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Impact of grain size evolution on the localization of deformation: 3D numerical simulations of mantle convection

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Thermodynamically consistent models of single phase grain size evolution have been proposed in the past years [Austin and Evans (2007), Ricard and Bercovici (2009), Rozel et al. (2011), Rozel (2012)]. In a recently updated version [Bercovici and Ricard (2012), PEPI], the mechanics of two-phase grain aggregates has been formulated following the same physical approach. Several non-linear mechanisms such as dynamic recrystallization or Zener pinning are now available in a single non-equilibrium formulation of grain size distributions evolution. The self-consistent generation of localized plate boundaries is predicted in [Bercovici and Ricard (2012), EPSL] using this model, but it has not been tested in a dynamically consistent way. We propose the first set of three-dimensional numerical simulations of mantle convection incorporating this formalism using the finite volume code StagYY [Tackley (2008)].

First, we detail how the model is numerically implemented. Pressure and velocity fields are solved on a staggered grid using a SIMPLER-like method. Multigrid W-cycles and extra coarse-grid relaxations are employed to enhance the convergence of Stokes and continuity equations. The grain size is stored on a large number of tracers advected through the computational domain, which prevent numerical diffusion and allows a high resolution in the shear zones developing in the lithosphere. We also describe the physical formalism itself and propose the set of free parameters of the model. Normal growth, dynamic recrystallization and phase transitions all have a strong effect on the average grain size. We use a visco-plastic rheology in which the viscous strain rate is obtained by summation of dislocation, diffusion and grain boundary sliding creep.

Second, we describe the 3D grain size distribution in the mantle and in the lithosphere. We characterize in which conditions plate margins can form, mainly investigating grain growth, recrystallization and rheology related parameters. We also observe the evolution of the average grain size in the mantle and compare it to previous studies [Korenaga (2005), Solomatov and Reese (2008)].

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