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The Stirring and Accumulation of Oceanic Crust in the Mantle: How it Changes with Time?

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It has been widely hypothesized that the Earth's mantle is compositionally-heterogeneous, containing reservoirs of MORB-source, ancient subducted oceanic crust, and possibly a more primitive component. Seismic observations of the two Large Low Shear Velocity Provinces (LLSVPs) in the lowermost mantle provide convenient, yet still speculative, candidate locations for compositional heterogeneity. Unfortunately, we do not know what the LLSVPs are, and various hypotheses have been put forth for their cause including thermal plume clusters, thermal megaplumes, remains of a primordial layer (i.e. primordial piles), and accumulations of previously subducted oceanic crust. Discovering the cause of LLSVPs promises to provide fundamental understanding toward the nature of global-scale mantle convection. Here, we focus on two of the possibilities: primordial piles and accumulations of subducted oceanic crust. In previous work, it seemed clear that each possibility provided a distinguishably-different morphology: primordial piles are clearly defined entities with sharp edges and tops, whereas accumulations of oceanic crust appear quite messy and have fuzzy, advective boundaries, particularly at their tops. Therefore, it was thought that by performing seismic studies that define the tops of LLSVPs, we could distinguish between these possibilities. Here, we ask the following question: Can piles formed by ancient oceanic crust eventually "clean themselves up" and evolve into structures that more-resemble what we think primordial piles should look like at the present day? We present geodynamics work that demonstrates that this is indeed the case. The driving mechanism is a thinning of oceanic crust through time (as the mantle cools, there is less melt at ridges, and therefore, crust is thinner). We find that in the early, hotter Earth, if crust is on the order of 20-30 km thick, it will accumulate into messy piles at the base of the mantle. As crust thins beyond a critical thinness, it will stop accumulating and be stirred into the background mantle instead. Once crust stops accumulating in the lower mantle, the pre-existing messy piles begin to sharpen into well-defined piles with sharp edges and tops due to the decrease in material advection with the background mantle. This scenario would have significant geochemical implications for the mantle, in which older, thicker crust is more sequestered into compositional reservoirs, whereas younger, thinner crust is preferentially stirred into the background, MORB-source mantle. Furthermore, we find that this process leads to a characteristically-different thermal evolution, in which the upper mantle cools more rapidly during the accumulation phase, and then perhaps heats up again afterwards. Finally, we find that the seismic detection of sharp edges on LLSVPs cannot be used to exclude accumulations of oceanic crust as a possible cause of LLSVPs.