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Role of Strain-Dependent Weakening Memory on the Style of Mantle Convection and Plate Boundary Stability

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The creation of narrow plate boundaries and the relation between surface motions and the convecting mantle remain one of the major problems in geosciences. In particular, the cause and consequence of strain localization and weakening remain debated, even though strain memory and tectonic inheritance, i.e. the ability to preserve and reactivate inherited weak zones over geological time, and strain localization appear to be critical features in plate tectonics.

Here, we analyze how a parameterized, strain-dependent weakening rheology affects the time-dependence of plate boundary formation and the reorganization of plates in visco-plastic convection models. The temperature-dependent viscosity is defined by an Arrhenius-type viscosity with a maximum temperature-controlled viscosity difference of 10^5. The weakening is described by a linear reduction of the yield stress (i.e. the strength of the material) with the accumulated viscous deformation which is governed by a source (i.e. the strain rate) and temperature-dependent healing component.

The strain-dependent weakening within our models allows for self-consistent formation and preservation weak zones in the lithosphere. In general, those weak zones are formed as remnants of subduction zones due to strong compressional deformation in the trench region, forming tectonic inheritance in the lithosphere when the slab breaks off. Such tectonic inheritance can be reactivated as intra-plate subduction zones, passive margin subduction, or as spreading centers. Moreover, the average strength of the lithosphere is reduced due to the accumulated damage along the spreading centers. The overall weakening of the lithosphere and along the plate boundaries, as well as the presence of tectonic inheritance, amplifies the longevity of mobile-lid convection and are essential for the cyclicity of plate reorganization. Strain-dependent weakening also enhances strain localization along convergent plate boundaries and increases their stability and longevity.