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Impact of thermo-chemical pile size in the generation of upwellings: insights from mantle convection models featuring paleo-subduction history

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The Large Low Shear Velocity Provinces (LLSVPs) below Africa and the Pacific may be evidence of compositionally dense and chemically distinct material deep in the Earth's mantle, based on data from geochemistry, mineral physics, and seismology. The paleo-position of mantle upwellings deduced from large igneous provinces has previously been attributed to plume generation zones at the edges of these LLSVPs. However, the geodynamic genesis of the upwellings, as well as the geodynamic nature of LLSVPs, are not well understood. One hypothesis is that subduction can mould LLSVPs to control the location of upwellings. In this study, we implement 3D global numerical models of mantle convection to explore the role of subduction and thermo-chemical piles on the position of upwellings following supercontinent formation.

Using the open-source geodynamic code ASPECT, our models combine a compressible mantle with Earth-like material properties, a strongly temperature dependent viscosity, chemical heterogeneities tracked by compositional fields, and prescribed surface velocities. In a suite of models, we analyse the impact of changing the size of a thermo-chemical layer at the core-mantle boundary on the position of upwellings in mantle convection models featuring 410 million years of paleo-subduction history (Matthews et al., 2016). Our model results of upwelling position are compared with present-day hotspot positions and with previous geodynamic modelling studies. Furthermore, we contrast slow and fast seismic anomalies in our models with recent vote map data of collated seismic studies. In our reference model, we find upwelling positions in the Atlantic, sub-Africa and under the Indian Ocean to compare well with present-day findings. In this hemisphere, we find that subduction may control the position of plumes over LLSVP dynamics, with models featuring no chemical heterogeneities producing a similar fit to present-day observations as models with thermo-chemical convection. In the Pacific, we find our upwelling positions (as well as deep mantle subduction location) to not correlate well with observations. This study discusses potential causes for this discrepancy, focussing on our numerical modelling setup alongside the possible areas of improvement in Pacific subduction history, and ultimately advances the debate on upwelling generation through large-scale global numerical models.