EPSC Abstracts,
Vol. 4, EPSC2009-782, 2009
European Planetary Science Congress,

Effect of low post-perovskite viscosity on mantle dynamics in super-Earths

P. J. Tackley (1), H. van Heck (1), M. Ammann, (2), J. P. Brodholt (2) and D. P. Dobson (2)

(1) Institute of Geophysics, ETH Zürich, Switzerland, (2) Department of Earth Sciences, University College London, UK. (ptackley@ethz.ch / Fax: +41-44-6331065)

Abstract

The discovery of extra-solar planets with terrestrial composition and sizes up to twice that of Earth, so-called "super-Earths", has prompted interest in their possible mantle dynamics and evolution. In (van Heck and Tackley, this session) and in [1], we demonstrate that super-Earths are equally likely or more likely than an equivalent Earth-sized planet to be undergoing plate tectonics, consistent with [2].

In Earth, viscosity and thermal conductivity increase with depth (pressure) while thermal expansivity decreases, resulting in lower convective vigour and large-scale features in the deep mantle. The pressure at the core-mantle boundary (CMB) of a 2* Earth-sized super-Earth is about 500 GPa, about four times the pressure at Earth's CMB, so if these trends continued to higher pressure then a super-Earth's deep mantle would have a rather low "effective" Rayleigh number and very sluggish convection.

The mantle of such a super-Earth would be made mostly of post-perovskite (PPv), which, however, has different physical properties than perovskite, the major mineral of Earth's lower mantle. Using density functional theory (DFT) as in [3], we compute parameters for diffusion creep in PPv at pressures of up to 505 GPa, and find that its diffusion creep viscosity is likely about 2 orders of magnitude lower than that of perovskite at 130 GPa, and perhaps as much as 3 orders of magnitude lower. Therefore, the viscosity at the base of a super-Earth's mantle is likely to be similar to that at the base of Earth's mantle, with a jump to lower viscosity occurring at the perovskite to PPv transition. Here we use the newly-computed rheological parameters for PPv in simulations of super-Earths of up to twice Earth size. The models assume a compressible anelastic approximation that includes the depth-dependence of material parameters, and is solved using StagYY [4]. Rheological parameters for minerals other than PPv are based on those for perovskite [3][5]. Plastic yielding at low pressures facilitates plate-like lithospheric behaviour, and the models are run at a somewhat lower than Earth-like convective vigour.

Viscosity fields (Figure 1) show the usual viscosity stratification for an Earth-size planet, but for a 50% larger planet the lowest ~half of the mantle has a relatively low viscosity similar to that of the upper mantle, resulting in a rheological sandwich with a high-viscosity perovskite layer sandwiched between relatively low viscosity PPv and upper mantle minerals. For a double sized super-Earth, the viscosity at the CMB becomes comparable to that at the base of Earth's mantle.

Temperature fields (Figure 2) show subducting slabs for all planet sizes, confirming expectations. When the slabs reach the low-viscosity PPv they become narrower, which makes them less visible in these figures. The deep mantle of super-Earths is still actively convecting, although the upwellings are quite broad. In conclusion, low post-perovskite viscosity makes a major difference to mantle dynamics in super-Earths.

References

[1] van Heck, H. and P. J. Tackley, *EOS Trans AGU, 89(53)*, Abstract 11107.

[2] Valencia, D., R. J. O'Connell and D. D. Sasselov, *Astro. J. 670*, L45-L48.

[3] Ammann, M., J. P. Brodholt and D. P. Dobson (2008) *PCM*, doi:10.1007/s00269-008-0265-z

[4] Tackley P. J. (2008) *PEPI 171*, 7-18.

[5] Yamazaki, D and S. Karato (2001) *Am Min 86*, 385-391.

EPSC Abstracts,
Vol. 4, EPSC2009-782, 2009
European Planetary Science Congress,

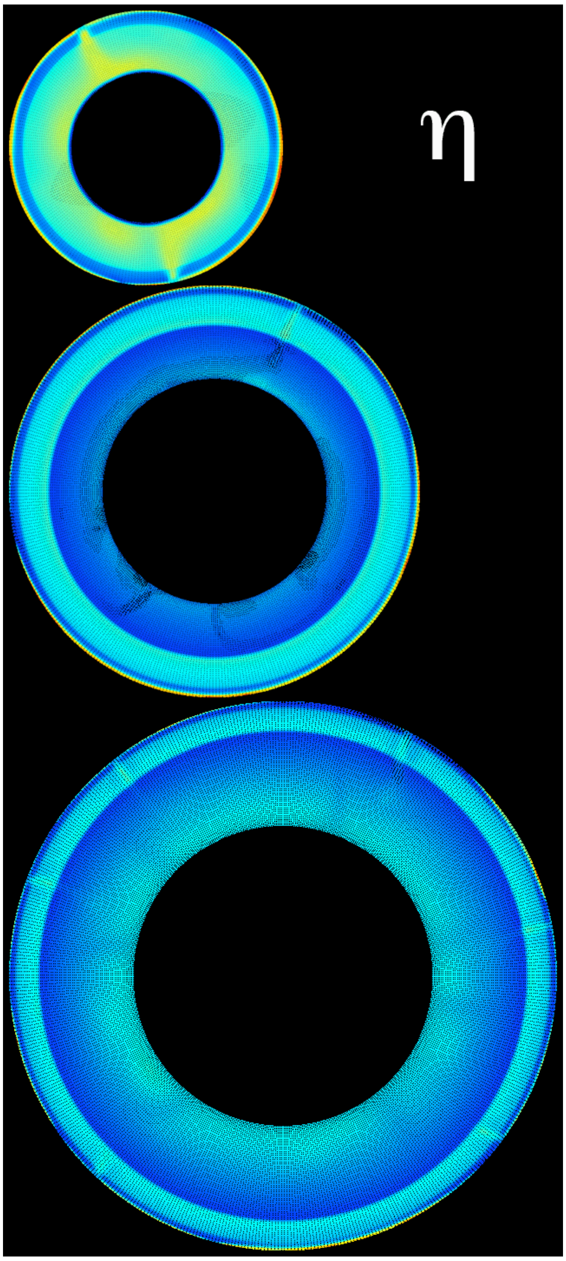

Figure 1. Viscosity fields for planets of 100%, 150% and 200% Earth size.

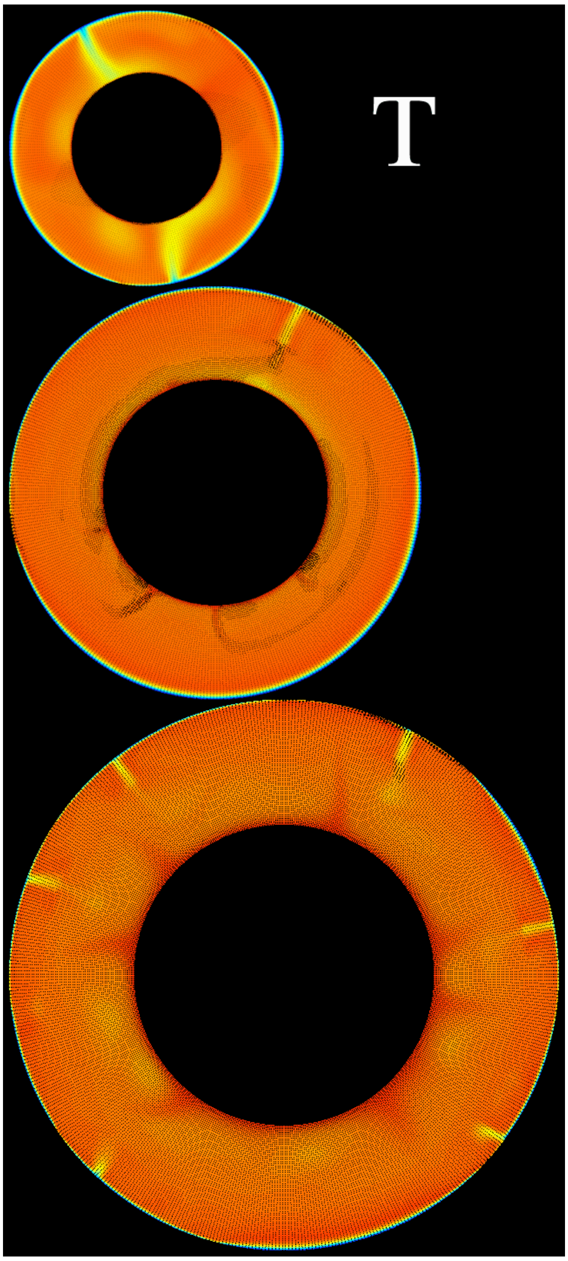

Figure 2. Temperature fields for planets of 100%, 150% and 200% Earth size.