Development and evolution of the lithospheric mantle: a case study from the Horoman peridotite, Japan

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The Horoman peridotite, Hokkaido, Japan is a layered upper mantle peridotite that is a piece of heterogeneous mantle created by melt formation, segregation, migration and wallrock/melt interaction. (Obata and Nagahara, 1987; Takahashi, 1991, 1992; Takazawa *et al.*, 1992b). In order to understand the scale and timing of these processes we studied 60 samples from a 40 m stratigraphic section (the Bozu section). This section is well exposed and several rock types as layers, 10's of meters thick.

Abundances of *REE*, Sr, Zr, Ti, Y, Cr and V in clinopyroxenes (cpxs) from 60 peridotites were analyzed by a secondary ion mass spectrometer at WHOI. Abundances of *REE*, Sr, Zr, Nb, Hf, Th and *REE* in 34 whole rocks were measured by ICP-MS at Université de Montpellier II, France. Plagioclase lherzolites are generally depleted in incompatible elements (Fig. 1). It is noted that Zr fractionates from Hf as the bulk rocks becomes more depleted in incompatible elements. Fig. 2 shows variation of chondrite-normalized La/Nd ratio [$(La/Nd)_N$] in cpxs in terms of stratigraphic height. Plagioclase lherzolites have the lowest values (<1), except in a subsection of *LREE* enriched plagioclase lherzolite (~ 2). In the lherzolite layer the ratio increases from near unity to 10 towards the boundary with the harzburgite, then decreases gradually within 3 meters from the boundary because abundances of Nd in the cpxs increase. Lherzolites near the phlogopite-bearing zone have $(La/Nd)_N$ ratio higher than unity. Harzburgite has constant $(La/Nd)_N$ ratio of $1 \sim 2$ while some harzburgite near a mafic layer has $(La/Nd)_N$ ratio lower than unity. Generally the lithological boundary is associated with steep compositional gradient. Fig. 3 shows variation of chondrite normalized patterns of *REE*, Sr, Zr and Ti along a traverse in the porphyroclastic cpx in a plagioclase lherzolite. The rim is enriched in *REE*, especially in *HREE*, and depleted in Sr relative to the core. It is noted that the core is relatively depleted in Zr but this depletion decreases toward the rim.

The geochemical data provide evidence for five sequential events:

Event 1. *Formation as asthenospheric mantle.* The plagioclase lherzolites are fertile peridotites, 3–4 % CaO and Al_2O_3, which have been variably depleted in incompatible elements by segregation of small and variable extents of partial melting (Fig. 1). Because the plagioclase lherzolite is the most

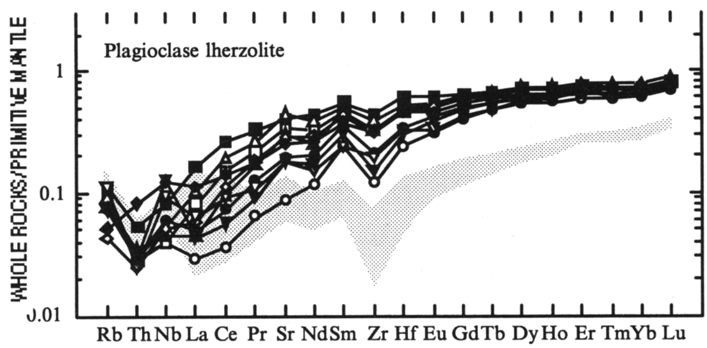

FIG. 1. Primitive mantle-normalized abundances of incompatible elements in whole-rock plagioclase lherzolites. Normalizing values from Sun and McDonough (1989). The shaded field indicates region for *LREE*-enriched plagioclase lherzolites.

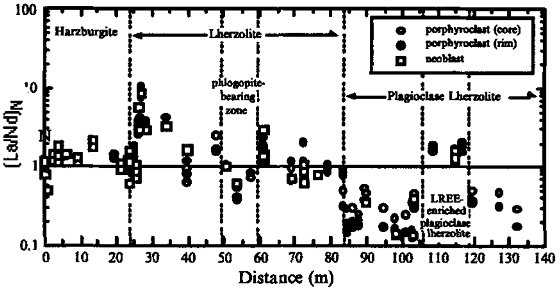

FIG. 2. $(La/Nd)_N$ variation in cpx as a function of stratigraphic height in the Bozu section.

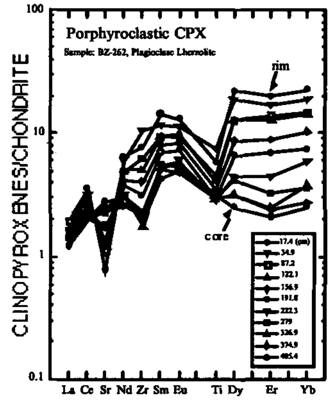

FIG. 3. Variation of chondrite-normalized patterns of *REE* and Sr, Zr and Ti in the porphyroclastic cpx along a traverse.

abundant rock type in the Horoman peridotite, and has the geochemical characteristics expected of MORB source, we infer that the Horoman peridotite was formerly a part of the asthenosphere.

Event 2. *Accretion to and long-term residence in the lithospheric mantle.* The depleted Sr and Nd isotopic characteristics of acid washed cpxs from plagioclase lherzolite (Takazawa *et al.*, 1992a) require a long residence time in lithospheric mantle isolated from convecting asthenospheric upper mantle (Downes *et al.*, 1991).

Event 3. *Reaction with LREE enriched percolated melt.* We infer that the harzburgite layers formed by extensive reaction between a fertile lherzolite and an exotic *LREE*-enriched melt. A harzburgite adjacent to the lherzolite is most strongly enriched in *LREE*: i.e., whole rock $(Ce/Yb)_N$ ~2.4, Ce_N ~0.38. The lherzolites adjacent to this harzburgite were wallrocks that only partially reacted with melts emanating from the main conduit for melt migration which is represented by harzburgite. In the context of this model the 3 m interval within the plagioclase lherzolite that is characterized by lower whole rock CaO and Al_2O_3 and cpxs with relatively high $(La/Nd)_N$ and low *HREE* is a region where the extent of melt rock reaction was much less than in the harzburgite (Fig. 2). Thus these lherzolites exhibit the commonly found trend of decreasing modal cpx and bulk-rock CaO, Al_2O_3 and *HREE* contents accompanied by an increase in $(La/Nd)_N$ (McDonough and Frey, 1989). This zone is an early stage of the transition from a relatively fertile, *LREE*-depleted plagioclase lherzolite to a less fertile, relatively *LREE*-enriched lherzolite, and we suggest that it represents an early stage of the melt-wallrock reaction process.

Event 4. *Cooling of the peridotite to form garnet in the least depleted lherzolite:.* Takazawa *et al.* (1992b, 1993) reported compositional zoning of Sr, Zr, Ti, Y, *HREE* in porphyroclastic cpxs from lherzolite and plagioclase lherzolite (Fig. 3). Because Zr and *HREE* are preferentially partitioned into garnet relative to coexisting cpx. The negative anomaly in Zr and the depletion in *HREE* in the cores of porphyroclastic cpxs are consistent with equilibration of the cpx core with garnet. The presence of former garnet is supported by the two pyroxenes-spinel symplectites in most of the lherzolites and some plagioclase lherzolites. The symplectites are reaction products from breakdown of garnet (Takahashi and Arai, 1989)

Event 5: *uplift and emplacement from the upper mantle to the crust.* Takazawa *et al.* (1992b, 1993) considered that enrichments of Sr, Zr, Ti, Y, *HREE* at the rims of cpx porphyroclast (Fig. 3) reflect sub-solidus redistribution after breakdown of garnet due to uplift and emplacement from the upper mantle to the crust. Flat profile of *LREE* from core to rim in cpx porphyroclast shows the mantle/melt reaction which caused *LREE* enrichment in depleted lherzolite preceded garnet breakdown. Plagioclases in the plagioclase lherzolite were recrystalized by the reaction of two pyroxenes and spinel (Obata and Nagahara, 1987; Takahashi and Arai, 1989) thereby causing depletion of Sr at the rim of cpx porphyroclast.