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On the generation of plate-like surface tectonics in whole-mantle convection models employing composite rheology

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Earth's lithospheric behavior is tied to the properties and dynamics of mantle flow. In particular, upper mantle rheology controls the coupling between the lithosphere and the asthenosphere, and therefore partly dictates Earth's tectonic behavior. It is thus important to gain insight into how Earth's upper mantle deforms in order to understand the evolution of plate tectonics. The presence of seismic anisotropy in the uppermost mantle suggests the existence of mineral lattice-preferred orientation (LPO) caused by the asthenospheric flow. Together with laboratory experiments of mantle rock deformation, this indicates that Earth's uppermost mantle can deform in a non-Newtonian way, through dislocation creep. Although such a deformation mechanism can significantly impact both mantle flow and the surface tectonic behavior, most numerical studies of whole-mantle convection use a viscoplastic rheology involving diffusion creep as the only deformation mechanism in the mantle.

Here, we investigate the effects of using a composite rheology (with both diffusion and dislocation creep) on the surface tectonic behavior in 2D-cartesian whole-mantle convection models that self-consistently generate plate-like tectonics. We vary the proportion of dislocation creep in the mantle by imposing different temperature- and depth-dependent transitional stresses between diffusion and dislocation creep. Using different yield stresses, we investigate how the amount of dislocation creep affects the planform of convection and promotes surface plate-like or stagnant-lid behavior. In particular, we show that for a given yield stress promoting plate-like behavior in diffusion-creep-only models, a progressive increase in the amount of dislocation creep affects the shape and dynamics of slabs, eventually leading to stagnant-lid convection. We discuss the spatio-temporal distribution of dislocation creep in the mantle in light of the observed geometry of slabs and the spatial distribution of seismic anisotropy in Earth's upper-mantle.