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Boromuscovite, a new member of the mica group, from the Little Three mine pegmatite, Ramona district, San Diego County, California

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ABSTRACT

Boromuscovite, ideally $KAl_2(Si_3B)O_{10}(OH,F)_2$, in which $^{[4]}Al$ is replaced by B relative to muscovite, occurs as a late-stage, postpocket rupture mineral within the New Spaulding Pocket, main Little Three pegmatite dike, Ramona district, San Diego County, California. The mineral is white to cream colored and occurs as a porcelaneous veneer and coating on primary minerals. The average grain size is less than 3–4 μm, but the coatings may be as much as 1 cm or more thick. Fragments of topaz, albite, elbaite, and other pocket minerals are included in the coating. The boromuscovite precipitated from a late-stage hydrothermal fluid; it occurs only as a snowlike coating.

Chemical analysis yielded (wt%): SiO_2 48.1, Al_2O_3 28.1, B_2O_3 7.0, CaO 0.1, MgO 0.15, Fe_2O_3 0.1, MnO 0.08, P_2O_5 <0.05, TiO_2 <0.01, K_2O 11.0, Na_2O <0.05, Li_2O 0.05, Rb_2O 0.52, Cs_2O 0.05, F 0.76, H_2O^+ 4.55, H_2O^- 0.22, O = F 0.32, total 100.46. An empirical formula calculated on the basis of 12 O + OH + F is: $(K_{0.89}Rb_{0.02}Ca_{0.01})_{\Sigma 0.92}(Al_{1.93}Li_{0.01}Mg_{0.01})_{\Sigma 1.95}(Si_{3.06}B_{0.77}Al_{0.17})_{\Sigma 4.00}O_{9.82}[(OH)_{2.02}F_{0.16}]_{\Sigma 2.18}$. The mineral is a mixture of about equal amounts of $2M_1$ and $1M$ polytypes. Refined unit-cell parameters for both polytypes are significantly smaller than those for muscovite: $2M_1$ $a = 5.075(1)$, $b = 8.794(4)$, $c = 19.815(25)$ Å, $\beta = 95.59(3)°$; $1M$ $a = 5.077(1)$, $b = 8.775(3)$, $c = 10.061(2)$ Å, $\beta = 101.31(2)°$. D_{calc} for the $2M_1$ and $1M$ polytypes are 2.89 g/cm³ and 2.90 g/cm³, respectively. D_{obs} of the mixture is 2.81 g/cm³.

In aggregate, the mineral has a Mohs hardness of 2.5–3, white streak, a dull to porcelaneous luster, perfect {001} cleavage, a poor parting on {010}, poor to subconchoidal fracture, and no fluorescence or luminescence. Optical properties are (for Na light): biaxial (−), $\alpha = 1.557$, $\beta = 1.587$, $\gamma = 1.593$ (all ±0.002), $2V_{x\ meas} = 44(2)°$, $2V_{x\ calc} = 47.5°$, dispersion is $r > v$ weak. For the $2M_1$ polytype, the OAP is normal to (010), $X{:}c = -1°$, $Y{:}a = +2°$, $Z = b$; X is in the acute angle of β and Y is in the obtuse angle of β. The mineral shows no absorption or pleochroism.

Boromuscovite crystallized from the evolved fluid phase present after the growth of the primary minerals in the New Spaulding Pocket. The coexistence of the $2M_1$ and $1M$ polytypes is consistent with growth in the interval 350–400 °C, a range consistent with fluid-inclusion geothermometry on pocket minerals in related pegmatitic occurrences.

INTRODUCTION

The Little Three layered pegmatite-aplite intrusion is located in the Ramona pegmatite district of central San Diego County, California (Foord et al., 1989). Bodies of granitic pegmatite on the Little Three mine property have been the subject of study since their discovery in 1903. The voluminous literature has been summarized in Foord et al. (1989). In June, 1976, while working the Little Three main dike for gem- and specimen-quality tourmaline and topaz, the mine owner, Louis B. Spaulding, Jr., uncovered a zone of pocket mineralization. The New Spaulding Pocket (NSP) was the largest and most productive of the pockets in this zone (see Stern et al., 1986). The NSP, with a volume of approximately 2.2 m³, occupied an irregularly shaped cavity averaging 0.25 m in height.

The contents of the NSP included quartz, tourmaline (schorl-elbaite), blue and colorless topaz, maximum microcline "pillars," clear and smoky quartz, cleavelandite,

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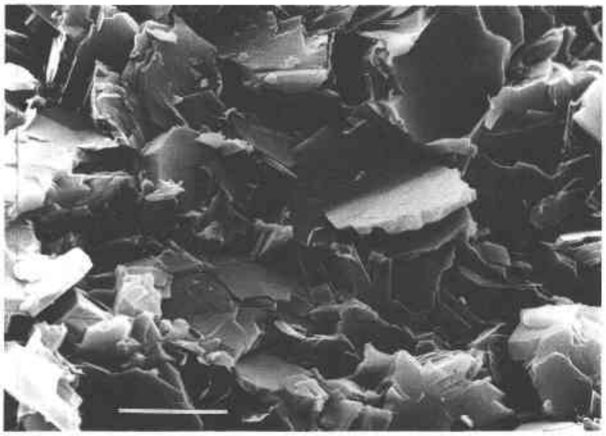

Fig. 1. SEM photograph of boromuscovite from the NSP. Scale bar equals 4 μm.

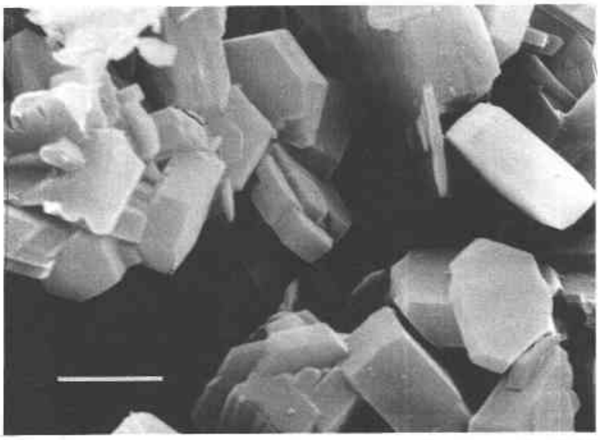

Fig. 2. SEM photograph of boromuscovite from the NAP showing euhedral pseudohexagonal flakes. Scale bar equals 2 μm.

F-rich lepidolite, microlite-uranmicrolite, and a new polymorph of stibiocolumbite-stibiotantalite. Coarse-grained ($\geq$5 cm across) euhedral books of lepidolite-*1M* irregularly lined the floor. Tourmaline crystals were attached to the roof within a mass of coarsely bladed cleavelandite, with lesser amounts of cleavelandite (~20%) rooted to the floor of the pocket. Several lepidolite crystals were attached to elbaite specimens on the roof (Stern et al., 1986). Large blue topaz crystals were removed from the sides of the pocket, the majority occurring on the floor. Small colorless topaz crystals grew on the elbaite faces along the roof of the pocket.

All minerals (principally lepidolite, quartz, microcline, and topaz) on the floor, including those broken off during pocket rupture and fragments of crystals lying on the floor, were coated with a fine-grained, hard, porcelaneous substance, which was subsequently determined to be boromuscovite. Deposition of the boromuscovite occurred after the initial rupturing event in the NSP as well as after another period of primary mineral growth and crystal repair. At a lower temperature, circulation of an aqueous solution, laden with crystal fragments, through the pocket resulted in abrasion of the boromuscovite coating and underlying minerals. Pockets peripheral to the NSP that were not reopened to migrating solutions ("dry pockets") contained only the snowlike coating of boromuscovite, muscovite, or cookeite. Hydrothermal pocket clays, consisting chiefly of montmorillonite, were described by Foord et al. (1986).

The name boromuscovite and the status of this mineral as a new species (89-027) were approved by the IMA Commission on New Minerals and Mineral Names (CNMMN). Type material (no. 166821) was deposited at the U.S. National Museum of Natural History.

PHYSICAL PROPERTIES

Boromuscovite is buff to pale cream colored, has an earthy to porcelaneous luster, a white streak, a hardness of 2.5–3, a poor to subconchoidal fracture (all in compact masses), one perfect cleavage {001}, a poor parting on {010}, is opaque, and does not fluoresce or luminesce (Figs. 1 and 2). D_{meas} on a Berman microbalance and by suspension in bromoform-acetone mixture is 2.81 g/cm^3. D_{calc} is 2.89 and 2.90 g/cm^3 for the *2M₁* and *1M* polytypes, respectively. The 0.09 g/cm^3 difference probably results from air trapped in the fine-grained masses of boromuscovite.

CHEMISTRY

Boromuscovite was analyzed by a variety of methods and, in some instances, in duplicate. An emission spectrographic analysis (Table 1) showed the presence of approximately 3 wt% B. Electron microprobe analyses (ARL SEMQ) indicated that the material is homogeneous on the micrometer scale, and X-ray fluorescence analysis (PW1600) yielded the same composition determined by electron microprobe. Concentrations of H_2O^+, H_2O^-, Li,

TABLE 1. Trace and minor element contents in boromuscovite from the New Spaulding Pocket

	Method	
Element	Emission spectroscopy	ICP-AES
Ca	0.03%	0.36%
Fe	0.1%	0.13%
Mg	0.07%	0.08%
Ti	0.01%	<0.04%
Mn	0.15%	0.07%
Ba	15	30
Be	5	<9
Ga	200	120
Li	300	240
Sr	7	40
Ge	30	n.d.
Zr	15	n.d.
Tl	50	n.d.
B	3.0%	2.18%
Bi	30	<20
Pb	15	<20
V	7	<10
Na	0.3%	n.d.
Rb	0.5%	n.d.
Cs	300	n.d.

Note: n.d. = not determined. All values given in ppm except where stated otherwise.

TABLE 2. Chemical composition of boromuscovite from the NSP

Oxide	Wt%	Analytical method(s)	EDS (wt%)
SiO_2	48.1	XRF and EMP	48.13
Al_2O_3	28.1	XRF and EPM	25.76
B_2O_3	7.0	ICP-AES	n.d.
CaO	0.1	XRF and EMP	0.10
MgO	0.15	XRF, EMP, and ICP-AES	1.12
Fe_2O_3	0.1	XRF, EMP, and ICP-AES	0.23
MnO	0.08	XRF and ICP-AES	n.d.
P_2O_5	none	XRF and ICP-AES	n.d.
TiO_2	none	XRF, EMP, and ICP-AES	0.06
K_2O	11.0	XRF and EMP	11.51
Na_2O	none	XRF and EMP	0.80
Li_2O	0.05	ICP-AES	n.d.
Rb_2O	0.52	emission spectroscopy and AA	n.d.
Cs_2O	0.05	emission spectroscopy and AA	n.d.
F	0.76	selective-ion electrode	n.d.
H_2O^+	4.55	microcoulometric moisture anal.	n.d.
H_2O^-	0.22	microcoulometric moisture anal.	n.d.
O for F	0.32		
Total	100.46		

Note: All Fe expressed as Fe_2O_3. EDS analysis is an average of 11 determinations performed on single flakes. EDS analysis total recalculated to 87.79 wt% to allow for 7.0 wt% B_2O_3, 0.76 wt% F, and 4.55 wt% H_2O^+. XRF = X-ray fluorescence, EMP = electron microprobe, AA = atomic absorption. ICP-AES = inductively coupled plasma–atomic emission spectroscopy.

Rb, Cs, and F were subsequently determined to complete the characterization. ICP-AES (inductively coupled, plasma–atomic emission spectrography) analysis (Table 1) of the bulk material confirmed the previously determined chemistry.

A composite of chemical data was used to derive the bulk composition of boromuscovite (Table 2). The structural formula of boromuscovite, calculated on the basis of 12 O + OH + F, is $(K_{0.89}Rb_{0.02}Ca_{0.01})_{\Sigma 0.92}(Al_{1.93}Li_{0.01}Mg_{0.01})_{\Sigma 1.95}(Si_{3.06}B_{0.77}Al_{0.17})_{\Sigma 4.00}O_{9.82}[(OH)_{2.02}F_{0.16}]_{\Sigma 2.18}$.

X-RAY DIFFRACTION AND UNIT-CELL DATA

Power diffraction data (Table 3) were obtained using a Guinier-Hägg camera with Cu$K\alpha_1$ radiation. Intensities were determined separately from a diffractometer trace of a randomly oriented back-packed sample, using graphite-monochromatized Cu$K\alpha$ radiation, at 40 kV and 30 mA. Refined unit-cell data were obtained using a modified version of the least-squares program of Appleman and Evans (1973). A mixture of approximately equal amounts of $2M_1$ and $1M$ polytypes accounts for the data. Because of the fine grain size, single-crystal X-ray studies were not possible; thus, space groups were assigned by analogy to those of muscovite.

The metric dimensions of the unit cells of the two polytypes are significantly smaller (1.1–2.5%) than those reported for both synthetic and natural B-free $2M_1$ and $1M$ muscovite (Table 3). The β angles also are smaller. The volumes of each are 93–94% of the volume of the equivalent polytypes of muscovite.

OPTICAL PROPERTIES

The optical properties of boromuscovite were determined on oil-immersion grain mounts and by spindle-

TABLE 3. X-ray powder diffraction and unit-cell data for boromuscovite polytypes from the NSP

hkl	d_{calc} (Å)	d_{obs} (Å)	I/I_0	Polytype
002	9.860	9.862	60	$2M_1$
001	9.865	9.862		$1M$
004	4.930	4.929	20	$2M_1$
002	4.933	4.929		$1M$
110	4.379	4.391	80	$2M_1$
$\overline{1}11$	4.354	4.350	<10	$2M_1$
$\overline{1}11$	4.240	4.239	40	$1M$
111	4.201	4.194	<10	$2M_1$
022	4.014	4.007	40	$2M_1$
$\overline{1}13$	3.796	3.799	10	$2M_1$
023	3.654	3.652	10	$2M_1$
$\overline{1}12$	3.570	3.569	100	$1M$
$\overline{1}14$	3.421	3.418	10	$2M_1$
006	3.287	3.287	40	$2M_1$
003	3.288	3.287		$1M$
024	3.281	3.280	20	$2M_1$
114	3.145	3.142	10	$2M_1$
112	3.010	3.008	80	$1M$
025	2.935	2.930	<10	$2M_1$
$\overline{1}13$	2.865	2.865	20	$1M$
201	2.534	2.533	30	$1M$
200	2.525	2.524	40	$2M_1$
$\overline{1}31$	2.504	2.505	80	$1M$
200	2.489	2.489	40	$1M$
$\overline{1}17$	2.466	2.467	<10	$2M_1$
113	2.427	2.427	10	$1M$
$\overline{2}02$	2.422	2.421	10	$1M$
131	2.387	2.388	20	$1M$
$\overline{2}04$	2.342	2.341	30	$2M_1$
201	2.309	2.309	20	$1M$
$\overline{2}21$, 040	2.195, 2.194	2.195	40	$1M$
204	2.164	2.165	20	$2M_1$
041	2.142	2.141	10	$1M$
$\overline{2}22$	2.120	2.119	10	$1M$
$\overline{2}06$	2.104	2.104	30	$2M_1$
135	2.086	2.087	10	$2M_1$
202	2.065	2.066	10	$1M$
221	2.043	2.043	10	$1M$
$00\underline{10}$	1.972	1.972	30	$2M_1$
005	1.973	1.972		$1M$
$\overline{2}04$	1.954	1.954	10	$1M$
113	1.912	1.910	10	$1M$
$\overline{2}08$	1.857	1.857	<10	$2M_1$
$\overline{2}24$	1.785	1.786	10	$1M$
$\overline{3}11$, $\overline{1}06$	1.661	1.661	10	$1M$
$20\underline{10}$	1.633	1.633	10	$2M_1$
204, $\overline{1}52$	1.601	1.601	10	$1M$
$\overline{1}54$	1.589	1.590	10	$2M_1$
$\overline{3}13$	1.588	1.588	<10	$1M$
$\overline{2}43$	1.555	1.555	<10	$1M$
$02\underline{12}$	1.539	1.539	<10	$2M_1$
$\overline{2}06$, $\overline{3}23$	1.515	1.515	<10	$1M$
135	1.484	1.485	<10	$1M$
060	1.465	1.465	40	$2M_1$

Unit-cell data

Boromuscovite-$2M_1$	Muscovite-$2M_1$ PDF 6-263	Boromuscovite-$1M$	Muscovite-$1M$ PDF 7-25
a = 5.075(1) Å	5.190 Å	5.077(1) Å	5.208 Å
b = 8.794(4) Å	9.030 Å	8.775(3) Å	8.995 Å
c = 19.815(25) Å	20.050 Å	10.061(2) Å	10.275 Å
β = 95.59(3)°	95.77°	101.31(2)°	101.6°
V = 879.7(15) Å³	934.90 Å³	439.53(14) Å³	471.5 Å³

Note: Operating conditions: Guinier-Hägg camera, Cu$K\alpha_1$ radiation, 12-h exposure, 40 kV, 30 mA. Si internal standard (NBS). Refinements done using computer program of Appleman and Evans (1973). Intensities are from random mounts scanned with a Philips powder diffractometer.

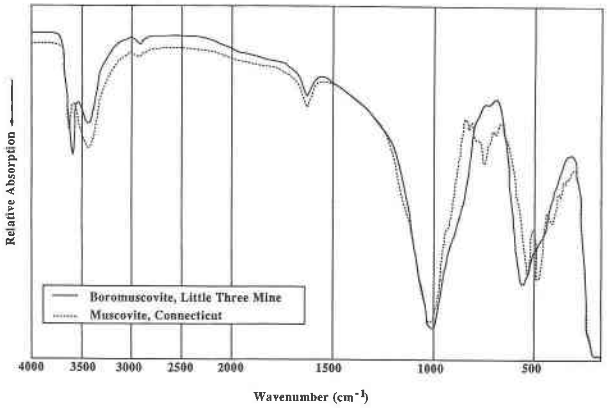

Fig. 3. IR spectra for boromuscovite and muscovite.

stage techniques, with flakes measuring about 5 μm across. The mineral is colorless, without pleochroism or absorption. Principal indices of refraction determined at 589 nm and 22 °C are $\alpha = 1.557$, $\beta = 1.587$, $\gamma = 1.593$ (each ± 0.002); $2V_{x\,\mathrm{meas}} = 44(2)°$ and $2V_{x\,\mathrm{calc}} = 47.5°$. Dispersion is weak, $r > v$. The orientation scheme for the *2M₁* polytype is OAP normal to (010), $X{:}c = -1°$, $Y{:}a = +2°$, and $Z = b$. X is in the acute angle β, and Y is in the obtuse angle β.

TEM STUDIES

Transmission electron microscopy (TEM) studies were carried out on Philips instruments (420ST operated at 120 kV, CM30 operated at 300 kV). A 2.3-mm disk was removed from a petrographic thin section of polycrystalline boromuscovite, mounted on a Cu grid, further thinned by standard Ar ion-milling techniques, and C coated. In addition, pulverized material was sedimented on a holey-carbon substrate on a Cu grid.

Boromuscovite was found to be unstable in the electron beam and became amorphous in seconds. Selected-area diffraction patterns containing **c*** were obtained from two crystals only; (001) lattice-fringe images could not be obtained before breakdown. The single row of sharp diffraction maxima along **c*** confirms the 10-Å repeat. There is no evidence of a mixture of 10-Å and 20-Å, polytypes within single flakes, at least at the scale of TEM observation.

Energy-dispersive spectra were obtained on 11 grains using an EDAX Si(Li) X-ray detector and a Princeton Gamma-Tech System IV analyzer. Raw data were reduced following Livi and Veblen (1987). An average bulk composition of the mica, calculated by assuming 7.0 wt% B_2O_3, 0.76 wt% F, and 4.55 wt% H_2O, is presented in Table 2.

INFRARED SPECTRAL STUDIES

Standard infrared absorption spectra for the region 200–4000 cm^{-1} were obtained using a Perkin-Elmer 580B instrument for boromuscovite and muscovite *2M₁* (Fig. 3). The two spectra are similar, including the 800–1200 cm^{-1} region, which contains the $(Si,Al,B)O_4$ stretching vibrations. The OH and H-O-H bands are present at 3440 cm^{-1} and 1650 cm^{-1}, respectively. However, some differences also are apparent near 500 cm^{-1} and 750 cm^{-1}. The vibration at 750 cm^{-1} may result from the substitution of tetrahedral B for Al.

DISCUSSION

The incorporation of tetrahedrally coordinated B in phyllosilcates has been well established through studies of synthetic systems and natural examples. Noda et al. (1944) synthesized a B-rich fluorophlogopite in which tetrahedrally coordinated Al is replaced by B. Eugster and Wright (1960) synthesized Al-free, B-bearing hydrous phlogopite and biotite and probably B-bearing muscovite. Harder (1959a, 1959b) found as much as 2000 ppm B in natural micas. Manandonite, $Li_2Al_4[(Si_2AlB)O_{10}](OH)_8$, possibly a serpentine mineral, contains Al partly replaced by B (Lacroix, 1922; Hawthorne and Černý, 1982; Ranorosoa et al., 1989). It is known only from Madagascar as a crust in cavities lined with elbaite, quartz, and albite. Cookeite also may contain B but in subordinate amounts (Hawthorne and Černý, 1982).

Boromuscovite is the natural analogue of a previously synthesized B-substituted mica. Boromuscovite may be a rare mica, considering the volume of chemical data available for muscovite and B-, Be-, rare-metal-, and rare-alkali-containing muscovite from granitic pegmatites.

At the time of crystallization of the pocket minerals in the NSP, the aqueous vapor phase was distinctly enriched in K, Al, B, and F. This enrichment is expressed by the abundance of F-rich lepidolite and topaz, elbaite, and potassium feldspar. In contrast, the later hydrothermal fluid, from which the boromuscovite crystallized, had become relatively depleted in F.

Boromuscovite formed from this evolved hydrothermal solution at a moderate temperature (350–400 °C) and low pressure (1–2 kbar). Stagnant conditions during nucleation and growth are indicated by the snowlike character of the coating. The inferred *P-T* conditions for the deposition of boromuscovite are based on extrapolation of temperatures of fluid-inclusion homogenization from "pocket" minerals in other pegmatite dikes in the region (Taylor et al., 1979; Foord et al., 1986). The *P-T* conditions also are consistent with the mineral assemblages found and phase-equilibrium studies in pegmatitic systems (London, 1984, 1986a, 1986b, 1987). By analogy with findings in muscovite (Hawthorne and Černý, 1982; Frey et al., 1983; Mukhamet-Galeyev et al., 1984), the deposition of the *2M₁* and *1M* polytypes of boromuscovite presumably reflects the low temperature of its nucleation and growth (Amouric and Baronnet, 1983) rather than an arrested stage of a progressive transformation by recrystallization of the *2M₁* polytype, considered to be more stable at higher temperature than the *1M* polytype.

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