

## Okayamalite, $\text{Ca}_2\text{B}_2\text{SiO}_7$ , a new mineral, boron analogue of gehlenite

SATOSHI MATSUBARA, RITSURO MIYAWAKI, AKIRA KATO, KAZUMI YOKOYAMA

Department of Geology, National Science Museum, 3-23-1 Hyakunin-cho, Shinjuku, Tokyo 169, Japan

AND

AKIYOSHI OKAMOTO

3-11-5 Oeoda Minami Fukunishi-cho, Nishigyo, Kyoto 610-11, Japan

### ABSTRACT

Okayamalite,  $\text{Ca}_2\text{B}_2\text{SiO}_7$ , tetragonal,  $P\bar{4}21m$ ,  $a = 7.116$ ,  $c = 4.815 \text{ \AA}$ ,  $Z = 2$ , is a new member of melilite group, the boron analogue of gehlenite. Electron microprobe analysis gave CaO 46.28,  $\text{B}_2\text{O}_3$  28.50,  $\text{SiO}_2$  24.24,  $\text{Al}_2\text{O}_3$  0.36, total 99.38 wt.%, corresponding to  $\text{Ca}_{2.01}\text{B}_{2.00}\text{Si}_{0.98}\text{Al}_{0.02}\text{O}_7$ , a natural counterpart of  $\text{Ca}_2\text{B}_2\text{SiO}_7$  known only synthetically. The strongest lines in the X-ray powder diffraction pattern are 3.479 (40)(111), 2.862 (55)(201), 2.654 (100)(211), 2.129 (20)(301), 1.920 (35)(212), 1.644 (29)(312), very close to those of the synthetic material ( $a = 7.115$ , and  $c = 4.812$ ). It is creamy white in colour with an earthy appearance due to the fine grain size. Streak white, cleavage not observed. Hardness  $\sim 5/2$ . Density calculated on the ideal formula is  $3.30 \text{ g/cm}^3$ . It is optically uniaxial negative with  $\omega = 1.700$ , and  $\epsilon = 1.696$ . It occurs as patches of a few millimetres across in grey homogeneous-looking aggregate of wollastonite, vesuvianite, calcite and johnbaumite from Fuka mine, Bicchu-cho, Okayama Prefecture, Japan. The patches consist of very fine grains of the mineral up to  $30 \mu\text{m}$ . Okayamalite is considered to be a product after the reaction formula:  $\text{CaCO}_3 + \text{CaSiO}_3 + \text{B}_2\text{O}_3 = \text{Ca}_2\text{B}_2\text{SiO}_7 + \text{CO}_2$ , arising from boron metasomatism of a wollastonite-calcite aggregate. The name is for the prefecture.

**KEYWORDS:** okayamalite, new mineral, melilite group, boron, gehlenite, X-ray data, electron microprobe data, optical data, Fuka, Japan.

### Introduction

THE incorporation of boron in the melilite structure has been confirmed by much of the experimental work initiated by Bauer (1962), who synthesized the boron analogue of gehlenite and confirmed the existence of complete diadochy between Al and B in two end members. The same material has been obtained in experiments on the thermal transformation of datolite (Tarney *et al.*, 1973), which converts to boron melilite under higher temperature conditions. Though boron-bearing melilite with up to 4.76 wt.%  $\text{B}_2\text{O}_3$  is known (Grew, 1996), the present find leads to the description of the natural boron analogue of gehlenite as a new mineral, and to the substantial confirmation of these conclusions.

There are many publications on boron-bearing minerals from Fuka, such as the description of the new mineral takedaite (Kusachi *et al.*, 1995). One of the authors (A.O.) visited a limestone mine in Fuka, where the occurrence of pentahydroborite has been reported (Fujiwara *et al.*, 1982). He collected small grey pieces of skarn including tiny creamy white patches of a few millimetres across from a pentahydroborite-bearing body, and the constituents have been studied. A preliminary X-ray powder study proved the constituents of the patches to be identical to that of synthetic  $\text{Ca}_2\text{B}_2\text{SiO}_7$  (Tarney *et al.*, 1973), and the chemical composition was subsequently confirmed. The mineral data and the name, have been approved by the Commission on New Mineral and Mineral Names of the International Mineralogical

Association. The type specimen is deposited at the National Science Museum, Tokyo, under the registered number NSM M-27525.

### Occurrence

The Fuka mine is worked for crystalline limestone. Only one pentahydroborite-bearing body is known within it. It is lenticular with approximately 50 cm in maximum thickness and 120 cm long at the adit wall. A vein-like skarn of less than 20 cm wide exists in the centre of a pentahydroborite body (Fujiwara *et al.*, 1982). This skarn looks similar to a porcelain-like mass, and consists principally of vesuvianite, wollastonite and calcite, and minor okayamalite, frolovite, sibirskite, uralborite, johnbaumite, thaumasite, datolite and some undetermined borates and borosilicates. Individual grains of all the above minerals are less than 50  $\mu\text{m}$  across. Two specimens of okayamalite are recognized; one of them, the type specimen, includes okayamalite composed of grains approximately 10  $\mu\text{m}$  across in close association with wollastonite, calcite, datolite and undetermined borates; the other is approximately 30  $\mu\text{m}$  across in diameter in association with vesuvianite and johnbaumite. Okayamalite occurs as equigranular aggregates and no crystal forms are observed (Fig. 1).

### Physical and optical properties

Okayamalite is creamy white with white streak, and is colourless in thin section. Due to the very fine grain size, the density could not be measured.

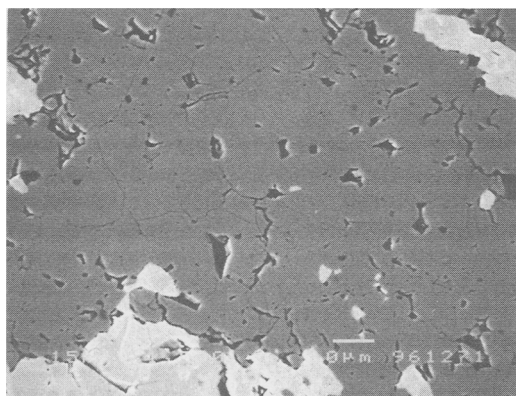


FIG. 1. Back-scattered electron image of okayamalite (grey) and vesuvianite (white to light grey). Bar indicates 10  $\mu\text{m}$ .

The calculated density is 3.30  $\text{g/cm}^3$  for the ideal formula. The Mohs' hardness is approximately 5½. It is optically uniaxial negative with refractive indices;  $\omega = 1.700(2)$ , and  $\epsilon = 1.696(2)$ .

### Chemical analyses

Chemical analyses were made using an electron microprobe, JXA 8800, the standards being wollastonite (for Ca and Si), anorthite (for Al), and danburite (for B) (Table 1). The composition is close to ideal. From the average of 5 analyses the empirical formula is given as  $\text{Ca}_{2.01}\text{B}_{2.00}\text{Si}_{0.98}\text{Al}_{0.02}\text{O}_7$ , leading to the ideal formula  $\text{Ca}_2\text{B}_2\text{SiO}_7$ , or the boron analogue of gehlenite. It was fortuitous that  $\text{B}_2\text{O}_3$  contents of the mineral and danburite, these having the same constituents, are nearly equal, 28.50 and 28.32 wt.%, respectively, making danburite a very suitable standard. Too low  $\text{Al}_2\text{O}_3$  content did not serve to specify the element to be substituted, Si, B, or both. Anyway, the natural existence of a new end member of the melilite group has been confirmed.

### X-ray powder study

The very fine grain size makes the X-ray powder diffractometer study a unique crystallographic work. As compared in Table 2, the pattern of the natural material is essentially the same as that of synthetic  $\text{Ca}_2\text{B}_2\text{SiO}_7$  (Tarney *et al.*, 1973). The unit-cell parameters calculated from the pattern are  $a = 7.116(2)$  and  $c = 4.815(1)$  Å. These are very close to those of synthetic material,  $a = 7.115$  and  $c = 4.812$  Å,  $Z = 2$ , after Bauer (1962), who realized the complete diadochy between Al and B in the gehlenite structure. Therefore, the space

TABLE 1. The chemical analyses of okayamalite from the Fuka mine

Wt. %	1	2	3	4	5
$\text{SiO}_2$	24.09	24.39	24.23	24.24	0.98
$\text{Al}_2\text{O}_3$	0.43	0.32	0.34	0.36	0.02
$\text{B}_2\text{O}_3$	27.76	29.79	27.95	28.50	2.00
CaO	46.41	46.28	46.16	46.28	2.01
Total	98.69	100.78	98.68	99.38	

1 to 3 EPMA analyses

4 Average of 1 to 3

5 Atomic numbers calculated from 4 on the basis of  $\text{O} = 7$

## OKAYAMALITE, THE BORON ANALOGUE OF GEHLENITE

 TABLE 2. X-ray powder data for okayamalite and synthetic Ca<sub>2</sub>B<sub>2</sub>SiO<sub>7</sub>

hkl	1		2		hkl	1		2			
	I	d(obs.)	d(calc.)	I		d	I	d(obs.)	d(calc.)	I	d
111	40	3.479	3.479	50	3.48	330	5	1.677	1.677	15	1.679
210	2	3.186	3.182	5	3.17	401	5	1.668	1.669		
201	55	2.862	2.862	60	2.86	312	20	1.644	1.644	30	1.646
211	100	2.654	2.655	100	2.66	411	8	1.625	1.625	10	1.626
220	2	2.518	2.516	20	2.52	003	7	1.605	1.605	5	1.605
002	2	2.410	2.408	10	2.41	331	7	1.584	1.584	15	1.588
102	7	2.283	2.281	20	2.28	113	2	1.529	1.529	5	1.528
310	10	2.251	2.250	25	2.25	322	2	1.526	1.526	5	1.524
221	15	2.231	2.230	30	2.23	421				<5	1.514
112				10	2.22	203				<5	1.465
301	20	2.129	2.128	25	2.13	213	5	1.434	1.433	<5	1.435
311	5	2.039	2.039	10	2.05	412	1	1.403	1.403	<5	1.406
212	35	1.920	1.920	50	1.924	223	1	1.354	1.353	<5	1.356
321	1	1.827	1.826	5	1.830	521	5	1.274	1.274	<5	1.278
400	2	1.778	1.779	10	1.782	440	1	1.258	1.258		
222	5	1.740	1.739	15	1.744	004	1	1.204	1.204		
410	10	1.726	1.726	15	1.732						

1. Okayamalite. Fuka mine, Okayama Prefecture, Japan.

2. Synthetic Ca<sub>2</sub>B<sub>2</sub>SiO<sub>7</sub>. After Tamey *et al.* (1973)

group of okayamalite is the same as that of gehlenite,  $P\bar{4}21m$ , and hence the mineral can be placed in the melilite group. The X-ray, physical and optical properties of okayamalite and gehlenite in a skarn from Kushiro, Hiroshima Prefecture, Japan (Henmi *et al.*, 1971), are compared in Table 3.

### Discussion

At the Fuka mine, the limestone body was recrystallized by contact metamorphism, and a vein-like skarn formed along the intrusive channel of a granitic solution. After formation of the skarn, many borates and borosilicates replaced

TABLE 3. The comparison of crystal data, and physical and optical properties between okayamalite and gehlenite

	Okayamalite	Gehlenite*
Cell constants	$a = 7.116, c = 4.815 \text{ \AA}$	$a = 7.74, c = 5.05 \text{ \AA}$
Main X-ray powder pattern	3.479(40)(111) 2.862(55)(201) 2.654(100)(211) 2.129(20)(301) 1.920(35)(212) 1.644(29)(312)	3.714(20)(111) 3.074(20)(201) 2.855(100)(211) 2.403(20)(102,221) 2.039(15)(212) 1.755(30)(312)
Hardness	5.5	5–6
Density	3.30(calc.)	3.02
Optical class	Uniaxial negative	Uniaxial negative
Refractive indices	$\omega = 1.700, \epsilon = 1.696$	$\omega = 1.655, \epsilon = 1.651$

\* Kushiro, Hiroshima Prefecture, Japan (Henmi *et al.*, 1971)

limestone and skarn around the vein. The okayamalite is presumably a product of subsequent boron metasomatism after skarn formation, following the equation:  $\text{CaSiO}_3$  (wollastonite) +  $\text{CaCO}_3$  (calcite) +  $\text{B}_2\text{O}_3$  =  $\text{Ca}_2\text{B}_2\text{SiO}_7$  (okayamalite) +  $\text{CO}_2$ . Such a form of incorporation of boron compounds following metasomatism has been suggested by Watanabe (1943) at the Hol Kol gold mine, North Korea, where he discovered two new borate minerals, kotoite (Watanabe, 1939) and suanite (Watanabe, 1953). The close coexistence of kotoite with calcite, forming so-called kotoite-marble, indicates it is the product of boron metasomatism of either periclase or a brucite-bearing marble formed by partial dissociation of dolomite through the thermal effect of granitic magma. The reaction is  $3\text{CaMg}(\text{CO}_3)_2 + \text{B}_2\text{O}_3 = \text{Mg}_3(\text{BO}_3)_2$  (kotoite) +  $3\text{CaCO}_3 + 3\text{CO}_2$  (Watanabe, 1943). He also discovered the third occurrence of kotoite, from Miyako, Japan (Watanabe *et al.*, 1963), where a similar association to that at the original locality was found, favourably corroborating his initial conclusion.

## References

- Bauer, H. (1962) Über Diadochie zwischen Aluminium und Bor in Gehlenit. *Neues Jahrb. Mineral. Mh.*, 127–40.
- Fujiwara, T., Takada, M., Masutomi, K., Isobe, T., Okada, H., Nakai, I. and Nagashima, K. (1982) Pentahydroborite from Fuka, Okayama Prefecture, Japan. *Chigaku Kenkyu (Geoscience Magazine)*, **33**, 11–20. (in Japanese).
- Grew, E.S. (1996) Borosilicates (exclusive of tourmaline) and boron in rock-forming minerals in metamorphic environments. In: *Reviews in Mineralogy* Vol. 33, (E.S. Grew and L.M. Anovitz, eds.), Mineral. Soc. America, 387–502.
- Henmi, K., Kusachi, I. and Numano, T. (1971) Contact minerals from Kushiro, Hiroshima Prefecture (1) Gehlenite and hydrogrossular. *J. Mineral. Soc. Japan*, **10**, 160–9 (in Japanese).
- Kusachi, I., Henmi, C. and Kobayashi, S. (1995) Takedaite, a new mineral from Fuka, Okayama Prefecture, Japan. *Mineral. Mag.*, **59**, 549–52.
- Tarney, J., Nicol, A.W. and Marriner, G.F. (1973) The thermal transformation of datolite,  $\text{CaBSiO}_4(\text{OH})$ , to boron-melilite. *Mineral. Mag.*, **39**, 158–75.
- Watanabe, T. (1939) Kotoit, ein neues gesteinsbildendes Magnesiumborat. *Tschermaks Mineral. Petrogr. Mitt.*, **50**, 441–63.
- Watanabe, T. (1943) Geology and mineralization of the Suian district, Tyosen (Korea). *J. Fac. Sci. Hokkaido Univ., Ser. IV*, **6**, 205–303.
- Watanabe, T. (1953) Suanite, a new magnesium borate mineral from Hol Kol, Suan, North Korea. *Mineral. J.*, **1**, 54–62.
- Watanabe, T., Kato, A. and Katsura, T. (1963) Kotoite,  $\text{Mg}_3(\text{BO}_3)_2$ , from the Neichi Mine, Iwate Prefecture, Japan. *Proc. Japan Acad.*, **39**, 164–9.

[Manuscript received 11 December 1997:  
revised 12 January 1998]