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Constraining LLSVPs initial conditions and heating scenarios from simulations of mantle convection with heterogeneous thermal conductivity

Joshua Guerrero[1], Frédéric Deschamps[1], Wen-Pin Hsieh[1], and Paul Tackley[2]
[1]Institute of Earth Sciences, Academia Sinica, Taipei,Taiwan
[2]Department of Earth Sciences, ETH Zürich, Zürich, Switzerland

New insights from models of thermo-chemical mantle convection featuring heterogeneous thermal conductivity indicate that heat-producing element (HPE) enrichment in large low shear velocity provinces (LLSVPs) significantly impacts the long-term stability of these regions. Because the internal heating rate was more significant in the past, thermal conductivity's influence on thermal buoyancy (and bulk erosion) must have also been more substantial. As a consequence, the initial volume of the LLSVPs may have been significantly larger than their present-day volume. In numerical models, the evolution and stability of LLSVPs are often initiated by considering a dense and uniformly distributed layer on top of the core-mantle boundary. From energy balance calculations, a thin layer of LLSVP material (small mantle volume fraction) supports more HPE enrichment than a thicker layer (larger mantle volume fraction) to maintain the mantle's heat budget. For example, an initial layer thickness of 160km (~3% mantle volume) implies present-day HPE enrichment factors up to ~70 times the ambient mantle heating rate. This should be compared with more conservative factors of 10 to 20 for similar dense layer thicknesses employed in previous studies of thermochemical pile stability. Thus, HPE enrichment may have been significantly underestimated in earlier models of LLSVP evolution. Conversely, and assuming that LLSVPs formed from a much larger reservoir, HPE enrichment may be overestimated based on the present-day LLSVP volume. Our study considers LLSVPs with a primordial geochemical reservoir composition (consistent with an undegassed $^4He/^3He$ signature and HPE enrichment). We examine models of thermo-chemical mantle convection models with time-dependent internal heating rates and HPE enrichment (implied by the initial dense layer thicknesses). In this new context, we re-examine, in particular, the impact of a fully heterogeneous lattice thermal conductivity (derived from conductivity measurements of upper and lower mantle minerals). Furthermore, in light of recent developments with radiative conductivity, we also examine the added effect of a strongly temperature-dependent radiative conductivity component on the stability of LLSVPs. Using LLSVPs' present-day volume and core-mantle boundary coverage as a constraint, we recover potential initial conditions, heating scenarios, and thermal conductivity for an Earth-like model.