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Metasomatic hydration of the Oeyama forearc peridotites: Tectonic implications

Toshio Nozaka *

Department of Earth Sciences, Okayama University, Okayama 700-8530, Japan

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ABSTRACT

In contrast to the widely recognized aspects of serpentinization, initial stages of hydration and tectonic processes of unserpentinized peridotites are still unclear, but have important implications for understanding the lithospheric architecture of supra-subduction zones. This study provides petrological evidence from the Oeyama ophiolite, SW Japan, of the effects of high-temperature metasomatic hydration immediately before the cooling and ductile deformation of forearc peridotites. Key findings in this study are: 1) complex association of high-temperature metasomatic minerals: tremolitic amphibole, cummingtonite, phlogopite, chlorite, olivine and orthopyroxene in veins and in mylonites; 2) the systematic variation in Si and Na + K contents of the tremolitic amphibole, corresponding to its mode of occurrence and mineral association; and 3) the presence of thin (<0.7 mm) veins of fine-grained olivine accompanied by a narrow diffusion zone of the host primary olivine. On the basis of petrography and mineral chemistry, the temporal sequence of hydration and deformation of the Oeyama ophiolite is considered as follows: 1) infiltration of slab-derived fluids, causing decomposition of primary pyroxene and chemical modification of primary olivine, 2) metasomatic formation of variable modal amounts of amphibole, phlogopite, chlorite, vein-forming olivine and secondary orthopyroxene at 650–750 °C; 3) early-stage mylonitization of the hydrous peridotites in localized shear zones; and 4) syntectonic serpentinization at 400–600 °C to form serpentinite mylonites. Paragenesis and amphibole compositions suggest comparable temperature conditions for metasomatism and early-stage mylonitization. Mylonitization occurred exclusively in hydrous peridotites, and the peridotite mylonites were preferentially overprinted by syntectonic serpentinization. Diffusion profiles of olivine cut by a vein suggest rapid cooling immediately after the metasomatic fluid infiltration. From these observations and calculations, it is concluded that the exhumation of the forearc peridotites was closely related to the infiltration of high-temperature metasomatic fluids and hydration occurred under a wide range of temperature conditions.

1. Introduction

Geological, geochemical and geophysical studies have revealed that dehydration of a subducting slab and coupled hydration of the overlying mantle wedge are common in subduction zones and cause fundamental geologic processes such as arc magmatism, dehydration-induced earthquakes and chemical element recycling (e.g., Hacker et al., 2003; Hasegawa and Nakajima, 2004; Hattori and Guillot, 2003; Iwamori, 1998; Peacock, 2001; Reynard et al., 2011; Scambelluri and Tonarini, 2012; Scambelluri et al., 2004; Schmidt and Poli, 1998; Stern, 2002; Tatsumi et al., 1983; Wyllie and Sekine, 1982). In particular, it is well known that serpentinization is the dominant hydration process of mantle rocks and plays an important role in the tectonic exhumation of forearc mantle materials (e.g., Fryer et al., 1985; Guillot et al., 2000; Maekawa et al., 2001). Also there is a growing body of evidence from mantle xenoliths and ophiolites showing that metasomatic alteration at higher-temperature (T) than that at which serpentinization occurs is common in the supra-subduction zone mantle (e.g., Franz et al., 2002; Ishimaru and Arai, 2011; Khedr and Arai, 2010; Marocchi et al., 2007; McInnes et al., 2001; Nozaka, 2005). Because the evidence of the high-T alteration or metasomatic reactions has been found in plastically deformed peridotites, a linkage between fluid/melt flow and the formation of shear zones has been pointed out (e.g., Arai et al., 2004; Downes, 1990; Kelemen and Dick, 1995; Nozaka, 2005). However, the entire sequence of alteration and tectonic processes in the supra-subduction zone mantle is not yet fully understood. Although juxtaposed exposures of peridotite mylonites and schistose serpentinites have been reported from the Alps (Hermann et al., 2000; Li et al., 2004; Scambelluri et al., 1995), the serpentinites seem to have been formed by prograde metamorphism of altered oceanic peridotites and do not show a direct linkage between the mylonitization of peridotites and later formation of the schistose serpentinites.

An important example of such linkage is the Happo ultramafic complex juxtaposed by a high-pressure (P) metamorphic belt of central Japan. Nozaka (2005) has shown that mylonitic shear zones within the Happo peridotites record multiple events of fluid-related deformation and metamorphism: a first stage of high-T alteration (700–800 °C)

* Tel.: +81 86 251 7883; fax: +81 86 251 7895.
E-mail address: nozaka@cc.okayama-u.ac.jp.

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was overprinted by serpentinization at 400–600 °C during exhumation of this ultramafic complex. More recently, Nozaka and Ito (2011) argued that during a sequence of hydration and exhumation, the formation of cleavable olivine took place in the Oeyama ophiolite, which is believed to belong to an ophiolite belt that includes the Happo complex (Fig. 1).

Initial studies of the Oeyama ophiolite point to a widespread distribution of minerals indicative of amphibolite-facies or higher-grade re-equilibration. This suggests that the ophiolitic complex was subjected to pervasive high-T alteration before juxtaposition with surrounding blueschist-facies metamorphic rocks. A detailed study of the high-T secondary minerals provides a key to unravel the linkage between alteration and tectonic processes in the ophiolite. This paper reports textural and chemical variations of secondary minerals in the peridotites of the Oeyama ophiolite in order to elucidate the spatial and temporal relationships between alteration and deformation processes. The data suggest that high-T metasomatic hydration was closely associated with the initiation of exhumation of forearc mantle peridotites.

2. Geological setting and general description of the Oeyama ophiolite

The Oeyama ophiolite is a collective name of the Oeyama, Sekinomiya, Wakasa and other small ultramafic complexes exposed in the Renge high-P/T metamorphic belt of SW Japan (Fig. 1a; Ishiwatari, 1989, 1990; Isozaki et al., 2010; Nishimura, 1998). Gabbroic rocks and amphibolites included in the ultramafic complexes show K–Ar radiometric ages of 470–400 Ma (Nishimura and Shibata, 1989; Tsujimori et al., 2000). The Oeyama ophiolite is similar to the Tari-Misaka, Ashidachi, Ohsayama and Happo ultramafic complexes (Fig. 1a) in lithology, age of amphibolite blocks and juxtaposition with high-P/T metamorphic rocks (Arai, 1980; Nishimura, 1998; Nozaka, 1999; Nozaka and Shibata, 1994; Takeuchi, 2002; Tsujimori and Itaya, 1999; Tsujimori et al., 2000). Geological and geochemical characteristics of the Tari-Misaka and Happo ultramafic complexes are suggestive of sub-arc or forearc mantle origin (Arai and Yurimoto, 1995; Khedr and Arai, 2010); consequently the Oeyama ophiolite could originate in a supra-subduction zone as well, although the peridotites of the Oeyama ophiolite show less degree of depletion (Ishiwatari and Tsujimori, 2003).

The ultramafic complexes of the Oeyama ophiolite are in fault contact with Paleozoic formations and the Renge Belt high-P/T metamorphic rocks, and have intrusions of Cretaceous or Paleogene granitic rocks, and are covered by younger sediments or volcanics (Fig. 1b–d; Igi and Kuroda, 1965; Igi et al., 1996; Isozaki et al., 2010; Kurokawa, 1985; Uda, 1984; Uemura et al., 1979). Typical high-P/T metamorphic minerals such as lawsonite and glaucophane have been reported from the Renge Belt metamorphic rocks in proximity to the ultramafic complexes (Hashimoto and Igi, 1970). The granitic intrusions formed contact aureoles in the Oeyama and Wakasa complexes and surrounding rocks (Kurokawa, 1985; Nozaka and Ito, 2011; Uda, 1984; Uemura et al., 1979).

The main components of the Oeyama ophiolite are serpentinized peridotites, which also include tectonic blocks or intrusions of other rock types: pyroxenite; gabbro; amphibolite; and jadeitite (Chihara, 1989; Igi and Kuroda, 1965; Kuroda et al., 1976; Kurokawa, 1975, 1985; Tsujimori and Liou, 2004; Uda, 1984; Uemura et al., 1979; Yamaguchi, 1990). The predominant lithology of the peridotites varies within the Oeyama ophiolite. The main lithology of the Oeyama and Wakasa complexes is dunite, a considerable part of which seems to be cumulates from basaltic melts (Kurokawa, 1985; Nozaka and Ito, 2011), whereas

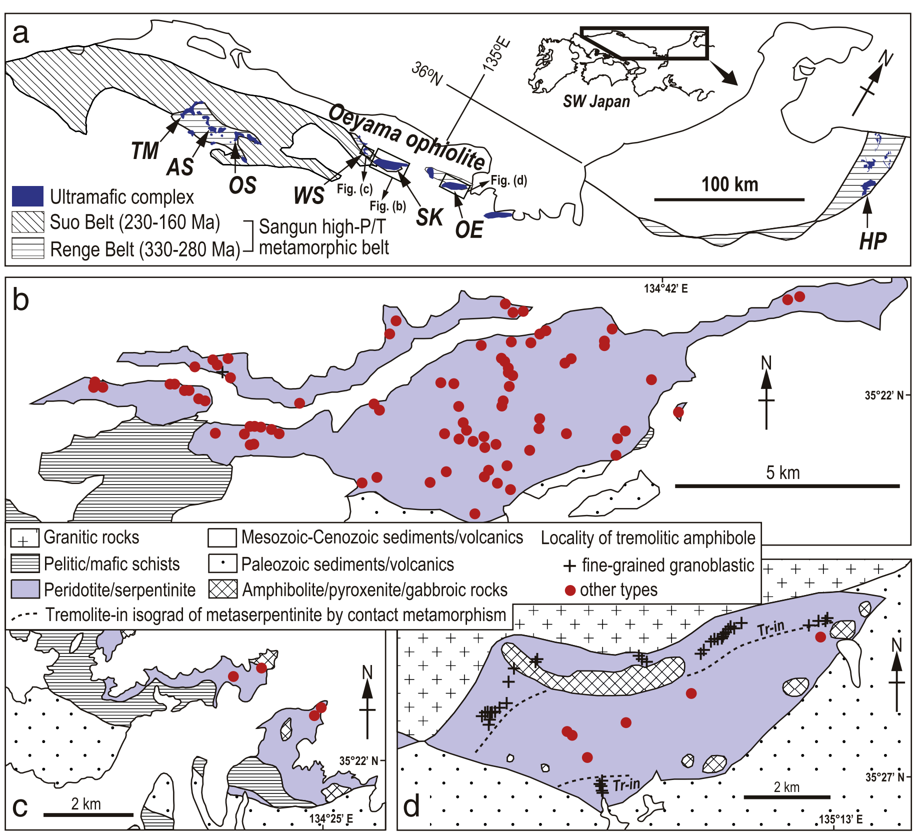

Fig. 1. (a) Distribution of ultramafic complexes and the Sangun high-P/T metamorphic belt (Renge and Suo Belts) in SW Japan (Ishiwatari, 1989, 1990; Isozaki et al., 2010; Nishimura, 1998; Takeuchi, 2002). Abbreviations for ultramafic complexes: OE, Oeyama; SK, Sekinomiya; WS, Wakasa; OS, Ohsayama; AS, Ashidachi; TM, Tari-Misaka; HP, Happo. (b) Geological sketch map of the Sekinomiya area (Igi et al., 1996). (c) Geological sketch map of the Wakasa area (Uemura et al., 1979). (d) Geological sketch map of the Oeyama area with the Tr (tremolite)—in isograds in the contact aureole of metaserpentinites (Igi and Kuroda, 1965; Kurokawa, 1985; Nozaka and Ito, 2011; Uda, 1984). Localities of tremolitic amphibole examined in this study are also shown.