JONESITE

a new mineral from the Benitoite Gem Mine, San Benito County, California

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JONESITE occurs in natrolite-filled veins at the Benitoite Gem mine, San Benito County, California, closely associated with neptunite and joaquinite, but not benitoite. A weighted average of 20 electron and ion microprobe analyses over several crystals yields the following composition: $\mathbf{SiO_2}$ 32.54, $\mathbf{TiO_2}$ 17.31, $\mathbf{B_2O_3}$ 0.008, $\mathbf{Al_2O_3}$ 5.52, $\mathbf{Fe_2O_3}$ 0.16, **MnO** 0.035, **MgO** 0.111, **CaO** 0.045, **SrO** 0.051, **BaO** 34.88, $\mathbf{Na_2O}$ 0.67, $\mathbf{K_2O}$ 2.70, $\mathbf{Nb_2O_5}$ 0.022, $\mathbf{H_2O}$ 5.9, **total** 99.952, giving a general formula $\mathbf{(K,Na,Ba)_{1-2}Ba_4Ti_4Al_{1-2}Si_{10-11}O_{36}\cdot 6H_2O}$.

Jonesite crystals are pointed blades up to 1 mm long and occur most commonly in rosettes. The blades exhibit orthorhombic symmetry of the **class** $m2m$ with the forms $\{\mathbf{010}\}$, $\{\mathbf{310}\}$, $\{\mathbf{2\bar{1}0}\}$, and $\{\mathbf{101}\}$ most common, and the forms {302}, {403}, {313}, and {312} only on the largest crystals. Single crystal X-ray diffraction photographs indicate the **space group** $B22_12$, and cell dimensions, refined from powder data, a = **13.730**(5)Å, b = **25.904**(5)Å, **and** c = **10.608**(3)Å; volume = 3773 Å^3; Z = 4.

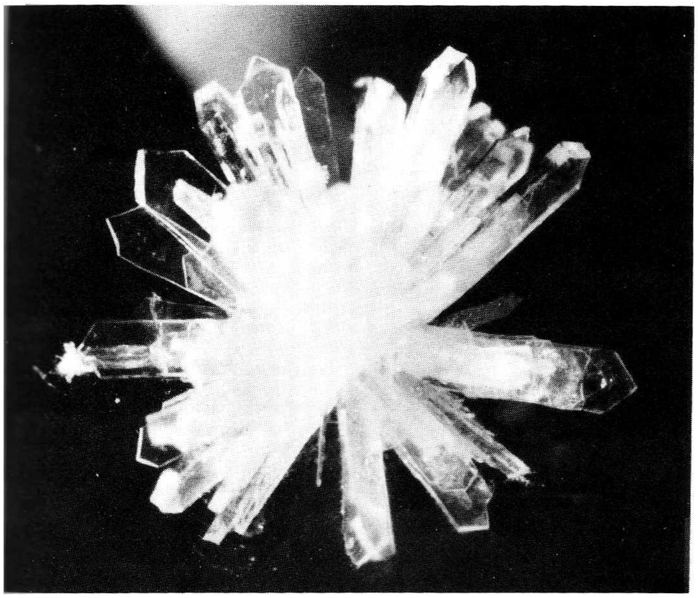
The crystals are colorless, but fluoresce orange in shortwave ultraviolet light. Cleavage is parallel to (010); hardness is near 3-4. The measured **density** is **3.25**(1) g/cm^3; the calculated density for average cell contents is 3.239 g/cm^3. Jonesite is **biaxial** (+), α = **1.641**, β = **1.660**, γ = **1.682**, and **2V** = **76°-78°**. The optic plane is parallel to (100) with X parallel to b and Z parallel to c.

The strongest lines of the X-ray powder pattern (d value in Å, relative intensity, indices) are 12.95 **100** *(020)*; 3.031 **45** *(440)*; 3.008 **18** *(262)*; 2.652 **30** *(004)*; 2.596 **17** *(024)*; 2.228 **20** *(2·11·0)*; 2.158 **17** *(0·12·0)*; 2.073 **18** *(622)*.

The name honors Francis T. Jones of Berkeley, California.

ure 1. (above) **A view of the open cut at the Benitoite Gem mine, owing the recovery of the large block of veined greenstone con-ning jonesite (Spring, 1970). W.C. Forrest photo.**

ure 2. (below) **A cluster of colorless jonesite crystals 3 mm across neptunite. Note the dominant pinacoid and dome faces. R. Gill ecimen and photo.**



INTRODUCTION

For the past 70 years the Benitoite Gem mine in San Benito County, California, has produced thousands of specimens of three unusual and rare minerals—benitoite, neptunite, and joaquinite. In 1907 Louderback published a brief description of benitoite as a new gem mineral and mentioned another mineral which proved to be identical with the neptunite from Greenland, described only a decade earlier. Because of the pleasing blue color and unusual symmetry, there quickly followed a flurry of papers describing the crystallography of benitoite, as well as neptunite. In 1909 a complete description of the occurrence was published by Louderback. By that time the deposit was actively being exploited by the Dallas Mining Company. In his report Louderback (1909) provided a careful and complete description of the deposit and its geologic relations, as well as the mineralogy. In this later report he also described another new mineral, joaquinite, with such a complicated composition that only recently has it been fully determined (Laird and Albee, 1972).

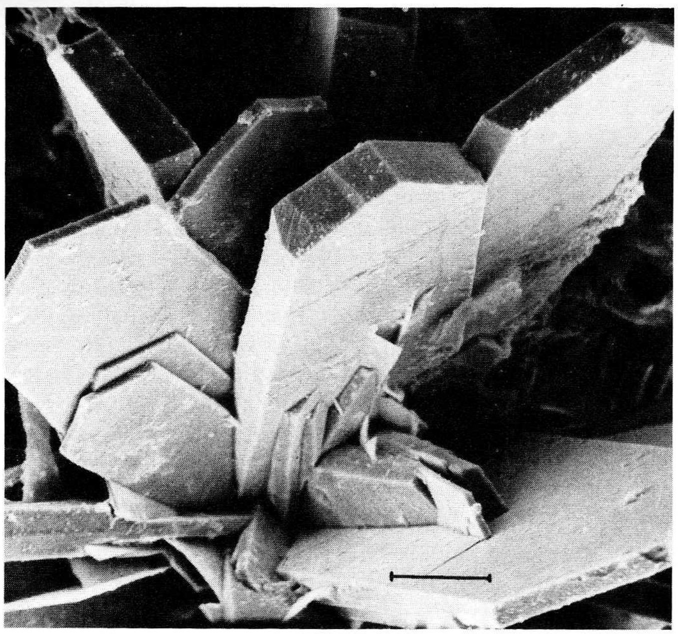


Figure 3. (left) **A scanning electron micrograph of a small jonesite cluster. Note that these small crystals are terminated with the simple form {101}. Length of the bar is 0.1 mm.**

Benitoite, neptunite, and joaquinite occur in natrolite-filled veins that branch and anastomose in blue-schist composed chiefly of actinolite and crossite. The benitoite, neptunite, and joaquinite have grown on the walls of fractures and cavities of brecciated greenstone. Most of the open spaces were later filled with natrolite, covering the earlier formed minerals. Specimens were prepared by treatment with hydrochloric acid, which decomposes the natrolite, leaving a silica gel. The reaction is stopped and the gel removed by immersion in a strong alkaline bath.

In 1957 Francis T. Jones found in the acid baths single blades or small clusters of crystals of a mineral not previously recognized from the mine. The amount of material was sufficient to determine that it was a new mineral, but insufficient to fully characterize it for description (Jones, 1971). The renewed mining activity by W. C. Forrest and Elvis Gray uncovered a huge block of the veined blue-schist in 1970 (see Fig. 1), from which many superb specimens of neptunite have been recovered. On a few of these specimens numerous rosettes of the new mineral were exposed by the acid treatment. This paper describes this new mineral, for which the name jonesite* is proposed in recognition of the discovery and early work by Francis T. Jones of Berkeley, California.

Table 1. Chemical composition of jonesite

weighted average of 18 microprobe analyses		**cell contents** (average)		(range)
SiO_2	32.54	Si	9.97	10.10 - 9.90
TiO_2	17.31	Al	1.99	1.86 - 2.10
B_2O_3*	0.008			
Al_2O_3	5.52	Ti	3.99	3.90 - 4.05
Fe_2O_3	0.16	Fe	0.04	—
MnO*	0.035	Mn	0.01	—
MgO*	0.111	Mg	0.05	—
CaO*	0.045	Ca	0.01	—
SrO*	0.051	Sr	0.01	—
BaO	34.88	Ba	4.19	4.15 - 4.41
Na_2O	0.67	Na	0.40	0.30 - 0.47
K_2O	2.70	K	1.06	0.70 - 1.10
Nb_2O_5*	0.022	H_2O	6.0	ω
H_2O**	5.9	Calculated density for average cell contents: 3.239		
total	99.952			

General formula:
$(K,Na,Ba)_{1-2}Ba_4Ti_4Al_{1-2}Si_{10-11}O_{36}\cdot 6H_2O$

Z = 4

*Elements determined by ion microprobe mass analyzer, others determined by electron microprobe

**Water determined by ion microprobe, also by difference in electron microprobe data.

DESCRIPTION

Chemical Composition

The determination of the composition of jonesite presented the most difficulty in the characterization of the mineral. It was evident in the early attempts at electron microprobe analysis that the composition was somewhat variable, even within a single crystal. Because the total available supply of the mineral was and remains small, analysis was only to be accomplished by microprobe methods. However, bubbling from the sample under the electron beam indicated that the sample was hydrated; water analyses cannot be made with an electron microprobe. For this reason, and because of a desire to determine all the major and minor elements in the mineral, complete mass scans (looking for every element) were made with the ion microprobe.

Several crystals were embedded in epoxy, ground to expose the centers, and coated with carbon. These crystals were analyzed at about ten spots. Ten additional analyses were obtained from the surface of a large single crystal. The electron microprobe analyses were carried out under the following conditions: accelerating voltage 15kV for all elements; sample current 8 nanoamps; spot size 20 micrometres; standards, benitoite for Ba, Ti, and Si; K-feldspar for K; and albite for Na. Data were reduced and interelement corrections applied with a modified version of EMPADR7 (Rucklidge and Gasparrínni, 1969, Department of Geology, University of Toronto). The ion microprobe analyses were carried out with a negatively charged primary beam of monatomic oxygen ($^{16}O^-$) at 17 kV. The spot size was approximately 20 micrometres and a sample current of 6 nanoamps. The hydrogen content was estimated from the working curves of Hinthorne and Anderson (1975), and the other element data were quantitatively reduced, using sensitivity factors derived from a theoretical ionization model (Anderson and Hinthorne, 1973).

In order to determine whether the hydrogen in the mineral was bonded as hydroxyl or water molecules, an infrared absorption spectrum was obtained by George R. Rossman at California Institute of Technology. The absorption spectrum was obtained from a pellet of the powder of several crystals (180 micrograms) in KBr. The strong absorption band at 1635 cm^{-1} indicates that water molecules are by far dominant in the mineral.

The resulting analyses are given in Table 1. From calculations using the measured density, the unit cell volume (Table 2), and the average composition, a general formula was obtained (Table 1). The composition is that of a hydrated form of $BaTiSi_3O_9$, **benitoite**, in which Al has replaced some of the Si, and the resulting charge is balanced by K, Na, and extra Ba. The variation in K, Al, Ba, and Si from spot to spot in the crystals is probably a result of the coupled substitution K+Si = Ba+Al.

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

Table 2

X-ray powder diffraction data for jonesite. Least squares refinement of cell dimensions gives a = 13.730(5) Å, b = 25.904(5) Å, c = 10.608(3) Å, and V = 3773(1.4) Å^3. Powder data were standardized with Si (a = 5.4309 Å) and taken with CuK (λ = 1.5418 A). The pattern was indexed for the space group $B22_12$, but *hkl*'s with *h* or *l* odd were also excluded. Intensities were derived from measurement of peak heights on a diffractometer strip-chart recording.

hkl	d_{calc}	d_{obs}	I/I_1
020	12.95	12.95	100
040	6.47	6.46	10
012	5.20	5.19	3
032	4.52	4.51	3
202	4.20	4.19	2
250	4.14	4.13	2
222	3.99	3.99	10
052	3.71	3.70	15
242	3.52	3.51	13
400	3.43	3.43	5
420	3.32	3.32	2
440	3.033	3.031	45
262	3.009	3.008	18
412	2.864	2.868	8
422	2.813	2.818	2
432	2.733	2.737	10
460	2.687	2.690	3
004	2.652	2.652	30
024	2.598	2.596	17
282	2.564	2.562	3
092	2.530	2.527	5
214	2.463	2.465	3
044	2.454	2.452	3
472	2.274	2.273	6
064	2.260	2.259	7
2.11.0	2.228	2.228	20
0.12.0	2.159	2.158	17
404	2.099	2.101	8
622	2.074	2.073	18
2.11.2	2.054	2.054	5
642	1.999		
444	1.996	1.998	10
2.13.0	1.914	1.914	8
464	1.887	1.888	2
294	1.876	1.875	3
0.14.0	1.850	1.850	3
474	1.825	1.826	2
4.11.2	1.823	1.822	2
690	1.791		
2.10.4	1.789	1.791	2
016	1.764	1.764	2
484	1.761		
0.11.4	1.761	1.760	2
624	1.717	1.719	2
810	1.712		
206	1.712	1.713	2
2.11.4	1.706	1.706	10
634	1.698	1.699	9
494	1.696		
2.14.2	1.693	1.695	5
2.15.0	1.675	1.675	3
246	1.655	1.656	4
0.15.2	1.642	1.642	12
860	1.552	1.551	4
0.16.2	1.548	1.549	4

plus at least 10 weak lines to 1.14

Crystal Geometry

Cell dimensions were determined by means of *h*O*l* and O*kl* precession photographs, a *c*-axis rotation photograph, and an *hk*O Weissenberg photograph, allowing two or three independent measurements on each cell edge. First, second, and third level Weissenberg photographs (*hk*1, *hk*2, and *hk*3) were taken to check for proper indexing and for systematic extinctions. The cell dimensions were refined from the X-ray powder diffraction pattern (see Table 2), standardized with Si metal (a = 5.4309 A), using CuKα radiation (λ = 1.5418 A).

The diffraction symmetry is *mmm* indicating orthorhombic symmetry. Indexing of the Weissenberg photographs is limited to $h+l = 2n$ in *hkl* reflections and $k = 2n$ for O*k*O, which lead to only one space group, $B22_12$. Not only are all *hkl*'s weak for *l* odd, as seen on the *c*-axis rotation photograph, but all *hkl*'s for *h* odd are also very weak. These observations indicate a smaller pseudocell, whose axes are a = 6.88 Å, b = 25.95 Å, and c = 5.31 Å. Reindexing leads to the pseudospace group for the cell $I\frac{2}{m}\frac{2}{m}\frac{2}{m}$.

Crystal Morphology

Jonesite crystals are slender blades terminated with dome faces. These blades most commonly form rosettes, composed of several tens of crystals (see Fig. 2 and 3). The rosettes may be as large as 3 mm across or as small as 0.2 mm.

Individual jonesite crystals commonly have six faces forming a prism (see Fig. 4). The relatively large crystal, shown in Figure 4, which was coated with gold for the SEM photograph, was suitable for optical goniometric measurements. The faces identified are {010} and {0$\bar{1}$0}, the largest pinacoid faces with {310}, {$\bar{3}$10}, {2$\bar{1}$0}, and {$\bar{2}\bar{1}$0} forming the prism (see Fig. 5). The dome faces terminating the crystal are simple—commonly {$\bar{1}$01} and {101}—if the crystal is small. However, complex, irregular surfaces develop on the larger crystals (compare Fig. 2 and 4). Goniometric measurements on the Figure 4 crystal indicate the crystal class *m*2*m*. Moreover, the goniometric measurements, as well as X-ray photographs clearly disprove the suggestion that the forms, illustrated in Figure 4, have resulted from twinning on the (010) plane.

Physical Properties

All the observed crystals are colorless. Jonesite fluoresces dull orange in shortwave ultraviolet light, but is nonfluorescent under the longer wavelengths. The density is 3.25 (± 0.01) g/cm^3, measured by a sink-float

Figure 4. (left) **A scanning electron micrograph of a single, large jonesite crystal. Faces other than the {010} pinacoid are {310} and {2$\bar{1}$0}. X-ray diffraction and goniometric measurements prove that the re-entrant faces are not a result of twinning, but from the rapid growth of the {010} faces. Length of the bar is 0.1 mm.**

method in acetone diluted di-iodomethane. The crystals have a hardness near 3 to 4.

Crystals break irregularly across the blades, but cleave parallel to the (010) plane.

Optical Properties

Jonesite is biaxial (+), α = 1.641, β = 1.660, γ = 1.682 (all ± 0.001), and 2V = 76° to 78°. The optic plane is parallel to (100) with X parallel to *b* and Z parallel to *c* (see Fig. 5).

Type Specimen

The type specimen is preserved in the mineral collection in the Department of Geological Sciences at the University of California, Santa Barbara, as specimen USCB 7325. A similar specimen is in the collection of the American Museum of Natural History.

ORIGIN

Jonesite, so far as it is presently known, occurred only in a few of the veins at the Benitoite Gem mine. It has been found closely associated with neptunite and joaquinite, most commonly having grown near or on those earlier formed crystals. Jonesite has not been found in close proximity to benitoite.

These observations lead to the conclusion that the jonesite grew from the same fluids from which the other minerals crystallized. Jonesite does not appear to have grown at the expense of benitoite, but rather in its place, possibly where the fluids were too aluminous for benitoite. Jonesite will most likely be found in the rare type of environment where benitoite can also grow at low temperatures.

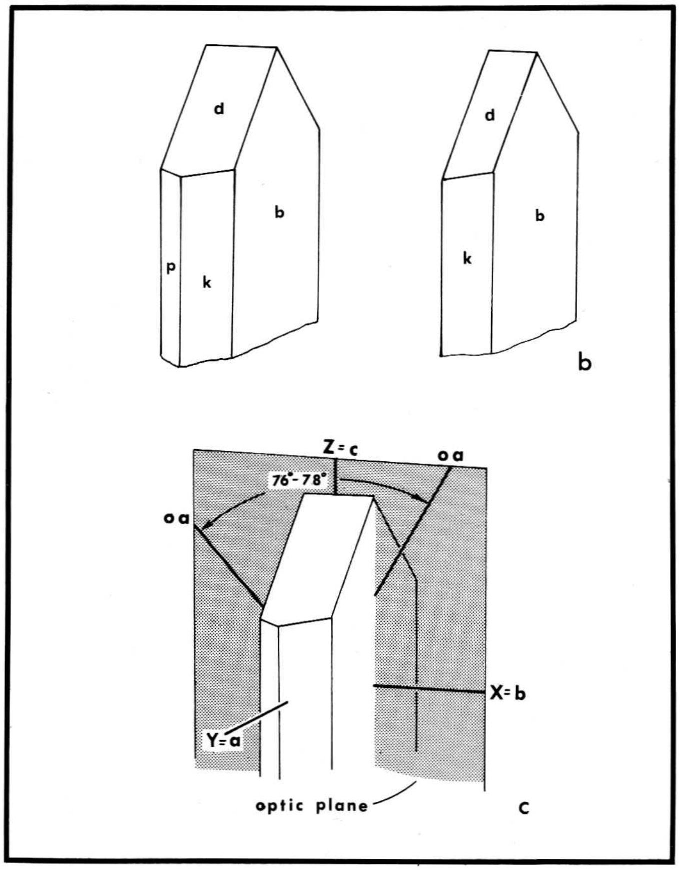

Figure 5. **Crystal forms and optical properties of jonesite crystals. (a and b) The crystals have the forms *b* {010}, *k* {310}, *p* {2$\bar{1}$0}, and *d* {101}, and belong to the crystal class *m2m*. (c) The optic orientation of jonesite.**

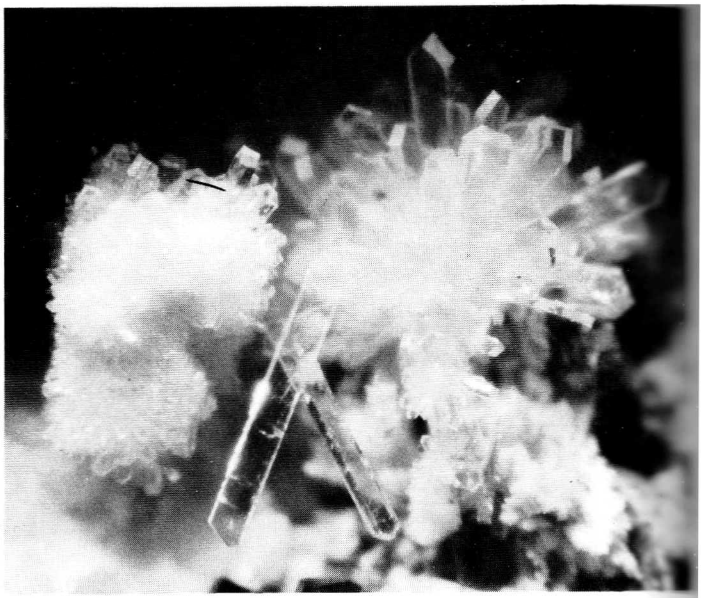

Figure 6. **Colorless jonesite clusters and single crystals. The longest jonesite crystal is less than ½ mm in length. R. Gill specimen and photo.**

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