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Survival of LLSVPs for Billions of Years in a Vigorously Convecting Mantle: Replenishment and Destruction of Chemical Anomaly

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We study segregation of the subducted oceanic crust (OC) at the core mantle boundary, its ability to accumulate and form large-scale compositional anomaly (such as the LLSVPs), and its susceptibility to get entrained by the hot rising plumes. Based on the results from our high-resolution numerical simulations of 2D thermochemical mantle convection, we propose that the longevity of LLSVPs for up to three billion years, and possibly longer, can be ensured by a balance in the rate of segregation of high-density OC-material to the CMB, and the rate of its entrainment away from the CMB by mantle upwellings.

For a range of parameters tested in this study, a large-scale compositional anomaly forms at the CMB, which is similar in shape and size to the seismically observed LLSVPs - high topography of over 1000 km, steep edges, and occupying a few % ($\sim$ 2%) of the total mantle volume. In our simulations, neutrally buoyant thermochemical piles - those in which the thermally induced negative density anomaly is balanced by the presence of a fraction of compositionally anomalous high density material - best resemble the geometry of LLSVPs. Such neutrally buoyant piles tend to emerge and survive for a long time (over 3Gyr) in simulations with quite different parameters. For moderate compositional density anomaly of oceanic crust, the neutrally buoyant piles form at the CMB and contain $\sim$ 80% of dense OC material. For high compositional density anomaly, a dense layer forms at the base of the mantle, and a neutrally buoyant pile develops on top of it. In the latter case, the dense basal layer and the neutrally buoyant pile on top of it are clearly separated by a jump in the concentration of the compositionally anomalous material. We conclude from our numerical study that for a plausible range of values of density anomaly of OC material in the lower mantle - it is likely that it segregates to the CMB, gets mechanically mixed with the ambient material, and forms neutrally buoyant large scale compositional anomalies similar in shape to the LLSVPs.

To perform this numerical study, we developed an efficient FEM code with dynamically adaptive time and space resolution, and marker-in-cell methodology. This enabled us to model thermochemical mantle convection at realistically high convective vigor, strong thermally induced viscosity variations, and long term evolution of compositional fields. Confidence in our numerical results was gained through thorough benchmarking of the code, together with the resolution studies, all in the light of the characteristic length and time scales of governing processes in our modeled system.