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The evolution and distribution of recycled oceanic crust in the Earth's mantle: insights from global thermochemical convection models

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A better understanding of the compositional structure of the Earth's mantle is needed to place the geochemical record of surface rocks into the context of Earth accretion and evolution. Cosmochemical constraints imply that lower-mantle rocks may be enriched in silicon relative to upper-mantle pyrolite, whereas geophysical observations tend to support whole-mantle convection and mixing. To resolve this discrepancy, it has been suggested that mid-ocean ridge basalt (MORB) of recycled oceanic crust segregates from harzburgite to be accumulated in the mantle transition zone (MTZ) and/or the lower mantle. However, the key parameters that control MORB segregation and accumulation remain poorly constrained. Here, we use global-scale 2D thermochemical convection models to investigate the influence of mantle-viscosity profile, plate tectonics and bulk composition on the evolution and distribution of chemical heterogeneity. In particular, we focus on the accumulation of subducted MORB/harzburgite in/beneath the MTZ. Our models robustly predict that, for all cases with Earth-like tectonics, a MORB-enriched reservoir is formed in the MTZ, and a corresponding harzburgite-enriched reservoir is formed just beneath the MTZ. This result is independent of the mantle viscosity profile, and explained by a balance between delivery and removal of MORB/harzburgite through deep-rooted plumes and subducted slabs. In turn, the amount of MORB accumulated above the core mantle boundary (CMB) strongly depends on the mantle-viscosity profile: lower-mantle viscosity directly affects the efficiency of MORB segregation (and entrainment) near the CMB; upper-mantle viscosity indirectly affects entrainment through its control on the thickness of subducted slabs. Our models further show that the enhancement of MORB and harzburgite in and beneath the MTZ, respectively, are laterally variable, ranging from 30% to 50% basalt, and 40% to 80% harzburgite enrichment relative to pyrolite. These predictions can be potentially tested using seismic observations. Finally, the composition of the bulk silicate Earth may be shifted relative to that of upper-mantle pyrolite if indeed significant reservoirs of MORB exist in the MTZ and lower mantle. Our results suggest that the segregation of MORB from harzburgite can act to filter mantle heterogeneity in order to sustain a layered distribution of mantle heterogeneity, even in the presence of whole-mantle convection. These processes may indeed play an important role in regulating heat and material fluxes through the mantle.