Three-dimensional numerical simulation of tectonic plates in thermal convection of a fluid with stress-history dependent rheology

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Rigid tectonic plates separated by sharp plate margins rather steadily move on the Earth. New plate margins develop, only when such tectonic processes as continental collision and vigorous magmatism known as Large Igneous Provinces induce unusually high stress in the lithosphere; once formed, plate margins remain there even after the stress level is reduced to the usual level in the lithosphere. Our earlier two-dimensional numerical studies of thermal convection of a Newtonian temperature-dependent viscosity fluid show that it is crucial to assume a stress-history dependent viscosity to reproduce these features of tectonic plates of the Earth: In our models, the viscosity takes a high value for plate interior, when the stress σ is sufficiently low; the viscosity drops to a low value typical for plate margins, when σ exceeds the rupture strength of plates σ_p; the viscosity remains low even after σ is reduced below σ_p, as long as it remains higher than another threshold σ_m, the coupling strength at plate margins. The viscosity is a two-valued function of stress in the range from σ_m to σ_p. We found that the basic features of tectonic plates arise, only when the typical stress in the lithosphere is within this range. We also found that the stress-history dependent viscosity is crucial for reproducing a thermo-chemical pile like the Large Low Shear Velocity Provinces, and to realize the asthenosphere that moves faster than the overlying plates around ridges. In this presentation, we extend this two-dimensional model of mantle convection to three-dimensional space by the use of the ACuTEMAN code we developed earlier. We calculated convection in a rectangular box with σ_p lower than the typical stress in the lithosphere to start a plate motion, and succeeded in reproducing sharp plate boundaries. We will raise σ_p and explore how the plates thus started behave, when the stress-history dependent viscosity plays a crucial role in their dynamics.

