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Dependence of lithospheric slab buoyancy on composition and convergence rate: insights from a thermally-coupled kinematic model

Kittiphon Boonma, Ajay Kumar Ajay Kumar, Daniel Garcia-Castellanos, Ivone Jiménez-Munt, and Manel Fernández

Institute of Earth Science Jaume Almera (CSIC-ICTJA), Barcelona, Spain

The buoyancy of the lithospheric mantle relative to the asthenospheric mantle is the driving force of plate subduction and mantle delamination (the peeling off of the lithospheric mantle from the crust and its detachment and sinking into the asthenospheric mantle). Mantle delamination is a geodynamic mechanism often invoked for the evolution of collision zones, yet there are still open questions about the conditions under which the mechanism operates. The general condition that is thought to lead to subduction or delamination is that the lithosphere must be denser than the underlying asthenosphere so as it sinks downwards, the buoyant asthenosphere makes contact with the crust, replacing the denser lithosphere. The densities adopted by previous studies have been considered to be temperature dependent only.

We adopt, here, a mineral physics viewpoint where the density depends on temperature, pressure, and composition such that the density of the lithospheric mantle can be lower than that of the underlying asthenosphere, posing a serious problem for the initiation of the delamination process. The density and its pressure, temperature dependence, in the lithosphere and asthenosphere are calculated from stable mineral assemblages computed using major oxides composition based on mantle xenoliths/garnet peridotites in the CaO-FeO-MgO-$Al2O_3$-SiO_2 (CFMAS) framework. We present a parametric study on the relationship between slab buoyancy and convergence rate using a simple 2D kinematic numerical model, incorporating thermal advection and diffusion. In the model setup, we consider different types of lithospheric mantle (e.g. Archon, Tecton, Proton, and Oceanic), subducting with varied convergence rate and constant angle, into the asthenosphere. At a certain convergence rate, the lithosphere subducts with a downward velocity that is fast enough to prevail on thermal re-equilibration with the surrounding asthenosphere. This facilitates the lithospheric mantle to become heavier due to pressure effect which dominates over the temperature effect. The subducted lithospheric mantle, therefore, acquires negative buoyancy, such that its density is higher than the asthenosphere, and this could cause a detachment from the crust and sink into the asthenosphere. This is a SUBITOP (674899-SUBITOP-H2020-MSCA-ITN-2015) and MITE (CGL2014-59516) contribution.