Effects of composite rheology on mantle dynamics

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The rheology of planetary mantles is a function of temperature, pressure, strain rate and grain size, whose relative importance strongly depends on the underlying deformation mechanism. In particular, the two main mechanisms controlling the deformation of olivine, the most abundant mineral of the Earth's upper mantle, are: diffusion and dislocation creep. Laboratory experiments [1, 2] have shown that dislocation creep exhibits a power low dependence on strain rate while diffusion creep is sensitively dependent on grain size. The dynamics of the mantle is locally controlled by the mechanism that delivers the highest deformation and hence the lowest viscosity. Yet the majority of global-scale convection models of the Earth and terrestrial planets are based on the use of a diffusion creep rheology with constant grain size.

The grain size is one of the least known parameters that control the dynamics of mantle convection. Only a limited number of studies [3, 4] have investigated the effects of mixed rheology, by considering both diffusion and dislocation creep but assuming a constant grain size. More recently, a model to determine the evolution of grain size self-consistently has been developed [5, 6] and has been applied to mantle convection [7]. However, the grain size evolution model depends on a large number of parameters which are currently poorly known.

Here we investigate the differences between pure diffusion creep and composite rheology for stagnant-lid bottom heated systems. Based on a parameter study on constant grain size we will outline under which conditions mantle convection operates via diffusion or dislocation creep and how the rheology affects the heat transport. In conclusion we can show that the heat transport is more efficient when a composite rheology is applied compared to a system in which deformation occurs only by diffusion creep.

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