Improving constraints on multi-scale heterogeneity in the upper mantle

*Nicholas J Mancinelli[1], Zhitu Ma[1], Colleen Dalton[1], Peter M Shearer[2]

1. Brown University, 2. UC, San Diego

Globally-averaged amplitudes of scattered coda waves suggest strong and pervasive heterogeneity throughout the uppermost mantle at lateral scale-lengths ranging from a few to thousands of km. The precise depth extent and root-mean-square velocity perturbation of this heterogeneous zone is poorly constrained owing to the linear tradeoff between these two quantities. Nonetheless, evidence from PKP precursors implies that small- and intermediate-scale heterogeneity throughout the lowermost mantle is, on average, at least a factor-of-ten weaker than that in the uppermost mantle.

Here we explore the possibility that the mantle is a self-similar mixture of basalt and harzburgite, in which case the dichotomy in heterogeneity strength between the uppermost and lowermost mantle may be due to the post-garnet phase transition at the base of the mantle transition zone, as the velocity contrast between basalt and harzburgite is thought to drop from about 10% to less than 1% across this boundary. To improve our understanding of the strength and scale of mid-mantle heterogeneity, we undertake a series of analyses including (1) characterization and modeling of coda-wave amplitude variation with event depth; (2) comparison with surface-wave phase-velocity maps to tighten constraints on uppermost mantle heterogeneity; and (3) determination of what fraction of root-mean-square heterogeneity comes from well-understood long-wavelength structure such as the continent--ocean function and the thermally controlled mid-ocean ridge system.

Keywords: mantle heterogeneity, scattering

Toward a comprehensive understanding of transition zone discontinuities: Inferences on the thermochemical state of the transition zone near a stagnant slab region beneath China

*Teh-Ru Alex Song[1], Xuzhang Shen[2], Lars Stixrude[1], Carolina Lithgow-Bertelloni[1]

1. Seismo Lab, Department of Earth Sciences, University College London, UK, 2. Lanzhou Institute of Seismology, China Earthquake Administration, China

Plate tectonics and subduction operating over much of the Earth’s history can induce mantle mixing, chemical heterogeneities and recycle volatiles into the mantle. Some slabs are penetrating into the deep lower mantle, but others are stagnated near the transition zone (TZ). Presumably, the thermochemical state of the TZ is a consequence of delicate balance and feedback between the short-term and long-term mixing.

TZ seismic discontinuities hold the key resolving the mystery of mass and heat transport in the Earth’s mantle as well as the composition of the Earth’s interior. But deciphering discontinuity properties are not trivial. Data were typically limited to either mantle triplications, converted waves (P-to-S or S-to-P) or mantle reflections (e.g. SS precursors, ScS reverberations). These observations place constraints on the velocity gradient near the discontinuity as well as discontinuity reflectivity, but hardly offer independent information on the density jump or/and density gradient. In few cases where multiple datasets are jointly analyzed to resolve the density jump, the region of sensitivity (or the fresnel zone) of different dataset does not necessarily coincide. Finally, the use of short period (~1 Hz) data (e.g., P’P’ precursors) or long period (~> 0.1 Hz) data (e.g., SS precursors) does not allow us to simultaneously address the transition width and the gradient near the discontinuity.

We advocate a simple and effective strategy. Specifically, we involve broadband direct converted waves (e.g., P410s, P660s) and the topside reflections (the multiples, e.g., PpP410s, PpP660s) in the context of P-wave receiver function technique. Such a tactic not only minimizes tradeoffs between velocity and density jumps, but also allows self-consistent estimates of the shear velocity jump, the density jump, the transition width and the velocity/density gradient near the boundary. We will detail our first attempt near the region of stagnant slab beneath China. These new observations, along with the thermodynamic framework, HeFESTo, allow us to test and validate hypotheses including the state of mantle mixing and equilibrium, compositional heterogeneities and the degree of hydration in the TZ.

Keywords: transition zone, receiver function, mantle mixing

Seismic Structure of the Mantle Discontinuities beneath Japan Sea and Adjacent Regions

*Juan Li[1,2], Xin Wang[3], Guangrui Guo[1,2]

1. key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, China, 2. University of the Chinese Academy of Sciences, China, 3. Earth Observatory of Singapore, Nanyang Technological University, Singapore

Seismic structure of the upper mantle discontinuities is important for understanding the thermal structure, composition of the mantle, and scales of mantle circulation as well. Northwest Pacific region is one of the ideal locations to study the interaction between a subducting slab and the upper mantle discontinuities. Seismic tomography images show that beneath the Japan Sea, the subducting slab has entered the depth of 400 km and has been trapped as a stagnant slab in the MTZ. Due to the sparse distribution of seismic stations in the sea, investigation of deep mantle structure beneath the broad sea regions is very limited. In this study, we applied the long-period multiple-ScS reverberations analysis to waveforms recorded by F-net. We took advantage of the dense distribution of stations and spatial clusters of intermediate and deep earthquakes occurred beneath Okhotsk Sea, Russia and Northeast China, and conducted a common-reflection-point (CRP) stacking to the data, that allows us to map the topography of the 410-km and 660-km discontinuities beneath Japan Sea. A series of systematic synthetic experiments have been conducted to test the validity and effectiveness of the ScS reverberation method and its resolution. Detailed topography variation features of the upper mantle discontinuities are revealed beneath the Japan Sea. The associated thermal structure and underlying geodynamic implications are discussed. Our results are not only consistent for the major features of the 410 and 660 beneath the Japan islands with previous short-period seismic wave studies, but also give a more comprehensive and complete image of the topography of the upper mantle discontinuities beneath a much broader sea region.

Keywords: Mantle Transition Zone, Mantle Discontinuities, Multiple-ScS Reverberations, Northwest Pacific Subduction region, Japan Sea

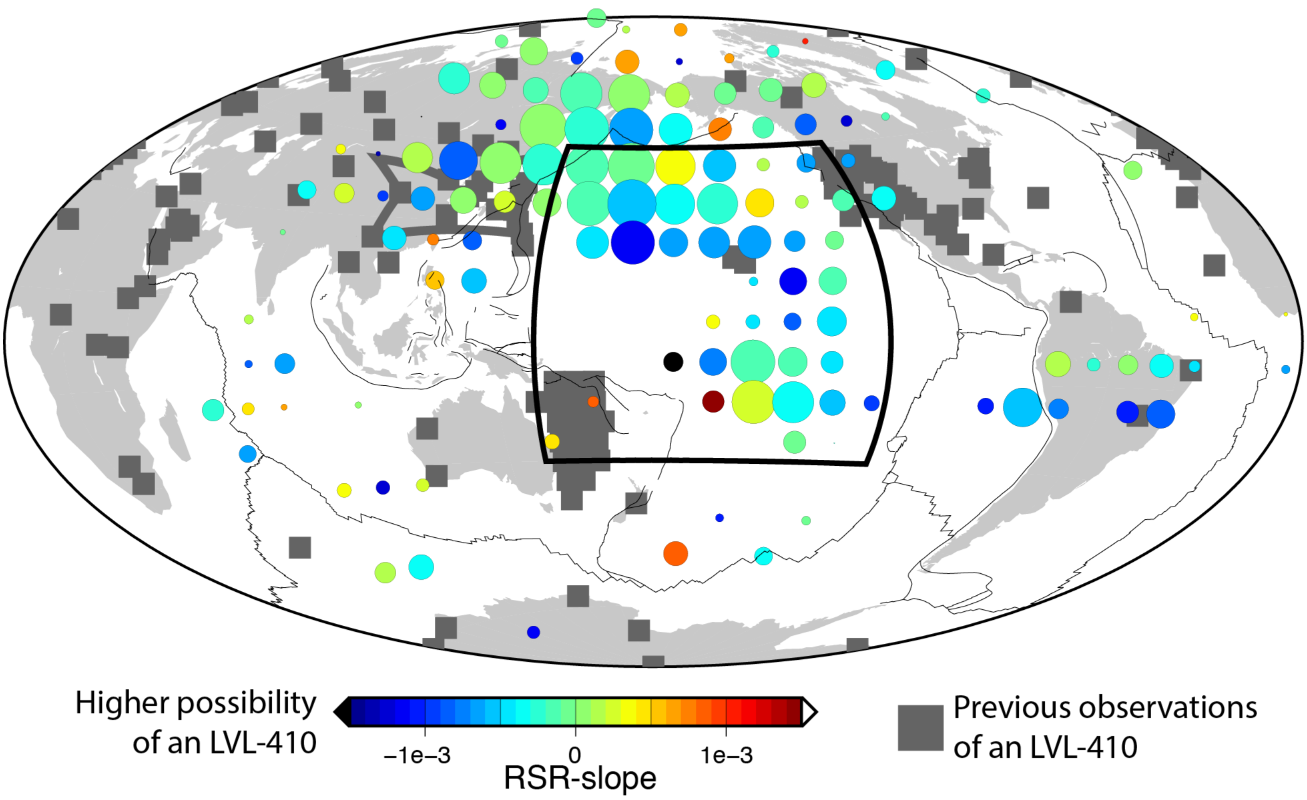
A sporadic low-velocity layer atop the 410-km discontinuity beneath the Pacific Ocean

*Songqiao Shawn Wei[1], Peter M Shearer[1]

1. Scripps Institution of Oceanography, UC San Diego

The seismic discontinuity at 410 km depth is usually attributed to an isochemical phase transformation from olivine to wadsleyite. In addition to this globally observed feature, a low-velocity layer immediately above it has been observed regionally in many places, mainly under continents and continental margins. This low-velocity layer is thought to represent partial melting due to dehydration of ascending mantle across the 410-km discontinuity. Here we present seismic observations of a sporadic low-velocity layer atop the 410-km discontinuity beneath the Pacific Ocean by stacking and analysing long-period seismic body waves. The lateral variations of this low-velocity layer show no geographical correlation with 410-km discontinuity topography or tomographic models of seismic velocity, suggesting that it is not caused by regional thermal anomalies. If this low-velocity layer indeed indicates dehydration melting across the 410-km discontinuity, its strong lateral heterogeneity needs to be taken into account in future geodynamic models of mantle convection and the deep water cycle.

Keywords: 410-km discontinuity, SS precursor, Partial melting



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

*Maxim Ballmer[1,2], Christine Houser[1], John W. Hernlund[1], Renata M. Wentzcovich[1,3,4], Kei Hirose[1]

1. Earth-Life Science Institute, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8551, Japan, 2. Institut für Geophysik, ETH Zürich, Sonneggstrasse 5, 8092 Zurich, Switzerland, 3. Department of Applied Physics and Applied Mathematics, Columbia University, New York, USA, 4. Department of Earth and Environmental Sciences, Columbia University, Lamont-Doherty Earth Observatory, Palisades NY, USA

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.

Keywords: Mantle Convection, Slab Stagnation, Primordial Reservoirs

Tracing plume morphology through the mantle using seismic tomography

*Keely Anne O'Farrell[1], Caroline Eakin[2], Carolina Lithgow-Bertelloni[3]

1. University of Kentucky, 2. Australia National University, 3. University College London

The behaviour of plumes in the mantle has the ability to tell us about the vigour of mantle convection, net rotation of the mantle, the roll of thermal versus chemical anomalies and the important bulk physical properties of the mantle such as viscosity structure. Understanding the journey of plumes through the mantle will help us understand the structure of the mantle and the links between the deep mantle and surface. We have developed an algorithm to trace plume-like features in shear-wave (Vs) seismic tomography models based on picking local minima in the velocity and searching for continuous features with depth. We apply this method to recent tomographic models and recover 60 or more continuous plume conduits that are >750 km long. Around a third of these can be associated with a known hotspot at the surface.

We study the morphology of these plume chains and find that the largest lateral deflections occur near the base of the lower mantle and in the upper mantle. We analyze the preferred orientation of the plume deflections and their gradient to infer large scale mantle flow patterns and the depth of viscosity contrasts in the mantle respectively. We find no preferred azimuthal direction to the plume conduits in the mantle. Increases in the plume gradients correspond to the lower transition zone and 1000 km depth (Bullen's layer C). We infer viscosity structure from these deflections and explore the dynamics of a plume travelling through these viscosity jumps. We also retrieve Vs profiles for our traced plumes and compare with velocity profiles predicted for different mantle adiabat temperatures. We use this to constrain the thermal anomaly associated with these plumes. We use these thermal anomalies in conjunction with our measured plume tilts/deflections to further explore the dynamics of plume conduits in the lower mantle and transition zone.

Keywords: plume, seismic tomography, viscosity

