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Evolutionary models of the Earth with a grain size-dependent rheology

Antoine Rozel, Gregor Golabek, and Paul Tackley
ETH, Geophysics Institute, Department of Earth Sciences, Zurich, Switzerland (antoinerozel@gmail.com)

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)]. Following the same physical approach, the mechanics of two-phase grain aggregates has been formulated [Bercovici and Ricard (2012a)]. 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 (2012b)] using this model, but it has not been tested in a dynamically consistent way.

Our preliminary results have shown that out of equilibrium grain size dynamics leads to localization of deformation below the lithosphere rather than subduction initiation. Yet this result was obtained assuming indealized conditions. We study here, for the first time, the evolution of grain size in the mantle and lithosphere in evolutionary models, starting from a just-frozen magma ocean until the present day situation. Following complexities are considered in these models: melting, phase transitions, compressible convection, and different pressure-temperature-dependent composite rheologies in upper and lower mantles. We use a visco-plastic rheology in which the viscous strain rate is obtained by summation of dislocation and diffusion creep.

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 (a 2D spherical annulus), which prevent numerical diffusion and allows a high resolution. We also describe the physical formalism itself and derive a set of free parameters for the model. The results show that Normal growth, dynamic recrystallization and phase transitions all have a strong effect on the average grain size.

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