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Large-scale trench-perpendicular mantle flow beneath central South America

Miriam Christina Reiss, Georg Rümpker, and Ingo Wölbern

Goethe University Frankfurt, Institute for Geosciences, Geosciences, Frankfurt am Main, Germany (reiss@geophysik.uni-frankfurt.de)

The subduction of an oceanic plate beneath a stable continent is one of the major geodynamical processes. Two concepts to explain the mantle deformation and resulting flow field have been put forward: 1) the mantle material above and below the subducting plate are entrained by the downward motion of the slab, or 2) the slab and underlying mantle are decoupled such that the flow beneath the slab flows parallel to the trench. This debate has been fueled by many studies from the South American margin, which was the first region where shear-wave splitting results were interpreted to originate from anisotropy caused by trench-parallel mantle flow beneath the subducting slab.

Here, we investigate the anisotropic properties of the forearc region of the central Andean margin by analyzing shear-wave splitting from teleseismic and local earthquakes from the Nazca slab. The data stems from the Integrated Plate boundary Observatory Chile (IPOC) located in northern Chile, covering an approximately 120 km wide coastal strip between ∼17°-25° S with an average station spacing of 60 km. With partly over ten years of data, this data set is uniquely suited to address the long-standing debate about the mantle flow field at the South American margin and in particular whether the flow field beneath the slab is parallel or perpendicular to the trench. Our analyses yield two distinct anisotropic layers located within the crust and mantle beneath the stations, respectively. The teleseismic measurements show a change of fast polarization directions from North to South along the trench ranging from parallel to subparallel to the absolute plate motion and, given the geometry of absolute plate motion and strike of the trench, mostly perpendicular to the trench. Shear-wave splitting from the local earthquakes shows fast polarizations roughly aligned trench-parallel but with short-scale variations which are indicative of a relatively shallow source. Comparisons between fast polarization directions and the strike of the local fault systems yield an excellent agreement.

We use full-waveform inversion and forward modelling to test for the influence of the upper layer on the teleseismic measurements. Accordingly, the mantle layer is best characterized by an anisotropic fast axes parallel to the absolute plate motion which is roughly trench-perpendicular. This orientation is likely caused by a combination of crystallographic preferred orientation of the mantle mineral olivine as fossilized anisotropy in the slab and entrained flow beneath the slab. The anisotropy in the crust of the overriding continental plate is explained by the shape-preferred orientation of micro-cracks in relation to local fault zones which are oriented parallel the overall strike of the Andean range. Our results do not provide any evidence for a significant contribution of trench-parallel mantle flow beneath the subducting slab to the measurements.