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Effect of the temperature- and depth-dependent viscosity on mantle convection

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Finite element numerical modeling has been carried out in order to investigate the effect of the depth- and temperature-dependent viscosity on the thermal convection occurring in the Earth's mantle. Calculations were made in a 2D spherical shell domain applying Boussinesq approximation.

It was established by systematic model calculations that the stronger depth-dependence of the viscosity (higher γ) hinders the convection rather in the deeper zone of the mantle that retards the heat from the core and cools the mantle. The less vigorous convection results in slower flow and increases the mobility of the surface (the ratio of the average surface and mantle velocity). Stronger temperature-dependence of the viscosity (higher δ) has qualitatively the opposite effect. Above the core mantle boundary, which is the hottest part of the mantle, the viscosity decreases that facilitates the heat transport from the core. Whereas the cold, more viscous surface retards the heat. It warms up the mantle, decreases its average viscosity and accelerates the creep flow. Due to the cold and more viscous surface layer the mobility reduces. The observed velocity, temperate, heat flux and viscosity parameters show a power law function of δ.

Two additional numerical model calculations were made with more realistic γ and δ parameters scaling the depth- and temperature-dependence of the mantle convection. In model 1 the viscosity increased exponentially 100 times (γ=100) and decreased 7 orders of magnitude ($\delta=10^7$) as the depth and temperature grew from the surface to the core, respectively. Owing to the strong temperature-dependence of the viscosity a rigid lid formed around the mantle that reduced the heat outcome effectively and resulted in a hot mantle. Model 2 had the viscosity scaling factors of γ=10 and $\delta=10^6$, and a 30 times viscosity jump was built in model at the depth of 660 km to reflect the effect of the olivine $\rightarrow$ perovskite + magnesiowustite mineralogical phase transition. Rigid lid did not evolved in model 2 because of the stronger depth-dependence (300) and the weaker temperature-dependence (10^6) of the viscosity. As a consequence, lower temperature, higher viscosity and less vigorous flow system characterized the mantle convection.

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