Evolution of mantle viscosity through geological time and its implications for geochemical mixing in the mantle

SUMIT CHAKRABORTY, CHRISTOPHER BEYER AND RALF DOHMEN[1]

[1]Institut für Geologie, Mineralogie und Geophysik, Ruhr Universität Bochum, Universitätstrasse 150, D-44801 Bochum, Germany

Viscous flow in the mantle is the primary control on geodynamic styles and rates. The exact mechanism of flow (e.g. by dislocation- or diffusion- creep) in different layers remains a matter of debate, and a quantitative connection between rates of migration of atoms / ions (i.e. diffusion) and rates of viscous flow remains to be established. However, the activation energies of diffusion of Si and O in primary silicate minerals in the mantle scale very closely with activation energies for viscous flow where the latter are known. Activation energies for diffusion of Si and O in olivine, wadsleyite, ringwoodite and bridgmanite have now been measured, and for Si, these values lie at ~ 530 kJ/mol (olivine), ~ 400 kJ/mol (wadsleyite), ~ 480 kJ/mol (ringwoodite) and ~ 300 kJ/mol (bridgmanite). Given any present-day viscosity profile and geotherm through the mantle, these data allow the calculation of viscosity profiles at earlier points of time in the history of the Earth when mantle temperatures were higher. The different activation energies result in different amounts of change in viscosity with increasing temperature for different minerals / layers of the mantle. Thus, the contrast in viscosity between different layers of the mantle was smaller in an earlier , hotter Earth compated to the present-day. We have assumed that the activation volumes of diffusion do not differ between the minerals by large enough amounts to offset these results. The change in viscosity contrast between different layers of the mantle has important implications for rates of mantle mixing and the timescales of survival of distinct geochemical reservoirs. For example, if a difference in viscosity of larger than a factor of ten inhibits mixing (e.g. Manga, GRL 23: 403-406, 1996), then it can be shown that the existence of distinct reservoirs and the suppression of mixing would have been much more likely since about 2 Ga. Smaller viscosity contrasts between different layers in an earlier hotter Earth would have promoted more efficient mixing.