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The viscosity of Earth′s lower mantle inferred from sinking speed of subducted lithosphere

H. Cizkova (1), A.P. van den Berg (2), W. Spakman (2), and C. Matyska (1)

(1) Charles University, Faculty of Mathematics & Physics, Dept. of Geophysics, Praha, Czech Republic (hana.cizkova@mff.cuni.cz), (2) Utrecht University, Institute of Earth Sciences, Utrecht, The Netherlands

The viscosity of the mantle is indispensable for predicting Earth´s mechanical behavior at scales ranging from deep mantle material flow to local stress accumulation in earthquakes zones. Mantle viscosity is, however, not well determined. For the lower mantle, particularly, only few constraints result from elaborate high-pressure experiments (Karato, 2008) and a variety of viscosity depth profiles result from joint inversion of the dynamic geoid and postglacial rebound data (Forte and Mitrovica, 1996; Kaufmann and Lambeck, 2000; Mitrovica and Forte, 2004). Here we use lower-mantle sinking speed of lithosphere subduction remnants as a unique internal constraint on modeling the viscosity profile. We perform a series of dynamic subduction calculations in the models with complex composite rheology spanning a range of viscosity profiles in the lower mantle. We focus on the models with detached remnants resulting from the slab break-off, that sink to the lower mante. Using these models we select profiles that predict the inferred sinking speed of 12 ± 3 mm/yr (van der Meer et al., 2010). Our modeling shows that sinking speed is very sensitive to lower mantle viscosity. The best-fitting viscosity profiles are associated with subduction models that show accumulation or thickening of the slab, but minor temporal stagnation associated with the phase change at 660 km and a mild increase of viscosity in the top of the lower mantle by a factor of about three. The sinking speed constrains almost uniform viscosity models of the lower mantle to a viscosity value of $1 - 2 \times 10^{22}$ Pas. Higher amplitudes of the lower mantle viscosity (and an associated step-wise increase at the 660 km phase boundary) are responsible for the detached slab being stagnant for several 10s of millions of years at the top of the lower mantle. This yields a corresponding delay in age-depth curves and leads to average deviating from the inferences of van der Meer et al. (2010). A weaker lower mantle, on the other hand, produces slabs that are too fast and reach the base of the mantle in much less than 200 Myr. Viscosity profiles incorporating a viscosity maximum in the deep lower mantle, as proposed in numerous studies, only lead to a good prediction if a significant viscosity reduction is prescribed just above the core-mantle boundary. The low viscosity anomalies at the bottom boundary layer could be explained by the presence of the weak post-perovskite (Ammann et al., 2010) or by the steep temperature gradient in the D” layer. Our prefered model with a viscosity maximum at 2500 km depth has an average lower mantle viscosity of 3×10^{22} Pas.