Composition-dependent viscosity in evolutionary models of thermo-chemical mantle convection

J.R.G. van Summeren[1] **A.P. van den Berg**[1] **and R.D. van der Hilst**[2]

[1] *Department of Earth Sciences, Utrecht University, Utrecht, The Netherlands*

[2] *Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA USA*

Several lines of seismological and geochemical evidence hint at the existence of compositional heterogeneity in the lowermost mantle of the Earth (e.g. (Van der Hilst and Karason, 1999), (Saltzer e.a., 2004), (Hofmann, 1997)). One of the existing models that include chemical heterogeneity is a global continuous reservoir in the deep lower mantle and with a surface that develops substantial topography (Kellogg e.a., 1999). Long-term survival occurs when a compositional buoyancy force balances or exceeds the thermal buoyancy force that acts on the deep reservoir. The presence of such a reservoir affects the convection regime of the mantle and, in addition, it thermally insulates the core. Because of the anomalous composition, its physical properties may differ from those of the background mantle. Unfortunately, there are many uncertainties concerning the compostion-dependence of those properties, and concerning the composition of the deep reservoir itself. In this study, the effects of composition-dependent viscosity on the evolution of the mantle and core are explored in a systematic parameter test.

We apply a thermo-chemical mantle convection model in the extended Boussinesq approximation. A finite element method was used to solve the convection equations, where the composition field is described by Lagrangian tracer particles and a Particle-in-Cell representation. The models are of 2-D cylindrical geometry and cover a time window of 4.5 Gyr. Two mineral phase transitions at 410 and 660 km depth were included and a thermal coupling model with the core allows us to study the cooling evolution of the core.

The results show that when viscosity in the deep mantle reservoir is decreased, heat transfer by means of convective motion is increased in the lowermost mantle. As a result, more heat is extracted from the core, leading to higher rates of core cooling. Also, heat inside the deep reservoir is lost relatively easily to the overlying mid-mantle so that its excess temperature is kept relatively low. In this way, the reservoir's positive thermal buoyancy is effectively reduced, leading to a more stable deep mantle reservoir.

References:

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