Dynamic processes in lithosphere-asthenosphere boundary zone; rheological structure from Ichinomegata mantle xenoliths

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Mantle xenoliths are fragments of mantle materials extracted by alkali basalts or kimberlites (Nixon, 1987). They have records of rheological structure of the upper mantle (e.g. Ave Lallemant et al., 1980; Lee, 2006) and may provide information on dynamics in lithosphere-asthenosphere boundary zone (LABZ), where conduction and convection carry heat (Sleep, 2005, 2006). Such rheological LABZ has been suggested by garnet peridotites; inflection in a pressure-temperature trend corresponds to change in microstructure from granular to sheared texture (e.g. Boyd, 1973; Agashev et al., 2013). However, lack of geobarometers for spinel peridotite, derivation depths of which are shallower than ~100km, has hampered examination of the shallow LABZ. This study focuses on depth variation and temporal change of rheological features (evolution of rheological structure) in shallower LABZ beneath Ichinomegata.

Ichinomegata located in the back-arc side of NE Japan arc is a latest Pleistocene andesitic-dacitic maar yielding spinel and plagioclase peridotites (Katsui et al., 1979). In our previous study, we succeeded in estimation of derivation depths of the examined 8 spinel peridotites (Sato & Ozawa, 2017, JpGU-AGU joint meeting; Sato & Ozawa, 2016, 2017, AGU fall meeting). We applied geothermobarometers of T_{BKN} and $T_{Ca\text{-}in\text{-}Opx}$ by Brey & Köhler (1990) to Ca-Mg-Fe components of the outermost rims of pyroxenes, and gained accurate thermal structure (0.7-1.6GPa, 28-54km, 832-1084°C) just before xenolith extraction. We reconstructed rheological structure beneath Ichinomegata by combining the derivation depth and microstructure of the xenoliths obtained using EBSD and FE-SEM at The University of Tokyo.

We detected systematic depth variations of rheological features. The lattice preferred orientation of olivine changes from A-type (24-41km) to D-type (41-54km) with depth. The fabric intensity (M- and J-indexes; Mainprice & Silver, 1993; Skemer et al., 2005) increases (M: 0.10-0.16, J: 4.27-4.45) from 24 to 41km and then decreases (M: 0.13-0.03, J: 4.02-2.71) from 44 to 51km. The petrologic features also show a systematic variation. The shallow part (24-41km) represents subsolidus mantle with interstitial fluid and the deep part (44-54km) supersolidus mantle with the presence of silicate melt now frozen as glass.

It is notable that bleb-shaped spinel grains (spinel blebs) in olivine and pyroxenes in contact with pyroxenes containing numerous spinel lamellae (Abe et al., 1995; Fig. 1) are observed exclusively in the deep, high temperature samples (44-51km), although the spinel lamellae are present in the shallow samples. The spinel blebs share elongation direction with spinel lamellae, and their morphologies abruptly change across the interface (Fig. 1). Topotaxy is confirmed between the lamellae host and spinel lamellae and even blebs (Spl {111} // Px (100) and Spl {011} // Px (010)), but there is no such relationship between spinel blebs and their host phases. These features suggest that the spinel blebs formed by grain boundary migration driven by deformation after or during formation of spinel lamellae by exsolution under slow cooling.

The absence of spinel blebs in the shallow lithospheric part (24-41km) suggests that the rheological features represent a memory of old lithosphere, which probably underwent high-temperature deformation related to the Japan Sea opening and later cooling (25-20Ma; Satsukawa and Michibayashi, 2014). The presence of spinel blebs and detection of heating event exclusively in the deep LABZ (44-51km), interpreted as partially molten rheological boundary layer, suggests that rheological features were in-situ structure established recently (24-20ka). It is inferred that the basal zone of lithosphere was heated by an asthenospheric upwelling and thermally and dynamically thinned, forming melt and D-type fabric. This study provides unequivocal evidence for development of rheological LABZ through thermal erosion of lithosphere.

Keywords: lithosphere-asthenosphere boundary zone, upper-mantle, rheological structure, deformation history, xenolith