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Effects of grain size evolution on mantle dynamics

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The rheology of planetary mantle materials is strongly dependent on temperature, pressure, strain-rate, and grain size. In particular, the rheology of olivine, the most abundant mineral of the Earth's upper mantle, has been extensively studied in the laboratory (e.g., Karato and Wu, 1993; Hirth and Kohlstedt, 2003). Two main mechanisms control olivine's deformation: dislocation and diffusion creep. While the former implies a power-law dependence of the viscosity on the strain-rate that leads to a non-Newtonian behaviour, the latter is sensitively dependent on the grain size. The dynamics of planetary interiors is locally controlled by the deformation mechanism that delivers the lowest viscosity. Models of the dynamics and evolution of planetary mantles should thus be capable to self-consistently distinguish which of the two mechanisms dominates at given conditions of temperature, pressure, strain-rate and grain size. As the grain size can affect the viscosity associated with diffusion creep by several orders of magnitude, it can strongly influence the dominant deformation mechanism. The vast majority of numerical, global-scale models of mantle convection, however, are based on the use of a linear diffusion-creep rheology with constant grain-size. Nevertheless, in recent studies, a new equation has been proposed to properly model the time-dependent evolution of the grain size (Austin and Evens, 2007; Rozel et al., 2010). We implemented this equation in our mantle convection code Gaia (Hüttig et al., 2013). In the framework of simple models of stagnant lid convection, we compared simulations based on the fully time-dependent equation of grain-size evolution with simulations based on its steady-state version. In addition, we tested a number of different parameters in order to identify those that affects the grain size to the first order and, in turn, control the conditions at which mantle deformation is dominated by diffusion or dislocation creep.

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