Three-dimensional mantle convection simulations with a low-viscosity asthenosphere

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We have used CitcomCU to perform three-dimensional, mixed heating mantle convection simulations with a thin low- viscosity channel for a range of aspect ratios to test whether a thin, submerged low-viscosity channel, an analog to the asthenosphere, (1) allows for flow channelization, (2) decreases lateral dissipation and (3) enables long wavelength convection (Höink and Lenardic, GRL 2008).

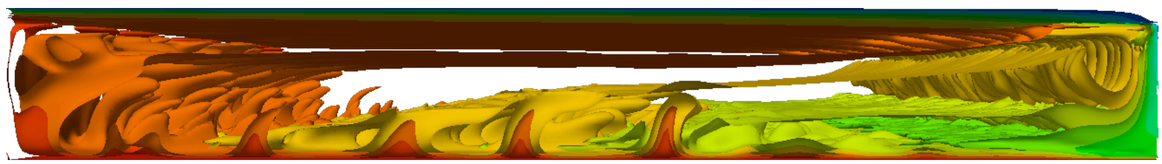

Figure
Temperature isosurfaces. Note the elongated convection cell with a broad upwelling on the left, a thin downwelling on the right. Thermal instabilities arising form the base are unable to disrupt the large scale flow.

For reasonable viscosity contrasts between lithosphere, asthenosphere and bulk mantle we find that very large aspect ratios can develop. Velocity profiles quantify the degree of channelization for various aspect ratios. Internal temperatures are found to decrease with aspect ratio and both surface heat flux and velocity are found to increase with aspect ratio. Our results are consistent with the idea that the asthenosphere channels lateral mantle flow which, in turn, stabilizes long wavelength convection cells and makes long wavelength flow energetically favorable.

The extension of this work to larger wavelengths (we find stable convection cells up to aspect ratio 32) shows that mantle flow in the lithosphere-asthenosphere region is a Poiseuille-Couette flow, suggesting that velocity amplitudes in the asthenosphere can exceed surface velocities (Höink and Lenardic, in prep). Our simulations predict preferentially localized fabric development and seismic anisotropy, and they suggest that a strong pressure driven flow can exist in the asthenosphere independent of mantle plumes. The regime crossover depends on the relative thicknesses of compositional and thermal boundary layers. Additional simulations with temperature- and yield-stress dependent viscosity show consistent behavior and further suggest that the regime crossover is also associated with a change between regimes with relative large versus small energy dissipation at plate margins.

References
Höink T. and A. Lenardic, Three-dimensional mantle convection simulations with a low-viscosity asthenosphere and the relationship between heat flow and the horizontal length scale of convection, Geophys. Res. Lett. 35, L10304, doi:10.1029/2008GL033854, 2008