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Heterogeneity Spectrum of Earth's Upper Mantle Obtained from the Coherence of Teleseismic P Waves

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Abstract. Fluctuations in log-amplitude and travel time of teleseismic P waves recorded by the EarthScope USArray are used to invert for the heterogeneity spectrum of P-wave velocity in a 1000 km thick region of the upper mantle beneath the array. These fluctuations are used to form coherence functions. Best fits to joint transverse coherence functions require a depth dependent heterogeneity spectrum, with peaks in narrow depth ranges. These peaks agree well with peaks predicted for the temperature derivative of seismic velocity from models of the chemistry and phase of silicate mineral assemblages appropriate for the upper mantle, correlating with the depths of phase changes. The results show that chemistry and phase act in concert with lateral and depth variations in temperature to produce the observed heterogeneity in seismic velocities in the upper mantle at spatial scales from 50 to 300 km.

AMS subject classifications: 86A15, 86A22, 74J20

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1 Introduction

The chemistry, distribution, and shapes of small-scale heterogeneity record the history of compositional mixing of Earth's mantle by convection and plate tectonics. Directionally dependent scattering, focusing, and diffraction of seismic waves by small-scale heterogeneity also affects estimates of viscoelastic attenuation and anisotropy, which in turn are important for estimating temperature, mineral composition, and mineral phase. Travel-time tomography, however, fails to resolve heterogeneities having dimensions less than several dominant wavelengths of band-passed body waves. Resolvable scale lengths are

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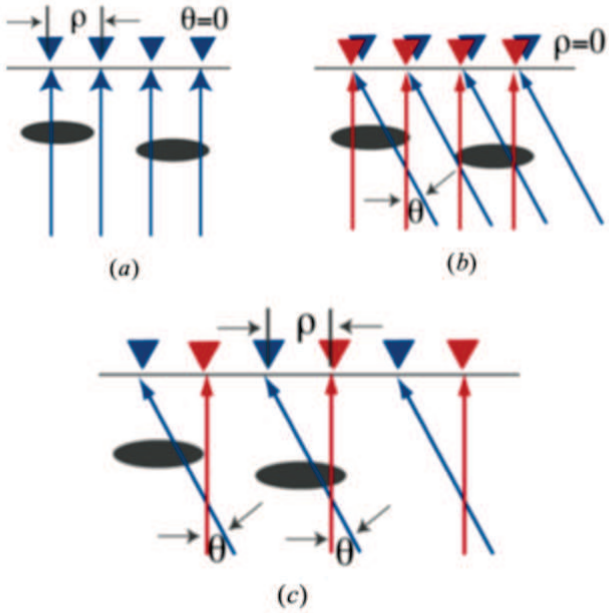

Figure 1: Teleseismic wave incidence on elements of receiver arrays (triangles) and their sensitivity to heterogeneity (gray ellipses) beneath the arrays determined from (a) Transverse Coherence Functions (TCF) [2], (b) angular coherence function (ACF) [3], and (c) joint transverse and angular coherence function (JTACF) [4,5], where θ denotes the incident angle between the two plane waves and ρ denotes the lag distance between receivers.

generally greater than 1,000 km from teleseismic body waves in the 0.01 to 0.2 Hz band. Tomographic imaging from higher frequency (1 Hz) body waves, recorded by dense regional arrays, occasionally is able to resolve structures smaller than several 100 kilometers, e.g., [1]. An alternative approach is to retrieve a statistical representation of structure from observations of the fluctuation of the amplitude and travel time of teleseismic body waves recorded by arrays. These fluctuations are created by small-scale heterogeneities beneath the arrays that scatter, focus, and defocus steeply incident body waves, which can be treated as plane waves incident on the upper mantle beneath the receivers. While deterministic seismic tomography gives both location, shape, and intensity of individual velocity heterogeneities, the stochastic approach provides an overall description about the assemblage of heterogeneities in terms of the spatial spectrum of velocity perturbations.

Aki [2] first proposed using the transverse coherence (Fig. 1a) of travel times and log amplitudes of teleseismic body waves to retrieve the heterogeneity spectrum of Earth structure beneath seismic arrays from steeply incident plane waves. Flatté and Wu [3] extended Aki's methods to include angular coherence (Fig. 1b), using seismic waves arriving from different incoming directions. Several studies by Wu and Flatté [4] and Chen and Aki [5] further extended this method to include observations of the joint transverse angular coherence (Fig. 1c). Wu and Xie [6] conducted successful inversions of joint