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Tectonic regime variety and stability in mantle convection with strain-induced weakening

Tobias Rolf[1,2] and Maëlis Arnould[1,3]
[1]Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Oslo, Norway (tobias.rolf@geo.uio.no)
[2]Institute of Geophysics, University of Münster, Münster, Germany
[3]Laboratoire de Géologie de Lyon: Terre, Planètes, Environnement, Université Lyon 1, Ecole Normale Supérieure de Lyon and CNRS, Villeurbanne, France

Earth's tectonic evolution and its link to global mantle dynamics are controlled by the pre-existing structure of the lithosphere which guides how strain localizes and causes the necessary weakness to (re-)activate plate boundaries. Recent models of global-scale mantle convection have self-consistently reproduced Earth-like tectonic regimes, consistent with several aspects of today’s observed tectonics. In many cases these models ignore the memory on pre-existing deformation though. Here, a mantle convection model is advanced to include the associated rheological inheritance via a parameterization of strain-induced plastic (brittle) weakening. Based on more than 180 simulations in a wide 2D cartesian box, the control of strain-induced weakening on the resulting tectonic regime is demonstrated. Strain-induced brittle weakening impacts the stability fields of the different tectonic regimes observed, but to first order it does not generate new tectonic regimes or change the dynamics of a given regime (e.g., its characteristic surface mobility). A time-dependent plate-like regime similar to Earth's becomes more feasible with decreasing critical strain at (and above) which maximum weakening is observed. It is less feasible with increasing temperature-dependence of the healing rate, but remains a possibility at small critical strain. While the critical yield stress that still allows for plate-like behavior is apparently larger with strain-induced weakening considered, the effective shift (incorporating the yield stress reduction due to strain weakening) is relatively small and only about 10% under the tested conditions. Strain accumulation in stable continental lithosphere is generally small because of the necessity of high rheological strength. This holds true even for continental collision events, although at least some strain is accumulated and preserved following such events in the immediate proximity of the colliding continental margins.