Omphacite-diopside vein in an omphacite block from the Osayama serpentinite melange, Sangun-Renge metamorphic belt, southwestern Japan

TATSUKI TSUJIMORI
Department of Earth Sciences, Faculty of Science, Kanazawa University, Kanazawa 920-11, Japan

Abstract
Omphacite \((\text{Jd}_{4.1-5.2}\text{An}_{0-8}\text{Di}_{0-51.2})\) and diopside \((\text{Jd}_{4.1-6.3}\text{An}_{0-4}\text{Di}_{3.6-91.6})\) coexist in a vein cutting an omphacite block in a serpentinite melange of the Oeyama ophiolite, central Chugoku Mountains. The compositional gap between omphacite and diopside is significantly wider than for other omphacite-diopside pairs reported in the literature. The intergrowth texture of the omphacite-diopside vein suggests that the clinopyroxene pair was contemporaneously crystallized in the fracture from a Ca-bearing, alkali-rich fluid in a sub-solution condition. Such a fluid may have been introduced from the surrounding serpentinitized clinopyroxene-bearing harzburgite. The stability of omphacite and Al-rich pumpellyte in the matrix and the omphacite-diopside vein indicate that the earlier matrix recrystallization and later fracture filling may have both taken place under high-\(P-T\) condition during the melange-forming stage.

KEYWORDS: omphacite, diopside, immiscibility, serpentinite melange, Oeyama ophiolite, Sangun-Renge metamorphic belt.

Introduction

Omphacite is a common metamorphic mineral in blueschist and eclogite facies metamorphic rocks, and also in metasomatic sodic pyroxene-rich rocks such as jadeite and omphacite. Coexisting omphacite-diopside pairs have been reported from high-pressure metamorphic rocks by several authors (e.g. Brown et al., 1978; Carpenter, 1980a; Enami and Tokonami, 1984), and they provide some evidence of a miscibility gap in the omphacite-diopside system. Coexisting omphacite and diopside have now been found in a vein from an omphacite block in a serpentinite melange of the Oeyama ophiolite, central Chugoku Mountains. As described in this paper, the compositional gap is wider than the other omphacite-diopside pairs reported in the literature.

Geology of the Osayama serpentinite melange

The Osayama serpentinite melange is located in the Sangun-Renge metamorphic belt of the Chugoku Mountains, in the Inner Zone of southwestern Japan. The Sangun-Renge metamorphic belt is the Carboniferous high-\(P-T\) type metamorphic belt, which tectonically underlies the Early Palaeozoic Oeyama ophiolite (e.g. Ishiwatari, 1991), and may be a western counterpart of the Omi gneissic schist (Banno, 1958) in the Hida Mountains.

The Osayama serpentinite melange is developed beneath the Osayama peridotite body of the Oeyama ophiolite in the central Chugoku Mountains, as a fragment of the Oeyama ophiolite (Fig. 1). It is a typical tectonic melange with a serpentinite matrix, which has probably been developed along a thrust fault between the Ordovician Oeyama ophiolite and Carboniferous Sangun-Renge blueschist nappe during the emplacement of the Oeyama ophiolite. The melange overlying the massive peridotite body is tectonically underlain by the 180 Ma basic schist of the Sangun-Chizu belt, which is in contact with the unmetamorphosed shallow marine sediments of the Jurassic Yamaoka Formation on the north because of a high-angle fault. All these rocks are unconformably overlain by the early Cretaceous Kyomiya conglomerate. The massive peridotite body and the Sangun-Chizu schist are affected by contact metamorphism of the Cretaceous granite intrusion on the west (Nozaka and Shibata, 1995). The protolith of the serpentinite matrix is harzburgite with minor dunite.
Fig. 1. Geological map of the Osayama serpentinite melange. [LP: schist of lawsonite-pumpellyite zone; E: schist of epidote zone; Gb: gabbro; Dk: dolerite; At: albitite]. The omphacitite block described in this paper occurs in the western part of the melange.
Omphacite-Diopside Vein

(Nozaka and Shibata, 1994; Tsujimori, in press), which may have been the residual peridotite of the Oeyama ophiolite.

The blueschist-facies schists, fragments of the Oeyama ophiolite (serpentinitized peridotite, gabbro, dolerite) and metasomatic rocks (albite, jadeite, omphacite, tremolite schist, etc.) are enclosed as tectonic blocks of various size (10 cm to 1.5 km in length) in a serpentinite matrix (Tsujimori, in press). The blueschist-facies schists are divided into a lawsonite-pumpellyite zone (230–270°C at 6–8 kbar) and an epidote zone by the mineral assemblages of the mafic blueschists. The epidote zone blocks contain two varieties i.e. a garnet-free, lower grade block (>300°C at 6–8 kbar) and a garnet-bearing higher-grade block (garnet-glaucophane schist) (400–530°C at 11–13 kbar). The gabbro and dolerite blocks also contain blueschist-facies mineral assemblages corresponding with the lawsonite-pumpellyite zone. Tsujimori (1995a) found relics of the eclogite-facies mineral assemblage (620°C at 15 kbar) in a garnet-glaucophane schist block. Tsujimori (1995b) reported a chromian omphacite-bearing tremolite schist of peridotite origin, suggesting that a part of the Oeyama ophiolite has experienced a high-\(P-T\) metamorphism with the Sangun-Renge metamorphic rocks. The blueschist blocks give phengite K-Ar ages of around 320 Ma (Tsujimori and Iwaya, submitted).

Petrography

The omphacite block, 1 × 1 m in size, occurs at a small outcrop in the central part of the melange. This is a well foliated, dark-green to black rock. It is surrounded by sheared serpentine.

The omphacite-diopside veins (<0.4 mm wide) consist mainly of omphacite and diopside with minor amounts of pumpellyite and biotite. The veins cut the foliation at high angles (Fig. 2a). Omphacite in the vein occurs as radiating anhedral crystals which are intergrown with fan-shaped diopside crystal (<0.3 mm) (Fig. 2b). Omphacite shows weak pleochroism between \(X'\) = colourless and \(Z'\) = faint green, and exhibits lower birefringence than the coexisting diopside. Diopside in the vein has a radiating habit and tends to be oriented perpendicular to the vein wall. The extinction positions of the two adjacent clinopyroxenes are different from each other. The two-pyroxene pair may have grown from the vein wall, and the texture suggests that the omphacite and diopside have contemporaneously crystallized in the vein.

The omphacite matrix consists mainly of omphacite with small amounts of chlorite, pumpellyite and titanite. Albite, apatite and biotite occur as accessories in the matrix, and quartz is absent.

Fig. 2. (a) Back-scattered electron image of the occurrence of the omphacite-diopside vein cutting a foliated omphacite matrix. (b) Back-scattered electron image of coexisting omphacite (Omp) and diopside (Di) of the omphacite-diopside vein.

Titanite and apatite are not found in the omphacite-diopside vein. The albite-rich layer (<3 mm wide) is rarely observed in the matrix. The foliation is defined by preferred orientation of elongated omphacite crystals. Matrix omphacite occurs as prismatic crystals (0.05–0.2 mm in length), and shows weak pleochroism between \(X'\) = colourless and \(Z'\) = pale green. A small number of crystals have a thin green rim. Chlorite occurs as oriented, tabular, colourless crystals, and shows a grey or brown interference colour. The elongation is positive. Pumpellyite is colourless and occurs as prismatic crystals (<0.05 mm in length). Apatite occurs as anhedral crystals (<0.1 mm).

Mineral chemistry

Chemical analyses of minerals were carried out with an AKASHI ALPHA-30A scanning electron micro-
Table 1. Representative microprobe analyses of clinopyroxenes in the omphacite

<table>
<thead>
<tr>
<th></th>
<th>Omphacite-diopside vein</th>
<th>Matrix</th>
<th>Green rim</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wt.%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>56.79</td>
<td>56.50</td>
<td>53.05</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.45</td>
<td>0.20</td>
<td>0.01</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>10.51</td>
<td>11.54</td>
<td>11.00</td>
</tr>
<tr>
<td>MgO</td>
<td>0.63</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>FeO*</td>
<td>7.13</td>
<td>7.06</td>
<td>7.51</td>
</tr>
<tr>
<td>MnO</td>
<td>0.13</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>MgO</td>
<td>6.12</td>
<td>5.39</td>
<td>7.00</td>
</tr>
<tr>
<td>CaO</td>
<td>11.55</td>
<td>11.71</td>
<td>11.38</td>
</tr>
<tr>
<td>Na₂O</td>
<td>7.46</td>
<td>7.31</td>
<td>7.04</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Total</td>
<td>100.20</td>
<td>100.05</td>
<td>100.46</td>
</tr>
</tbody>
</table>

Number of cations on the basis of 6 oxygens

Si 2.032 2.022 1.998 1.977 2.013 1.998 2.029 1.997 2.028 2.008
Ti 0.012 0.005 0.008 0.004 0.002 0.000 0.005 0.006 0.003 0.004
Al 0.443 0.487 0.464 0.094 0.063 0.053 0.410 0.408 0.348 0.116
Cr 0.001 0.004 0.004 0.004 0.005 0.004 0.006 0.006 0.004 0.003
Fe⁺ 0.213 0.211 0.225 0.331 0.341 0.325 0.182 0.173 0.222 0.637
Mn 0.004 0.005 0.006 0.010 0.013 0.011 0.003 0.001 0.007 0.014
Mg 0.326 0.288 0.374 0.622 0.563 0.621 0.376 0.417 0.399 0.239
Ca 0.443 0.449 0.436 0.876 0.923 0.930 0.527 0.545 0.587 0.759
Na 0.517 0.507 0.488 0.097 0.057 0.058 0.440 0.470 0.436 0.296
K 0.001 0.001 0.001 0.004 0.000 0.001 0.000 0.003 0.000 0.000

* Total Fe.

The nomenclature of sodic pyroxene is based on the classification of Morimoto et al. (1988). The estimation of Fe²⁺ and Fe³⁺ was based on the assumption of four total cations and six oxygens. Jadeite, aegirine and augite (diopside) components of the metamorphic pyroxene were calculated as follows: (1) Jd = Al⁶⁺; (2) Ac = Fe³⁺; (3) Di(Aug) = Ca, (4) and these components were normalized to 100. Analysed clinopyroxenes are plotted in a jadeite-aegirine-diopside ternary diagram (Fig. 3). Omphacite in the omphacite-diopside vein has a significantly higher jadeite component (Jd₄₆.₁₋₅₂.₀A₀₋₈.₄A₈₋₅₂.₁) than the omphacite in the matrix (Jd₃₇.₁₋₄₆.₃A₀₋₅₃.₈A₈₋₆₀.₄). The FeO (total iron) content (av. 7.4 wt.%) of the vein omphacite is slightly higher than that of the matrix omphacite (av. 6.6 wt.%). Diopside coexisting with omphacite in the vein is poor in the jadeite component (Jd₁₃.₆₋₅₃.₄A₀₋₄A₈₋₉₅.₆). The green rim on matrix omphacite is also poor in jadeite, but has a slightly higher aegirine component than the vein diopside (Jd₄₂₋₅₂.₀A₀₋₁₁.A₈₋₈₂.₀). Some jadeites in the Osayama melange also contain omphacite. However, the omphacite in the jadeite shows quite different occurrences. The omphacite (Jd₂₅₋₇₁.₃A₀₋₄₈₂.₅A₈₋₅₂.₇) occurs as overgrowths on pure (Jd₄₁₋₉₈) or impure (Jd₄₂₋₉₈) jadeite, and as veinlet clots (2–5 mm wide), consisting of radial aggregates of needle-like crystals.
The omphacite in jadeite may have been retrogressively formed in jadeite.

Other minerals

Pumpellyite in omphacite has an Al-rich composition with \( \text{Al}/(\text{Al}+\text{Fe}^3+\text{Mg}) = 0.78-0.81 \). The \( \text{Fe}^3/(\text{Fe}^3+\text{Mg}) \) ratio (0.28–0.39) is slightly lower than that of pumpellyite from other blueschist blocks in the Osayama serpentinite melange (0.41–0.69). Chlorite has a composition of \( \text{Fe}^3/(\text{Fe}^3+\text{Mg}) = 0.40 \) and \( \text{Al}/(\text{Al}+\text{Fe}^3+\text{Mg}) = 0.33 \). Biotite in omphacite has a composition of \( \text{Mg}/(\text{Mg}+\text{Fe}^2+) = 0.62 \), \( \text{TiO}_2 = 0.4 \) wt.% and Si = 5.8 (p.f.u. for O = 22).

Discussion

Comparison with the other omphacite-diopside pairs

The occurrence of coexisting omphacite and diopside pyroxene pairs has previously been reported from high-P metamorphic rocks. The coexistence is often ascribed to the presence of a miscibility gap between omphacite and diopside pyroxene. For example, omphacite and diopside coexist in a blueschist specimens from Piemont, Italy (Jd35–50 and Jd3–12; Brown et al., 1978) and from the Russian River, Franciscan Complex, U.S.A. (Jd28.4 and Jd8.15; Carpenter, 1980a). The paired clinopyroxenes reported by Brown et al. (1978) occur in an unusual manganese-rich, metamorphic rock containing manganese minerals such as braunite, hollandite, piemontite, manganese phengite and manganese phlogopite. The omphacite coexisting with diopside contains up to 2.5 wt.% MnO and less than about 5 mole% aegirine component. Peak metamorphic condition was estimated as 8 ± 1 kbar and 300 ± 50°C. The paired clinopyroxenes reported by Carpenter (1980a) form sector-zoned composite grains constituting emerald-green veins (up to 1 cm wide) and cutting an epidote-blueschist. The veins rarely contain quartz and white mica. The omphacite has about 25 mole% aegirine component.

Several studies on the microstructure of sodic pyroxene (e.g. Matsumoto et al., 1975) have revealed that cation ordering can occur in omphacite with compositions close to Jd35Di75, causing a symmetry change from C-face-centred (C2/c) to primitive (P2/n). Carpenter (1979) determined the composi-
tional limits of the ordered P2/n omphacite relative to
disordered C2/c pyroxenes in blueschist-facies rocks.
Recently, Carpenter et al. (1990) thermodynamically
described the cation ordering in omphacite using
Landau theory.

Two different possible equilibrium phase relations
between omphacite and diopside were presented.
Carpenter (1980b) suggested the phase relations in
the jadeite-diopside system shown in Fig. 4a. The
apparent consolute temperature for the solvus
between P2/n omphacite and C2/c diopside is about
500°C. He proposed a second-order transformation
mechanism for the C2/c P2/n transition. On the
other hand, Enami and Tokonami (1984) found two
different coexisting clino- and pyroxene pairs, C2/c
omphacite (Jd14b) C2/c diopside (Jd14c) in the
epidote-amphibolite facies stage (above 500°C), and
a P2/n omphacite (Jd14d) C2/c diopside (Jd14o) in later
epidote-blueschist facies stage (below 500°C) from
the Ibari eclogite amphibolite mass, Sambagawa
belt, Japan. They proposed a first-order transforma-
tion model for the transformation C2/c to P2/n to
explain the persistence of the C2/c omphacite
structure. Although the two interpretations for
omphacite transformation from P2/n to C2/c are
quite different, the solvus between P2/n omphacite
and C2/c diopside becomes wider with decreasing
temperature in both cases. Although the space group
of omphacite coexisting with diopside in the vein
from the Osayama is not yet determined, it is
probably ordered (P2/n), judged from its high
jadeite component and low temperature of formation.

The compositional gap between the omphacite and
diopside in the Osayama vein is significantly wider
than for other studies (Fig. 3). This may be due to the
lower temperature of formation. The presence of Al-
rich pumpellyite and the absence of epidote in the
Osayama omphacite constrains the metamorphic
temperature condition to <350°C at 6–8 kbar. This
temperature is lower than for the other omphacite-
diopside pairs. As mentioned above, the coexisting
omphacite and diopside in the Osayama omphacite
have a radiating habit. This texture suggests that the
omphacite and diopside underwent a relatively rapid
rate of growth. The rapid growth would probably
have resulted in omphacite with a degree of cation
order, less than the case of equilibrium growth at that
temperature. In general, the miscibility gap is highly
sensitive to cation ordering. Although the omphacite-
diopside pair in the Osayama serpentinite melange
may not have achieved strict thermodynamic
equilibrium, the simultaneous growth of the two
clino- and pyroxene with a wide compositional gap
suggests the lowest temperature (< 350°C) ever
reported. The low temperature has undoubtedly
promoted cation ordering.

\[\text{Geological significance of the omphacite-diopside vein}\]

Omphacite veins have been found at many localities
in the Franciscan metamorphic rocks, such as in
blueschist, amphibolite, greenstone and metagrey-
wacke. Essene and Fyfe (1967) described some
omphacite veins cutting blueschists from the
Franciscan Complex. The vein omphacite occurs as
prismatic crystals normal to the vein wall, or as radial
aggregates, and Essene and Fyfe interpreted these
textures as having been formed in a hydrostatic
environment during omphacite crystallization.
Coleman (1961) reported jadeite veins cutting
blueschist in the Franciscan Complex, New Idria,
U.S.A., and he interpreted the jadeite vein as having
been produced by mobilization of a liquid rich in the
jadeite component and low in H2O during tectonic
movement of the host blueschist. Philippot and
Kienast (1989) described an omphacite-rich vein
that cut mylonite zones in an eclogite-facies
metagabbro, Monviso, Western Alps, Italy, and
they found sector-zoned omphacite-chloromelanite

---

**Fig. 4.** (a) Phase relations in the Fe³⁺-free diopside-
jadeite system proposed by Carpenter (1980b). See
Fig. 3 for abbreviations. (b) Phase relations between
Fe³⁺-free diopside and omphacite proposed by Enami
and Tokonami (1984), which were partly based on
Carpenter's diagram. BS: blueschist-facies, EA: epidote-
amphibolite facies.
Omphacite-diopside vein

they used Essene and Fyfe’s (1967) nomenclature) in the veins. It was inferred that the vein pyroxenes of the eclogite-facies metabasalt were precipitated from aqueous solution during successive periods of fracturing and healing.

The texture of our omphacite-diopside vein suggests that the clinopyroxene pair was formed contemporaneously in the fracturing stage following the metamatism from a Ca- and alkali-rich fluid at a lower temperature than the solvs between omphacite and diopside. Such a fluid might be introduced from the surrounding serpentinite, because CaO may have been released from clinopyroxene-bearing harzburgite during its serpentization. The stability of omphacite and Al-rich pumpellyite, both in the matrix and in the vein, indicates that the matrix-forming stage and the later fracturing stage may have been under relatively high-pressure conditions of 6–8 kbar at < 350°C. The omphacite-diopside vein may have formed during the melange-forming stage at relatively high-P-T.

Conclusion

The compositional gap between the coexisting omphacite (Id₅₋₄₋₂) - diopside (Id₄₋₃₋₂) in the Osayama omphacite vein is significantly wider than that for other omphacite-diopside pairs reported in the literature. This may be due to the lower temperature of their formation. They may have grown simultaneously from a vein-filling fluid in the omphacite block at relatively high pressure during the melange-forming stage.

Acknowledgements

I express sincere thanks to Dr A. Ishiwatari at Kanazawa University for his valuable advice and critical reading of the manuscript. I am also grateful to Professor T. Matsuzato at Kanazawa University for his important suggestion about omphacite. Dr H. Miyajima at Fossa Magna Museum is also thanked for discussion on omphacite in jadeite. I wish to thank Drs M.A. Carpenter and P.E. Crampin, whose suggestions helped much to improve the manuscript.

References


[Manuscript received 16 December 1996; revised 2 May 1997]