Geophysical Research Abstracts,
Vol. 11, EGU2009-10366, 2009
EGU General Assembly 2009

A model of grainsize evolution in a convecting mantle

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In the mantle, deformation occurs mostly in diffusion creep or dislocation creep, depending on the temperature, the pressure and the grainsize. The grainsize itself tends to grow in the absence of deformation but reduces by dynamic crystallisation under shear. This leads potentially to a non-linear rheology and a plate-like behaviour of the lithosphere, with strain localization. In this perspective, we have built a new physical formalism, directly usable in a fluid mechanics simulation. In order to apply our model to experimental datas, we have chosen to focus this study on olivine, which is the major constitutive material of the upper mantle. This study is based on a simplified version of a more general statistical theory, which considers the whole grainsize distribution with the requirements of mass and energy conservations and positivity of entropy production. We applied this model to the case of olivine using experimental observations of dynamic recrystallization. We predict two different steady state grain-size equilibrium curves under a constant deviatoric stress. One is stable and situated in the dislocation regime, it corresponds to the usual piezometric relation. The second one, in the diffusion regime is unstable: the grains diverge from it, either they shrink to zero (thus leading to the failure of the material) or grow to the piezometric state. The theory predicts the existence of a yield stress. The temperature dependence of the piezometric curve and the yield stress are shown to have very low activation energies. We present the consequences of this model illustrated by a preliminary set of 2D numerical simulations of mantle convection in which this microscopic model defining the local rheology and the large scale circulation controling the stress regime are coupled. We will show that not only the internal temperature but also the surface temperature affect the rheology by changing the balance between the grain growth rate and the rate of grainsize reduction. The implications of this model for localisation in the mantle and in the lithosphere of the Earth and Venus will be discussed.