EGU21-7545, updated on 02 Dec 2021
https://doi.org/10.5194/egusphere-egu21-7545
EGU General Assembly 2021


# Coupled dynamics of primordial and recycled heterogeneity in Earth's lower mantle, and their present-day seismic signatures

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The nature of compositional heterogeneity in Earth's lower mantle is a long-standing puzzle that can inform about the thermochemical evolution and dynamics of our planet. On relatively small scales (<1km), streaks of recycled oceanic crust (ROC) and lithosphere are distributed and stirred throughout the mantle, creating a "marble cake" mantle. On larger scales (10s-100s of km), compositional heterogeneity may be preserved by delayed mixing of this marble cake with either intrinsically-dense or -strong materials of e.g. primordial origin. Intrinsically-dense materials may accumulate as piles at the core-mantle boundary, while intrinsically viscous (e.g., enhanced in the strong mineral $MgSiO_3$ bridgmanite) may survive as blobs in the mid-mantle for large timescales (i.e., as plums in the mantle "plum pudding"). So far, only few, if any, studies have quantified mantle dynamics in the presence of different types of heterogeneity with distinct physical properties.

Here, we use 2D numerical models of global-scale mantle convection to investigate the coupled evolution and mixing of (intrinsically-dense) recycled and (intrinsically-strong) primordial material. We explore the effects of ancient compositional layering of the mantle, as motivated by magma-ocean solidification studies, and the physical parameters of the primordial material. Over a wide parameter range, primordial and recycled heterogeneity is predicted to coexist with each other. Primordial material usually survives as mid-to-large scale blobs in the mid-mantle, and this preservation is largely independent on the initial primordial-material volume. In turn, recycled oceanic crust (ROC) persists as piles at the base of the mantle and as small streaks everywhere else. The robust coexistence between recycled and primordial materials in the models indicate that the modern mantle may be in a hybrid state between the "marble cake" and "plum pudding" styles.

Finally, we put our model predictions in context with geochemical studies on early Earth dynamics as well as seismic discoveries of present-day lower-mantle heterogeneity. For the latter, we calculate synthetic seismic velocities from output model fields, and compare these synthetics to tomography models, taking into account the limited resolution of seismic tomography. Because of the competing effects of compositional and thermal anomalies on S-wave velocities, it is difficult to identify mid-mantle bridgmanitic domains in seismic tomography images. This result suggests that, if present, bridgmanitic domains in the mid-mantle may be "hidden" from seismic

tomographic studies, and other approaches are needed to establish the presence/absence of these domains in the present-day deep Earth.