RESORPTION-OVERGROWTH OF GARNET FROM THE SAMBAGOYA
PELITIC SCHISTS IN THE CONTACT AUREOLE OF THE
SEBADANI METAGABBRO MASS, SHIKOKU, JAPAN

Akira Takasu*

Abstract Garnet in the Sambagawa metamorphic belt commonly shows a chemical zoning of bell-shaped MnO profile. However, in the contact aureole by the Sebadani high-temperature eclogite mass, garnets in the pelitic schists show a composite zoning. The garnet consists of two internal zones, the core and the mantle with a discontinuity between them. Inclusions in the core are arranged gently in sigmoidal shape, but those in the mantle are arranged parallel to the matrix schistosity. The internal fabric in the core is truncated by the mantle. The core as well as the mantle of the composite-zoned garnet shows normal zoning with outward decrease of MnO and increase of MgO.

The dual normal zonings with a discontinuity reflect two-fold events of the prograde metamorphism and a resorption stage between them. The former prograde metamorphism corresponds to the prograde portion of the Sambagawa metamorphism, and the latter to the contact metamorphism by the Sebadani mass. The temporary resorption of the garnet to be decomposed into chlorite was caused by decrease of temperature and increase of water pressure in the pelitic schists during the formation of the tectonic mélangé zone in the high grade zone of the Sambagawa metamorphic belt.

Introduction

Chemical zoning of garnet in low- to medium-grade metamorphic rocks has been discussed in detail to reveal metamorphic history (e.g. Banno, 1965; Hollister, 1966; Atherton & Edmunds, 1966; Kretz, 1973; Tracy et al., 1976). The most commonly developed type of zoning, that is the normal zoning, is that of "bell-shaped" MnO profile with FeO and MgO behaving antipathetically (Hollister, 1966). However, the other types of zoning are not uncommon (e.g. Chinner, 1962; Hollister, 1969; Kano & Kuwada, 1973; Plimer & Moazedes, 1981). They include in terms of MnO from the core to rim, the profiles having the minimum of its content in an intermediate part, and discontinuity between the core and the rim.

In the Sambagawa (Sanbagawa) metamorphic belt, the normal zoning of garnet is popular, but the other types of zoning are not rare. They are reverse zoning with Mn-rich rim (e.g. Itaya, 1978; Takasu, 1979; Hara et al., 1983; Sonoda, 1985), and composite-zoning formed by overgrowth on detrital garnet (Higashino & Takasu, 1982). The author has recently found another type of zoned garnet which suggests resorption-overgrowth history of the garnet. The mode of occurrence of such a composite-zoned garnet will be described and its implication in thermal history of metamorphic regime will be discussed.

Geologic setting

The Sambagawa metamorphic belt in Southwest Japan (Fig. 1) suffered a high pressure intermediate metamorphism (Miyashiro,
garnet and omphacite porphyroblasts-bearing basic schists. The pelitic schists in the contact aureole contain the composite-zoned garnets as described below.

Petrography

The mineral assemblages of the pelitic and basic schists in the Sebadani area are listed in Table 1. The representative chemical compositions of the composite-zoned garnet are shown in Table 2.

Pelitic schists

Pelitic schists are composed mainly of quartz, phengite and garnet, with subordinate amounts of albite, clinzoisite, chlorite, rutile, sphene, apatite, ilmenite and graphite, and occasionally with some of biotite, hornblende, zoisite, paragonite, chloritoid, tourmaline, calcite, apatite, pyrite and ilmenite. They are highly schistose, and white micas and chlorite show a preferred orientation.

Garnet usually forms porphyroblast up to 5 mm in diameter, the size of which increases towards the Sebadani metagabbro mass. The composite-zoned garnet occurs in a narrow zone surrounding the Sebadani mass (Fig. 3). It includes quartz, phengite, paragonite, albite, rutile, clinzoisite, chlorite, chloritoid, pyrrhotite, ilmenite and graphite. Garnet is sometimes replaced by chlorite along the rim and crack. Albite has two modes of occurrence; one is discrete grain, up to 1 mm in diameter, often including graphite, and the other is a constituent of symplectite together with albite, occurring in the neighbor of the

Table 1. Mineral assemblages of the pelitic and basic schists in the Sebadani area.

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Sebadani metagabbro mass (Fig. 3). $X_{\text{AB}}$ (Ca/Ca+Na+K) ranges from 0.01 to 0.04 with less than 0.01 of $X_{\text{OR}}$ (K/Ca+Na+K).

Clinozoisite is a euhedral to subhedral prism, 0.1–0.5 mm in length. Hornblende is pale green to pale bluish green (Y=Z) magnesiophpilblende, and has two modes of occurrence: one is subhedral prismatic, 0.3–1 mm in length, and the other forms symplectite. Chloritoid, bluish gray in color and 0.05–0.1 mm in size, rarely occurs included in the core of the garnet porphyroblast (Takasu, in prep.).

**Basic and eclogitic basic schists**

Basic and eclogitic basic schists have been already described (Takasu, 1984a). They are composed mainly of epidote, hornblende, garnet and phengite, with minor amounts of albite, quartz, chlorite, sphene, rutile and ore minerals. Omphacite ($X_{\text{OR}}=0.25–0.40$) porphyroblast without preferred orientation occurs in the eclogitic basic schist in the aureole of the Sebadani mass (Fig. 3).

**Texture and chemistry of the composite-zoned garnet in the pelitic schists**

Most garnets in the pelitic schists in the aureole of the Sebadani mass have two internal textural zones, i.e., the core and the mantle. The inclusions in the core are arranged gently in sigmoidal pattern (Plate II–A) as are most garnets in the pelitic Sambagawa schists, but those in the mantle are nearly parallel to the matrix schistosity. In some garnets the inclusions especially graphite are concentrated at the core-mantle boundary (Plate I–B). The internal fabric of the core is truncated by the core-mantle boundary (Plate II–C). The Becke’s line is observed there in some garnets.

Plates I–A and C and II–B and D show the backscattered electron images of the composite-zoned garnets. The core shows euhedral growth with concentric zoning, but is subrounded or rounded with irregular embayments. It is concordantly wrapped by the mantle, and the outer part of the mantle
shows again euhedral concentration zoning.

The compositional trend of the garnet discontinuously changes at the textural core-mantle boundary, across which MnO and CaO increase and FeO and MgO decrease (Fig. 4). The core shows a normal zoning with decrease of MnO and increase of MgO from the center towards the core-mantle boundary, and in the mantle MnO also decreases towards the outermost rim (Figs. 4 and 5). In some garnets, MnO slightly increases at the outermost rim.

Fig. 6 shows a MnO contour map in a composite-zoned garnet. The contours of 4% and 6% of MnO are apparently cut by the core-mantle boundary.

**Discussion**

**Formation process of composite-zoned garnet**

Garnets in the Sambagawa pelitic schists essentially grew keeping a surface equilibrium with chlorite (e.g. Sakai et al., 1985; Banno et al., 1986). In the core as well as in the mantle of the composite-zoned garnet, MgO and Mg/Fe increase antipathetically with the decrease of MnO. If the surface equilibrium model is accepted also for the composite-zoned garnets, the core and mantle crystallizations can be explained by dual events of the prograde metamorphism.

Across the boundary between the core and the mantle, the internal schistosity and the contours of MnO content in the core are dis-
Fig. 4. Zoning profile of the composite-zoned garnet. (a) 1405-A Ga–1. A and B in the figure correspond to A and B in the photomicrograph of Plate II–A. (b) 1405–C Ga–1. A and B correspond to A and B in the backscattered electron image of Plate II–D.

Fig. 5. Chemical composition of the composite-zoned garnet (1405–A Ga–1) and the detrital garnets of the eclogite and granulite facies (HIGASHINO & TAKASU, 1982). The area surrounded by the broken line shows the compositional range of the garnets in the Sambagawa pelitic schists (BANNO et al., 1986, and the author's unpublished data).
Fig. 6. MnO contour map of the composite-zoned garnet (1405–A Ga–2). See the backscattered electron image in Plate I–C.

continuous to those of the mantle (Plate I–C and Fig. 6). This suggests a resorption of the garnet having crystallized during the first prograde metamorphism.

The innermost part of the mantle has distinctly higher MnO content than the outermost part of the core (Figs. 4 and 5). In general, MnO contents of coexisting garnet and chlorite deprecate as the metamorphic temperature increases during prograde metamorphism (e.g. Higashino, 1975; Banno et al., 1986). When the first prograde metamorphism was completed, both the garnet-rim and chlorite must have had low MnO contents. Then the resorption of the garnet supplied Mn to the chlorite to form Mn-richer chlorite. Thereafter, the MnO-richer garnet again grew at the expense of the secondary MnO-richer chlorite at the beginning of the second prograde metamorphism.

The resorption may have owed to decrease of temperature, decrease of pressure, increase of water pressure or their combinations. It is difficult to determine what the major factor of the resorption was. However, the fact that the associated basic schists were converted into eclogites after the resorption stage, as will be discussed later, suggests that the pressure never decreased much.

This study has revealed that a type of composite zoning was formed by dual events of the prograde crystallization with a stage of resorption between them. This is, namely, a resorption-overgrowth model to give rise to reverse or composite-zoned garnet. The origin of the reverse and composite-zoned garnets has been discussed intensively. The models include i) polymetamorphism (Hollister, 1969; Edmunds & Atherton, 1971; Kano & Kuroda, 1973), ii) overgrowth on detrital garnet (Higashino & Takasu, 1982), iii) nonequilibrium crystallization (Kretz, 1973), iv) resorption or retrograde metamorphism (Grant & Weiblen, 1971; Béthune et al., 1975; Sivaparakash, 1981; Tyler & Ashworth, 1981; Dietvorst, 1982), and v) surface equilibrium crystallization with limited diffusion in garnet and chlorite (Kretz, 1973; Banno & Chi, 1976, 1978). The garnet described above is an example of another mechanism to form the composite-zoned garnet. A similar formation mechanism of a composite-zoned garnet from southern Vermont has been suggested by Karabinos (1984). It is considered that the Sambagawa garnet from eastern Kyushu reported by Sonoda (1985) was also formed by the resorption-overgrowth mechanism.

Occasional increase of MnO content at the outermost rim of the composite-zoned garnet can be explained by inwards Mn-diffusion accompanied by a retrograde metamorphism (model iv) (Béthune et al., 1975).

**Geological implications**

The pelitic schists bearing the composite-zoned garnet coexist with the eclogitic basic schists in the Sebadani contact aureole, and hence both of them certainly shared the same P–T history. The eclogitic basic schists have at least two stages of metamorphism, the Sambagawa prograde metamorphism and the contact metamorphism by the Sebadani mass (Takasu, 1984a) (Fig. 7).

The chemistry and the zoning pattern of the core of the composite-zoned garnet in the pelitic schists adjacent to the Sebadani mass coincide with those of the Sambagawa garnet in the common pelitic schists of the biotite zone. Moreover, the rotation fabric in the core of the composite-zoned garnet is compatible with the development of the schistosity in the eclogitic basic schists accompanied by deformation flow. Hence the core of the composite-zoned garnet was formed at the
stage of the Sambagawa prograde metamorphism.

The resorption of the garnet probably took place during the formation stage of the tectonic mélangé zone (TAKASU, 1984a; KUNUGIZA et al., 1986), accompanied by the uplift of the metamorphic regime. The formation of the mélangé zone was followed by the decrease of the metamorphic temperature. Besides, the pelitic schists in this zone were strongly sheared, and water phase flowed more easily through there than before the formation of the tectonic mélangé zone. Then, the garnets in the sheared pelitic schists were partly resorbed.

The composite-zoned garnet having resorption-overgrowth texture is confined to the contact aureole of the Sebadani mass defined by the occurrence of the eclogitic basic schists (Fig. 3). Also from a viewpoint of the texture, the inclusions without rotation fabric in the mantle of the composite-zoned garnet correspond to the formation of omphacite porphyroblasts, which are randomly oriented in the matrix of the eclogitic basic schists (TAKASU, 1984a). This suggests that both omphacite and the mantle of the composite-zoned garnet in the pelitic schists simultaneously crystallized under static condition. On the other hand, the fact that the garnets in the eclogitic basic schists have no evidence of resorption is probably explained by poor shearing and limited supply of water phase in basic schists during the formation of the tectonic mélangé zone.

The mantle of the composite-zoned garnets is also similar in chemistry to the ordinary Sambagawa garnets (Fig. 5). This indicates that the crystallization of the mantle underwent
the condition not so far from the Sambagawa prograde metamorphism. 630–650°C and 7–17 kb are the estimated condition of the contact metamorphism forming the eclogitic basic schist (Takasu, 1984a), and this temperature is similar to or slightly higher than 610±25°C as the maximum temperature of the Sambagawa metamorphism as proposed by Enami (1983) (Fig. 8). This fact suggests that the eclogite facies metamorphic rocks are regionally distributed a little below the present surface of the high grade portion of the Sambagawa metamorphic terrane. In fact, recent discovery of the tectonic blocks consisting of the progradate eclogites from the Besshi and Kotsu districts in Shikoku (Takasu & Kōsaka, 1985 ; Takasu & Kaj, 1985), supports the presence of regional eclogite facies in the high grade part of the Sambagawa metamorphism.

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帯に形成された融食・再成長の組織を示すざくろ石. 地質雑, 92, 781-792.)

表題地域の泥質片岩中より, 融食・再成長の組織をもって, 複雑な変成構造を示すざくろ石が見いだ
された. 組織と化学組成より, このざくろ石は核部と外帯部に区分できる. 核部の包有物の配列は弱
いS字形を示し, これは外帯部の包有物の配列に即される. 核部, 外帯部とも, 内側から外側へ向か
って Mn 減少, Mg 増加の正変成構造を示す. 核部と外帯部の境界では, 化学組成にも著しい不連
続が認められ, これは, すでに形成されていた核部のざくろ石が一度融食されたことを示すものであ
る. このざくろ石の核部は三波川変成作用で形成された. 核部の融食は, 三波川変成帯上昇変成
部におけるテクトニック・メランジェ帯の形成にもともなって変成温度の低下, あるいは, 水蒸気圧の上
昇により生じた. その後, テクトニック・メランジェ帯を上昇させてきた. 高温のメランジェイト岩体
である濱場谷変はんれい岩体の接触変成作用により外帯部のざくろ石が再成長した.

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Explanations of Plates

Plate I.
A. Backscattered electron image of the composite-zoned garnet (1840 Ga-7). The resorbed core is rounded. Graphite is concentrated at the core-mantle boundary. See Plate I-B.
B. Photomicrograph of the composite-zoned garnet (1840 Ga-7).
C. Backscattered electron image of the composite-zoned garnet (1405-A Ga-2). The euhedral growth traces are apparently cut by the mantle.

Plate II.
A. Photomicrograph of the composite-zoned garnet (1405-C Ga-1). Inclusions, mainly graphite, show a sigmoidal pattern in the core. See the scanning profile from A to B in Fig. 4 (a).
B. Backscattered electron image of the composite-zoned garnet (1405-C Ga-1). The scale is the same as Plate II-A.
C. Photomicrograph showing the boundary between the core and the mantle. The inclusion trail in the core is cut by the core-mantle boundary.
D. Backscattered electron image of the composite-zoned garnet (1405-A Ga-1). See the scanning profile from A to B in Fig. 4 (a).