Mechanical coupling between the plate and lowermost mantle controlled by the subducted lithosphere strength

*Tomoeki Nakakuki[1], Takeo Kaneko[1], Daisuke Yamazaki[2]

1. Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, 2. Institute for Planetary Materials, Okayama University

Hotspot volcanoes are regarded as an indication of mantle plumes that originate from the deep mantle. Relative migration between the hotspot tracks suggests much slower horizontal motion of the deep mantle layer than that of the surface plates. Viscosity increase in the lower mantle is often attributed to the cause of the slow motion in the deep mantle. Numerical modeling on subducted lithospheres integrated into a mantle convection system showed that the lithosphere penetrating into the lower mantle is not assimilated thermally to the surrounding mantle, so that the subducted lithosphere should work as a substance to transmit viscous stress from the deep mantle. This implies that motion of the deep mantle layer is strongly coupled with that of the surface plate.

We performed numerical simulation of an integrated lithosphere-mantle convection system in which the subducted lithosphere penetrates into the core-mantle boundary region. We investigated effects of yield strength and viscosity reduction due to the grain-size reduction or interconnection of ferro-periclase generated at the 660-km phase transition. The viscosity in the lower mantle was controlled as the value fit to the range inferred from geoid anomalies. In addition to them, depth-dependent thermal expansivity was also considered.

When the viscosity reduction is not incorporated, viscous resistance in the deepest mantle substantially controls the lithosphere motion in the case with the yield strength of 300 MPa. The large yield strength causes that the plate motion averaged in time is maintained to be less than 5 cm/yr, except in the cases with the viscosity of the lowermost mantle less than 10^{22} Pa s. Furthermore, the horizontal motion in the lowermost region is equivalent to half value of that of the surface plate. When the yield strength is set to 200 MPa, the viscosity increase in the lower mantle generates periodic slab folds by sharp bending. This substantially absorbs difference in the motion between the surface and the lowermost mantle. The slab folding generates a lump of the subducted lithosphere, which has large negative buoyancy. Toppling of the slab lump colliding the core-mantle boundary induces episodic acceleration of the slab descent motion. At this time, the plate motion exceeds 10 cm/yr. The slab is regarded as a stress guide between the surface and lowermost mantle in spite of the deformation. The slab interaction with the CMB region would therefore appear to the surface as significant fluctuation of the plate motion. Although the slab folds are generated when the depth-dependent thermal expansivity is introduced with the yield strength of 300 MPa, the decoupling between the surface and lowermost mantle motion is not enough to explain the stationary hotspot.

When viscosity reduction beneath the 660-km phase boundary is introduced, the viscous resistance of the deep mantle is not transmitted to the surface. The viscosity of the uppermost lower mantle controls the speed of the plate motion in the range of 5 to 10 cm/yr, which is consistent with the observation. On the contrary, the speed of the deep mantle flow is reduced to about 1/5 of the surface plate motion. Slab deformation induced by the viscosity reduction is therefore an important mechanism to weaken the coupling between the plate and deep mantle and to regulate subducting plate motion.

Keywords: mantle convection, plate motion, lower mantle, subducted slab, rheology