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The interplay between recycled and primordial heterogeneities: predicting Earth's mantle dynamics via numerical modeling

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According to geochemical and geophysical observations, Earth's lower mantle appears to be strikingly heterogeneous in composition. An accurate interpretation of these findings is critical to constrain Earth's bulk composition and long-term evolution. To this end, two main models have gained traction, each reflecting a different style of chemical heterogeneity preservation: the 'marble cake' and 'plum pudding' mantle. In the former, heterogeneity is preserved in the form of narrow streaks of recycled oceanic lithosphere, stretched and stirred throughout the mantle by convection. In the latter, domains of intrinsically strong, primordial material (enriched in the lower-mantle mineral bridgmanite) may resist convective entrainment and survive as coherent blobs in the mid mantle. Microscopic scale processes certainly affect macroscopic properties of mantle materials and thus reverberate on large-scale mantle dynamics. A cross-disciplinary effort is therefore needed to constrain present-day Earth structure, yet countless variables remain to be explored. Among previous geodynamic studies, for instance, only few have attempted to address how the viscosity and density of recycled and primordial materials affect their mutual mixing and interaction in the mantle.

Here, we apply the finite-volume code **STAGYY** to model thermochemical convection of the mantle in a 2D spherical-annulus geometry. All models are initialized with a lower, primordial layer and an upper, pyrolitic layer (i.e., a mechanical mixture of basalt and harzburgite), as is motivated by magma-ocean solidification studies. We explore the effects of material properties on the style of mantle convection and heterogeneity preservation. These parameters include (i) the intrinsic strength of basalt (viscosity), (ii) the intrinsic density of basalt, and (iii) the intrinsic strength of the primordial material.

Our preliminary models predict a range of different mantle mixing styles. A 'marble cake'-like regime is observed for low-viscosity primordial material (~30 times weaker than the ambient mantle), with recycled oceanic lithosphere preserved as streaks and thermochemical piles accumulating near the core-mantle boundary. Conversely, 'plum pudding' primordial blobs are also preserved when the primordial material is relatively strong, in addition to the 'marble cake' heterogeneities mentioned above. Most notably, however, the rheology and the density anomaly of basalt affect the appearance of both recycled and primordial heterogeneities. In particular, they

control the stability, size and geometry of thermochemical piles, the enhancement of basaltic streaks in the mantle transition zone, and they influence the style of primordial material preservation. These results indicate the important control that the physical properties of mantle constituents exert on the style of mantle convection and mixing over geologic time. Our numerical models offer fresh insights into these processes and may advance our understanding of the composition and structure of Earth's lower mantle.