1. Introduction
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) segregates from harzburgite to be accumulated in the mantle transition zone (MTZ) and/or the lower mantle (see Fig. 1). However, the key parameters that control MORB segregation and accumulation remain poorly constrained.

We use global-scale 2D thermochemical convection models to investigate the influence of mantle heterogeneity, 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 the lower mantle. We explore the global-scale thermochemical mantle-convection models to investigate the influence of mantle parameters that control MORB segregation and accumulation.

2. Methods
(1) Equations
The global-scale thermochemical mantle-convection models are performed using StagYY (Tackley, 2008), which solves the conservation equations of mass, momentum, energy, and bulk chemistry for an anelastic, compressible fluid with infinite Prandtl number.

(2) Rheology
A strongly temperature and pressure-dependent rheology given by the Arrhenius-type formula

\[
\sigma = \mu \left(\frac{T}{T_0}\right)^n \exp\left(-\frac{\gamma}{R T}\right)
\]

In order to obtain plate-like behavior, plastic yielding is included using a Drucker-Prager yield criterion with the pressure-dependent yield stress \(\sigma\):

\[
\sigma = \mu I + \mu \epsilon
\]

where \(\mu\) is friction coefficient and \(\epsilon\) is cohesion coefficient.

(3) Composition, phase changes, and melting
Minerals: Olivine and Pyroxene-garnet, which undergo different solid–solid phase transitions.

Composition: 100% Pyrolyte = 20% Basalt + 80% Harzburgite, Basalt = 100% Pyroxene-garnet, Harzburgite = 25% Pyroxene-garnet + 75% Olivine.

(4) Partial melting:
It generates basaltic oceanic crust and a complementary depleted residue.

(5) Core cooling:
The core cools as heat is extracted by the mantle according to a parameterized heat balance on Buffet (2002).

3. Reference model

4. Effects of mantle viscosity

5. Effects of plate-tectonic style and initial mantle composition

6. Distribution of chemical heterogeneity and seismic observations

7. Conclusions
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, which are independent of a large range of viscosity structures.

- The enhancement of MORB and harzburgite in and beneath the MTZ, respectively, are laterally variable, ranging from 30% to 50% basalt fraction, and 40% to 80% harzburgite enrichment relative to pyrolite, which can potentially be tested using seismic observations.

- The composition of bulk-silicate Earth may be shifted relative to the upper-mantle pyrolite if indeed significant reservoirs of MORB exist in the MTZ and over mantle.