

# Mapping the Earth's thermochemical and anisotropic structure using global surface wave data

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[1] We have inverted global fundamental mode and higher-order Love and Rayleigh wave dispersion data jointly, to find global maps of temperature, composition, and radial seismic anisotropy of the Earth's mantle as well as their uncertainties via a stochastic sampling-based approach. We apply a self-consistent thermodynamic method to systematically compute phase equilibria and physical properties ( $P$  and  $S$  wave velocity, density) that depend only on composition (in the  $\text{Na}_2\text{-CaO-FeO-MgO-Al}_2\text{O}_3\text{-SiO}_2$  model system), pressure, and temperature. Our 3-D maps are defined horizontally by 27 different tectonic regions and vertically by a number of layers. We find thermochemical differences between oceans and continents to extend down to  $\sim 250$  km depth, with continents and cratons appearing chemically depleted (high magnesium number (Mg #) and Mg/Si ratio) and colder ( $>100^\circ\text{C}$ ) relative to oceans, while young oceanic lithosphere is hotter than its intermediate age and old counterparts. We find what appears to be strong radial  $S$  wave anisotropy in the upper mantle down to  $\sim 200$  km, while there seems to be little evidence for shear anisotropy at greater depths. At and beneath the transition zone, 3-D heterogeneity is likely uncorrelated with surface tectonics; as a result, our tectonics-based parameterization is tenuous. Despite this weakness, constraints on the gross average thermochemical and anisotropic structure to  $\sim 1300$  km depth can be inferred, which appear to indicate that the compositions of the upper (low Mg# and high Mg/Si ratio) and lower mantle (high Mg# and low Mg/Si ratio) might possibly be distinct.

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## 1. Introduction

[2] Since its infancy in the late 1970s and early 1980s, seismic tomography [e.g., Dziewonski *et al.*, 1977; Woodhouse and Dziewonski, 1984; Dziewonski, 1984] has become a well-established discipline that has done much to enhance our understanding of deep Earth processes, providing detailed information on the large-scale velocity variations that pervade the mantle. In particular, the last decade has seen a growing level of consensus where studies employing different data sets and/or forward or inverse modeling techniques are converging toward a consistent picture of the long wavelength pattern of elastic wave speeds (see reviews and model comparisons by, e.g., Nolet *et al.* [1994],

Montagner [1994], Ritzwoller and Lavey [1995], Trampert and Woodhouse [2001], Becker and Boschi [2002], Romanowicz [2003], Trampert and van der Hilst [2005], and Rawlinson *et al.* [2010]).

[3] In spite of the success of seismic tomography in elucidating the physical structure (seismic  $P$  and  $S$  wave speeds) of the mantle, knowledge of seismic wave velocities is not an end in itself as it only provides clues about the underlying processes that determine the evolution of the mantle, i.e., chemical makeup and thermal state.

[4] The case for compositional heterogeneity playing a major role has steadily increased in significance over recent years. Analyses of the ratio of relative changes in shear and compressional wave velocities ( $V_S$  and  $V_P$ , respectively), defined as  $R_{P/S} = \partial \ln V_S / \partial \ln V_P$ , have been inferred from seismic tomography studies and been given ample consideration as a possible means to unravel the physical causes of the observed velocity variations [e.g., Robertson and Woodhouse, 1996; Su and Dziewonski, 1997; Masters *et al.*, 2000; Saltzer *et al.*, 2001; Romanowicz, 2001; Resovsky and Trampert, 2003; Simmons *et al.*, 2009]. From the aforementioned studies it is generally agreed that  $R_{P/S}$  increases radially, although important lateral variations are also acknowledged to exist. However, more often than not, independent overlapping information on  $P$  and  $S$  wave

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