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The earliest mantle fabrics formed during subduction zone infancy

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ABSTRACT

Harzburgites obtained from the oldest crust–mantle section in the Philippine Sea plate (∼52 Ma) along the landward slope of the southern Izu–Ogasawara Trench, preserve mantle fabrics formed during the infancy of the subduction zone; that is during the initial stages of Pacific plate subduction beneath the Philippine Sea plate. The harzburgites have relatively fresh primary minerals despite of their heavy serpentinizations, and show inequigranular interlobate textures, and crystal preferred orientation patterns in olivine (001)[100] and Opx (100)[001]. The harzburgites have the characteristics of residual peridotites, whereas the dunites, obtained from the same location as the harzburgites, provide evidence for the earliest stages of arc volcanism during the inception of subduction. We propose that the (001)[100] olivine patterns began forming in immature fore-arc mantle with an increase in slab-derived hydrous fluids during the initial stages of subduction in *in situ* oceanic island arc.

1. Introduction

Fore-arcs provide key information on the initiation of magmatic and subduction zone processes during island arc formation (Bloomer et al., 1995; Stern and Smoot, 1998; Stern 2002, 2004). However, since fore-arc sections are exposed deep on the landward trench slope accessibility is limited. Thus only a few studies have considered the mantle structure in fore-arcs, in contrast to the many studies of the evolution of crustal structures in island arcs (e.g., Kodaira et al., 2010; Ishizuka et al., 2011). Furthermore, fore-arc mantle structures formed during the initial stages of subduction might be erased or modified during subsequent subduction-related tectonic events in mature and ancient arc accreted terrains (e.g., Arcay et al., 2005). For instance, many modern fore-arc regions are thought to be highly serpentinized mantle, infiltrated by slab-derived fluids in steady-state subduction systems (e.g., Bostock et al., 2002; Hyndman and Peacock, 2003; Hilairet and Reynard, 2009; Katayama et al., 2009; Boudier et al., 2010; Hirauchi et al., 2010). Here, we document for the first time the structure of immature fore-arc mantle at the time of subduction zone initiation as preserved in peridotites exposed on the deep seafloor along the landward slope of the southern Izu–Ogasawara Trench (Fig. 1).

2. Geological background

Dive 7K417 of the ROV *Kaiko 7000II* during R/V *Kairei* cruise KR08-07, and Dredge 31 of R/V *Hakuho-Maru* cruise KH07-02, operated by the Japan Agency for Marine–Earth Science and Technology, explored the landward slope of the southern Izu–Ogasawara Trench (Fig. 1A). Outcrops of peridotite, gabbro, dolerite, and basalt were observed during the dive from 5336 to 5792 meters below sea level (mbsl) (Morishita et al., 2011) and 48 samples of 35 peridotites, 9 troctolites, pyroxenite, and 3 gabbros were dredged between 5293 and 5738 mbsl (Fig. 1B). It appears that these slopes expose a mantle-derived peridotite body developed in the Izu–Bonin–Mariana (IBM) arc (Morishita et al., 2011), whereas some doleritic samples have a fore-arc tholeiitic basalt signature that is considered to represent the earliest magmatism during subduction initiation (Fig. 1B; Ishizuka et al., 2011).

3. Microstructure

The five harzburgite samples were selected for study: two from the dive (R9 and R19) and three from the dredge (D31-1, -3, and -10). The two harzburgites (R9 and R19) have visible foliations and

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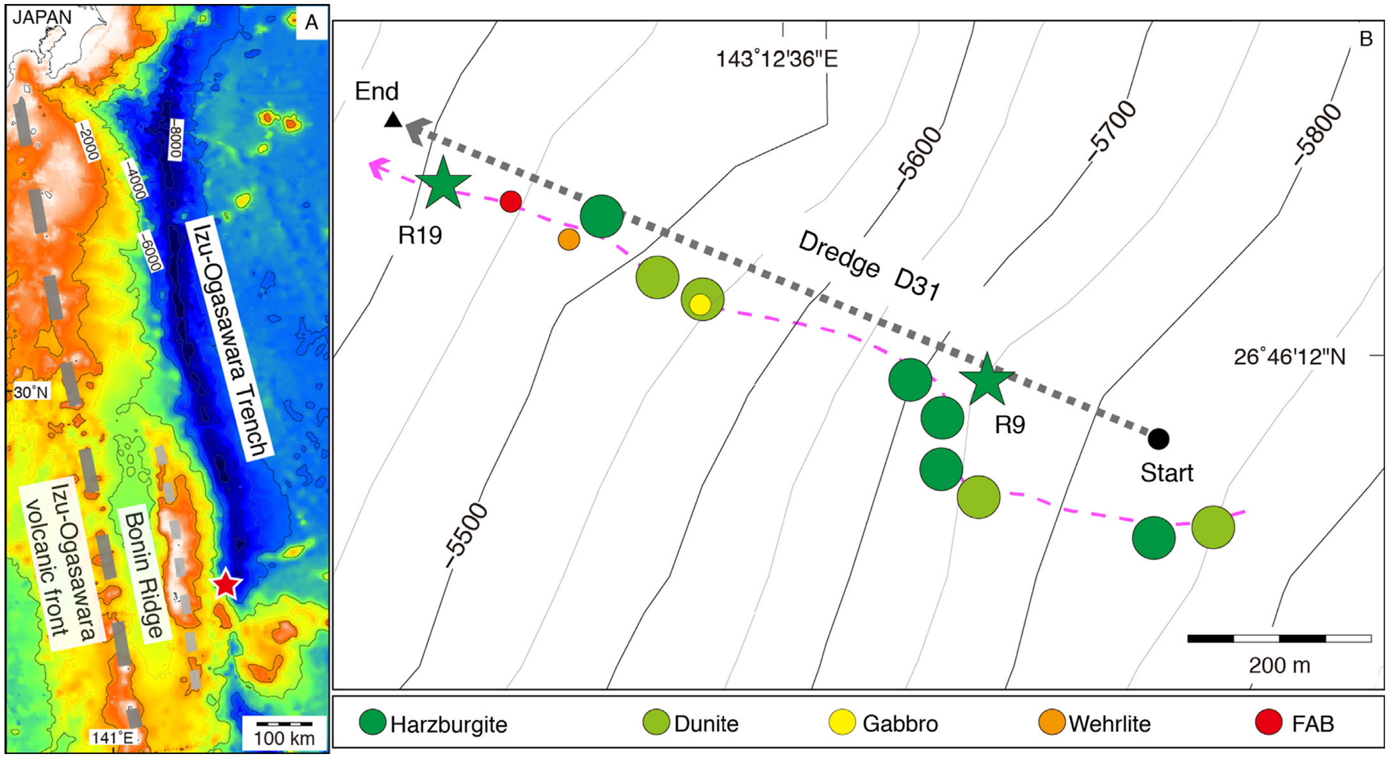

Fig. 1. A: Bathymetric map of the Izu–Ogasawara arc region. Study area shown by the red star on the landward slope of the trench close to the Bonin ridge. Broken gray line indicates the Izu–Ogasawara volcanic front. B: Bathymetric map showing the sampling points and track (pink dashed line) for ROV dive KR08-07-7K417 and the approximate track for Dredge KH07-02-D31 (grey dashed line). Colored symbols show the typical lithologies collected at each ROV sampling location: green – harzburgite, light green – dunite, yellow – gabbro, orange – wehrlite. A doleritic rock with fore-arc tholeiitic basalt signature (FAB) is red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

lineations defined by the alignments of spinel and pyroxene grains on bleached and saw-cut samples (e.g., Michibayashi et al., 2009). Thin sections were cut in two samples perpendicular to the foliation and parallel to the lineation defined by pyroxene's structure. However, the other three harzburgites (D31-1, -3, and -10) have no or very weak structures with their small sizes; thin sections of these samples were made in arbitrary sections.

The main constituent minerals are olivine (15.6%), orthopyroxene (Opx; 13.1%) and spinel (0.5%), although serpentine is currently the most common mineral as more than 70% modal compositions within the five samples due to heavy serpentinization (Fig. 2). The harzburgites have coarse inequigranular interlobate (or protogranular) textures (e.g., Passchier and Trouw, 1996) consisting of largely coarse-grained olivine with serrated grain boundaries and coarse- to medium-grained Opx (Fig. 2A, B, C, D). They exhibit signs of intracrystalline deformation such as wavy extinction, and subgrain boundaries, but without intense grain-size reduction. Elongate Opx grains were dynamically recrystallized into medium-sized aggregates, and wavy extinction provides evidence for intracrystalline deformation (Fig. 2A, B, C, D). Harzburgite D31-10 is internally complex with a sharp-sutured contact between Opx-rich and Opx-poor harzburgite, with finer grained pyroxene in the latter; a gabbro vein crosscuts the Opx-rich harzburgite with a razor sharp straight contact that is oblique to the Opx-rich–Opx-poor contact (Fig. 2E, F). Secondary serpentine shows the mesh texture in these harzburgites (Fig. 2), whereas we cannot observe the deformation microstructure of serpentine. Therefore, we argue that these harzburgites could preserve an original microstructure in the mantle structure at IBM region despite of their heavy serpentinizations.

4. Mineral chemistry

The chemical composition of primary minerals in three harzburgite samples (D31-1, -3, and -10) were analyzed using a JEOL JCXA-733 electron probe micro-analyzer (Shizuoka University, Japan). Analyses were made with a probe current of 12 nA, accelerating voltage of 15 kV, and a correction procedure after Bence and Albee (1968). The harzburgite samples have high olivine forsterite (90.6–92.1 mol.%) and NiO (∼0.4 wt%) contents (Table 1), low Opx Al_2O_3 (< ∼1.5 wt%) and Na_2O (<0.03 wt%) (Table 2), and high spinel Cr# (65–67) (Table 3). These data is similar to that for two harzburgites (KR08-07-7K417R9 and R19) in Morishita et al. (2011). These mineral compositions lie largely outside the range for abyssal peridotites from mid-ocean ridges (Fig. 3; e.g. Dick and Bullen, 1984), indicating that the harzburgites are refractory consistent with an origin in a supra-subduction zone mantle wedge (Morishita et al., 2011).

5. Crystal fabric analysis

The crystallographic preferred orientations (CPOs) of olivine and Opx grains in highly polished thin sections were analyzed with a JEOL JSM6300 SEM and a HITACHI S-3400N SEM, equipped for electron back-scattered diffraction (EBSD with HKL Channel5), at Shizuoka University, Japan. We measured the crystal orientations of 91 to 233 olivine grains and 59 to 171 Opx grains in 5 harzburgites, visually checking the computerized indexation of each diffraction pattern. We then calculated the *J*-index (Mainprice et al., 2000; Michibayashi and Mainprice, 2004; Michibayashi et al., 2006) to determine the fabric strength and distribution densities of the principal crystallographic axes. The *J*-index has a value of 1