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Subduction of Crust to the CMB and its Role in explaining Mantle Heterogeneity

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Based on extrapolating current oceanic production rates into the past, at least 95% of the mantle has been processed through mid-ocean ridge melting, and therefore the mantle likely consists of a heterogeneous mixture of strips of stretched and folded subducted crust and material that has been depleted by varying amounts of melt extraction. Some fraction of the subducted crust may segregate into a dense layer above the core-mantle boundary, where it has been hypothesised to act as a geochemically-distinct source (of HIMU and perhaps EMI and EMII), as well as explaining various seismological evidences for chemical heterogeneity in the deep mantle. Subducted crust that does not settle above the CMB is stretched and folded by mantle stirring and likely contributes to the geochemical heterogeneity of mid-ocean ridge basalts and ocean-island basalts.

Here we present numerical models of these processes in three-dimensional spherical geometry. These models encompass the entire mantle depth, and include self-consistent generation of oceanic crust by melting. Plate tectonics is generated by plastic yielding of the lithosphere. Density contrasts, phase changes, and seismic velocities are calculated self-consistently from composition by minimization of free energy. With time, an extremely heterogeneous mantle builds up, including an accumulation of subducted crust at the core-mantle boundary. Models in which this segregated crust covers only part of the CMB are most consistent with seismic observations. Post-perovskite is found to play a major role in generating seismic heterogeneity in the deepest mantle. In the rest of the mantle, heterogeneity is observed at all scales, and the spectrum and lengthscale distribution is compared to geochemical and seismological observations, as well as theoretical considerations. Deep subduction of crust and its subsequent evolution is a key process in generating mantle heterogeneity.