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Towards implementing plate tectonics in 3D mantle convection simulations

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One of the great challenges in numerical mantle convection simulations is to achieve models that naturally develop plate tectonic like behaviour at the surface. In this work we are looking to achieve such models by investigating the set of models where a single consistent rheology is used for the whole model. We have started by investigating a viscoelastic rheology, related to the Oldroyd-B model from the field of polymers.

The goal will be to have the parameter that controls the relaxation between elastic and viscous behaviour to depend upon temperature, pressure and strain-rate. With an appropriate choice of this dependence we have, on the near surface, high viscous/elastic regions interfaced with lower, pure viscous, regions of high strain-rate; while it also becomes more viscous at depth in the interior. In this way we hope to obtain plate like behaviour at the surface which naturally progresses to viscous convective behaviour in the interior.

We have started to implement this model in the established mantle 3D finite element spherical mantle convection code TERRA (Baumgardner, 1984). Some parts of the model have been implemented as a force (to be combined with the gravitational body force) on the right hand side.

The work has required us to develop and code in TERRA:
(i) methods to overcome the continuity problem of the stress field stemming from the fact that the velocity field is represented by linear finite elements;
(ii) new operators to handle stress and its gradients;
(iii) methods to analyse plate-like behaviour at the surface
(iv) the necessary functional dependence of viscosity and elastic relaxation time on temperature, strain-rate and pressure

We will present the background to the work, its implementation and results.