.005
<i>c</i>	13.08 $\pm$ 0.01	7.837 $\pm$ 0.004	6.687 $\pm$ 0.005
$\alpha$			69° 51'
$\beta$		94° 32' $\pm$ 8'	102° 14'
$\gamma$			97° 6½'
<i>a</i> : <i>b</i> : <i>c</i>	0.5979:1:0.5561	0.7965:1:0.7378	0.7019:1:0.6961
Density	2.27 $\pm$ 0.02 (meas.) 2.27 calculated from Ba <sub>4</sub> Ca <sub>16</sub> Si <sub>60</sub> O <sub>140</sub> · 44H <sub>2</sub> O	3.14 $\pm$ 0.02 (meas.) 3.10 calculated from Ba <sub>4</sub> Si <sub>8</sub> O <sub>20</sub> · 12H <sub>2</sub> O	3.67 $\pm$ 0.06 (meas.) 3.73 calculated from Ba <sub>2</sub> Ca <sub>4</sub> Si <sub>6</sub> O <sub>18</sub>
Cell Content	4[Ba <sub>4</sub> Ca <sub>16</sub> Si <sub>60</sub> O <sub>140</sub> · 11H <sub>2</sub> O]	4[BaSi <sub>2</sub> O <sub>8</sub> · 3H <sub>2</sub> O]	2[BaCa <sub>2</sub> Si <sub>3</sub> O <sub>9</sub> ]

TABLE 4. CRYSTALLOGRAPHIC DATA FOR THE SEVEN NEW BARIUM MINERALS FROM EASTERN FRESNO COUNTY, CALIFORNIA—(continued)

System Space Group	Fresnoite	Verplanckite	Muirite	Traskite
<i>a</i>	tetragonal <i>P</i> 4/ <i>m</i> <i>b</i> <i>m</i> , <i>P</i> 4 <i>b</i> <i>m</i> , or <i>P</i> 4 <i>b</i> 2,	hexagonal <i>P</i> 6/ <i>m</i> <i>m</i> <i>m</i> , <i>P</i> 62 <i>m</i> , <i>P</i> 6 <i>m</i> 2, <i>P</i> 6 <i>m</i> <i>m</i> , or <i>P</i> 622.	tetragonal <i>P</i> 4/ <i>m</i> <i>m</i> <i>m</i> , <i>P</i> 4 <i>m</i> <i>m</i> , <i>P</i> 422, <i>P</i> 42 <i>m</i> , or <i>P</i> 4 <i>m</i> 2.	hexagonal <i>P</i> 6/ <i>m</i> <i>m</i> <i>m</i> , <i>P</i> 6 <i>m</i> <i>m</i> , <i>P</i> 622, <i>P</i> 62 <i>m</i> , or <i>P</i> 6 <i>m</i> 2.
<i>c</i>	8.52 ± 0.01 Å	16.35 ± 0.02 Å	13.942 ± 0.015 Å	17.88 ± 0.02 Å
<i>c/a</i>	5.210 ± 0.005	7.17 ± 0.02	5.590 ± 0.010	12.30 ± 0.02
Density	0.6115	0.4388	0.4009	0.688
	4.43 ± 0.02 (meas.)	3.52 ± 0.02 (meas.)	3.86 ± 0.02 (meas.)	3.71 ± 0.02 (meas.)
	4.45 calculated from Ba <sub>1</sub> Ti <sub>2</sub> Si <sub>2</sub> O <sub>10</sub>	3.45 calculated from (Ba <sub>11.84</sub> , Ca <sub>0.15</sub> , K <sub>0.02</sub> ) <sub>12</sub> (Mn <sub>4.23</sub> , Ti <sub>10.74</sub> , Fe <sub>0.94</sub> , Mg <sub>0.10</sub> )/(Si <sub>1.55</sub> , Al <sub>0.40</sub> ) <sub>12</sub>	3.87 calculated from (Ba <sub>0.92</sub> , Sr <sub>0.02</sub> , K <sub>0.02</sub> ) <sub>10</sub>	3.76 calculated from (Ba <sub>23.25</sub> , Ca <sub>1.05</sub> , Sr <sub>0.27</sub> , K <sub>0.09</sub> ) <sub>30</sub> (Fe <sub>1.15</sub> , Mn <sub>1.29</sub> , Mg <sub>0.22</sub> )/(Ti <sub>3.59</sub> , Al <sub>0.40</sub> ) <sub>18</sub>
Cell Content	2[Ba <sub>2</sub> TiSi <sub>2</sub> O <sub>8</sub> ]	O <sub>26.70</sub> (OH <sub>0.39</sub> , OH <sub>7.05</sub> , Cl <sub>3.47</sub> ) <sub>12</sub> · 18H <sub>2</sub> O 6[Ba <sub>2</sub> MnSi <sub>2</sub> O <sub>8</sub> (OH, Cl) <sub>2</sub> · 3H <sub>2</sub> O]	O <sub>29.73</sub> (OH <sub>6.73</sub> , Cl <sub>3.21</sub> ) <sub>10</sub> [Ba <sub>10</sub> Ca <sub>2</sub> TiMnSi <sub>10</sub> O <sub>30</sub> (OH, Cl) <sub>10</sub> ]	(Si <sub>55.75</sub> , Al <sub>0.23</sub> ) <sub>36</sub> O <sub>107.60</sub> (OH) <sub>24</sub> 6[Ba <sub>3</sub> FeTiSi <sub>6</sub> O <sub>18</sub> (OH) <sub>4</sub> ]

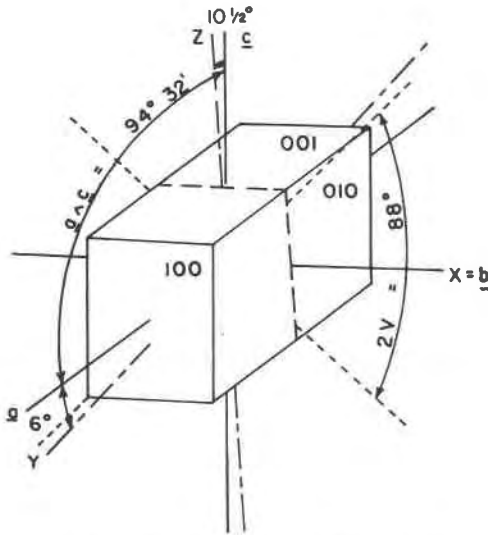


FIG. 5. Optical orientation of krauskopfit.

16.7 per cent. The results of the analyses are given in Tables 2 and 3. The ideal formula is  $\text{BaSi}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$ .

Krauskopfit is readily decomposed by cold dilute acids leaving a white to transparent silica residue. The mineral is not affected by weak bases.

Krauskopfit gives off water in a closed tube test and fuses at about 5 to a colorless bead. The mineral is stable at  $100^\circ \text{C}$ ., but when heated in an electric furnace to  $300^\circ \text{C}$ . it decrepitates and turns opaque white. At  $450^\circ \text{C}$ . the mineral has a total weight loss of 16.7 per cent. On continued heating there is no further change up to  $1200^\circ \text{C}$ .. When heated to  $1300^\circ \text{C}$ ., the mineral partially melts to a colorless glass. One grain of krauskopfit was fused before a blowpipe, placed in an electric furnace at  $1300^\circ \text{C}$ ., and allowed to cool slowly to room temperature. The resulting material, which had a gray pearly sheen, was then x-rayed; it gave a powder diffraction pattern identical to sanbornite ( $\text{BaSi}_2\text{O}_5$ ) with no extraneous lines. The composition of krauskopfit is thus confirmed to be  $\text{BaSi}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$  or some very similar hydrate.

*X-ray Data.* The crystallography of krauskopfit is given in Table 4, together with the calculated and measured densities. The powder diffraction data given in Table 5 have been indexed from the single crystal data in Table 4.

#### WALSTROMITE

*Physical Properties.* Walstromite is white to colorless, has a white streak, and fluoresces dull pink under short wave ultraviolet light ( $2652 \text{ \AA}$ ), and



TABLE 5. X-RAY POWDER DATA FOR THE NEW BARIUM MINERALS FROM EASTERN FRESNO COUNTY, CALIFORNIA

Indexed on cell dimensions given in Table 4. (Camera diameter 114.59 mm, Cu/Ni radiation,  $\text{CuK}\alpha = 1.5418 \text{ \AA}$ , intensities estimated by comparison with photographic scales.)

Macdonaldite				Krauskopfte				Walstromite				Fresnoite			
I	$d_{\text{meas.}}$	$d_{\text{calc.}}$	hkl	I	$d_{\text{meas.}}$	$d_{\text{calc.}}$	hkl	I	$d_{\text{meas.}}$	$d_{\text{calc.}}$	hkl	I	$d_{\text{meas.}}$	$d_{\text{calc.}}$	hkl
5	@12.0	11.76	020	30	6.7	6.618	110	5	9.0	9.005	010	10	6.0	6.025	110
40	8.9	8.87	111	45	6.36	6.293	011	20	6.58	6.579	100	20	5.20	5.210	001
10	7.0	7.03	200	45	5.34	5.311	020	5	6.17	6.172	001	10	4.26	4.260	200
100	6.5	6.54	002	7	4.94	4.902	111	5	5.44	5.458	$\bar{1}\bar{1}0$	15	3.94	3.944	111
50	6.3	6.30	012	7	4.53	4.498	120	10	5.07	5.178	110	20	3.81+	3.811	210
25	6.1	6.07	131	30	3.94	3.930	210	15	4.40	{4.502 020 4.454 01 $\bar{1}$ }		50	3.305	3.299	201
30	5.9	5.88	040	100	3.84	3.830	121	10	4.13	4.141	101	100	3.08-	3.076	211
30	5.0	5.02	032	15	3.72	3.667	012	5	4.02-	4.004	$\bar{1}21$	10	3.01+	3.012	220
25	4.7	4.69	212	30	3.66	3.620	$21\bar{1}$	10	3.88	3.882	$11\bar{1}$	20	2.695	2.695	310
20	4.5	4.51	240	22	3.27	3.267	130	5	3.53	3.524	$1\bar{1}\bar{1}$	20	2.610	{2.608 221 2.605 002}	
80	4.36	4.37	042	22	3.22	3.225	031	15	3.35	3.377	121	10	2.392	{2.394 311 2.392 112}	
10	4.22	4.22	151	22	3.14	3.147	022	10	3.28	{3.289 200 3.267 012}		10	2.222	{2.223 202 2.152 321}	
5	4.10	{4.10 113 4.09 232}		5	3.04	3.106	$13\bar{1}$	15	3.20-	{3.203 $2\bar{1}\bar{1}$ 3.151 20 $\bar{1}$ }		30	2.150	{2.151 212 2.065 410}	
10	3.71	3.68	133	40	3.01	3.013	$12\bar{2}$	10	3.15	{3.146 2 $\bar{1}0$ 3.056 022}		10	2.010	2.008 330	
5	3.51	3.52	400	30	2.88	2.878	$21\bar{2}$	100	2.99	{3.013 $10\bar{2}$ 3.010 $1\bar{3}1$ 3.002 030}		10	1.975	{1.972 401 1.971 222}	
15	3.43	3.42	260	13	2.76	2.763	202	10	2.91	2.923	$12\bar{1}$	20	1.870	{1.874 331 1.873 312}	
50	3.36	3.363	062	9	2.722	2.726	310	15	2.78	2.789	$21\bar{1}$	15	1.619	1.619 412	
12	3.32	3.270	004	15	2.652	2.656	040	15	2.78	{2.729 $2\bar{2}0$ 2.707 201 2.701 112}		15	1.591	1.590 332	
16	3.24	3.240	014	13	2.603	2.605	003	20	2.70	{2.617 102 2.613 212}		15	1.580	{1.582 520 1.580 213}	
6	3.17	3.172	171	9	2.533	{2.534 140 2.529 013 2.525 231 2.515 311}		15	2.61	2.589	$21\bar{1}$				
30	3.08	{3.080 323 3.070 412 3.033 262}		9	2.481	2.491	320	5	2.585	2.589	$220$				
45	3.02	{3.018 034 3.017 440 2.995 422}		15	2.467	2.469	132	5	2.485	2.488	$20\bar{2}$				
35	2.99	{3.017 440 2.987 072 2.966 204}		9	2.423	2.422	$32\bar{1}$	10	2.425	2.427	221				
30	2.89	2.881	432	4	2.322	2.320	$31\bar{2}$								
30	2.87	2.858	044	11	2.246	2.248	$21\bar{3}$								
45	2.74	2.740	442	30	2.210	{2.214 123 2.206 330}									
6	2.64	2.647	244	16	2.188	2.186	$24\bar{1}$								
5	2.62	2.617	460			{2.143 203 2.138 241 2.115 400}									
25	2.508	2.505	282	16	2.118										
10	2.289	2.294	292	4	2.099	2.101	213								
				13	2.062	2.067	$13\bar{3}$								
				22	2.045	2.037	322								

(Table 5 continued at top of following page)

bright pink under long wave ultraviolet light (3650 Å). The luster is sub-vitreous, but is pearly on cleavage plates. The mineral occurs as nearly equant to short prismatic anhedral to subhedral crystals. Walstromite has three nearly perfect cleavages; (011), (010) and (100); usually (011) and (010) predominate. The angles between the cleavages are given in

TABLE 5—(continued)

Verplanckite				Muirite				Traskite			
I	d <sub>meas.</sub>	d <sub>calc.</sub>	hk·l	I	d <sub>meas.</sub>	d <sub>calc.</sub>	hkl	I	d <sub>meas.</sub>	d <sub>calc.</sub>	hk·l
65	13.8	14.16	10·0	25	10.0	9.859	110	50	15.4	15.48	10·0
15	8.23	8.17	11·0	15	7.17	6.971	200	5	9.7	9.63	10·1
5	7.28	7.17	00·0	5	6.33	6.235	210	5	7.1	7.23	11·1
45	5.39	{ 5.390 5.352	{ 11·1 21·0	5	5.57	5.590	001	5	5.7	5.85	10·2
7	5.08	5.038	20·1	10	5.20	5.188	101	5	5.1	5.16	30·0
20	4.31	4.289	21·1	20	4.95	4.929	220	15	4.8	{ 4.816 4.760	{ 20·2 30·1
5	4.095	4.087	22·0	5	4.67	4.644	300	10	4.2	4.240	21·2
100	3.95	3.942	30·1	75	4.42	{ 4.409 4.361	{ 310 201	5	4.04	4.048	31·1
30	3.58	{ 3.585 3.579	{ 00·2 22·1	20	4.21	4.162	211	5+	3.92	{ 3.955 3.871	{ 30·2 40·0
5	3.28	3.283	11·2	60	3.73	3.698	221	15	3.70	{ 3.727 3.694	{ 11·3 40·1
15	3.22	3.198	20·2	50	3.60	3.573	301	10	3.61	3.616	22·2
7	3.10	3.090	41·0	60	3.31	3.287	330	40	3.51	3.518	31·2
70	2.97	2.976	32·1	10	3.14	3.118	420	25	3.27	3.276	40·2
30	2.858	{ 2.855 2.838	{ 30·2 41·1	15	2.97	2.958	401	20	3.21	3.211	30·3
70	2.738	2.725	33·0	100	2.91	2.893	411	35	3.08	3.076	32·2
30	2.652	{ 2.832 2.648	{ 50·0 31·2	15	2.85	2.833	331	100	2.96	{ 2.980 2.963	{ 33·0 31·3
5	2.564	2.547	33·1	40	2.814	{ 2.795 2.789	{ 002 500	25	2.90	{ 2.962 2.926	{ 41·2 42·0
5	2.522	2.519	40·2	40	2.743	2.723	421	5	2.85	2.858	20·4
7	2.398	2.397	51·1	25	2.607	{ 2.594 2.590	{ 202 520	15	2.72	2.723	21·4
15	2.348	{ 2.571 2.341	{ 212 41·2	20	2.571	2.551	212	10	2.68	{ 2.685 2.682	{ 33·1 32·3
20	2.246	{ 2.495 2.238	{ 501 43·0	15	2.515	2.495	431	5-	2.64	2.643	42·2
7	2.225	{ 2.475 2.242	{ 440 60·1	10	2.475	2.465	440	20	2.53	2.526	60·1
30	2.176	{ 2.404 2.329	{ 530 52·0	15	2.404	2.391	530	10	2.42	{ 2.430 2.411	{ 10·5 33·3
20	2.144	2.222	50·2	15	2.335	2.324	600				
		{ 2.182 2.169	{ 21·3 33·2	15	2.276	2.255	441				
		2.132	30·3	25	2.214	2.205	620				
				40	2.154	{ 2.154 2.146	{ 412 601				
				40	2.094	{ 2.081 2.078	{ 422 630				
				25	2.042	{ 2.051 2.029	{ 401 541				

Table 6. Cleavage fragments are commonly elongated parallel to *a*, the intersection of the (010) and (011) cleavages.

The grain size ranges from a fraction of a millimeter to 15 mm and averages about 3 mm in length. The mineral has a hardness of about 3½. A density of 3.67 ± .06 gm/cm<sup>3</sup> was determined on 4 grains with an aggregate weight of 5.35 mg.

*Optical Data.* Walstromite is colorless in all orientations in transmitted light. The optical properties are given in Table 1.

TABLE 6. MORPHOLOGICAL ANGLE TABLE FOR WALSTROMITE<sup>1</sup>

TRICLINIC; crystal class <i>P</i> $\bar{1}$ or <i>P</i> 1					
$a:b:c=0.7019:1:0.6961$		$\alpha$ 69°51', $\beta$ 102°14', $\gamma$ 97°6 $\frac{1}{2}$ ' <sup>2</sup>			
$p_0:q_0:r_0=0.9539:0.6856:1$		$\lambda$ 109°10', $\mu$ 79°31', $\nu$ 86°50'			
$p_0'=1.0334; q_0'=0.7427, x_0'=0.3557, y_0'=-0.2174$					
Forms: <sup>3</sup>	$\phi$	$\rho$	A	B	C
<i>b</i> 010	0°00'	90°00'	86°50'	—	109°10'
<i>a</i> 100	86°50'	90°00'	—	86°50'	79°31'
<i>w</i> 011	29°19'	23°56'	77°25'	69°17'	29°53'

<sup>1</sup> Follows the conventions set forth in Dana's System of Mineralogy, 7th ed. Vol. I, p. 9 to 15, 1944.

<sup>2</sup> Axial elements and angles calculated from lattice constants determined by *x*-ray techniques.

<sup>3</sup> All forms listed have been observed as cleavage. No other forms have been identified with certainty.

The orientation of the optic directions was determined with the universal stage by Alfors and checked with *x*-ray oriented crystals by Pabst.

	$\phi$	$\rho$
X	236° ± 6°	59° ± 2°
Y	122 $\frac{1}{2}$ ° ± 7°	56° ± 3°
Z	358° ± 6°	49° ± 2°
Extinction angles: X' to <i>a</i> .	<i>observed</i>	<i>constructed</i>
seen perpendicular to (010)	20° and 22°	24°
seen perpendicular to (011)	31° and 33°	35°

These are the extinction angles most frequently seen as (010) and (011) cleavages are more conspicuous than the (100) cleavage. Other extinction angles can be constructed from the stereographic projection, Fig. 6.

*Chemical Properties.* Two separate chemical analyses of walstromite have been made by d-c arc emission spectrograph. The results of these analyses are presented in Tables 2 and 3. The ideal formula is BaCa<sub>2</sub>Si<sub>3</sub>O<sub>9</sub>.

Walstromite is readily decomposed by cold dilute acids leaving a white silica residue, but it is not affected by bases.

The mineral fuses to a clear glass at about 4. On heating in an electric furnace the mineral shows no change in appearance until 1200° C. when it is partially melted to a colorless glass.

A barium calcium silicate with the composition BaO · 2CaO · 3SiO<sub>2</sub> was

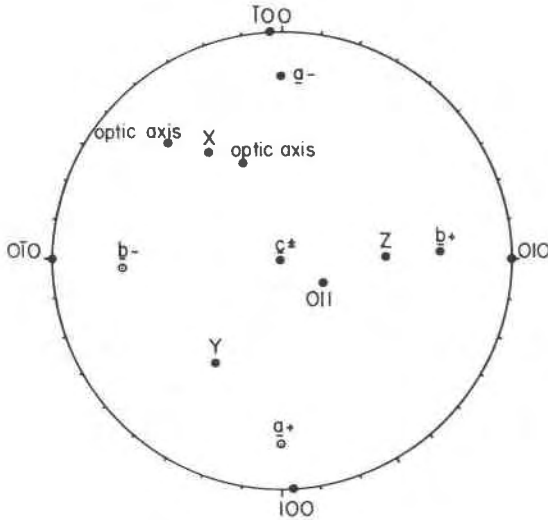


FIG. 6. Stereographic projection of walstromite showing the orientation of the optic directions, cleavages, and crystallographic axes. Solid dots are plotted on upper hemisphere; open circles are plotted on lower hemisphere.

made artificially by Eskola (1922) who considered the material to be hexagonal. The reported optical properties for this artificial material are similar to those of walstromite.  $\text{BaCa}_2\text{Si}_3\text{O}_9$  was synthesized for this study. The synthesis of  $\text{BaCa}_2\text{Si}_3\text{O}_9$  furnished confirmation that walstromite is the same phase as the compound described by Eskola. A pellet prepared from well mixed "Baker's Analyzed"  $\text{BaCO}_3$ ,  $\text{CaCO}_3$  and "silicic acid" in the proportions required by the formula was melted at  $1350^\circ\text{C}$ . The fusion crystallized coarsely upon slow cooling to single crystals of pseudowollastonite and pseudomorphs of such crystals composed of sheaf-like aggregates of  $\text{BaCa}_2\text{Si}_3\text{O}_9$ . The pseudowollastonite was checked by single crystal  $x$ -ray observations. A powder diffraction pattern of the mixture showed it to be principally  $\text{BaCa}_2\text{Si}_3\text{O}_9$  in the same form as walstromite. The entire mass, reground and sintered at  $950^\circ\text{C}$ . with ca. 10 per cent  $\text{BaCl}_2$  flux, recrystallized to  $\text{BaCa}_2\text{Si}_3\text{O}_9$  with no pseudowollastonite. These observations are in full conformity with what might be expected from Eskola's phase diagram which shows that  $\text{BaCa}_2\text{Si}_3\text{O}_9$  melts incongruently at  $1320^\circ\text{C}$ . with separation of pseudowollastonite.

$\text{Ca}_2\text{BaSi}_3\text{O}_9$  has also recently been synthesized by Glasser and Glasser (1961). They find it to be triclinic and report cell dimensions different from those given for walstromite. Comparison of the two cells shows that

the walstromite lattice can be referred to axes closely corresponding to those reported by Glasser and Glasser.

The matrices for the transformation are:

walstromite to $\text{Ca}_2\text{BaSi}_3\text{O}_9$ (this paper) (G. & G., 1961) 001/100/01I	$\text{Ca}_2\text{BaSi}_3\text{O}_9$ to walstromite (G. & G., 1961) (this paper) 010/101/100
--	--

When the walstromite cell is transformed accordingly the following comparison results:

	walstromite transformed setting	differences	$\text{Ca}_2\text{BaSi}_3\text{O}_9$ Glasser and Glasser, 1961
<i>a</i>	6.687 Å	0.031	6.71 <sub>8</sub>
<i>b</i>	6.743	0.010	6.73 <sub>8</sub>
<i>c</i>	9.631	0.014	9.61 <sub>7</sub>
$\alpha$	88° 38'	16'	88° 22'
$\beta$	110° 32'	31'	111° 3'
$\gamma$	102° 14'	6'	102° 20'

The agreement is not perfect. However, it may be that there are small but real differences in lattice dimensions between the natural and the synthetic material.

The cell chosen for walstromite corresponds to the three shortest translations. The [101] translation in the lattice reported by Glasser and Glasser has been calculated to be 9.550 Å, so if they had used the same basis for a choice of axes they would have been led to a cell corresponding to that chosen for walstromite.

Glasser and Glasser (1961) reported an indexed powder pattern for  $\text{Ca}_2\text{BaSi}_3\text{O}_9$ . It corresponds closely to the one tabulated here for walstromite and our indexing can be wholly transformed to that of Glasser and Glasser by means of the first matrix given above. We are, thus, in agreement on the interpretation of the powder pattern.

In a most recent paper Glasser and Glasser (1964) have further called attention to the fact that margarosanite,  $(\text{Ca}, \text{Mn})_2\text{PbSi}_3\text{O}_9$ , for which a unit cell and unindexed powder pattern have been reported by Armstrong (1963), is very similar to  $\text{Ca}_2\text{BaSi}_3\text{O}_9$ . Hence margarosanite and walstromite are closely related minerals, probably with comparable structures.

*X-ray Data.* The crystallography of walstromite is given in Table 4, together with the calculated and measured densities. The *x*-ray powder data, indexed using the cell dimensions given in Table 4, are presented in Table 5.

## FRESNOITE

*Physical Properties.* Fresnoite is lemon or canary yellow, has a vitreous luster, and a white streak. The mineral fluoresces pale yellow under short wave ultraviolet light (2652 Å), but does not fluoresce under long wave ultraviolet light (3650 Å).

The mineral occurs as subhedral to euhedral tetragonal crystals which are elongated slightly in the direction of the *c* axis. The forms {001} and {110} were identified during goniometrical studies, and several prism and pyramid faces were observed but could not be surely identified. The crystals nearly always exhibit the forms {001} and {110}, but they are not always well developed.

The mineral has one fair cleavage, (001). The grain size of the crystals ranges from 0.1 mm or less up to 3 mm with the average about 0.3 mm. Aggregates of grains range up to 5 mm. The hardness is between 3 and 4. The specific gravity of  $4.43 \pm .02$  gm/cm<sup>3</sup> was determined using a sample totaling 10.77 mg. The sample consisted of a few hundred grains in the 0.1 to 0.2 mm size range.

*Optical Data.* Fresnoite is pleochroic in transmitted polarized light from yellow to colorless. The mineral characteristically shows anomalous blue interference colors. The optical properties are given in Table 1.

*Chemical Properties.* Two separate chemical analyses of fresnoite have been made by d-c arc emission spectrograph. The results of these analyses are presented in Tables 2 and 3. The ideal formula is Ba<sub>2</sub>TiSi<sub>2</sub>O<sub>8</sub>.

Fresnoite is insoluble or only slightly soluble in most cold dilute acids and bases; however, it is decomposed by hot 1:1 HCl and cold glacial acetic acid leaving a colorless residue.

The mineral fuses at about 4 and is partially melted when heated in an electric furnace to 1200° C. It is completely melted at 1300° C. to a yellow glass.

The synthetic equivalent of fresnoite was prepared by thoroughly mixing "Baker's Analyzed" BaCO<sub>3</sub>, "silicic acid" and TiO<sub>2</sub> (the last in the form of ultrafine particles in the metastable anatase structure) in the proportions required by the formula Ba<sub>2</sub>TiSi<sub>2</sub>O<sub>8</sub>, pelleting, and sintering 5½ hours at 1350° C. The product yielded a powder pattern identical with that of fresnoite with no change in *d* values. After recrystallization with ca. 10 per cent BaCl<sub>2</sub> flux at 985–885° C. the *x*-ray powder diffraction pattern remained unchanged.

*X-ray Data.* The crystallography of fresnoite is given in Table 4, together with the calculated and measured densities. The powder diffraction data given in Table 5 have been indexed from the single crystal data in Table 4.

## VERPLANCKITE

*Physical Properties.* Verplanckite ranges in color from brownish orange to light brownish yellow, has a vitreous luster, and a pale orange streak. The mineral does not fluoresce under ultraviolet light.

Verplanckite forms prismatic subhedral to euhedral hexagonal crystals which are elongated parallel to the  $c$  axis. One crystal measured by 2-circle goniometer showed the following forms:

Forms:

(0001), one very rough face

$\{10\bar{1}0\}$ , two or more faces

$\{11\bar{2}0\}$ , all six faces

$\{hk\bar{1}0\}$ , several faces, not certainly indexed

$(h0\bar{h}1)$ , one face, possibly  $(50\bar{5}2)$

$(hh\bar{2}h1)$ , one face, possibly  $(55\bar{1}04)$

$\{hk\bar{1}1\}$ , two or more very small, not indexed

Verplanckite has one good cleavage ( $11\bar{2}0$ ) and a poor cleavage or fracture parallel to (0001). The grain size of the crystals ranges from a fraction of a millimeter to 3 mm, the average length being about 0.5 mm. The hardness is between  $2\frac{1}{2}$  and 3. The specific gravity of  $3.52 \pm .02$  gm/cm<sup>3</sup> was determined on a weighted average of 2 samples weighing a total of 20.46 mg.

The measured gravity is higher than the calculated density shown in Table 4. If the density is calculated from  $Ba_{12}(Mn_{4.31}, Fe_{0.93}, Ti_{0.76})_6 Si_{12}O_{36}(O_{1.52}, OH_{7.01}, Cl_{3.47})_{12} \cdot 18H_2O$  or from  $Ba_{12}Mn_6Si_{12}O_{36}(OH_{8.53}, Cl_{3.47})_{12} \cdot 18H_2O$  the value is 3.51 which is very close to the measured density. The measured density of verplanckite may be slightly high because of small inclusions of fresnoite.

*Optical Data.* Verplanckite is pleochroic in transmitted polarized light from dull orange-yellow to colorless. The mineral is length fast and characteristically displays a prominent cross fracture perpendicular to its length. The optical properties are given in Table 1.

*Chemical Properties.* Two chemical analyses of verplanckite were made by d-c arc emission spectrograph and they are presented in Tables 2 and 3. The water content of 10.6% was determined on a separate sample by ignition loss. Robert Langston of the University of California at Berkeley, heated a 58 mg sample up to 860° C. He heated the sample in a vacuum to 750° C. and in an argon atmosphere from 750° C. to 860° C. The total weight loss at 860° C. was 8.5%. A point count of the heated sample showed 10% anhydrous impurity, mainly fresnoite and celsian.

The weight loss for the verplanckite was thus 9.4% at 860° C. Most of the weight loss took place below 300° C. A 20-mg portion of the same sample was heated by Alfors to 1000° C. in a covered graphite crucible. An additional weight loss of 1.2% occurred. After ignition to 1000° C. the sample was off white in color and did not show any evidence of melting or oxidation. The heated material gave a test for chlorine. The total weight loss of 10.6% is assigned to water.

The ideal formula proposed is  $\text{Ba}_2(\text{Mn, Fe, Ti})\text{Si}_2\text{O}_6(\text{O, OH, Cl})_2 \cdot 3\text{H}_2\text{O}$ . A somewhat different formula could be written based on different amounts of water assigned to (OH) and  $\text{H}_2\text{O}$ . Roughly one fourth of the water was considered to be (OH) on the basis of the ignition loss results. The formula of verplanckite as written in Table 3 was arranged so that (O, OH, Cl) totaled 2.00. The chlorine is the amount actually determined, enough O is added to account for substitution of Mn by Ti, and an amount of (OH) to just total 2.00 is added. The substitution of O for (OH, Cl) is made to maintain the electrostatic balance when Ti is substituted for Mn. This substitution is speculative, but a somewhat similar substitution of Ti for Mg, and O for (OH, F) is reported for clinohumite (Deer *et al.*, 1962, p. 53).

Verplanckite is completely but slowly soluble in dilute hydrochloric acid. The mineral is quickly bleached, and the transparent or white fragments are slowly dissolved. The mineral reacts essentially the same in other dilute acids; but the bleached fragments do not dissolve completely. Verplanckite undergoes no apparent change in concentrated sodium hydroxide.

The mineral fuses at about  $3\frac{1}{2}$  and gives off water in a closed tube test. Rapidly heated to 900° C. in an electric furnace, verplanckite retains its shape but turns black. At 1100° C. the mineral turns purple, and at 1200° C. has melted completely to a reddish brown glass.

*X-ray Data.* The crystallography of verplanckite is given in Table 4, together with the calculated and measured densities. The powder diffraction data given in Table 5 have been indexed from the single crystal data in Table 4.

#### MUIRITE

*Physical Properties.* Muirite is orange, has a subvitreous luster, and has a pale orange streak. The mineral does not fluoresce under ultraviolet light.

The mineral generally occurs as anhedral grains; however, subhedral to euhedral tetragonal crystals are common. The common forms are {001} and {100}; other forms noted include {110} and a few (h01) faces.

Muirite has two indistinct cleavages, (001) and (100). The grain size



ranges from a fraction of a millimeter to aggregates up to 3 mm. the average being about 0.5 mm. The hardness is about  $2\frac{1}{2}$ . The specific gravity of  $3.86 \pm 0.02$  gm/cm<sup>3</sup> was determined on a sample weighing 8.95 mg. The sample consisted of several hundred grains in the 0.1 to 0.2 mm size range.

*Optical data.* The optical properties are given in Table 1. Muirite is most readily distinguished from the other colored new barium minerals by its uniaxial (+) character. It also commonly displays an anomalous purplish-brown interference color.

*Chemical Properties.* One chemical analysis of muirite has been made by d-c arc emission spectrograph. The analysis is presented in Tables 2 and 3. The water content was determined by ignition loss on 11 mg of material. The sample was loaded into a platinum foil tube and placed in a covered graphite crucible. A small amount of steel wool was placed in the graphite crucible to inhibit oxidation of the sample. At 400° C. the weight loss was 0.4%, at 700° C. it was 1.7% and at 1000° C. the weight loss totaled 2.4%. After ignition the sample gave a test for chlorine. All of the weight loss is attributed to water and because of the relatively high temperature at which the water comes off, it is all considered hydroxyl water. The proposed ideal formula is Ba<sub>10</sub>Ca<sub>2</sub>MnTiSi<sub>10</sub>O<sub>30</sub>(OH, Cl)<sub>10</sub>.

Muirite is decomposed by dilute hydrochloric and nitric acids. The grains lose their color and then disintegrate to a white or colorless residue. The grains are apparently not affected by sulfuric acid, acetic acid or concentrated sodium hydroxide.

Muirite gives off water in a closed tube test and fuses at about 3. Heated rapidly to 900° C. in an electric furnace, the mineral turns brown, and on further heating turns pinkish and partially melts at 1100° C. At 1200° C. the mineral completely melted to a pale lavender glass.

*X-ray Data.* The crystallography of muirite is given in Table 4 together with the calculated and measured densities. The powder diffraction data given in Table 5 have been indexed from the single crystal data in Table 4.

#### TRASKITE

*Physical Properties.* Traskite is brownish red, has a vitreous luster, and a pale reddish-brown streak. The mineral does not fluoresce under ultra-violet light.

Although the mineral generally occurs as equant anhedral grains, several well-formed euhedral crystals have been found. The forms {0001} and {10 $\bar{1}$ 0} are most prominent, but many tiny pyramid faces occur on

some crystals. The following forms were tentatively identified:  $\{11\bar{2}2\}$  two faces,  $(41\bar{5}2)$  one face, and  $(61\bar{7}1)$  one face.

Traskite has a conchoidal fracture and no cleavages have been observed. The grain size ranges from 0.1 mm to 3 mm and averages 0.5 mm. The hardness is about 5. The specific gravity of  $3.71 \pm .02$  gm/cm<sup>3</sup> was determined on a weighted average of 2 samples totaling 18.48 mg.

*Optical Data.* Traskite is pleochroic in transmitted polarized light from brownish-red to colorless. The optical properties are given in Table 1.

*Chemical Properties.* One chemical analysis of traskite has been made by d-c arc emission spectrograph and it is presented in Tables 2 and 3. The water content was determined on a separate 21 mg sample by a modification of the Penfield method. The ideal formula is  $\text{Ba}_5\text{FeTiSi}_6\text{O}_{18}(\text{OH})_4$ .

Traskite is insoluble in dilute acids and bases. On prolonged standing in dilute hydrochloric acid, the mineral turns almost opaque brown and loses its glassy appearance.

Traskite fuses at about  $3\frac{1}{2}$  and gives off water in a closed tube test. Rapidly heated to 900° C. in an electric furnace, the mineral turns light brown. At 1200° C. the mineral melts completely to a straw yellow glass.

*X-ray Data.* The crystallography of traskite is given in Table 4, together with the calculated and measured densities. The indexed powder diffraction data are given in Table 5.

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#### NOTE ADDED IN PRESS

When this paper was in press, traskite was found to contain  $3\frac{1}{2}\%$  chlorine and verplanckite, muirite and traskite were found to contain several tenths of a per cent fluorine. In light of the new data, the analyses given for these three minerals must be revised. Only a slight revision is necessary for verplanckite and muirite, but a substantial revision is necessary for traskite. It was not possible to incorporate the changes in the present paper, so the revisions will be given in a subsequent paper.