Seismological and experimental constraints on metastable phase transformations and rheology of the Mariana slab

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Recent seismological studies have observed a 5% low velocity wedge down to the depth of 630km implying a wedge of metastable olivine and depressions of the 660 km discontinuity down to 680-690 km inside the Mariana slab. These observations are critical for understanding the dynamics of slabs around the upper and lower mantle boundary because the depths of phase transformations in cold subducting slabs greatly affect their density and rheological properties. Combining these seismic observations with recent experimental kinetic data and calculated thermal structures of the slab, we discuss on metastable phase transformations, grain-size evolution, and rheology of the Mariana slab.

The temperatures of the central coldest part of the Mariana slab were calculated to be about 870 K and 1100 K at the 630 km and 680-690 km depths, respectively, roughly taking the latent heat release due to the olivine-spinel transformation into accounts. Experimental kinetic studies suggest that the observed depth of the metastable olivine inside the Mariana slab can be explained by growth-controlled olivine-spinel transformation under relatively dry condition such as the water content of about 50 wt.ppm H2O. On the contrary, previous kinetic studies suggest that the nucleation process controls the depth of the post-spinel transformation in the slab. The nucleation may occur when overstepping by the overpressure of 1+-0.5 GPa from the equilibrium boundary. The observed depressions of the 660 km discontinuity inside the Mariana slab should be explained by combination of the overpressure needed for the nucleation and the Clapeyron slope in the post-spinel transformation. The Clapeyron slope of -0.5 MPa/K recently reported in the peridotite composition is consistent with the overpressure of 0.5 GPa assuming the temperature of 1873 K in the surrounding mantle.

Grain-size evolution in central parts of the Mariana slab was calculated based on these metastable phase transformations. Significant grain-size reduction down to less than 1 micron is expected at both 630 km and 680-690 km depths in the Mariana slab. The grain size is kept less than a few microns even considering grain growth after these transformations. Central parts of the Mariana slab deeper than 630 km depths are most likely to plastically deform by the diffusion creep. The viscosity in the diffusion creep regime, which was estimated from grain size and diffusion coefficient of rate-controlling species (Si), is maintained to be lower than the surrounding mantle.

Seismicity and seismic tomography have revealed that the Mariana slab vertically descends, and largely deforms and thickens at the top of the lower mantle. Because depths of metastable transformations have been observed in the Mariana slab, details of density and viscosity structures in the slab can be obtained based on experimental mineral physics data and calculated thermal structures. 2-D Numerical simulations of the subducting slab considering non-equilibrium phase transformations and rheology discussed here will lead to better understanding the dynamic behavior of the Mariana slab across the upper and lower mantle boundary.