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A global view of shear wave splitting and mantle flow in subduction systems

Maureen Long (1), Paul Silver (2), Jenny Hanna (1), Erin Wirth (1), Chris Kincaid (3), and Laurent Montesi (4)

(1) Department of Geology and Geophysics, Yale University, New Haven, CT, USA (maureen.long@yale.edu), (2) Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC, USA, (3) Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, USA, (4) Department of Geology, University of Maryland, College Park, MD, USA

The character of the mantle flow field in subduction zone regions remains poorly understood, despite its importance for our understanding of subduction dynamics. Observations of seismic anisotropy, which manifests itself in shear wave splitting, can shed light on the geometry of mantle flow in subduction zones, but placing constraints on anisotropy in various parts of the subduction system (including the overriding plate, the mantle wedge, the subducting slab, and the sub-slab mantle) remains challenging from an observational point of view. In order to identify dynamic processes that make first-order contributions to the pattern of mantle flow in subduction zones, we analyze a global compilation of shear wave splitting measurements for a variety of ray paths, including SK(K)S and teleseismic S phases as well as local S and source-side splitting from slab earthquakes. Key challenges associated with assembling such a compilation include correctly assessing and accounting for any dependence of local S splitting parameters on frequency and correctly characterizing any contribution to SKS splitting measurements from anisotropy within the subducting slab that is unrelated to active mantle flow. We present local case studies from the Japan and Izu-Bonin-Marianas subduction zones that explore frequency-dependent splitting due to heterogeneous anisotropy in the mantle wedge and that use a variety of raypath combinations to isolate the contribution from anisotropy within the slab.

Keeping these results in mind, we have compiled shear wave splitting measurements from subduction zones globally from the literature and from our own work to produce estimates of average shear wave splitting parameters – and their spatial variation – for the mantle wedge and the sub-wedge region for individual subduction segments. These estimates are then compared to other parameters that describe subduction. The sub-wedge splitting signal is relatively simple and is dominated by trench-parallel fast directions in most subduction zones worldwide (with a few notable exceptions). Average sub-wedge delay times correlate with the absolute value of trench migration velocities in a Pacific hotspot reference frame, which supports a model in which sub-slab flow is usually trench-parallel and is induced by trench migration. Shear wave splitting patterns in the mantle wedge are substantially more complicated, with large variations in local S delay times and complicated spatial patterns that often feature sharp transitions between trench-parallel and trench-perpendicular fast directions. Using our global compilation of local S splitting measurements and other subduction-related parameters (such as convergence and trench migration velocities, the age, dip, and morphology of the subducting slab, thickness and stress state of the overriding plate, volcanic production, and depth to volcanism), we carry out hypothesis testing of the wide variety of models that have been proposed to explain mantle wedge anisotropy. These include models that invoke corner flow, transpression due to oblique subduction, trench-parallel flow, crustal foundering, B-type olivine fabric, the LPO of serpentinite, melt-controlled anisotropy, or a combination of these mechanisms. We are currently working to integrate our seismological results with the results from geodynamical modeling (both numerical and analog) to test the geodynamic plausibility of our proposed model for mantle flow in subduction systems and to explore the implications of the model for subduction zone processes and, more generally, for mantle dynamics.