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Investigating the effect of rheological and tectonic parameters on the preservation of primordial reservoirs in Earth's lower mantle: a numerical study

Anna Gülcher, Maxim Ballmer, and Paul Tackley
Institute of Geophysics, Department of Earth Sciences, ETH Zürich, Switzerland (anna.guelcher@erdw.ethz.ch)

The composition and structure of Earth's lower mantle control the style of mantle convection and, through it, the evolution of our planet's interior. Constraining this composition and structure, however, remains a scientific challenge and requires putting recent seismic and geochemical discoveries into a coherent geodynamical framework. One question that receives particular attention is whether the lower mantle is heterogeneous in composition, and what such heterogeneity would imply for the evolution of mantle convection and plate tectonics.
Both seismology and geochemistry provide opposing interpretations concerning this topic. Most global tomographic studies show subducted lithosphere and deep-rooted plumes that pervade the whole mantle (van der Hilst et al., 1997; French and Romanowicz, 2015), indicating efficient whole-mantle convection and mixing over timescales shorter than the age of the Earth. On the other hand, more recent seismic studies reveal a sharp seismic impedance contrast around 1000 km depth that points towards regional chemical heterogeneity in the uppermost lower mantle (Jenkins et al., 2017; Waszek et al., 2018). To compliment these latter observations, recent geochemical investigations promote the existence of a primordial reservoir somewhere in the Earth's mantle (e.g. Mundl et al., 2017). A new regime of mantle convection that integrates these discrepancies has recently been presented by Ballmer et al. (2017) using simplified Cartesian numerical models. In this novel convective regime, intrinsically viscous primordial domains (enriched in bridgmanite) can persist in the mid-mantle for longer than the age of the Earth, with whole-mantle circulation being accommodated around them (Ballmer et al., 2017).

In this study, we use state of the art 2D numerical models with a spherical annulus geometry to provide a more rigorous assessment on the convective regime put forward by Ballmer et al. (2017). In particular, we explore the effects of rheological parameters on the style of mantle convection and primordial heterogeneity preservation. These parameters include the reference viscosity profile (e.g. Rayleigh number and viscosity contrast between primordial and ambient mantle material), plate yielding strength and temperature/pressure dependence of the viscosity. Preliminary results show that higher Rayleigh numbers promote whole-mantle convection and efficient mixing of primordial material into the ambient mantle. The plate yielding strength controls the abundance and stiffness of subducting slabs that in turn interact with the primordial domains, and therefore affect their preservation. Our results can be used for a more thorough integration with geophysical observations and are thereby useful for addressing the long-standing debate of the feasibility of primordial heterogeneity in the Earth's mantle.

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