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Strain-weakening rheology in Earth's lower mantle: a multi-scale numerical endeavour

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Rocks in the Earth's interior are not homogeneous but consist of different mineralogical phases with different rheological properties. Deformation of heterogeneous rocks is thus also heterogeneous, and strongly depends on the rheological contrasts and spatial distribution of the mineral phases. In Earth's lower mantle, the main rock constituents are bridgmanite (Br) and smaller amounts of ferropericlase (Fp). Bridgmanite is substantially stronger than ferropericlase [1]. Recent studies propose that lower mantle rheology is highly dependent on the relative mineral abundances and distribution of these two phases [1,2]. It has been suggested that for bridgmanite-depleted compositions, the viscosity decreases with accumulating strain due to the interconnection of the weaker ferropericlase. This implies that deformation may localize in the lower mantle, potentially aiding the formation and preservation of compositionally distinct and "hidden" reservoirs away from these regions of localized deformation [3]. Therefore, understanding the rheological nature of Br-Fp aggregates on a small-scale is crucial for assessing the dynamics of global mantle convection. Here, we address this objective with multi-scale numerical approaches.

Using a numerical-statistical approach, a connection between ferropericlase morphology and effective rheology of Earth's lower mantle has recently been established [4]. Results show that bulk-rock weakening depends on the topology of the weak phase as well on its rheology, but also that significant rheological weakening can already be achieved when ferropericlase does not (yet) form an interconnected weak layer.

In a second suite of models, we implement a macro-scale description of strain-weakening based on the micro-scale solutions found in [4] in a global mantle convection model to test the first-order effect of strain weakening on convection dynamics in the lower mantle. We present 2D numerical models of thermochemical convection in a spherical annulus geometry [5] that include a new implementation of tracking the strain ellipse at each tracer through time. We further allow lower mantle materials to rheologically weaken once a certain strain threshold has been reached. Preliminary results indicate that strain localizes along both up- and downwellings in the lower

mantle and that rheological weakening has a stabilizing effect on these conduits.

This multi-scale approach is essential for addressing lower-mantle rheological behavior and our results form an important step towards addressing the feasibility of isolated, long-lived geochemical reservoirs in Earth's lower mantle.

[1] Yamazaki and Karato (2001), *Am. Mineral.* 86, 385-391. [2] Girard et al. (2016), *Science* 351, 144-147. [3] Ballmer et al. (2017), *Nat. Geosci.* 10, 236-240. [4] Thielmann et al. (2020), *Geochem. Geophys. Geosyst.*, doi:10.1029/2019GC008688. [5] Hernlund and Tackley (2008), *Phys. Earth Planet. Int.* 171, 48-54.