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Slab dynamics and water transport in the lower mantle

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Cold and dense subducting slabs characterize Earth's mantle convection. The structure and evolution of the lower mantle must be significantly influenced from the lower mantle slab, as seismic tomographic images indicate that the slabs penetrate into the lower mantle. For example, the morphology of the large low shear velocity provinces (LLSVPs) at the base of the lower mantle (Romanowicz, 2003) and distribution of a fluid mobile component show the relationship with the subduction history (Iwamori and Nakamura, 2012). We perform a numerical study to investigate influences of the lower mantle properties on the mechanical interactions of the subducted slab with the lower mantle structure.

We use a 2-D Cartesian model of the mantle convection system in which plate-like motion is realized without any imposed forces. We incorporate hydrous mineral phase diagrams (Iwamori, 2004, 2007) and water transport into the model. A chemically dense layer and a post-perovskite (PPV) phase change are introduced to examine interaction between the subducted slab and the D" layer. We also consider effects of various depth dependence of viscosity and a thermal expansivity. Furthermore, yield strengths of the slab are varied.

In the cases with the slab yield strength of 200 MPa except when the lowermost mantle viscosity is as small as 10^{22} Pa s, the subducted slabs experience buckling. By introducing the thermal expansivity declining with the depth, the slab buckling occurs even when the slab yield strength is 300 MPa. The reason of this is that the depth dependence of the thermal expansivity decreases the slab negative buoyancy in the deeper mantle. On the other hand, the depth-dependent thermal expansivity promotes the subduction of the lithosphere, because of the larger value of the thermal expansion coefficient than that for the constant case in the shallow mantle. Accordingly, the plate motion at the surface is less affected by the slab behavior in the lower mantle. The wavelength and the slab descent rate depend on the viscosity profile.

The slab viscosity in the lowermost mantle also influences segregation of the slab materials in the CMB region. In the case with small lowermost mantle viscosity, the slab descends as fast as 20 cm/yr. The rapid slab collision with CMB generates a kink of the slab above the CMB. This reduces the viscosity of the slab by means of the yielding. This causes that a hydrated layer in the upper-side of the slab tends to be segregated from the slab. The hydrated materials are distributed to the overriding-plate side of the slab. When the slab sluggishly descends in the CMB region, the hydrated layer is not peeled. Even in this case, introduction of the viscosity reduction due to the PPV phase transition induces the hydrated slab layer segregation.

In summary, the yield strength and the thermal expansivity play a key role to control the slab-lower mantle interaction. We also emphasize that the viscosity of the PPV phase affects water transport in the lowermost mantle.

Keywords: free convection, subducting slab, slab buckling, lower mantle structure, water transport