Petrology of Abyssal Peridotites in Diverse Tectonic Settings : Generalities and Differences in Mantle Melting, Melt Extraction and Post-melting Proesses, and Significance of Small-scale Variations

Petrology of abyssal peridotites in diverse tectonic settings: generalities and differences in mantle melting, melt extraction and post-melting processes, and significance of small-scale variations

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It is generally accepted that oceanic crust represents solidified partial melts formed by partial melting of adiabatically decompressing mantle peridotite. Understanding of the formation processes of oceanic lithosphere is therefore a major issue in the Earth Sciences. Peridotites tectonically exposed on ocean floors are called as abyssal peridotites and occur in a variety of tectonic settings such as mid-ocean ridges, back-arc, fore-arc and amagmatic passive continental margins. Although experimental and theoretical approaches are useful to reveal mantle melting, melt extraction and post-melting processes in the mantle, petrology and geochemistry of abyssal peridotites still provide direct information on these processes beneath ocean floors. Furthermore, characterization of abyssal peridotites should be essential to know origin of ophiolites.

There are many data sets including both petrology and geochemistry of peridotites from mid-ocean ridge peridotites (e.g., Niu & Hékinian, 1997; Hellebrand et al., 2001; Niu, 2004 and references therein) but those data from back-arc peridotites (Mariana Trough, Ohara et al, 2002; Parece Vela Basin, Ohara et al., 2003) and fore-arc peridotite (Izu-Bonin-Mariana Forearc; Parkinson & Pearce, 1998) are limited. Irrespective of differences in sampling frequency, we summarize petrology and mineral chemistry of abyssal peridotites. Many studies on abyssal peridotites were conducted based on local averages and did not pay much attentions to local variations in modal and chemical compositions. Field-work like close-spaced observation and sampling on a wall of the Atlantis II Fracture Zone in the slow-spreading Southwest Indian ridge (14 mm/year full spreading rate) were conducted by submersible SHINKAI 6500 of the Japan Marine Science Technology Center. We, therefore, also show these results, which provide extremely important constraints on magmatic processes at slow-spreading ridges.

Although abyssal peridotites are usually serpentinized and/or weathered, they can be divided into three groups, (1) spinel harzburgite-lherzolite, (2) spinel-dunite, and (3) plagioclase-bearing peridotite.

(1. Spinel harzburgite-lherzolite) Several lines of evidence have led to widespread acceptance of spinel harzburgite-lherzolite as mantle residue left after partial melting (e.g, Dick & Bullen, 1984; Niu & Hékinian, 1997). Spinel Cr# (= Cr/(Cr + Al) atomic ratio) is generally accepted as a sensitive indicator for the extent of melting (Dick & Bullen, 1984; Arai, 1994). Spinel Cr# in spinel harzburgite-lherzolite from mid-ocean ridge is higher in fast-spreading ridge than in slow-spreading ridge, indicating that degree of partial melting beneath normal ocean ridges increases with increasing spreading rate (Niu & Hékinian, 1997). However, spinel Cr# from ultraslow-spreading ridge peridotites (Gakkel ridge, < 12 mm/year full spreading rate) is significantly higher than that expected from this rule (Hellebrand et al., 2002). High Cr# of spinel in ultraslow-spreading peridotites might be caused by melt focusing at a magmatic period (Hellebrand et al., 2002). Spinel compositions in back-arc peridotites plot in the compositional range of mid-ocean ridge peridotites (Ohara et al, 2002, 2003). Spinel Cr# in fore-arc peridotites ranges from 0.3 to 0.9, and some of them are apparently higher than those from mid-ocean ridge peridotites (Ishii et al., 1992; Parkinson & Pearce, 1998). It is interesting to note that spinel Mg# (= Mg/(Mg + Fe^{2+}) atomic ratio) in fore-arc peridotites are lower than those in mid-ocean ridge peridotites at similar Cr#, probably indicating lower equilibrium temperature in fore-arc peridotites than in mid-ocean ridge peridotites (Ishii et al., 1992; Parkinson & Pearce, 1998).

Clinopyroxenes in spinel harzburgite-lherzolite from mid-ocean ridges are highly refractory in LREE and are not equilibrium with mid-ocean ridge basalt (Johnson et al., 1990). Strong LREE depleted signatures in residual clinopyroxene confirm that melt extraction beneath mid-ocean ridges is nearly fractional (Johnson et al., 1990). Although HREE in clinopyroxene from mid-ocean ridges are highly correlated with Cr# of coexisting spinel, LREE in clinopyroxene are not well correlated (Hellebrand et al., 2001). This is partly because minor amounts of melt are held back in the residue

(Hellebrand et al., 2001). Chondrite-normalized REE patterns of clinopyroxene in spinel lherzolite from back-arc have similar characteristics of those in mid-ocean ridge peridotites (Ohara et al., 2002, 2003). In the case of fore-arc peridotites, although HREE contents of clinopyroxene are consistent with a simple fractional melting, LREE and Sr have a higher concentrations than can be explained by fractional melting (Parkinson & Pearce, 1998). LREE and Sr enrichments can be explained by melt and/or fluid interaction within the mantle wedge. This coupled with low-equilibrium temperature for fore-arc peridotites is consistent with that hydrous minerals such as amphibole and phlogopite are found in fore-arc peridotites (Parkinson & Pearce, 1998).

(2. Spinel dunite) Mantle-hosted dunite is common in many ophiolitic peridotites and orogenic peridotites. Phase equilibria and field evidence from these peridotites show that dunite forms by dissolution of pyroxene from host peridotites due to melt-mantle interactions, indicating that dunites were act as conduits for focused melt flow (e.g., Kelemen et al., 1995). Dunites are minor but were collected from mid-ocean ridge, back-arc and fore-arc settings. This means that dunites may act important role as melt conduit beneath ocean floor in diverse tectonic settings. Further works on ocean floor dunites are needed to understand magmatic processes beneath ocean floor.

(3. Plagioclase-bearing peridotites) Plagioclase-bearing peridotite is not rare in mid-ocean ridges as well as back-arc but has never been reported from fore-arc. Plagioclase in plagioclase-bearing peridotites occurs as interstitial phase or veins. It is widely accepted that many plagioclase-bearing peridotites are products of melt-mantle interactions (Dick & Bullen, 1984; Seyler & Bonatti, 1997; Tartarotti et al, 2002). LREEs have a higher concentration in clinopyroxene from plagioclase-bearing peridotite than plagioclase-free peridotite even in the same area. LREE enrichment is related to melt-rock interactions. Chondrite-normlized REE patterns of clinopyroxene in plagioclase-bearing peridotite from back-arc peridotites are similar to those from mid-ocean ridge peridotites.

An example of small-scale variations: the slow-spreading Southwest Indian Ridge

Two dives traversed a southwestern facing slope of Atlantis Bank in a northeastern direction with interval of 1000 m water depth and has succeeded to achieve a cross-sectional observation of an outcrop where layered gabbros are directly underlain by granular peridotites (gabbro/peridotite boundary hereafter). A dunite occurs as dike-like feature (~ 20cm in thickness) highly oblique to the gabbro/peridotite boundary. Other peridotites are plagioclase-free spinel lherzolite with Cr# of spinel 0.2-0.35. The dunite is accompanied with dunitic lherzolite (olivine-rich rock with high cpx/opx ratio) at the edge of the sample and is intruded by gabbro vein (< 2cm in thickness) (Morishita et al., 2004). Chromian spinel is locally concentrated as several small pods with a few cm in size in the dunite parallel to the lithological boundary between the dunite and the dunitic lherzolite. The lithological relationships between the chromian spinel-rich vein and the host peridotites are the same as those for podiform chromitite in ophiolites/orogenic peridotites. Clinopyroxene in the dunitic lherzolite occurs as porphyroclast, interstitial grain between olivine matrix and rarely rimming of orthopyroxene. Chondrite-normalized REE patterns of clinopyroxene in the dunitic lherzolite are variable corresponding to the occurrences above, LREE-depleted, LREE-enriched and high-concentrations of REEs with negative Eu anomaly, respectively. The dunitic lherzolite is therefore interpreted to be residue of high-degree of partial melting with crystallization of clinopyroxene from interstitial melts. The Cr# of spinel in the dunite (0.3) is similar to those in the SWIR MORB far from hot spots (Le Roex et al., 1983). Because the dunite would be equilibrated with the SWIR MORB formed by low-degree of partial melting, it may act as melt conduits in slow-spreading ridges.

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