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Rheology of the stagnant slab inferred from plate-motion velocity

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Studies for the slab stress field (Gurnis and Hager, 1988) and geoid (Hager, 1984) predict viscosity increase by 10 to 100 times at the 660 km disconsituity. The 20 times larger viscosity of the lower mantle than that of the upper mantle is also expected from the postglacial rebound study (Okuno and Nakada, 2001). On the other hand, moving velocity of the subducting plate is determined by the force balance between the slab pull (negative buoyancy of the slab) and the slab resistance (viscous resistance from the ambient mantle). Our previous model predicts that the plate velocity is proportional to the viscosity to the power of (-2/3). This occurs when stagnant slabs are contacting with 660 km discontinuity or slabs are penetrating into the lower mantle. When the viscosity jump at the 660km depth exists, we can expect that the plate motion with the subducted slab interacting with the lower mantle is strongly reduced. Although the slab reaches the depth of 660 km in many subduction zones because of the age from the subduction initiation, the plate velocity reduction is not observed. This would mean that the subducted slab in the mantle transition layer has smaller effective viscosity than that of the surface lithosphere.

We therefore studied influences the viscosity of the stagnant slab in the transition zone and the slab penetrating into the lower mantle. As mechanisms to reduce the viscosity, we consider (1) reducing the maximum viscosity of the transition-zone slab, (2) reducing the yield strength of the transition zone slab, (3) viscosity reduction due to cessation of grain growth at the 660 km phase transition. It is necessary to obtain the plate velocity of 5 to 10 cm/yr, the direct viscosity reduction (1) to 10ˆ22 to 10ˆ21 Pa.s is necessary. The yield stress reduction (2) does not promote the plate motion because the uniform yield stress reduction can only induce uniform yielding in the transition zone slab, but not deformation concentration with large viscosity reduction. The grain-size reduction due to the post spinel phase transition (3) increase the velocity by about 2 times, as coincides with Stokes' law for a dropping less viscous sphere in a more viscous fluid. These means that the slab viscosity must be reduced in the transition zone.

On the other hand, existence of the deep-focus earthquakes implies high stress in the transition zone slab so that the slab viscosity is not so low in whole transition zone slab. More complex mechanisms such as localized yielding generated by damage rheology coupled with weakening of the bending rigidity due to the gerain-size reduction in the slab centre may induce the larger deformation that causes lower averaged effective viscosity of the slab. This mechanism should be studied in the near future.