Onset of plate tectonics and the effect of continental-like heterogeneities

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One of the first order and still debated questions in Earth sciences is why the Earth exhibits plate tectonics. Understanding the onset and development of plate tectonics in terrestrial planets is a key to the comprehension of the internal dynamics of planets and of their thermal history.

What controls the appearance and the position of weak zones at the surface of a planet? What dictates the shape of the plates, their velocity and motion direction? These questions are still open and can be addressed by numerical modelling of mantle convection with an approach that allows the self-consistent development of rigid plates and of weak zones, marking the boundaries of these plates.

We use the approach described by Moresi and Solomatov (1998) and Tackley (2000): the mantle is modelled by a fluid with a strongly temperature-dependent viscosity, which stiffens its cold upper part into a rigid lid, and this fluid exhibits plastic yielding above a given yield stress σ_y, which generates weak zones and allows to break the upper rigid lid into plates.

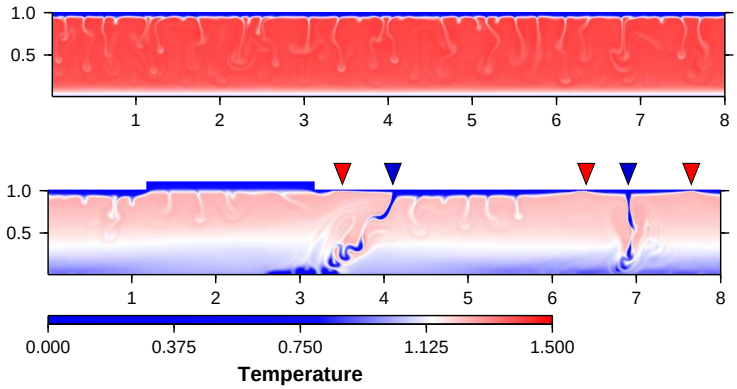

Figure 1: *Fluid heated from below and from within (Rayleigh number Ra=10^7 and internal heating rate H=25 (∼15 nW.m^{-3})) with a strongly temperature-dependent viscosity (contrast $\Delta\eta = 10^5$) and pseudo-plastic yielding, with a yield stress $\sigma_y = 3.10^5$ (∼250 MPa). (Top) Without a continental lid, a stagnant-lid regime is observed. (Bottom) With a continental lid that is internally heated (H=25), a plate-like regime occurs: the red and blue triangles denote respectively the divergent and convergent plate boundaries.*

One shortcoming of this method is that a fairly low yield stress σ_y (generally around five times lower than what is given by laboratory experiments on the strength of rocks) has to be used in those models in order to break the highly viscous stagnant lid. The conditions that allow the development of plate tectonics even with a high imposed yield stress σ_y will be presented.

A factor that helps the onset and the stability of plate tectonics is the presence of lateral heterogeneities at the surface of the modelled mantle. Homogeneous boundary conditions at the surface of the mantle lead to a stagnant lid regime under conditions that yield a plate-like regime when thermally insulating continental-like heterogeneities are added at the surface of the model (see figure 1). The characteristics and possible origins of such heterogeneities will be discussed. The position of weak zones and the organization of tectonic plates in regard to the position of these heterogeneities will also be addressed.

References:

Moresi, L. and Solomatov, V., 1998, "Mantle convection with brittle lithosphere: thoughts on the global tectonic styles of the Earth and Venus", *Geophys. J. Int*, Vol.133, pp.669-682.

Tackley, P., 2000, "Self-consistent generation of tectonic plates in time-dependent, three-dimensional mantle convection simulations: 1, Pseudo-plastic yielding", *Geochem. Geophys. Geosystems*, Vol.1.