SANBORNITE, A NEW BARIUM SILICATE MINERAL FROM MARIPOSA COUNTY, CALIFORNIA*†

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I am indebted to Mr. Frank Sanborn of the Division of Mines, Department of Natural Resources, State of California (formerly the State Mining Bureau), for the specimen which contains the new mineral, sanbornite, herein described. This mineral proves to be a triclinic barium dimetasilicate with the formula $BaSi_2O_5$; it is named in honor of Mr. Sanborn in recognition of his faithful work as determinative mineralogist for the past eleven years. According to my reckoning, thirty-nine new minerals in all have been described from California.

The specimen was collected and sent by Mr. Anthony Marsh of Incline, Mariposa County, to the Division of Mines for identification, evidently because of the presence of spots of a rose-red mineral which on careful examination proved to be gillespite, $BaFe''(Si_2O_5)_2$, a mineral recently described from Dry Delta, Alaska Range, Alaska, by Schaller.[1] This is the second known occurrence of gillespite. The locality for the Sanbornite is about one mile north of Trumbull Peak, near Incline. Incline is about five miles west of El Portal, near which there is a commercial deposit of barite recently described by Fitch.[2] The specimen however did not come from a mine or quarry; since lichens are present, it must be an outcrop sample.

The specimen consists largely of quartz with the rose-red spots of gillespite and plates of a cleavable white mineral (sanbornite) with a pearly luster. Thin sections show in addition: diopside, a

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[1] *Jour. Wash. Acad. Sci.*, vol. 12, pp. 7–8, 1922. *Amer. Mineralogist*, vol. 14, pp. 319–322, 1929.

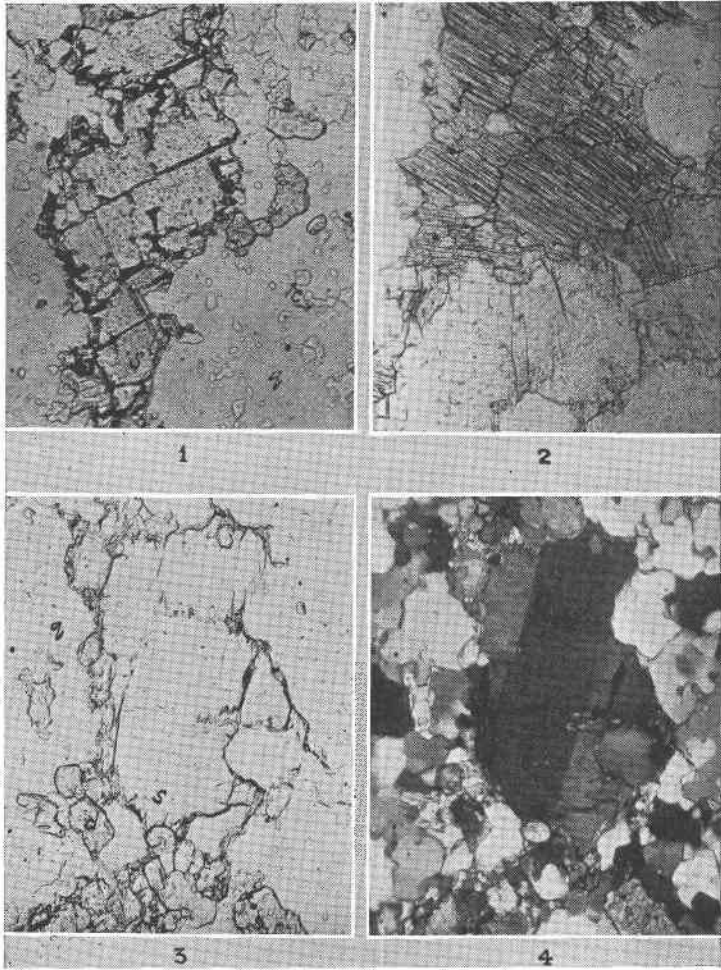[2] *Amer. Mineralogist*, vol. 16, pp. 461–468, 1931.

FIG. 1. (× ca. 55 diameters). Anhedral sanbornite (s) with alteration product (x) in matrix of quartz (q), with small celsian (c) anhedra.

FIG. 2. (× ca. 55.) Sanbornite parallel to cleavage in lower half and normal to cleavage in upper half.

FIG. 3. (× ca. 55.) Anhedral sanbornite (s) in matrix of quartz (q). The sanbornite is cut approximately parallel to the (001) cleavage. d=diopside.

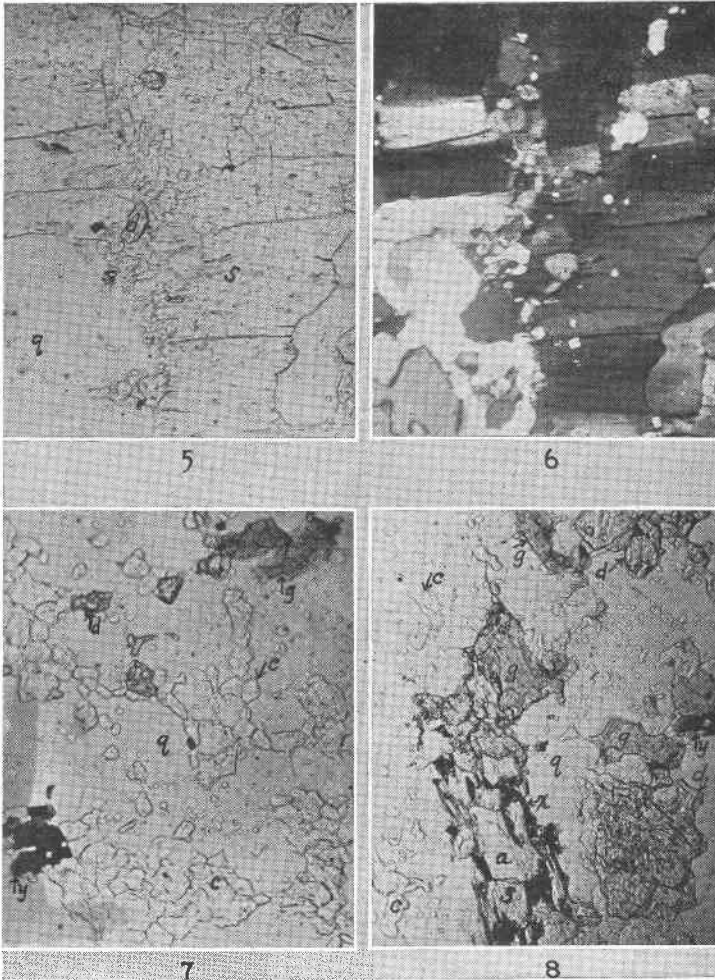FIG. 4. (× ca. 55.) The same as Fig. 3 between crossed nicols showing twinning.

FIG. 5. ($\times$ ca. 55.) Portion of anhedral sanbornite (s) cut approximately parallel to the (001) cleavage. The horizontal lines are traces of the (010) cleavage. d=diopside, q=quartz.

FIG. 6. ($\times$ ca. 55.) The same as Fig. 5 between crossed nicols showing polysynthetic twinning. [Tw. pl.=(010).] Quartz is shown in the lower left-hand corner.

FIG. 7. ($\times$ ca. 55.) Celsian (c) anhedra in matrix of quartz. The dark mineral in the upper right-hand corner is gillespite (g), and the one in the lower left-hand corner is the unknown brown pleochroic mineral (y) (probably a new mineral).

FIG. 8. ($\times$ ca. 55.) This area shows eight minerals: g=gillespite, s=sanbornite, x=alteration product of sanbornite, c=celsian, q=quartz, d=diopside, a=alstonite, (?), y=unknown brown pleochroic mineral.

little tourmaline (schorlite), celsian ($BaAl_2Si_2O_8$), pyrrhotite, and several unknown minerals which also may be new. The sanbornite occurs in veins from a few inches up to 20 inches in width in the metamorphic zone on the western border of the Sierra Nevada batholith. The country rock consists of metamorphosed sediments, largely quartzites and hornfels.

Description of Sanbornite

The sanbornite occurs in white to colorless subtransparent plates up to 2 or 3 cm. and 3 or 4 mm. thick. The luster is somewhat pearly. The crystals are unfortunately anhedral; the irregular outlines of Figs. 1 and 3 are typical. A few roughly rectangular subhedral crystals were noted but they are very rare. There is perfect cleavage in one direction which is taken as (001). An imperfect cleavage at about 82° to (001) is selected as (010). In Fig. 2 in the lower part of the photograph the section is cut parallel to the cleavage; in the upper part traces of the perfect cleavage are evident. In Fig. 5 the section is parallel to (001) and the horizontal lines are traces of the (010) cleavage. Here there is also a third cleavage, traces of which are nearly normal to traces of the (010) cleavage. A prominent feature of the mineral is polysynthetic twinning with (010) as twinning-plane. The twinning is not as sharp and well defined as the usual albite twinning of plagioclase. The plates are usually somewhat bent and distorted, so much so that the angle between (001) and twinned (001) could not be determined with the reflection goniometer. The angle between (001) and twinned (001) was measured in a thin section and found to be about 16°. In this way the approximate angle (001:010) = 82° was obtained.

Although no euhedral crystals of sanbornite were found, the optical tests prove that it belongs to the triclinic system, as will be shown presently.

The hardness of sanbornite is about 5. The specific gravity determined on 0.3 g. is about 4.19. The value is approximate as the mineral contained a very small amount of included minerals.

Chemical Composition

Since the sanbornite was decomposed by hydrochloric acid with the separation of silica and gave microchemical tests for barium and aluminum, and showed polysynthetic twinning, it was thought

to be the triclinic dimorph of celsian ($BaAl_2Si_2O_8$). It was later discovered that the aluminum came from intimately associated celsian. With the pure mineral no aluminum test could be obtained with cesium chloride and dilute sulfuric acid. My colleague, Professor F. G. Tickell, kindly made several spectrograms of the mineral in the region between 3600 and 5000 Å.U. for me. The very strong barium line at 4934 and good ones at 4131 and 3993 are prominent. Many strontium lines are shown, many calcium lines, one silicon line (3905), and two aluminum lines (3944 and 3961). The spectrographic examination gave a clue of what to expect in the chemical analysis. The aluminum is present in the associated celsian. The calcium is probably present as the carbonate mineral alstonite[3] [$BaCa(CO_3)_2$]. A quantitative analysis made upon one gram of carefully selected mineral which was, however, not quite pure, gave my colleague, Mr. O. C. Shepard, the following results:

ANALYSIS OF SANBORNITE BY O. C. SHEPARD

	I	II	III	IV	V
SiO_2	42.2	.703	−.028 = .675	.675	2.15
Al_2O_3	1.5	.014	−.014		
Fe_2O_3	tr				
CaO	0.1	.002	−.002		
SrO	0.2	.002	.002 ⎱	314	1.00
BaO	50.4	.328	−.016 = .312 ⎰		
Total	94.4				

After taking the aluminum as celsian with equivalent amounts of baryta and silica and the lime as alstonite with an equivalent amount of baryta (column III), we have the ratios of columns IV and V, which lead to the formula: $BaO \cdot 2\ SiO_2$ or $BaSi_2O_5$, barium metadisilicate.

Treated with dilute hydrochloric acid sanbornite behaves in a rather peculiar manner. It is decomposed; the cleavage plates swell and open up into characteristic shreds with weak double refraction which probably have the composition $H_2Si_2O_5$, the hydrogen replacing the barium. A similar phenomenon was noted by Schaller[4] in treating gillespite, $BaFe''(Si_2O_5)_2$, with hydrochloric acid.

[3] Recent x-ray work by Gossner and Mussgnug (*Centr. Min.*, Abt. A, 1930, pp. 230–238), indicates that alstonite or bromlite is a double salt with the above formula and not an isomorphous mixture of witherite and aragonite.

[4] *Amer. Mineralogist*, vol. **14,** pp. 319–322, 1929.

After standing a few minutes, the hydrochloric acid solution deposits crystals of $BaCl_2 \cdot 2 H_2O$. These are thin tabular (parallel to 010) crystals, which, as the solution becomes more concentrated, exhibit characteristic polysynthetic twinning. Dilute nitric acid gave isometric barium nitrate and dilute sulfuric acid, granular crystals of barium sulfate, but the barium chloride microchemical test is, I believe, by far the best test for barium. I have never found any mention of it in any of the works on microchemistry.

Optical Properties

The three principal indices of refraction of sanbornite are n_α $= 1.597 \pm .001$, $n_\beta = 1.616 \pm .001$, $n_\gamma = 1.624 \pm .001$, obtained by the immersion method. The values for the α and β directions were obtained on cleavage flakes parallel to $\{001\}$. Other cleavage fragments elongated in the direction of the faster ray and hence parallel to (010) gave the third value n_γ. Since the principal optical sections are not parallel to the cleavage directions, the values for the indices may not be quite correct, but they are very close to the true value on account of the small extinction angles.

In order to determine the indices of refraction to within ± 0.001, a set of liquids differing from each other by 0.01 were used. After an approximate value between $1 \cdot xy0$ and $1 \cdot x(y+1)0$ is found, four drops of one and one drop of the other, three of one and two of the other, two of one and three of the other, and one drop of one and four of the other were used. Each of these five mixed gave four liquids with indices $1 \cdot xy2$, $1 \cdot xy4$, $1 \cdot xy6$, and $1 \cdot xy8$. By using these and the end liquids $1 \cdot xy0$ and $1 \cdot x(y+1)0$, the indices may be determined within 0.001, provided the temperature is taken into account and monochromatic light is used.[5]

The maximum double refraction derived from the indices is: $n_\gamma - n_\alpha = 0.027 \pm .002$. The double refraction obtained by means of a Berek compensator from a thin section, the thickness being found from the maximum retardation of the quartz, is 0.027. The sanbornite has practically the same double refraction as the associated diopside.

Cleavage fragments of the sanbornite are flat plates with a tendency to elongation parallel to the slow ray, sometimes with a fairly straight edge which is the trace of the imperfect (010) edge,

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[5] A Wratten orange (E 22) screen made by the Eastman Kodak Co. may be used as an approximation to sodium light except for very accurate work.

and occasionally with a broad twin-band in the same direction. The extinction angle on the (001) cleavage fragments is 3° 36′ (average of 10 varying from 3° to 4°). The extinction angle between two individuals turned on (010) in a section with the highest interference color ($\alpha\gamma$ section) gave 8° 12′ (the average of 10 values). Occasionally cleavage fragments parallel to (010) are encountered and in these the extinction angle is 5° 30′ (average of 10 varying from $4\frac{1}{2}$° to $6\frac{1}{2}$°).
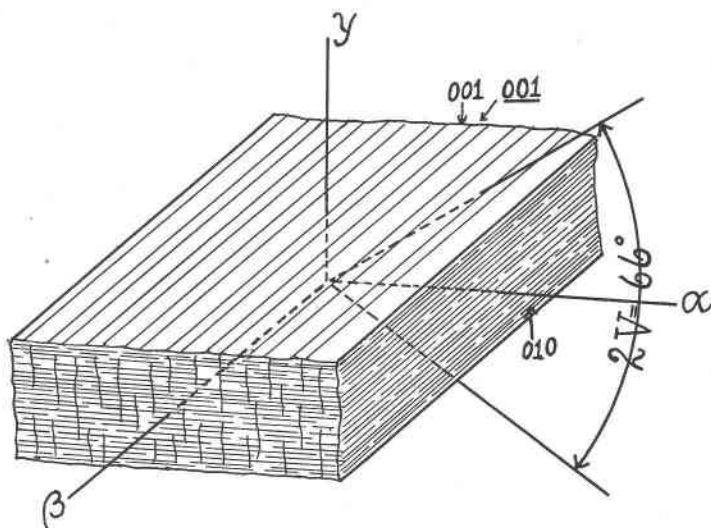

FIG. 9. Optical orientation of sanbornite. The $\alpha\beta$ plane is not quite parallel to (001); the $\beta\gamma$ plane is not quite parallel to (010) and the axial optic plane ($\alpha\gamma$) is not quite normal to (001) and (010).

In thin sections the maximum extinction angles in sections cut normal to the twin-plane is about 10°.

In thin sections parallel to (010) very thin twin-lamellae which make an angle of 3° (average of 10 with the limits $2\frac{1}{2}$ and $3\frac{1}{2}$°) with the (001:010) edge are observed. This suggests polysynthetic twinning analogous to the pericline twinning of plagioclase.

Sections parallel to (001) give an obtuse bisectrix interference figure; sections approximately parallel to (010) give an acute bisectrix figure. The isogyres of the figure are just beyond the field so the axial angle can not be obtained directly. The value of 2V calculated from the indices is 66°. The optical character is nega-

tive. The optical orientation is shown in Fig. 9. The plane of the optic axes is approximately normal to (001) and (010) and γ is almost normal to (001). As in other triclinic crystals it is difficult to determine the exact optical orientation.

DIMORPHISM OF BARIUM DIMETASILICATE

While sanbornite is the first simple barium silicate mineral to be discovered, it should be pointed out that barium dimetasilicate ($BaSi_2O_5$) has been obtained artificially. It was first described by Bowen,[6] who found tabular and elongated six-sided crystals of 2 to 3 mm. in size in barium crown glass. Bowen assigned his crystals to the orthorhombic system. Eskola[7] also obtained the orthorhombic form of $BaSi_2O_5$ in elongated tabular crystals with the indices $n_\alpha = 1.597$, $n_\beta = 1.612$, and $n_\gamma = 1.621$, 2V ca. 75°, and with a scaly cleavage parallel to the $\alpha\beta$ plane (almost the same orientation as that of sanbornite).

The work of Bowen, Eskola, and the present writer proves[7a] that $BaSi_2O_5$ is dimorphous; the triclinic form occurs as a mineral and the orthorhombic form is a laboratory product. The properties tabulated below show just such differences as one would expect for dimorphous modifications of a chemical substance.

	n_α	n_β	n_γ	2V
$BaSi_2O_5$ { Orthorhombic........	1.597	1.612	1.621	ca. 75°
Triclinic (Sanbornite).	1.597	1.616	1.624	ca. 66°

It seems likely that $BaSi_2O_5$ and $K_2Si_2O_5$ are isomorphous.[8] Morey[9] states that a $K_2Si_2O_5$ crystal immersed in a drop of water gives "shred-like forms." There is a hint that $K_2Si_2O_5$ is also dimorphous. Niggli[10] in his observations on $K_2Si_2O_5$ crystals mentions polysynthetic twinning which "resembles albite twinning" and states "the direction of elongation forms a very small angle with the twin-plane." This is very similar to the polysynthetic twinning of sanbornite and suggests that $K_2Si_2O_5$ is dimorphous.

[6] *Jour. Wash. Acad. Sci.*, vol. **8**, pp. 265–268, 1918.

[7] *Amer. Jour. Sci.*, [5] vol. **4**, p. 331, 1922.

[7a] Since this article was written I have found that Nicolardot and Gaubert (*Bull. Soc. fr. Min.*, **51**, pp. 333–8, 1928) have described spherulites of $BaSi_2O_5$ in barium glass They are biaxial and probably triclinic.

[8] Bowen, *loc. cit.*, p. 267.

[9] *Jour. Amer. Chem. Soc.*, vol. **39**, p. 1191, 1917.

[10] *Jour. Am. Chem. Soc.*, vol. **35**, p. 1710.

Morey[11] comments on the rarity of natural disilicates. He cites the rivaite $(Ca,Na_2)Si_2O_5$ of Zambonini as being the only simple nonaluminous disilicate known. Since then, gillespite, $BaFe(Si_2O_5)_2$, has been described and now there is added sanbornite to the list of disilicates.

THE STRUCTURE OF SANBORNITE

In the recent work of structural crystallographers[12] we have valuable contributions toward the elucidation of the structure of
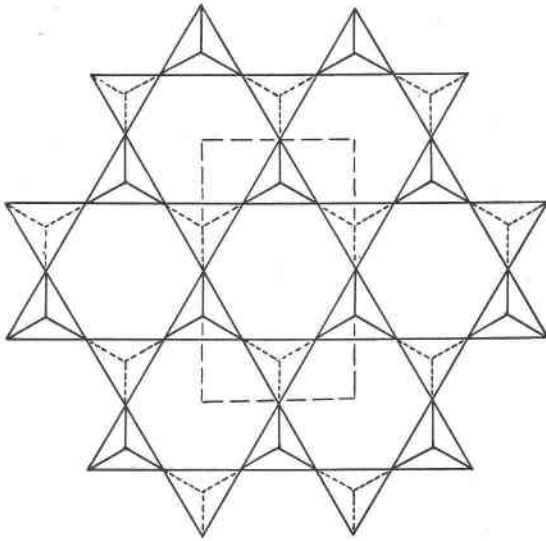

FIG. 10. One layer of the probable structure of Sanbornite. The triangles represent SiO_4 groups. The barium atoms are in the centers of the open hexagons but on levels above and below the plane of the drawing. The unit cell is $2BaSi_2O_5$, shown by the dotted rectangle.

silicate minerals. The x-ray workers have found evidence of the presence of tetrahedral SiO_4 groups in all silicate minerals thus far investigated.[13] W. L. Bragg[14] and Pauling[15] have simultaneously

[11] *Jour. Am. Chem. Soc.*, vol. **36**, p. 225, 1914.

[12] The writer has recently (*Amer. Mineralogist*, vol. **16**, p. 117, 1931) proposed the term *structural crystallography* for the division of crystallography concerned with the internal structure of crystals.

[13] See summary by Gruner, *Amer. Mineralogist*, vol. **16**, pp. 437–454, 1931.

[14] *Zeit. f. Kryst.*, Abt. A, vol. **74**, p. 137, 1930.

[15] *Proc. Nat. Acad. Sci.*, vol. **16**, pp. 123–129, 578–582, 1930.

postulated the presence of interlinked SiO_4 groups for the micas and related minerals which have perfect basal cleavage and pseudo-hexagonal symmetry.

According to Pauling, the micas, brittle micas, pyrophyllite, the chlorites, and talc all contain the radical Si_4O_{10} or $(Si_3Al)O_{10}$ or $(Si_2Al_2)O_{10}$. Between the sheets of Si_4O_{10} groups the cations lie.

It seems likely that sanbornite has a structure similar to that of the micas and related minerals, though there is no direct evidence that it is pseudohexagonal. Fig. 10 is a drawing of one layer of the probable structure of sanbornite. The triangles are projections of tetrahedra which point alternately in opposite directions. Each tetrahedron has a silicon atom at its center and an oxygen atom at each vertex. The oxygen atoms in the plane of the paper are each common to adjacent tetrahedra. The barium atoms are on higher and lower levels in the center of the open hexagons. The coordination number for barium is six, i.e., each barium atom is connected with three oxygen atoms on one level and three alternate oxygen atoms on the next level. This gives the correct valence for all of the atoms concerned. The unit of structure is $2BaSi_2O_5$ as shown in projection by the dotted rectangle. It is not predicted that this is the exact structure but it is probably one similar to this. The triclinic nature of the sanbornite probably means that the structure is like Fig. 10 but somewhat distorted.

My colleague, Dr. Maurice L. Huggins of the Department of Chemistry is engaged in a study of the crystal structure of sanbornite by means of x-rays.

Associated Minerals

GILLESPITE. Of the associated minerals the most interesting is probably gillespite, barium iron dimetasilicate, which occurs in beautiful rose-red anhedral crystals with a perfect cleavage in one direction (001). In thin sections it shows striking pleochroism with the greatest absorption when the cleavage traces are normal to the vibration plane of the lower nicol. Gillespite is shown in Figs. 7 and 8. Isolated fragments with dilute hydrochloric acid give birefringent shreds ($8SiO_2 \cdot 5H_2O$ according to Schaller)[16] and microchemical tests for iron and barium.[17]

[16] *Amer. Mineralogist*, vol. **14**, p. 320, 1929.
[17] The barium chloride test mentioned on p. 165.

CELSIAN. A rather inconspicuous mineral scattered through the quartz matrix and often intimately associated with the sanbornite was with some difficulty identified as celsian ($BaAl_2Si_2O_8$), the rare barium feldspar. This is, I believe, the first mention of celsian in the United States. It was identified by microchemical tests for barium ($BaCl_2 \cdot 2H_2O$ from an HCl solution) and aluminum (cesium alum with CsCl and dilute H_2SO_4), refractive index of 1.590 $\pm .005$, double refraction about the same as that of quartz, and an extinction angle of 28° (average of 5 readings) measured against the cleavage cracks parallel to (001), this vibration direction being the slow ray. The maximum size of the celsian grains is only 0.13 mm., but the identification is certain. Celsian is shown in Figs. 1, 7, and 8.

ALSTONITE. A carbonate mineral with strong double refraction, change of relief, and no indication of cleavage is identified as alstonite (or bromlite),[17a] which according to the recent work of Gossner and Mussgnug[18] is a double salt with the formula $BaCa(CO_3)_2$. The identification rests largely upon the axial angle 2V which is 8° 30′ (7° 14′ recorded value for alstonite).

DIOPSIDE, TOURMALINE (SCHORLITE), QUARTZ, and PYRRHOTITE are identified in thin sections. There are no special features worthy of comment.

UNKNOWN MINERALS. There are three minerals which have not yet been identified. These are in all probablity new minerals.[18a] They are briefly described:

First there is x, an alteration product of sanbornite. It is pale brown and appears opaque white by reflected light. The index of refraction is less than Canada balsam. It is probably a hydrous barium silicate, though this is not certain. It is well shown in Figs. 1 and 8.

The next is y, a brown mineral with very high relief and strong absorption. It is present in small amounts. Fig. 8 (lower left-hand corner) is typical of this mineral.

The next is z, a pale yellow isotropic mineral with low relief.

[17a] This is probably witherite since no micro-chemical test for calcium could be obtained.

[18] *Loc. cit.*

[18a] Since this article was written better material has been obtained. It is my intention to describe these minerals at a later date.

Summary

Sanbornite is a triclinic form of barium metadisilicate with the formula $BaSi_2O_5$. It occurs near Incline, Mariposa County, California, associated with gillespite, celsian, diopside, tourmaline, quartz, pyrrhotite, and three unknown minerals which may be new. It is probably from a contact metamorphic zone.

Tabular anhedral crystals show a perfect (001) cleavage and an imperfect (010) cleavage. The extinction angles on these two faces are respectively 3° 36′ and 5° 30′. Polysynthetic twinning with (010) as the twin-plane is a prominent feature. The maximum extinction angle in sections normal to the twin-plane is about 10°. The principal indices of refraction are $n_\alpha = 1.597$, $n_\beta = 1.616$, $n_\gamma = 1.624$, all $\pm .001$. The maximum double refraction is 0.027. The plane of the optic axes is approximately normal to (010) and γ is approximately normal to (001). 2V calculated from the indices is 66°.

Sanbornite is decomposed by cold dilute hydrochloric acid with the production of birefringent shreds of $H_2Si_2O_5$ (?). The solution on evaporation furnishes a microchemical test for barium ($BaCl_2 \cdot 2H_2O$ in characterisitic polysynthetically-twinned thin tabular crystals).