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The dynamic connection between small and large-scale mantle heterogeneity

Daniel Frost (1), Sebastian Rost (2), Edward Garmero (3), Mingming Li (4), and Barbara Romanowicz (1)

(1) Berkeley Seismological Laboratory, UC Berkeley, Berkeley, United States (dafrost@berkeley.edu), (2) School of Earth and Environment, University of Leeds, Leeds, United Kingdom, (3) School of Earth and Space Exploration, Arizona State University, Tempe, United States, (4) Department of Physics, University of Colorado Boulder, Boulder, United States

Seismological study reveals a heterogeneous mantle with lateral variations in seismic wavespeed, reflections from anomalous interfaces, and scattering from discrete heterogeneities. These complexities span length scales from a few to thousands of kilometres. On larger length scales seismic tomography images oceanic slabs subducting into the deep Earth, in the process introducing compositionally distinct oceanic crust to the bulk mantle. In the deep Earth, slab-related flow interacts with the Large Low Velocity Provinces (LLVPs) which display reduced seismic velocities with sharp contrasts to the ambient mantle and a spatial association with chemically anomalous igneous terrains on the Earth's surface, properties that have led them to being interpreted as chemically distinct from the surrounding mantle. On smaller length scales, the high-frequency seismic wavefield shows evidence of scattering from small-scale heterogeneities throughout the mantle, especially in the upper and lower boundary layers. Scattering heterogeneities are modelled to have sharp velocity and density contrasts, properties that, along with sizes on the order of kilometres, are often interpreted as chemically distinct. These mantle structures, their spatial distribution, and morphology likely result from incomplete and ongoing mixing of different compositions and rheologies driven by subduction and upwelling.

In this study we investigate small-scale heterogeneity. We analyse scattering related to the core waves PKPPKP (PKP.PKP) and PKKP (PK.KP), where the "." indicates the location of scattering on the ray path, to resolve small-scale heterogeneity at various depths distributed throughout the mantle. Using a collection of over 1000 earthquakes recorded at 13 small-to-medium aperture seismic arrays, we are able to investigate about 60% of the volume of the mantle for scattering heterogeneities and precisely resolve the scattering location within the Earth in latitude, longitude, and depth. Analysis of the frequency of scattered energy suggests that heterogeneities in the lower mantle are of a range of sizes, but dominantly 4-7 km. More abundant scattering is observed in the uppermost and lowermost mantle, a pattern that mirrors the amplitude of large-scale seismic structure. In the lower mantle, abundance of scattering heterogeneity correlates with the edges of the LLVPs. Higher into the mantle heterogeneities remain associated with LLVPs and also show an affinity for hotspots that rise from the CMB to the shallow Earth. The observed size and distribution of scattering heterogeneities in the lower mantle relative to the LLVPs matches the result of mantle dynamics simulations showing a relationship between the distribution of oceanic crust and location of dense thermo-chemical piles. In the upper mantle, scattering heterogeneity shows no statistically significant correlation with either high or low seismic velocities. We investigate the properties of the causative heterogeneities to better understand their origin. The observed spatial patterns suggest a connection between large- and small-scale mantle structures, and the dynamic processes that govern them, thus the distribution of small-scale heterogeneities may trace prevailing patterns in mantle convection.