

REVIEW

Early Paleozoic jadeitites in Japan: An overview

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Paleozoic jadeitite-bearing serpentinite-matrix *mélange* represents the oldest mantle wedge record of a Pacific-type subduction zone of proto-Japan. Most jadeitites are fluid precipitates (P-type), but some jadeitites are metasomatic replacement (R-type) which preserve relict minerals and protolith textures. The beauty and preciousness of some gem-quality, semi-translucent varieties of jadeitites in the Itoigawa-Omi area led to the designation of jadeitite as the national stone of Japan by the Japan Association of Mineralogical Sciences. Zircon geochronology indicates jadeitite formed prior to Late Paleozoic Renge metamorphism that formed blueschist and rare eclogite. For example, in the Itoigawa-Omi and Osayama localities, older jadeitites and younger high-pressure/ low-temperature metamorphic rocks in a single *mélange* complex imply different histories for the subduction channel and jadeite-bearing serpentinite-matrix *mélange*. This suggests that the jadeitite-hosted *mélange* (or serpentinitized peridotite) can stay within the mantle wedge for a considerable time; thus recrystallization, resorption, and re-precipitation of jadeitite can continue in the mantle wedge environment. Therefore, studies of Paleozoic jadeitites in Japan have great potential to elucidate the earliest stages of orogenic growth (oceanward-accretion and landward-erosion) associated with the subduction of the paleo-Pacific oceanic plates, and to test geophysical observations of modern analogues from a mixture of fossilized mantle wedges and subduction channels.

Keywords: Jadeitite, Paleozoic, Oeyama ophiolite, Renge metamorphic rocks, Forearc mantle wedge

INTRODUCTION

Jadeitite is a plate tectonic gemstone that records the interaction of high-pressure and low-temperature (HP-LT) fluids with forearc mantle wedge at relatively shallow depths (<100 km). The beauty and preciousness of some gem-quality jadeitites led to a designation of ‘jadeite (and jadeitite)’ as the national stone of Japan by the Japan Association of Mineralogical Sciences in 2016. Since Kawano (1939) first identified monomineralic jadeitites as boulders in the Kotaki-gawa River in the Itoigawa-Omi area of the Hida Mountains (HDM, an eastern portion of Southwest Japan), numerous jadeitite boulders have also been confirmed in the area and the Happou ultramafic body in the HDM (Chihara, 1979), as well as in Sekinomiya (Oya), Wakasa, and Osayama ultramafic bodies of the Chugoku Mountains (CGM, a western portion of Southwest Japan) (e.g., Masutomi 1966; Tazaki and Ishiuchi, 1976; Kobayashi et al., 1987) (Fig. 1). These jadeitite localities, belonging to the Oeyama

(or Renge) belt (e.g., Ishiwatari and Tsujimori, 2003), are characterized essentially by Alpine-type ultramafic rocks (or serpentinite-matrix *mélange*), are accompanied by Paleozoic (HP-LT) metamorphic rocks. Note that ultramafic bodies of the HDM have been distinguished as the most representative rock of so-called ‘Hida-Gaien (Hida marginal) belt’. Although outcrops of the jadeitite within serpentinite *mélanges* are extremely rare and poorly understood, the occurrence of jadeitites suggests an Early Paleozoic subduction along a relatively cold geothermal gradient that marked the margins of proto-Japan.

In this article, the author provides new insights regarding Japanese Paleozoic jadeitites in the Oeyama (or Renge) belt (Fig. 2) and addresses current perspectives on jadeitite. This review also includes recent knowledge of Paleozoic jadeite-bearing metamorphic/ metasomatic rocks in the Kurosegawa belt in the Shikoku and Kyushu of Southwest Japan.

JADEITITE CLASSIFICATION

Jadeitite is a metasomatic rock that consists predominantly of jadeitic clinopyroxene (cf. Harlow et al., 2015). The

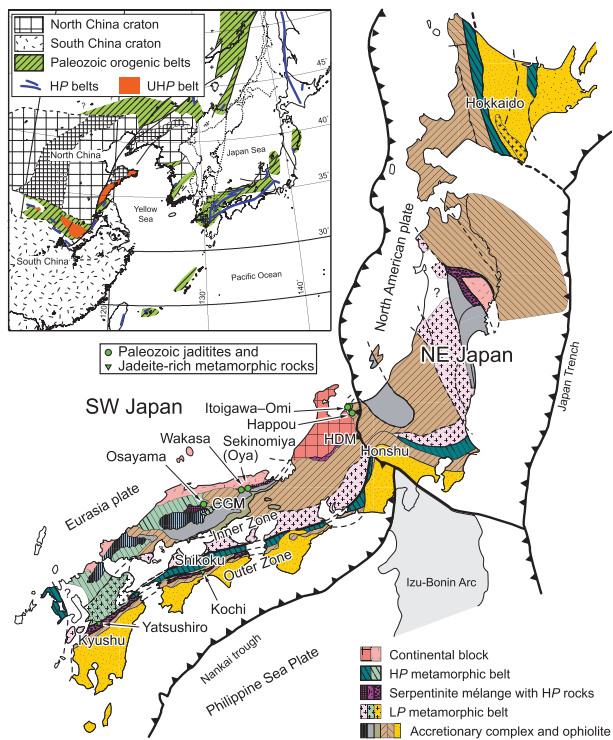


Figure 1. Geotectonic subdivision of the Japanese Islands (modified after Isozaki et al., 2010), showing localities of Paleozoic jadeitites and jadeite-bearing metamorphic rocks.

unique whole-rock composition precludes a simple metamorphic model for jadeitite formation. Tsujimori and Harlow (2012) proposed two classifications of jadeitite based on the processes of formation: (1) P-type jadeitite is crystallized directly from a hydrous fluid as vein-fil-

lings or overgrowths on other rocks, and (2) R-type jadeitite is a metasomatic replacement of another rock, such as a sedimentary (e.g., greywacke) or igneous (e.g., trondhjemite or tonalite) rock. Another mineralogy-based classification scheme for jadeitite was also proposed by Harlow et al. (2015); in a *P-T* diagram, the stability fields of lawsonite, paragonite, Ca-Na amphibole (taramitic), two coexisting pyroxenes, and kyanite defined five mineralogical types; namely lawsonite jadeitite, paragonite jadeitite, taramite jadeitite, two-pyroxene jadeitite, and kyanite jadeitite. Moreover, the titanite-bearing or rutile-bearing mineral assemblages further separate rutile-bearing jadeitite from rutile-free jadeitite.

JADEITITES IN THE HIDA MOUNTAINS (HIDA-GAIEN BELT)

In the HDM, several ultramafic bodies of the Early Paleozoic Oeyama belt are exposed along the Hida-Gaien belt. The Itoigawa-Omi area is an important occurrence of Japanese jadeitite and a minor occurrence was also reported from the Happou area (e.g., Chihara, 1989; Miyajima et al., 1999) (Fig. 1). Some Itoigawa-Omi jadeitites are gem quality with high commercial values for ornaments (Fig. 3). All jadeitite localities lie within serpentinite mélanges with tectonic blocks or slices of *HP-LT* rocks (e.g., Nakamizu et al., 1989; Tsujimori, 2002). However, the occurrences of jadeitite are limited to boulders along several different branches of the Kotaki-gawa River and Omi-gawa River (Fig. 4). Most jadeitites in the Itoigawa-Omi area are P-type and quartz-free, but rare R-type jadeitites preserving relict hornblende and gabbroic textures also

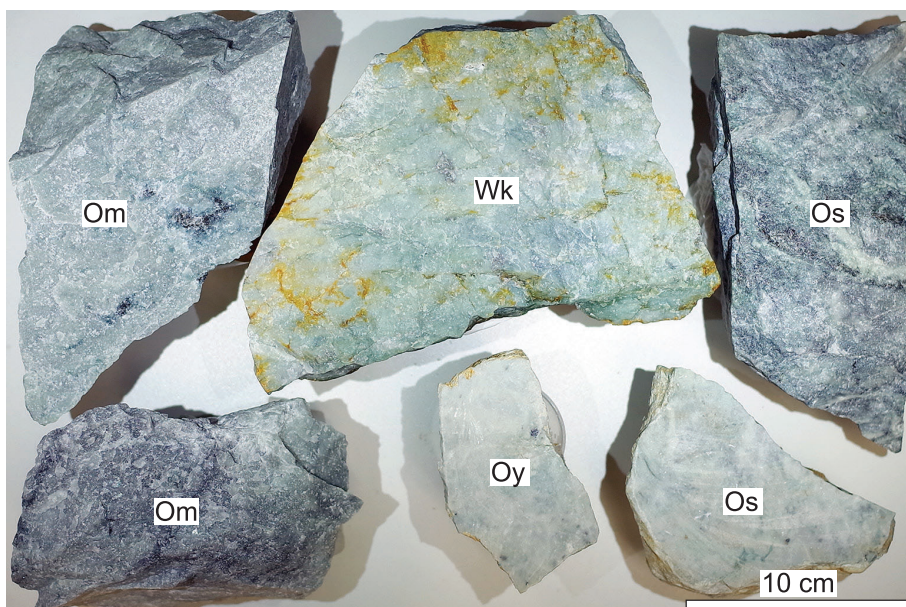


Figure 2. Common appearance of Japanese Paleozoic jadeitites from the Itoigawa-Omi, Sekinomiya (Oya)-Wakasa, and Osayama areas. The jadeites have no commercial value as non-gem quality. Abbreviations of localities: Om, Omi; Oy, Oya; Wk, Wakasa; Os, Osayama.

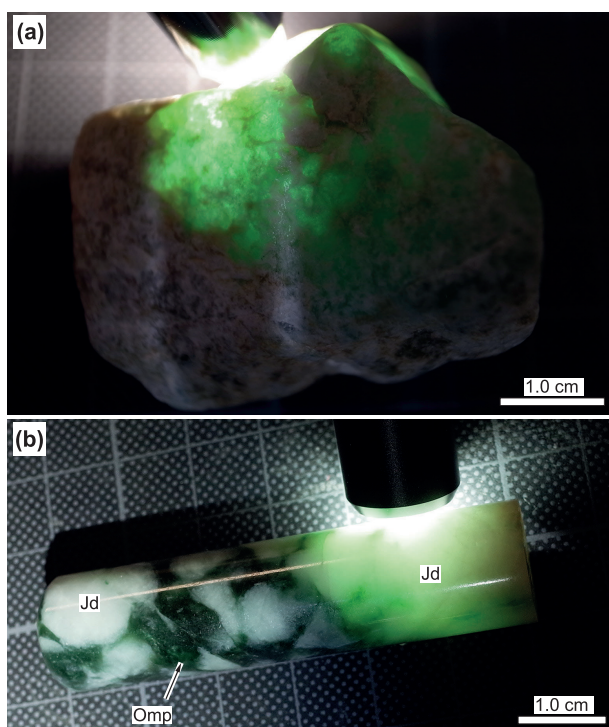


Figure 3. Appearance of gem quality jadeitites from the Itoigawa-Omi area. (a) A jadeite pebble from the Omi-gawa River exhibits a semi-translucent vivid green color when held to a light. (b) the author's name seal made from Itoigawa jadeite. Note that the cylinder is composed of both white jadeite (Jd) and green omphacite (Omp); the jadeite in this sample is also semi-translucent when held to light.



Figure 4. Occurrence of giant jadeite boulders (J) in the Omi-gawa River.

occur (Kunugiza and Goto, 2010). Chihara (1989) proposed three lithologic types of jadeitites in the HDM; Kotaki-type (massive zoned white jadeitites with greenish jadeite rim and rare albitite core), Omi-type (fine- to coarse-grained layered jadeitites), and Tsugaike-type (coarse-grained vein jadeitites). Details of phase relations and sequential changes of metasomatic mineral assem-

blages are still poorly understood. In particular, essential information reported in the late '70s and early '80s, such as identification of amphiboles based on optical appearance, should be reconfirmed.

In general, jadeitites in the area show various degrees of deformation, veining (fluid infiltration and mineral precipitation), and recrystallization in the jadeite stability field, fundamentally limited by the reaction jadeite + $H_2O = \text{analcime}$ ($P = \sim 0.6$ GPa at 200 °C and ~ 0.7 GPa at 400 °C). Although a variety of strontium minerals, such as itoigawaite [$SrAl_2Si_2O_7(OH)_2 \cdot H_2O$], renegeite ($Sr_4ZrTiSi_4O_{22}$), and matsubaraite [$Sr_4Ti_5(Si_2O_7)_2O_8$], have been discovered from the area, the key accessory minerals and mineral parageneses (e.g., lawsonite, zoisite, and paragonite) to define the mineralogical type of jadeite are not well confirmed. Some jadeitites contain rutile as the stable Ti-bearing phase and edenitic and/or paragonitic amphibole, whereas rutile in some jadeitites is replaced by titanite during retrogression. Some jadeitites coexist with natrolite (e.g., Miyajima et al., 1999; Kunugiza and Goto, 2010); this type of mineral equilibrium has been identified in the latest stage of mineral precipitation in some jadeitites (e.g., Coleman, 1961).

Metasomatic albitization of jadeite is also a common feature. *In-situ* trace element abundances of jadeite from some jadeitites were determined by Sorensen et al. (2006) and Morishita et al. (2007). Oxygen isotope compositions of jadeites from the Itoigawa jadeitites display zoning, with $\delta^{18}O$ values ranging from +4.5 to +7.1‰ (Sorensen et al., 2006). Notably the isotope values overlap with those of metamorphosed and serpentinized peridotites (e.g., Früh-Green et al., 2001; Barnes et al., 2009).

Veined jadeitites in the Happou area have not been well studied due to the limited occurrence and poor access. Coexisting of quartz was incorrectly reported by Komatsu and Yamazaki (1981). As similar to the Itoigawa-Omi area, the P-type jadeite from the Haou area also lacks quartz.

Zircons from Itoigawa jadeitites, interpreted as fluid precipitates on the basis of their rhythmic zoning and rare-earth elements (REE) patterns, yield ion-microprobe (Cameca ims-1270) U-Pb ages of 519 ± 17 ($n = 2$ from one grain) and 512 ± 7 Ma ($n = 7$ from two grains) (Kunugiza and Goto, 2010); note that those results were originally published in a conference abstract in Kunugiza et al. (2002). Tsutsumi et al. (2010) have also analysed one zircon grain from a jadeite with a mean age of 497 ± 23 Ma ($n = 10$; ranging from 525 to 427 Ma). Jadeite formation is likely to be coeval with or slightly older than the Early Paleozoic epidote-amphibolite facies metamorphism of the Oeyama belt (Fig. 4). Epidote-amphibolite facies rocks yield hornblende K-Ar ages of ~ 470 –400

Ma (Nishimura and Shibata, 1989; Tsujimori et al., 2000) and a zircon U-Pb age of 494 ± 20 Ma (T. Tsujimori, unpublished data). In contrast, albitite that may represent retrograded equivalents of jadeitite yields phengite K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ ages of approximately 340–320 Ma. These ages overlap with K-Ar, $^{40}\text{Ar}/^{39}\text{Ar}$, and Rb-Sr ages of phengitic white micas from pelitic schists of either greenschist-epidote-amphibolite facies or epidote-blueschist-eclogite facies blocks, as well as a phlogopite $^{40}\text{Ar}/^{39}\text{Ar}$ age (339 ± 7 Ma) from a tremolite-rich rock (cf. Tsujimori, 2010).

Although jadeitite-hosted ultramafic rocks in the HDM are highly serpentinized or recrystallized, the chemical compositions of relict chromian spinel (or chromite) and bulk-rock compositions of serpentinite suggest a mostly harzburgite and subordinate dunite protolith (e.g., Machi and Ishiwatari 2010; Khedr and Arai, 2010, 2011). In ultramafic rocks along the Omi-gawa River, the protolith of antigorite-dominant serpentinite is mainly dunite and harzburgite with rare chromitite; high Cr/(Cr + Al) atomic ratio (0.70 – 0.77) of chromian spinel in the chromitite contains abundant igneous pargasite, suggesting a mantle-wedge peridotite origin (Tsujimori, 2004). In contrast, those along the Kotaki-gawa River have both lherzolitic and harzburgitic protolith (Machi and Ishiwatari, 2010); relict chromian spinel exhibits vermicular intergrowth with clinopyroxene, which is the most common petrographic features in the residual peridotite of the Oeyama belt (e.g., Arai, 1980; Matsumoto et al., 1997). Ultramafic bodies have been partly overprinted by contact metamorphism during the intrusion of Cretaceous or Cenozoic granitic plutons (e.g., Machi and Ishiwatari, 2010), although some ultramafic bodies had undergone a regional metamorphism before contact metamorphism (Nakamizu et al., 1989; Nozaka 2005; Khedr and Arai, 2010). The metamorphosed peridotites in the HDM have been subjected to a regional metamorphism and deformation. In the Happou, highly deformed metamorphosed peridotites often show a penetrative schistosity defined by preferred orientation of antigorite and tremolite and with a trend similar to that of Late Paleozoic Renge HP-LT schists (Yamazaki, 1981; Nakamizu et al., 1989; Nozaka, 2005; Khedr and Arai, 2010). This implies that the Early Paleozoic ophiolite fragments of the Oeyama belt have undergone the Late Paleozoic subduction zone metamorphism.

JADEITITES IN THE CHUGOKU MOUNTAINS

Jadeitites have been known from the Sekinomiya (Oya)-Wakasa area (the eastern portion of the CGM) and Osayama (central CGM) (Fig. 1). The jadeitite-hosted Seki-

nomiya ultramafic body is the largest ($\sim 20 \times 5$ km) serpentinized peridotite body of the Oeyama belt. In the Sekinomiya (Oya) area, lawsonite blueschist (containing aegirine-augite with up to 29 mol% jadeite), pelitic schist, calcite marble, albitite, and rare jadeitite occur as tectonic blocks along the southern margin of the ultramafic body (Hashimoto and Igi, 1970; Tsujimori and Liou, 2007). An exposure of highly weathered albitized jadeitite (not gem quality), locally called ‘Kaho no Hisui’ (Jadeitite of Kaho), is still accessible. The jadeitite contains radial aggregates of coarse-grained jadeite crystal; coarse-grained paragonite and rare corundum also occur (Tazaki and Ishiuchi, 1976). An ultramafic rock suite, mainly serpentinized dunite with minor metamorphosed clinopyroxenite and metagabbroic rocks, of the Wakasa area is a western extension of the Sekinomiya ultramafic body; the ultramafic rocks structurally overlie the Renge HP-LT schist of the Shitani Formation (Uemura et al., 1979). Jadeitites that have been mined as river float are likely derived from within the serpentinite (Masutomi, 1966; Chihara, 1989); rare fine-grained variety exhibits gem quality similar to some Itoigawa-Omi jadeitites. Some jadeitite contain itoigawaite (Sr equivalent of lawsonite) and pumpellyite (Shimobayashi, 2004). The Sekinomiya (Oya)-Wakasa jadeitites have not yet been dated, but on the basis of petrotectonic continuity, the jadeitite formation is likely coeval with the Early Paleozoic metamorphism (e.g., Fuku Pass metacumulates: Tsujimori and Liou, 2004a) rather than the Late Paleozoic metamorphism (Renge blueschists: Nishimura, 1998; Tsujimori and Itaya, 1999).

In the central CGM, about 180 km to the west of the Sekinomiya (Oya)-Wakasa occurrence, exposures of ultramafic bodies of the Oeyama belt are more frequent (e.g., Tari-Misaka, Ashidachi, Osayama areas etc.). Arai (1980) suggested that these ultramafic bodies originally constituted the lowest part of an ophiolitic suite, which was subsequently emplaced as dismembered fragments. Gabbro associated with moderately depleted residual peridotite of the central CGM yield zircon ion-microprobe (SHRIMP II) U-Pb ages (weighted mean ages) of 545.4 ± 2.6 Ma and 532.4 ± 3.1 Ma (Kimura and Hayasaka, 2015). A jadeitite-bearing serpentinite-matrix mélange is developed in the Osayama area (Fig. 1). The serpentinite mélange contains tectonic blocks of Late Paleozoic Renge HP-LT metamorphic rocks (Tsujimori and Itaya, 1999; Tsujimori and Liou, 2005a), and occurrences of jadeitite, omphacitite, omphacite-bearing tremolite rock, and albitite have been described (e.g., Kobayashi et al., 1987; Tsujimori, 1997, 1998; Tsujimori and Liou, 2004b; Tsujimori et al., 2005b). Some albitites contain aegirine-augite, and may represent the retrograded equivalent of jadeitite. Blocks of gabbro and dolerite derived from the Oeyama

belt also underwent blueschist-facies metamorphism. The Osayama jadeitites are mostly P-type and quartz-free, and jadeite crystals show oscillatory zoning in cathodoluminescence (CL). Rutile and zircon are common accessory minerals (Fig. 6), whereas omphacite, pectolite, analcime, titanite and rare phlogopite are common secondary minerals. Some jadeitites are calcium-rich and contain grossular-rich garnet. Fluid inclusions of both primary and secondary origins are ubiquitous in jadeite, and the homogenization temperature of the fluid inclusions ranges from 135 to 345 °C (Shoji and Kobayashi, 1988).

Osayama jadeitites are characterized by relatively heavy oxygen isotope values, $\delta^{18}\text{O} = +7.77$ to $+9.15\%$ (Fu et al., 2010), suggesting a possible fluid source from subducting slab materials (e.g., altered oceanic crust and sediments). Zircons from Osayama jadeitites also contain abundant fluid inclusions, with mainly two phases ($\text{H}_2\text{O} + \text{CH}_4$). Zircon contains inclusions of rutile, jadeite and rare grossular; note that grossular enclosed in zircon contains inclusions of jadeite (Fig. 6c). These fluid-precipitated zircons, Tsujimori et al. (2005b)'s type-I and Fu et al. (2010)'s h-type, yield ion-microprobe (SHRIMP RG) U-Pb ages scattering from 531 ± 38 to 447 ± 18 Ma (Tsujimori et al., 2005b). Rare inherited cores of a zoned zircon [see Tsujimori et al. (2005b)'s Fig. 4B and Fu et al. (2010)'s Fig. 2a] suggest possible igneous protolith of an oceanic crustal origin (Fu et al., 2010); these yielded ages ranging from 527 ± 20 to 488 ± 20 Ma (Tsujimori et al., 2005b). As shown in Figures 6e and 6f, internal texture of zircon shows multiple events; obviously metasomatic (or overgrown) zircons with a brighter-CL formed during the latest event. Tsutsumi et al. (2010) reported ion-microprobe (SHRIMP II) U-Pb ages of two grains having different mean ages (496 ± 12 Ma and 532 ± 17 Ma; Tsutsumi et al., 2010). A new LA-ICPMS U-Pb age of grossular-bearing zircons yields 512 ± 3.4 Ma ($n = 85$, MSWD = 1.8). As shown in Figure 5, the age of jadeite formation is significantly older than the HP-LT metamorphism of the Renge schist in the same mélangé. The wide range of zircon ages implies a long-sustained process of jadeite formation.

Oxygen isotope composition of zircon crystallized during jadeite formation is unusually higher ($\delta^{18}\text{O} = +3.6 \pm 0.6\%$) than those of the inherited core, which likely formed in equilibrium with mantle ($\delta^{18}\text{O} = +5.0 \pm 0.4\%$) (Fu et al., 2010). Oxygen isotope fractionation between jadeite (Jd) and zircon (Zrn), $\Delta^{18}\text{O}_{\text{Jd-Zrn}} (= \delta^{18}\text{O}_{\text{Jd}} - \delta^{18}\text{O}_{\text{Zrn}})$ value of $+4.0$ or $+5.7\%$, implies a very low apparent temperature ~ 250 °C, suggesting zircon is out of oxygen isotope equilibrium with jadeite. In contrast, Ti-in zircon thermometry results in relatively high-temperature of ~ 640 – 720 °C (Fu et al., 2010). It is noteworthy that

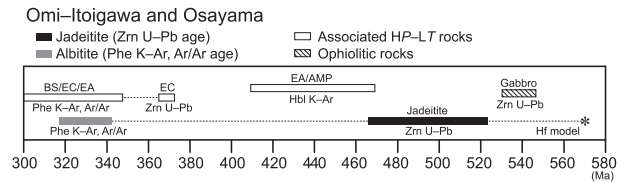


Figure 5. Summary of geochronological data for jadeite and associated HP-LT metamorphic rocks from the Itoigawa-Omi and Osayama areas (modified after Tsujimori and Harlow, 2012). Data of gabbroic rocks of the Oeyama ophiolite are after Kimura and Hayasaka (2015). Abbreviations of minerals and metamorphic facies: Jd, jadeite; protolith, protolith age; Zrn, zircon; Phe, phengite; Hbl, hornblende; GS, greenschist facies; BS, blueschist facies; EC, eclogite facies; EA, epidote amphibolite facies; AM, amphibolite facies.

Early Paleozoic high-pressure epidote-amphibolite facies metamorphism in tectonic blocks associated with the Oeyama belt has the similar temperature range (Tsujimori and Liou, 2004a).

Initial epsilon hafnium values of zircon, $\epsilon\text{Hf}(t)$, lie between the CHUR (chondritic uniform reservoir) and the DM (depleted mantle) evolution lines (Fu et al., 2010) (Fig. 7). The model age defined by metasomatic zircons would represent a timing of a zircon source differentiated from the mantle at ~ 570 Ma (Fig. 7); hafnium might have remobilized from protoliths (or source of fluids) of jadeite during jadeite formation.

JADEITE-BEARING METAMORPHIC ROCKS IN THE KUROSEGAWA BELT

The Kurosegawa belt is a serpentinite-matrix mélangé belt, running parallel to the orogenic trend west from central Kyushu passing Shikoku to the Kanto Mountains, which has been interpreted as a tectonic klippe consisting of pre-Jurassic equivalents of the CGM and HDM (e.g., Isozaki and Itaya, 1991; Isozaki and Maruyama, 1991; Isozaki et al., 2010). In this context, ultramafic rocks and HP-LT metamorphic rocks of the Kurosegawa belt are correlated with those of the Oeyama and Renge belts (e.g., Tsujimori and Itaya, 1999). Jadeite-rich metasomatic rocks have been known from serpentinite-matrix mélangé of the Kurosegawa belt in Kyushu and Shikoku (Fig. 1). A jadeite-bearing lawsonite-blueschist-facies metagabbro occurs as a tectonic block in the Hakoishi serpentinite unit of the Yatsushiro area, central Kyushu; the metagabbro contains centimeter-scale cavities (or veins) filled by jadeite (Saito and Miyazaki, 2006). The unusual monomineralic nature suggests that the jadeite was precipitated in local cavities. Similar monomineralic jadeite veins have been known in some Franciscan blueschist (e.g., Banno et al., 2000). The jadeite-bearing

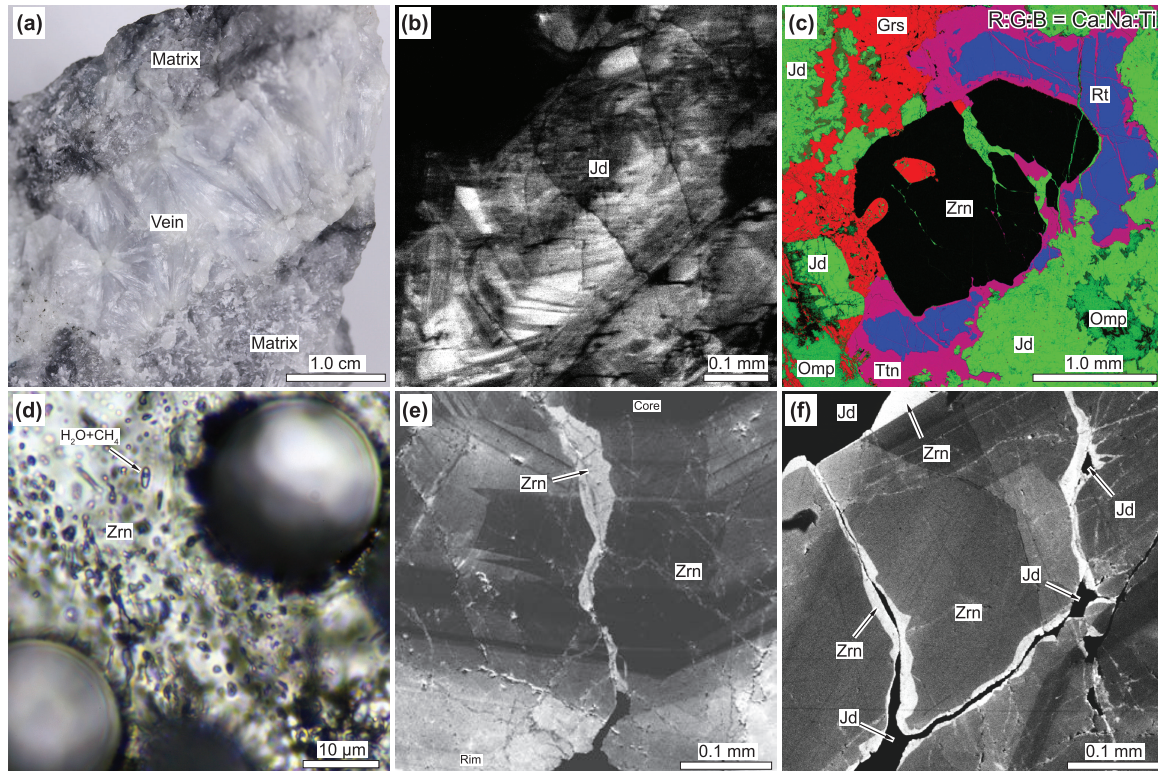


Figure 6. Microtextures of the Osayama jadeitites. (a) Coarse-grained jadeite vein cross-cutting a jadeite matrix (b) Monochromatic CL image of a jadeite crystals with oscillatory growth zoning. (c) X-ray image of a zircon (Tsuji-mori et al. (2005)'s type-I and Fu et al. (2010)'s h-type) in jadeiteite (R:G:B = Ca:Na:Ti). Grossular enclosed in zircon contains tiny jadeites. Along the fractures of zircon, secondary jadeites were precipitated. Rutile is replaced partly by titanite. Note that original RGB color space was converted to the CMYK color space for printing. (d) Zircon of (c) with abundant fluid inclusions. Note that two circles (holes) are laser abrasion craters. (e) CL image of zircon in the Osayama jadeitite, showing an early formed zircon metasomatized by newly formed zircon (bright CL) along a crack. Note that no significance age differences were detected. (f) CL image of zircon in the Osayama jadeitite, showing secondary jadeite along the cracks.

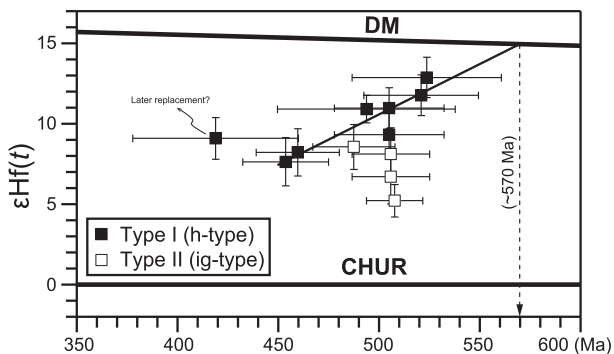


Figure 7. U-Pb age versus $\epsilon_{\text{Hf}}(t)$ (initial epsilon hafnium values of zircon) of zircons from the Osayama jadeitite (Modified after Fu et al., 2010). The regression line ($R^2 = 0.83$) is defined by type-I (h-type) zircons excluding one outlier. Abbreviations: DM, depleted mantle; CHUR, chondritic uniform reservoir.

metagabbro has not yet been dated, but the jadeitite precipitation is likely correlated with Late Paleozoic blueschist-facies metamorphism of the Kurosegawa belt that is equivalent to the Renge *HP-LT* schist in the CGM and

HDM. Another jadeite-rich metamorphic rock was reported as boulders from a serpentinite mélangé of the Kochi area of Shikoku (Tsutsumi et al., 2010). The rock consists mainly of jadeite and quartz with glaucophane; relict igneous zircons with melt inclusions yield ion-microprobe U-Pb ages of 501 ± 5 Ma ($n = 26$). Similar detrital zircons (~ 500 Ma) were also confirmed from jadeite-bearing lawsonite blueschist in this area (Yang et al., 2016). Zircons extracted from rodingites and serpentinites in the Kochi area show major U-Pb age peaks at 485 Ma and 469 Ma as formation of the protoliths (Hu et al., 2017). These Cambro-Ordovician igneous events are consistent with previous thoughts that Oeyama belt and of the proto-Japan formed during the Early Paleozoic.

PERSPECTIVES

Research interest in jadeitite has not only included petro-tectonics, geochronology, and geochemistry (e.g., Harlow et al., 2004; Brueckner et al., 2009; Fu et al., 2010; Simons et al., 2010; Sorensen et al., 2010; Yui et al., 2012;

Flores et al., 2013; Harlow et al., 2016), but current attention also reflects their significance regarding geochemical components of arc magmas (e.g., Marschall and Schumacher, 2012). Studies over the last two decades have interpreted jadeitite either as the direct aqueous fluid precipitate from a subduction channel into the overlying mantle wedge or as the metasomatic replacement by such fluids of oceanic plagiogranite, greywacke, or metabasite along the channel margin (cf. Harlow et al., 2015). Most jadeitites are principally fluid precipitates (P-type), but some jadeitites that preserve relict minerals and protolith textures also occur and are thus metasomatic replacements (R-type; Tsujimori and Harlow, 2012). This new jadeitite classification (P- and R-types) based on formation process has been widely accepted in the geoscience community.

Jadeitite is a petrotectonic indicator that found only in Neoproterozoic and younger orogenic belts (Stern et al., 2013, 2016). At least 19 jadeitite localities demonstrate that jadeitite-bearing serpentinite-matrix mélanges were exhumed to the Earth's surface along major transform-type or thrust faults cutting paleo-forearcs or accretionary wedges (Harlow et al., 2015). The *P-T* conditions of jadeitites correlate to forearc mantle wedge and *HP-LT* metamorphism within a Pacific-type subduction zone at relatively shallow depths (<~ 100 km). Ascending aqueous fluids in a mantle wedge are also supported by a vertical wall-like low-*V* zones in the forearc region visualized by a high-resolution seismic tomography of NE Japan ('Water Wall': Zhao et al., 2015). The jadeite-forming aqueous fluids transfer various elements from subduction slab into the transitional mélange and overlying mantle wedge (e.g., Flores et al., 2013; Harlow et al., 2016); these fluids also promote mass circulation within a subduction channel and mantle wedge. Chemical differentiation and transportation of the fluids caused by jadeitite formation are crucial topics requiring further research.

Finally, what can we learn from the Early Paleozoic jadeitites in Japan? Paleozoic jadeite-bearing serpentinite-matrix mélange represents the oldest mantle wedge above the Pacific-type subduction zone of proto-Japan. The jadeitites provide a petrotectonic constraint on the earliest subduction event in proto-Japan. Geochronological data of both jadeitites worldwide and associated *HP-LT* metamorphic rocks have shown temporal discrepancies between jadeitite formation and *HP-LT* metamorphism (e.g., blueschist- and eclogite-facies metamorphism) at some localities (Tsujimori and Harlow, 2012). As a representative case of the Itoigawa-Omi and Osayama localities (Fig. 5), the close association between older jadeitites and younger *HP-LT* rocks in a single mé-

lange complex implies different histories for the subduction channel and jadeite-bearing serpentinite-matrix mélange. Notably, the jadeitite-hosted mélange (or serpentinitized peridotite) can stay within mantle wedge for a considerable time. Consequently, recrystallization, resorption, and re-precipitation of jadeitite are continued in the mantle wedge environment. Characteristic features of the proto-Japan remnants are a less voluminous amount of tonalite-trondhjemite-granodiorite (TTG) or basaltic rocks and ubiquitous occurrence of ultramafic rocks (e.g., Oeyama/ Renge and Kurosegawa belts). Although, the crustal rocks of the proto-Japan might have been lost by tectonic erosion (e.g., Tsujimori, 1998; Isozaki et al., 2010; Yang et al., 2016). Serpentinite of the Kurosegawa belt contains zircon with U-Pb ages of 500 and 560 Ma; the zircon grains were likely contaminated with those from disrupted crustal rocks incorporated to a subduction channel (Yang et al., 2016). Such zircons or zircon-bearing igneous rocks in mantle wedge environment can be involved in formation of jadeitite (e.g., Lei et al., 2016; Hertwig et al., 2016). However, there is still more studies to be done in order to better understand the proto-Japan's mantle wedge environment (jadeitite-formation and tectonic erosion). In any case, studies of Paleozoic jadeitites in Japan continue to provide opportunities to tie up fossilized mantle wedge and subduction channels to geophysical observations of modern analogues, and to constrain tectonic development during the earliest stages of orogenic growth associated with the subduction of the paleo-Pacific oceanic plates. For the next step, more advanced approach will be required than those documented in previous studies.

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