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Reconstruction of the lithosphere-asthenosphere boundary zone beneath Ichinomegata maar, Northeast Japan, by geobarometry of spinel peridotite xenoliths

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Abstract

Accurate estimation of the depths of spinel peridotite xenoliths for which reliable geobarometers are not available is imperative to be able to reconstruct the precise structures of the lithosphere-asthenosphere boundary (LAB). The LAB can be defined based on thermal, chemical, rheological, and petrological contrasts, and knowing its depth is crucial to understanding mantle dynamics. We attack this problem by examining spinel peridotite xenoliths from Ichinomegata maar in the back-arc side of Northeast Japan Arc. Extensive mineral compositions of nine xenolith samples revealed various patterns of chemical zoning in pyroxenes, suggesting diverse thermal histories. We examined the timescales of development of each zoning pattern and identified minerals, grain portions, and components closely approached equilibrium just before xenolith extraction as orthopyroxene and clinopyroxene, the outermost rims, and Ca-Mg-Fe components, respectively. Applying the best pair of geothermobarometers to the chosen analyses, plausible derivation depths of eight samples were obtained. They range from 0.72–1.6 GPa in pressure and from 830–1080 °C in temperature, which defines a high thermal gradient of 10 K/km or 290 K/GPa. There is an intimate correlation between the zoning patterns of pyroxenes and the depth estimates: pyroxenes in the deeper samples have zoning indicating cooling followed by heating just before xenolith extraction, and those of the shallower samples have zoning indicating monotonic cooling.

Depth variations of rock microstructures, grain size of olivine, chemical compositions of minerals, and phase assemblage, including the presence or absence of glass or fluid phase, show that the mantle beneath Ichinomegata consists of two distinct layers. The shallower (28–32 km) layer is granular, less oxidized, amphibole- and plagioclase-bearing, and subsolidus, whereas the deeper (41–55 km) layer is porphyroclastic, amphibole- and plagioclase-free, oxidized, and partially molten. The contrasts between the two layers suggest that the upper layer represents a lithospheric mantle and the lower layer a LAB zone. These layers are similar to those reported from the bottom of subcontinental lithospheric mantle in various aspects, but the LAB beneath Ichinomegata is much shallower (40–60 km) and cooler (~1100 °C). The coincidence of (1) the depth of a rheological transition, marked granular to porphyroclastic textures, and (2) the depth of a phase transition, from subsolidus hydrous peridotite to a hydrous mantle with melt in localized pockets, is the remarkable feature of the LAB beneath Ichinomegata. This suggests that a rheological boundary zone in arc settings is governed by melting of the hydrous mantle and that the underlying asthenosphere is partially molten. The depth-dependent thermal history shown by chemical zoning in pyroxenes and the presence of melt as pockets suggest that the LAB beneath Ichinomegata was in a transient state that was affected by thermal and material transport.

Keywords: Spinel peridotite xenolith, geobarometry, upper mantle structures, lithosphere-asthenosphere boundary