Differential attenuation in teleseismic shear-waves: measurement and applications

Joseph Asplet[*†1], James Wookey[1], Michael Kendall[2] and Mark Chapman[3]

1. School of Earth Sciences, University of Bristol, UK
2. Department of Earth Sciences, University of Oxford, UK
3. School of Geosciences, University of Edinburgh, UK

Abstract

Melting is an important process within the mantle, exerting control over the composition and dynamic processes throughout the mantle. Upper mantle melt weakens the lithosphere, facilitating rifting (Buck, 2004, Kendall et al., 2005) and other surface expressions of tectonic processes. In the mantle transition zone, the presence of deep melts can be interpreted as a proxy for increased volatile content, which acts as a catalyst for melting and results in intraplate volcanism (e.g., Yang and Faccenda, 2020). Observed low seismic velocity zones in the mantle transition zone are interpreted in terms of melt (e.g., Schmant et al., 2014, Liu et al., 2016a) although these features can also be interpreted as temperature anomalies or as artefacts of seismic anisotropy (Bezada et al., 2016). Melt is hypothesized to by present in the lowermost mantle, often localized within ultra-low velocity zones (ULVZs, e.g., Liu et al., 2016b, Li et al., 2022) and perhaps represent remnant fragments of a basal magma ocean (Labrosse et al., 2007). However, the presence and extent of melt in the lowermost mantle is unknown. Observations of seismic anisotropy in the lowermost mantle can also be plausibly explained by the shape-preferred orientation of melt inclusions and it is challenging to differentiate between these models and the lattice-preferred orientation of bridgmanite, post-perovskite or ferropericlase. Preserving discrete melt pockets at the base of a mantle that do not coalesce into a global layer is geodynamically challenging (Dannberg et al., 2021) and unambiguous observations of melt would grant insights into the temperature and composition of the lowermost mantle. Measurements of differential shear-wave attenuation offer an alternate approach to seismically detect the present of melt at a range of length scales throughout the mantle. Here we present a technique for measuring differential attenuation (Δt^*) by matching the instantaneous frequencies of the fast and slow shear-waves using an adaptation of the method of Mathenay and Nowack (1995). We demonstrate the effect that Δt^* can have on standard techniques for measuring shear-wave splitting, such as eigenvalue minimization (Silver and Chan, 1991). Using synthetic data and SKS measurements from the Yellowknife array, Canada and Afar, Ethiopia we illustrate how instantaneous frequency can be used to jointly measure Δt^* and shear-wave splitting using. Through forward modelling of Δt^*, using both crack scattering (Hudson, 1982) and squirt flow (Chapman, 2003) models, we demonstrate the power of differential attenuation to constrain the extent of melt in different regions of the mantle.

Keywords: Seismic Attenuation, Mantle Composition, Shear-wave splitting

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[*]Speaker
†Corresponding author: joseph.asplet@bristol.ac.uk