Mechanical coupling of plate motion with the subducted slab penetrating into the lowermost mantle

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The oceanic plate subduction unique to the Earth is one of the key factors characterizing the mantle convection and plate tectonics. Observed velocity of subducting plates increases monotonically with their tip depth in each section in the upper mantle. On the contrary to this, comparison of numerical modeling incorporating subduction history with seismic tomographic images revealed that slab descent rates do not depend on the slab depth, and are much smaller than that of the surface plate motion. We concentrate our efforts to quantitatively clarify the effects of rheological and thermodynamical properties of the subducted lithosphere and the lower mantle on the plate subduction to examine mechanisms that decouple surface plate motion from subducted slab in the deep lower mantle, using a 2-D mumerical model of an integrated plate-mantle convection system in which the plate-like motion is realized without any forces imposed on the lithosphere. We consider viscosity jump at 660 km discontinuity and an activation volume, which control the background mantle viscosity, a yield strength, which determines the plate strength, and a thermal expansivity, which governs slab buoyancy, as variable parameters. We observed the motion of the surface plate and subducted slab penetrating into the deep lower mantle.

Our results indicate that keeping the adequate mobility of both the surface plate and the subducted slab descending in the lower mantle requires the high lower mantle viscosity and the weak slab strength. The surrounding mantle viscosity is a most important parameter that controls velocities of the surface plate and the lower mantle slab. When the viscosity of the lower mantle is small, the subducting plate reaches the bottom quickly. The yield stress affects the slab buckling near the 660 km phase transition. Small yield stress magnifies slab deformation that plays a role as an absorber of the difference in the motion of the shallow and deep sections of the subducted lithosphere. Generation of the slab buckling induces mutual enhancements between slab deformation and the motion difference in the slab sections. The depth-dependent thermal expansivity further promotes these positive feedbacks between the slab deformation and motion. The plate subduction on the shallow mantle layer is therefore encouraged in spite of the sluggish motion of the slab tip. These mechanisms do not yet quantitatively satisfy compensation for the discrepancy between the surface and slab-tip motion. This means that additional mechanism such as slab viscosity reduction induced by the phase transition is required to explain subducting lithosphere motion.

