Mantle Flow in the Chile-Argentina Flat Slab Subduction Zone from Seismic Anisotropy

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Abstract

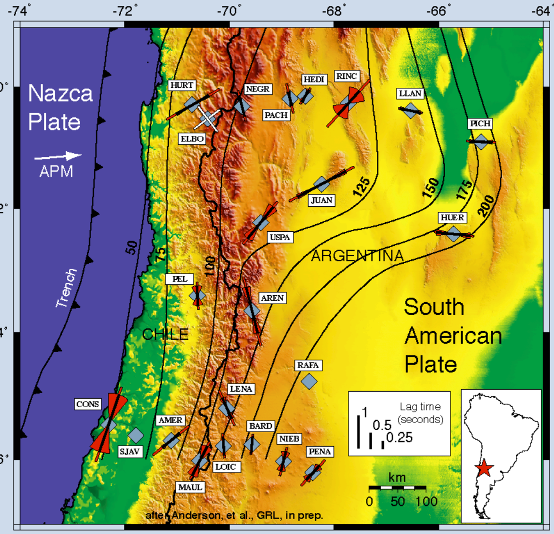
The purpose of this study is to characterize the seismic anisotropy of a part of the South American subduction zone. This particular subduction zone affords us the opportunity to try and characterize the effect of a change in subducting slab dip on mantle flow, a factor that has been hard to tease out of other studies where station coverage is sparse, or no change in dip of the slab exists. At 30° S the subducting Nazca slab flattens at a depth of approximately 100 km under Argentina and extends at this depth almost 300 km eastward before continuing its descent into the mantle. South of 33° S, the slab has a uniform dip of approximately 30°.

Earthquakes were recorded by 22 portable broadband seismic stations as a part of the CHile ARgentina Geophysical Experiment (CHARGE). We estimate anisotropic fast-axis orientation and magnitude from split teleseismic SKS and SKKS waves and from shear waves from local earthquakes in the subducting plate. The magnitude of the shear wave splitting (0.5-1 s) for teleseismic results is too large to be reasonable for a thin layer such as the crust or even for the mantle wedge in some areas. In addition, receiver function analysis from other studies in our working group show small magnitude to no anisotropy in the crust of some parts of the study area, while estimates for the mantle wedge from local events shows magnitudes of anisotropy only in the 0.1 second range. Therefore it is likely that the largest source of anisotropy is within or below the subducting slab. We interpret the fast anisotropic axis as the direction of mantle flow.

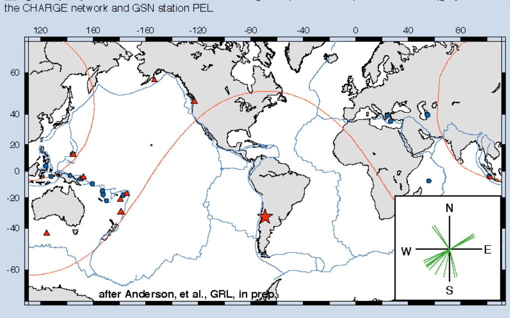
Estimates of fast axis direction across our network show a dramatic change in anisotropic fast axis azimuth across this zone of change in dip of the slab. The fast axis rotates from N-S under the southern part of our network to E-W in the northeastern part of our network. This general pattern does not change even when one corrects for a possible layer of anisotropy with a fast axis parallel to APM. One possibility is that retrograde motion of the subducting Nazca plate is causing N-S strain of the mantle below the trench retreat point, an idea suggested by Russo and Silver (1994). In our area, the local slab geometry may create an accommodation zone under the flattened slab that allows mantle in that area to flow eastward, entrained by the Nazca plate.

We give preliminary observations of the fit of two-layer models with data from a variety of backazimuths where we have constrained mantle wedge anisotropy. These models show that even a two-layer model may be too simplified to adequately explain variation in anisotropic parameters with polarization direction. Future work will enable us to further constrain more complicated models.

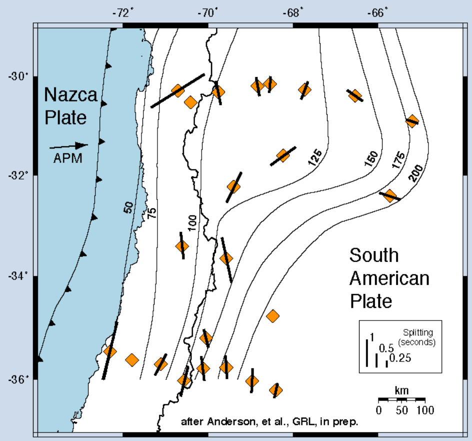
Teleseismic Shear-Wave Splitting



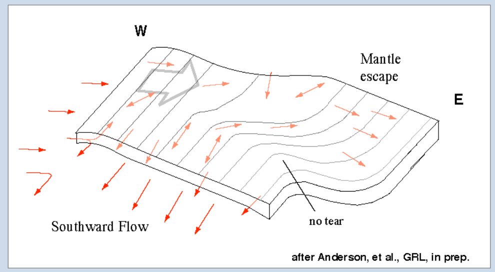
▲Highest quality resolved fast axis orientation and lag time (refer to scale) for each station (gray diamonds) of the CHARGE network and GSN station PEL.



◀Teleseismic earthquakes used in this study. Star indicates the location of the CHARGE network and lines indicate distances of 85 and 140 degrees of arc away from this location. Earthquakes we investigated for this study are within these bounds and are shown by the blue dots (inset shows distribution of backazimuths for these earthquakes) and earthquakes used for the results shown in figure 1 are indicated by red triangles.

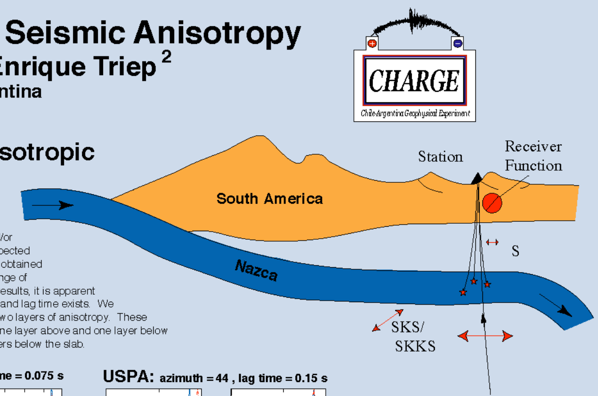


▲Fast axis and lag time for an asthenospheric layer of anisotropy beneath the subducting slab after removing the effects of an APM-parallel oriented layer of fossil anisotropy within the slab with lag time = 0.3 s.

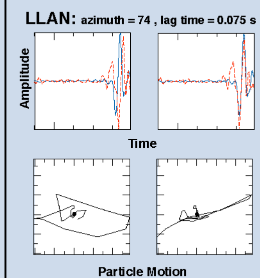


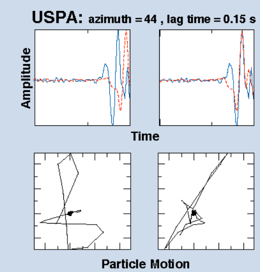
▲Schematic representation of asthenospheric mantle flow beneath the subducting slab interpreted from the resolved asthenospheric anisotropy above. We indicate a continuous Nazca plate due to the slab contour-parallel direction of anisotropy along the bend of the slab.

Two-Layer Anisotropic Models

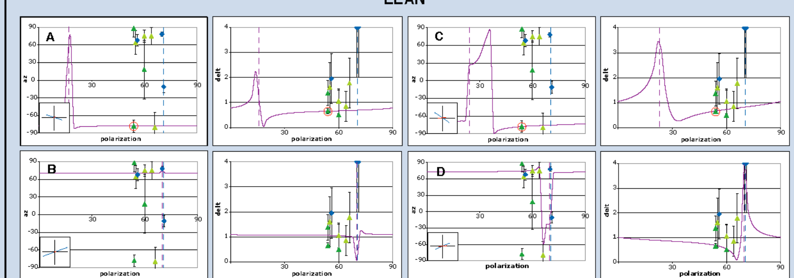


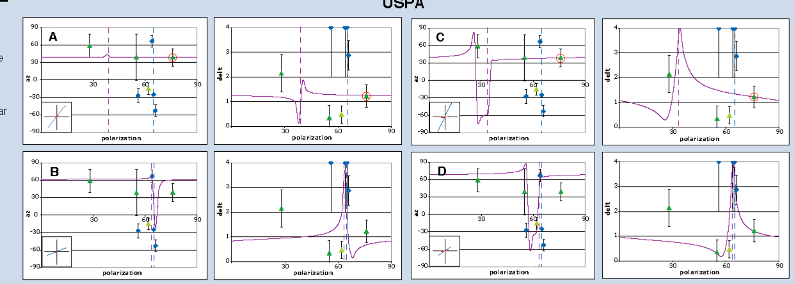
▶ Multiple layers of anisotropy and/or a dipping anisotropic fast axis is expected in a subduction zone. Although we obtained splitting parameters for a narrow range of backazimuths with our teleseismic results, it is apparent that some variation in fast direction and lag time exists. We test some preliminary models with two layers of anisotropy. These models fall into two categories: 1) one layer above and one layer below the subducting slab, and 2) two layers below the slab.

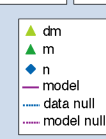




◀ Anisotropy resolved from receiver functions and from shear-wave splitting in local slab s-waves can serve to constrain above-slab sources of anisotropy. Over the flat-slab area, crustal anisotropy from receiver functions is very small to non-existent (Gilbert et al., 2003). We have also obtained results for a few local slab events for LLAN and USPA (examples of events directly below the stations are shown). We use these preliminary results in two-layered models A and B below.







▶ We use the method of Silver and Savage (1992) to test four two-layer anisotropic cases: A) upper layer = anisotropy resolved from local slab events, lower layer is adjusted to fit the most well-resolved solution (red circle) for both azimuth and lag time; B) as in A, except lower layer is adjusted to fit best null result; C) ignoring above slab anisotropy, upper layer = fossil anisotropy within the subducted slab, lower layer is adjusted to fit the most well-resolved solution; D) as in C, except lower layer is adjusted to fit best null result. Symbols: n = null, m = fairly well-resolved parameters, dm = errors stretched in the time domain, indicating that the backazimuth may be near the null direction.

Conclusions

▶ Seismic anisotropy in the South American subduction zone between 30° and 33° south resolved from teleseismic earthquakes is localized largely within or below the subducting Nazca plate.

▶ The seismic fast axis orientation is correlated spatially with a change in dip of the subducting slab.

▶ We suggest a model to explain the observed pattern of anisotropy in which mantle flow responds to westward retreat of the trench and the subducting Nazca plate, a barrier to mantle flow at depth, and a local slab geometry with a continuous flat-to-normal transition in dip.

▶ Two-layer models for anisotropy inadequately fit the variation of resolved splitting parameters within the flat-slab area. A three-layer model for anisotropy may be a better fit.

▶ Further work will include analysis of local slab s-waves at all stations in order to fully resolve the above-slab component of anisotropy in all regions. We will also investigate ScS phases in order to isolate the within and below-slab anisotropic components. This will better constrain three-layer models and models including dipping anisotropic axis.

Acknowledgements

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