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RESEARCH TOPIC FROM JAMS: ORIGIN AND DYNAMIC PROCESSES OF THE LITHOSPHERE-ASTHENOSPHERE BOUNDARY IN SUBDUCTION ZONE SETTINGS

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The lithosphere–asthenosphere boundary (LAB) is located between the rigid lithosphere (the tectonic plate in the framework of plate tectonics) and the ductile asthenosphere, across which the heat and material transport mechanisms change drastically owing to dynamic processes such as conduction, convection, and magma transport. The constant supply of water-rich fluids released from the subducting slab significantly hydrate the LAB in subduction zone settings, affecting its origin and the dynamic processes operating in the LAB. This is because the water in the mantle significantly decreases its viscosity and melting temperature. Previously, our group revealed the petrologic structure across the LAB in subduction zone settings based on careful geothermobarometry of spinel peridotite xenoliths from the Ichinomegata maar on the back-arc side of the Northeast Japan Arc (Sato and Ozawa 2019). Accordingly, the mantle beneath Ichinomegata consists of two distinct layers. The lithospheric mantle (25–40 km) is granular, amphibole-bearing, and subsolidus, whereas the top of the asthenosphere (40–55 km) is porphyroclastic, amphibole-free, and partially molten. Their boundary was interpreted as the petrologic LAB, in which the pressure and temperature conditions coincided with the melting condition of the hydrated mantle. Here, I briefly introduce two papers discussing the origin of the LAB (Sato et al. 2023) and the temporal changes in the thermal state and dynamics of the LAB (Sato and Ozawa 2023).

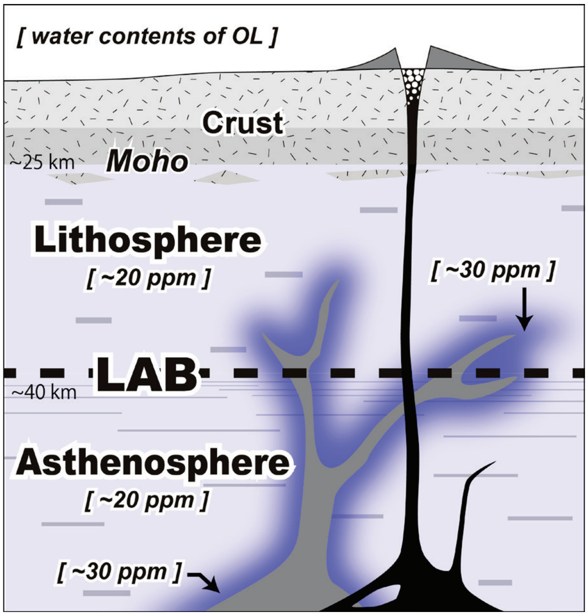

Figure 2 A schematic cross-section for the region beneath Ichinomegata, with the proposed distribution of olivine water content in the mantle

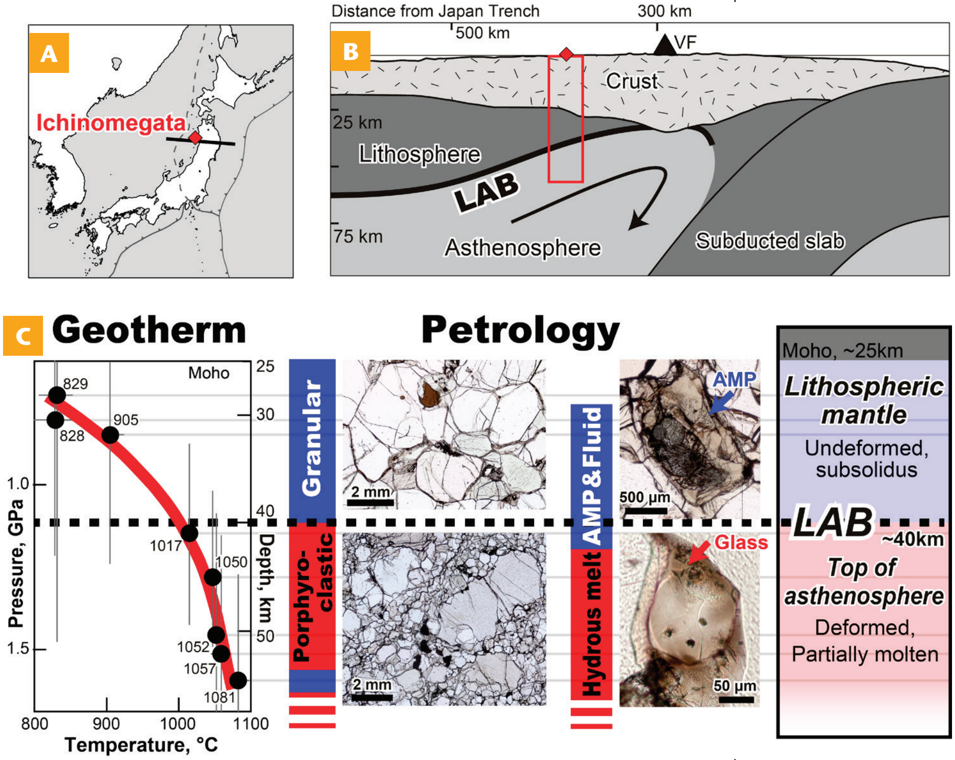

Figure 1 (**A**) Location of Ichinomegata maar in Northeast Japan Arc. (**B**) Schematic cross-section along the black line shown in (B). (**C**) Reconstructed thermal and petrologic structures in the mantle beneath Ichinomegata.

Origin of the LAB

Two models for the origin of the LAB have been proposed, which are the 'partial-melting model' to explain the low seismic velocity of the asthenosphere by the presence of melt (Kushiro et al. 1968), and the 'olivine-water model' to explain the low viscosity of the asthenosphere by assuming the presence of water in olivine (Hirth and Kohlstedt 1996). To examine these models, the depth profile of the water content using Ichinomegata xenoliths was reconstructed. However, obtaining the depth profile remains challenging because of the rapid diffusive loss of hydrogen during magma ascent and eruption. This problem was checked by examining the diffusion profiles of water using FTIR mapping and SIMS line analysis for olivine and orthopyroxene.

Extensive analysis of the water content of 17 Ichinomegata xenoliths revealed that olivine and pyroxene exhibited a variety of zoning patterns, from which the timescale of diffusive loss was estimated. The xenoliths from Ichinomegata underwent only limited diffusive water loss (<1 h duration) because of the low temperature of the andesitic host magma and the rapid quenching in the maar deposit. The water content of the mantle is well preserved in the homogeneous core parts of the large olivine and pyroxene grains. The water content of olivine suggests clear correlations with petrogenetic factors, except for those marking anomalously high values, implying hydrous metasomatism by a water-rich

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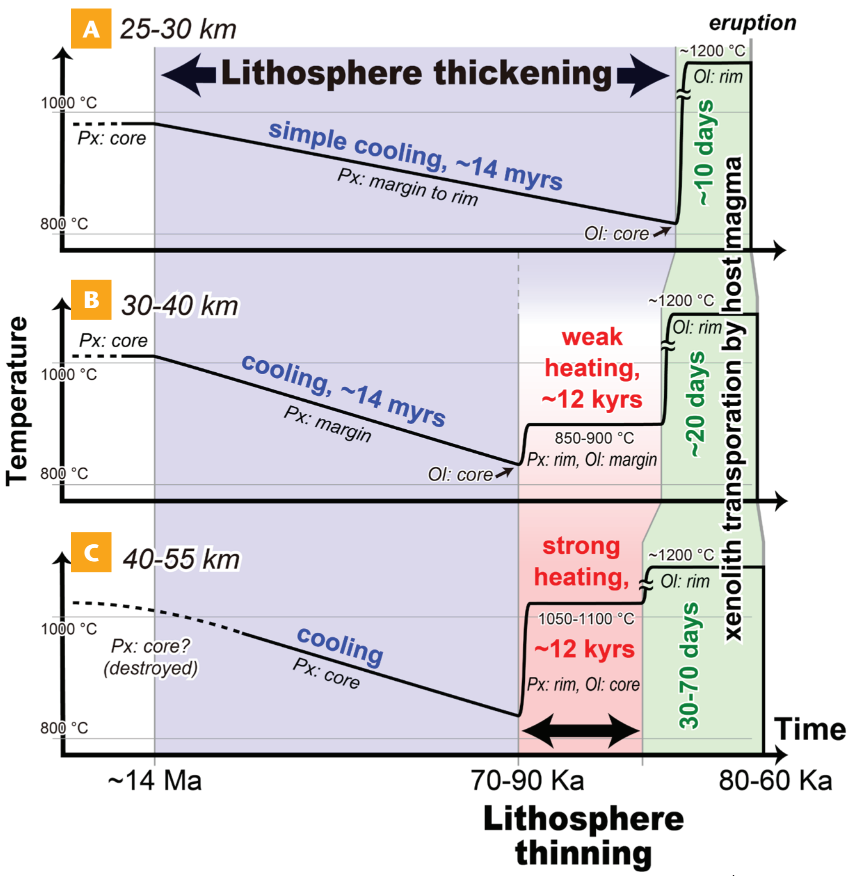

FIGURE 3 Schematic diagrams showing the overall thermal history of the mantle beneath Ichinomegata (thick solid line) at depths ranging from (**A**) 25–30 km, (**B**), 30–40 km, and (**C**) 40–55 km, deduced from zoning profiles in olivine and pyroxenes. Blue, red, and green backgrounds indicate stages of cooling, heating, and magma transport, respectively.

fluid. By combining the estimated water content of the minerals and depth estimation of the xenolith samples, the depth profile of the water content of the mantle was obtained, including the LAB, down to ~55 km. The results showed that olivine, orthopyroxene, and clinopyroxene in the lithospheric mantle (depth range of 28–38 km) contained 21 ± 2, 302 ± 64, and 616 ± 99 wt. ppm H_2O, respectively, which are similar to those at the top of the asthenosphere (depth range of 39–52 km) that contain 20 ± 2, 258 ± 38, and 561 ± 80 wt. ppm H_2O. In the region that experienced local metasomatism, a higher water content was recorded (30 ± 4, 414 ± 48, and 741 ± 43 wt. ppm H_2O). Accordingly, this result verifies that there is no contrast in the water content across the LAB beneath the Ichinomegata maar. Therefore, the 'partial-melting model' for the origin of the LAB is supported rather than the 'olivine-water model' for the western Pacific Plate subduction zone.

Dynamic processes operating in the LAB

The thermal history of the Ichinomegata xenolith was decoded from the chemical heterogeneity of the constituent minerals. The timescale of the dynamic processes operating in the LAB is discussed based on the depth variation of the decoded thermal history. Extensive mineral chemical analyses of olivine and pyroxene in nine Ichinomegata xenoliths from a depth range of 28–55 km revealed a wide variation in chemical zoning patterns. There are two types of CaO zoning of olivine in the vicinity of clinopyroxene; four types of chemical zoning in CaO, Al_2O_3, Cr_2O_3, and TiO_2 contents of orthopyroxene; and four types of chemical zoning in CaO, Al_2O_3, Cr_2O_3, and TiO_2 contents of clinopyroxene. A systematic depth-dependent variation in the chemical zoning was reconstructed based on the derivation depths of the xenoliths. The depth variation of the thermal histories of the Ichinomegata xenoliths was decoded by applying diffusion-controlled reaction modelling to reproduce the zoning patterns. The decoded thermal events in the order of occurrence are (1) ~14 million years of cooling via thermal conduction, causing lithosphere thickening up to ~55 km depth, (2) subsequent ~12,000 years of heating from the underlying asthenosphere, resulting in lithosphere thinning up to depths of ~40 km, and (3) 1–68 days of heating during xenolith transport by the host magma. The duration of the lithosphere thickening was consistently explained by the period of the Japan Sea opening. However, the timescale of the lithosphere thinning is too short to be explained by heat conduction through the ~15-km-thick LAB and requires a more effective heat transport mechanism, such as direct magma injection into the LAB or a significant viscosity reduction of the mantle peridotite aided by the pervasive permeable flow of silicate melt.

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