Calcic analog of clinojimthompsonite from the Oeyama Ophiolite, Southwest Japan

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Key words: clinojimthompsonite, clinochesterite, biopyribole, triple chain silicate, Oeyama Ophiolite

Introduction Veblen and Burnham (1978a, b) discovered jimthompsonite and clinojimthompsonite $[(\text{Mg,Fe})_{10}\text{Si}_{12}\text{O}_{32}(\text{OH})_4]$ which are Mg-Fe triple chain silicate, and chesterite $[(\text{Mg,Fe})_{17}\text{Si}_{20}\text{O}_{54}(\text{OH})_6]$ which is a double and triple Mg-Fe mixed chain silicate in the blackwall alteration zone of a metamorphosed ultramafic body at Chester, Vermont. Jimthompsonite was also found from Orijärvi, Finland by Schumacher and Czank (1987). The first occurrence of Ca-rich triple chain structure (a triple chain analog of augite and actinolite), which is up to $1000\text{\AA}$ wide, has been reported from hydrothermally altered clinopyroxenes in the Akatani mine, although the material has not been named (Akai, 1982). Small patches of Ca-rich triple chains have been reported in altered pyroxenes (e.g., Veblen & Buseck, 1981), and in actinolite in the Salton Sea geothermal field, California (Yau *et al.*, 1986). Similar small materials were also found in synthetic products (Ahn *et al.*, 1991). However, large Ca-rich triple chain silicate has not yet been found under an optical microscope. To date, calcic chesterite-type structure has also not been discovered in natural or synthetic specimens.

Here, we report for the first time the occurrence of a Ca-rich triple chain silicate of optical microscopic size and a Ca-rich double/triple

mixed chain structure from the Oeyama (pronounced O-e-yama) Ophiolite.

Experimental Electron probe microanalysis (EPMA) was carried out with a JEOL JXA-8600SX electron microprobe (15 keV, beam current 1.3×10^{-8} A and beam diameter $1\text{ }\mu\text{m}$). The correction method employed was Oxide-ZAF for JEOL JXA-8600SX.

Thin foil specimens for electron microscopic observations were prepared by ion-milling and lightly coated with carbon to eliminate charging effects. Moreover, powdered specimens were prepared by crushing and placed on a microgrid. Transmission electron microscopy (TEM) was performed with a JEOL JEM-200CX microscope, operating at 200 keV or 160 keV, equipped with a Tracor Northern EDS Detector of TN-2000.

Geology The Oeyama Ophiolite is a meta-ophiolitic complex located in the Inner Zone of southwest Japan (Fig. 1). The complex is mainly composed of serpentinite, serpentized ultramafic rocks (dunite, harzburgite, lherzolite), clinopyroxenite, gabbro and diabase. The Oeyama Ophiolite was thermally affected by the intrusion of late Cretaceous to Paleogene Miyazu Granite, and can be divided into five zones. The critical mineral assemblage of each zone is as follows (Uda, 1984; Kurokawa, 1985):

Zone I antigorite + brucite + diopside

Zone II metamorphic olivine + antigorite + diopside

Zone III metamorphic olivine + antigorite + tremolite

Zone IV metamorphic olivine + talc + tremolite

Zone V metamorphic olivine + enstatite + tremolite $\pm$ hornblende

Mode of occurrence The newly found pyribole was confirmed to be calcic clinojim-

Received May 21, 1993. Accepted June 24, 1993.

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Fig. 1. Metamorphic zoning of the contact metamorphic aureole formed by younger granite. Stars: Localities of samples described (#1: Nabetsuka and #2: Oniana). 1: Shimomidani Formation, 2: Miyazu Granite, 3: Serpentinite and serpentinitized ultramafic rocks (dunite, harzburgite, lherzolite), 4: Clinopyroxenite, 5: Gabbro and diabase. Solid triangles: Mountaintops. (Modified from Kurokawa, 1985).

Fig. 2. A microphotograph of the calcic clinojimotothompsonite intergrown with tremolite in the [001] section (#1: Nabetsuka). Arrows indicate calcic clinojimotothompsonite. Bar: 10 μ m. Single nicol.

thompsonite by EPMA and TEM. It occurs as (010) intergrowths with tremolite in Zones III and IV (Figs. 1 and 2). The associated minerals are antigorite, lizardite, chrysotile, olivine, chlorite, tremolite, magnetite, spinel, ($\pm$) talc and ($\pm$) calcite. The calcic clinojimotothompsonite occurs as lamellae up to 10 μ m in width along the **b**-axis of pyribole. The intergrowths of tremolite and calcic clinojimotothompsonite are long-prismatic or fibrous up to 0.5 mm in length. The calcic clinojimotothompsonite is colorless or slightly pinkish in thin sections and its refractive index is lower than that of tremolite in [001] sections. The

Table 1. EMPA analyses of calcic clinojimotothompsonite and tremolite (#1: Nabetsuka). All iron was calculated as Fe^{2+} . 1-3: Calcic clinojimotothompsonites. 4: Tremolite.

No.	1	2	3	4
SiO ₂	60.55	60.15	59.98	57.90
TiO ₂	0.00	0.05	0.00	0.00
Al ₂ O ₃	0.22	0.18	0.12	0.64
Cr ₂ O ₃	0.06	0.11	0.00	0.03
FeO*	1.18	1.18	1.33	1.24
MnO	0.02	0.07	0.08	0.04
MgO	26.96	26.18	26.17	24.13
CaO	9.04	9.01	9.16	12.79
Na ₂ O	0.10	0.10	0.08	0.18
K ₂ O	0.00	0.01	0.21	0.00
Total	98.13	97.04	97.13	96.95

(O,OH)	36	36	36	24
Si	11.932	11.984	11.984	12.000
Al	0.052	0.016	0.028	0.067
Al	0.000	0.027	0.000	0.036
Ti	0.000	0.008	0.000	0.000
Cr	0.009	0.017	0.000	0.003
Fe	0.194	0.197	0.222	0.142
Mn	0.004	0.012	0.014	0.005
Mg	7.198	7.774	7.783	4.927
Ca	1.909	1.924	1.958	1.877
Na	0.040	0.039	0.029	0.048
K	0.000	0.003	0.054	0.000

*: Total Fe as FeO

birefringence of calcic clinojimotothompsonite is higher than that of tremolite in [001] sections. It is easy to distinguish the calcic clinojimotothompsonite from the amphibole exsolution lamellae in thin sections, because amphibole exsolution features are usually restricted to (100) or (001).

Chemistry The results of the EPMA an-

Fig 3. Electron micrographs of the calcic clinojimthompsonite (#1: Oniana). a: Low magnification image of the calcic clinojimthompsonite. Arrows denote small tremolite lamellae in the calcic clinojimthompsonite. b: [001] image of the calcic clinojimthompsonite. c: $hk0$ reflections of calcic clinojimthompsonite and tremolite. Small arrows denote diffractions of calcic clinojimthompsonite, and the large arrow marks a diffraction common to tremolite (040) and calcic clinojimthompsonite (060).

analyses of calcic clinojimthompsonite and tremolite are shown in Table 1. The chemical formula is $(\text{Ca}_{1.924}\text{Na}_{0.039}\text{K}_{0.003})\Sigma_{1.966}(\text{Mg}_{7.774}\text{Fe}_{0.197}\text{Mn}_{0.012}\text{Cr}_{0.017}\text{Ti}_{0.008}\text{Al}_{0.027})\Sigma_{8.035}(\text{Si}_{11.984}\text{Al}_{0.016})\Sigma_{12}\text{O}_{32}(\text{OH})_4$ for No. 2. The newly found pyribole is a Ca-rich analog of clinojimthompsonite. EPMA analyses revealed that the calcic clinojimthompsonite contains Ca in the M5 sites rather than (Mg, Fe) as in clinojimthompsonite and the ideal chemical formula is closed to $\text{Ca}_2(\text{Mg,Fe})_8\text{Si}_{12}\text{O}_{32}(\text{OH})_4$.

Electron microscopic observations It was confirmed in this study that the calcic clinojimthompsonite is largely composed of triple chains and is as large as several microns wide along the **b**-axis (Fig. 3a, b). The zone of pure triple chain structure without other chains was 254 chains in width or $3429 \text{ \AA}$. The $hk0$ reflections were not observed for $h+k \neq \text{even}$ (Fig. 3c). The approximate unit cell dimensions are $a\sin\beta = 9.3 \text{ \AA}$ and $b = 27 \text{ \AA}$. These extinctions of electron diffraction spots are consistent with maximum symmetry $C2/c$ for clino triple chain silicate. Cleavage angles of calcic clinojimthompsonite were measured to be 141° .

For the first time, calcic chesterite-type material was confirmed under the TEM (Fig. 4). Maximum width of chesterite-type material with a small amount of disordered chain sequence is $1500 \text{ \AA}$ along the **b**-axis. Twenty two repeats of (23) chain sequence [2: double chain, 3: triple chain] were observed (Fig. 4b). Major element contents obtained by the analytical electron microscope analyses are Mg, Si, Ca and Fe (Fig. 4d). This is presumably a structure in which the MT5 and MD4 contain Ca, rather than (Mg, Fe) as in "clinocheesterite". The electron diffraction pattern of an a^*-b^* plane was consistent with $A2/m$ clino- and $A2_1ma$ orthocheesterite (Fig. 4c). However, the chesterite-type structure is forced into the clino stacking sequence (++++), by virtue of its intimate (010) intergrowth with clinoamphibole (tremolite). The approximate unit cell dimensions are $a\sin\beta = 9.3 \text{ \AA}$ and $b = 45 \text{ \AA}$.

Summary For the first time, a calcic analog of clinojimthompsonite of optical microscopic size (up to 10 microns wide) and a calcic "clinocheesterite" of electron microscopic size (up to $1500 \text{ \AA}$ wide) were found from the metamorphosed serpentinite of the Oeyama Ophiolite.

Fig. 4. Electron micrographs of calcic “clinocchesterite”. a: [001] image of calcic “clinocchesterite” structure in tremolite (#2: Oniana). b: Twenty two repeats of chain sequence (23) are found. Bars denote the calcic “clinocchesterite” structure (#2: Oniana). c: c^* . c: $hk0$ reflections of calcic “clinocchesterite” and tremolite (#1: Nabetsuka). Small arrows denote diffractions of calcic “clinocchesterite”, and the large arrow marks a diffraction common to tremolite (040) and calcic “clinocchesterite” (0 10 0). d: An energy dispersive X-ray pattern of the calcic “clinocchesterite” (#2: Oniana). The signals at 8 keV and 8.9 keV are due to Cu grid.

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* in Japanese with English abstract