Persistence of Strong Silica-Enriched Domains in the Earth's Lower Mantle

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The composition of the Earth's lower mantle is poorly constrained. Among the major elements, the lower-mantle Mg/Si ratio remains controversial, ranging from upper-mantle “pyrolite” composition (Mg/Si 1.2~1.3) to a “perovskititic” composition similar to primitive chondrites and the Sun's photosphere (Mg/Si 0.9~1.1). Geophysical evidence for deep subduction of lithospheric slabs into the lower mantle implies that whole-mantle convection and mixing may have homogenized the entire mantle. However, previous models did not consider the effects of variable Mg/Si upon the viscosity of lower-mantle rocks. Here we use geodynamical models to show that rocks with Mg/Si smaller than pyrolite can avoid efficient mixing throughout Earth's history owing to an intrinsically high viscosity in the lower mantle. In the lower mantle, rocks with relatively low Mg/Si are mostly composed of the strong mineral bridgmanite. We find a new style of whole-mantle convection that consists of viscous cores of “bridgmanite-enriched ancient mantle structures” (BEAMS) in the lower mantle (at 1000~2200 km depth), separated by conduits of relatively weak pyrolitic rocks that circulate between the shallow and deep mantle. The resultant pattern of convection is stable over time-scales longer than the age of the Earth, and sustains significant differences in Mg/Si between the lower and upper mantles. The BEAMS model provides a physical mechanism to explain the hypothesized long-term stability of deep-mantle convection patterns and the geographical fixity of upwelling centers. It can also account for the deflection of upwelling plumes in the uppermost lower mantle, since mantle “wind” is predicted to circulate around BEAMS. Analogously, the BEAMS model with large-scale lateral heterogeneity in the lower mantle can readily explain why some (but not all) slabs stagnate at ~1000 km depth. The presence of BEAMS in the lower mantle can further account for the inferred “viscosity hill” in the mid mantle, as well as differences in the long-wavelength seismic structure between the shallow and deep mantle. Possibly, organization of mantle wind around BEAMS may even contribute to anomalous mountain-building events due to heterogeneous coupling between the lithosphere and mesosphere. Finally, BEAMS may help to balance the Earth's silicon budget, and could host “primordial” noble-gas and/or $^{182}W/^{184}W$ reservoirs over billions of years despite persistent whole-mantle convection.

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