Olivine-plagioclase assemblage in orogenic peridotites: Proxy for the extent of lithosphere thinning and asthenosphere shallowing

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The lithosphere and asthenosphere boundary zones (LABZ), where the transfer mechanisms of heat, material, and momentum from the Earth's interior to the surface drastically change, played an important role in plate tectonics. Deepening or shallowing of LABZ is intimately related to the transient and dynamic aspects of the plate tectonics, the time and spatial scales of which are important to understand the heat and material transfer across LABZ through the Earth's history. In this regard, orogenic peridotites are excellent research target. They provide direct information with high spatial resolution for a better understanding of the processes taking place in LABZ.

Plagioclase peridotite or olivine-plagioclase assemblage reported from some orogenic peridotites is a record of dynamic LABZ because of the following reasons. The olivine-plagioclase assemblage in fertile systems is in principle not stable even at the depth of the upper most subcontinental lithospheric mantle (SCLM) at steady thermal state because (1) the common crustal thickness in normal non-cratonic SCLM is ~35km, (2) the Moho temperature for the mean steady-state continental geotherm is much lower than 600°C, (3) the upper stability limit of plagioclase (plagioclase to spinel facies transition) becomes shallower with decrease in temperature, and (4) kinetic barrier for subsolidus reactions in the peridotite system becomes enormous at temperatures below 600°C. Oceanic lithospheric mantle could have plagioclase-bearing peridotites just beneath the Moho, but they are records of magmatism took place beneath mid ocean ridges, the most extensive lithosphere thinning on the Earth.

The occurrence of olivine-plagioclase assemblage in some orogenic peridotite bodies, therefore, implies transient and dynamic high-temperature (>800°C) processing at depth shallower than 20km (plagioclase-spinel facies boundary at ~800°C), i.e., high-temperature decompression of LABZ up to the depth closer to the Moho. Adiabatic decompression of high-temperature LABZ leading to decompressional melting with inefficient melt segregation may give rise to plagioclase peridotite. Decompression along moderately high temperature adiabatic path or heating to allow subsolidus reactions leading to transformation of either spinel peridotites or garnet peridotites may give rise to plagioclase peridotite. However, decompression of LABZ associated with efficient cooling does not produce any olivine-plagioclase assemblage. Plagioclase peridotites thus could provide precious information on the dynamics of shallowing LABZ and underlying asthenosphere.

We have examined several orogenic peridotite complexes, Ronda, Pyrenees, Lanzo, and Horoman, to clarify the extent of shallow thermal processing based on olivine-plagioclase assemblage. The key approach of this study is searching olivine-plagioclase assemblage not only in various lithologies but also in microstructures, whose scale and mode of occurrence provide extent and strength of thermal processing in the shallow upper mantle. The wide-spread occurrence of plagioclase peridotites and localized partial melting in Lanzo suggest exhumation along high temperature adiabatic paths from the thermally structured LABZ in the Seiland subfacies; the predominance of plagioclase peridotites and its localized partial melting in Horoman suggest exhumation along variously heated paths from the garnet stability field; the moderate development of plagioclase peridotites without partial melting in Ronda suggest exhumation along variously but weekly heated paths from the spinel-garnet stability field, and the occurrence of minor plagioclase peridotites in Pyrenees suggest exhumation along cold path from the garnet-spinel facies boundaries except for localized thermal anomaly induced by shear heating. The extent of shallower thermal processing decreases, and thus lithosphere thinning becomes less extensive in this order.

Keywords: lithosphere-asthensphere boundary, subcontinental mantle, temperature-pressure history, plagioclase peridotite, orogenic peridotites