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The role of fluids in the Nazca flat slab near 31°s revealed by the electrical resistivity structure

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INTRODUCTION

The Sierras Pampeanas of Argentina lie between about 26°S and 34°S. They are a region of active thick-skinned deformation between stable cratonic South America and the Andean Cordillera and are located east of both a quiescent Andean volcanic arc and the thin-skinned thrust belt of the Eastern Cordillera. These ranges largely consist of Precambrian to Lower Paleozoic granitic and metamorphic basement blocks which have been differentially tilted and uplifted along broad, high-angle, N-S trending thick-skinned thrust systems. They represent the Neogene eastward progression of Andean deformation into cratonic South America.

The Sierras Pampeanas coincide with a region of flat subduction of the Nazca Plate (see Fig. 1). The flat portion of the subducted slab is widest in the south and progressively narrows to the north. It has been suggested that the slab dip at the northern end of the Sierras Pampeanas is evolving from a past flat configuration to more normal dip and that this is responsible for the volcanic flare-up that characterizes the Puna Plateau northwest of the Sierras Pampeanas (Kay and Abruzzi, 1996)

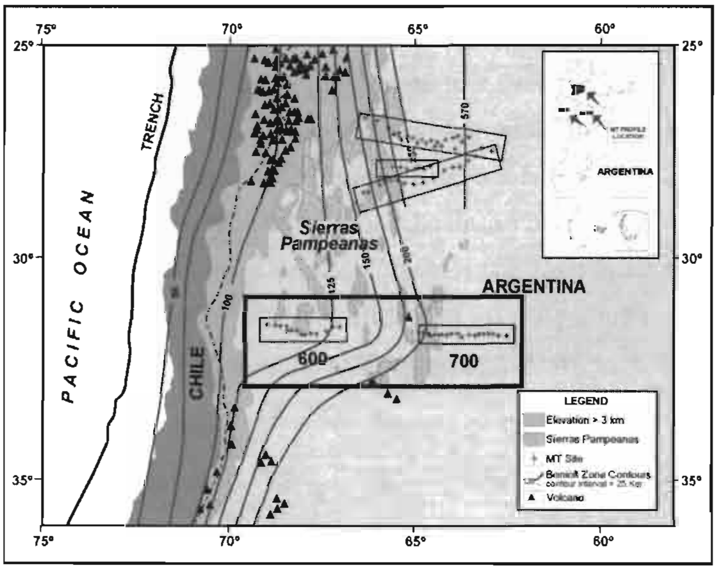

Figure 1. Map showing the location of MT sites collected prior to 2004. The contours of the Wadati-Benioff Zone depth are from Cahill and Issacs (1992). The filled triangles are volcanoes younger than 5 Ma.

MAGNETOTELLURIC DATA AND ANALYSIS

The Sierras Pampeanas are a particularly good place to use magnetotellurics (MT) to study deep active processes because the lithosphere is resistive and therefore transparent to electromagnetic energy. Furthermore, a thin coating of sediments mutes the difficulties often associated with making measurements in areas of crystalline crust.

A total of 53 sites have been collected along a profile near 31° S that stretches from near the Chilean border in San Juan Province to Enter Rios Province near the Uruguay border in eastern Argentina. Only 32 of these have been inverted for structure as this is being written. These are the 600 and 700 lines shown in Fig. 1 Although there is a 200 km gap within this profile, the data are sensitive to structure within this gap and off the ends. New sites have partially filled the gap and extended the profile to the east.

The data were processed using robust multi-site statistical time series methods (Egbert, 1997). The regional strike was determined to be acceptably close to north-south at all sites using MT impedance tensor decomposition. (Chave and Smith, 1994). In this process, we determined the level of data misfit below which 2D interpretation of these data is statistically un-acceptable.

The MT responses for both strike-parallel (TE) and strike-perpendicular (TM) electric current polarizations and the vertical to horizontal magnetic field transfer function were jointly inverted using the NLCG algorithm of Rodi and Mackie (2001). This algorithm minimizes model roughness subject to fitting the data to prescribed misfit. We generated a series of inversions of progressively lower misfit and increased complexity. As we crossed below the level of misfit acceptable for a 2D interpretation, model roughness increased rapidly presumably due to trying to fit 3D features in the data with 2D structure. These model features are considered unreliable and we have considered only much smoother models corresponding to trade-off points significantly above the minimum acceptable misfit.

Because we are inverting for a large-scale model with limited data, it is desirable to add constraints that are clearly justifiable. We assume that resistivity below the seismic transition zone decreases to 3 Ohm-m. This has a solid foundation from both laboratory studies of deep mantle phases and global geomagnetic induction studies. The exact value of conductivity in the deep zone is unimportant to our results. It also makes no difference if we insert a tear in the roughness constraint at 660 km to prevent the bottom of the model being smoothed upward in the absence of data constraint. A second constraint, which no one can argue with, is the presence of the highly conducting Pacific Ocean west of the Chilean coast. Structure below the ocean water remained free to vary. Although this is off the end of our profile, our data, particularly the vertical to horizontal magnetic field transfer functions, are sensitive to electric currents flowing outside the region directly below our sites.

RESULTS

Fig. 2 shows the model with an r.m.s. misfit 1.2 times the minimum considered acceptable for 2D interpretation. The model is smoother than a model of the 700 line data presented by Booker, et al.. (2004) but the details should be more robust than their model which has an r.m.s misfit 1.1 times the minimum acceptable.

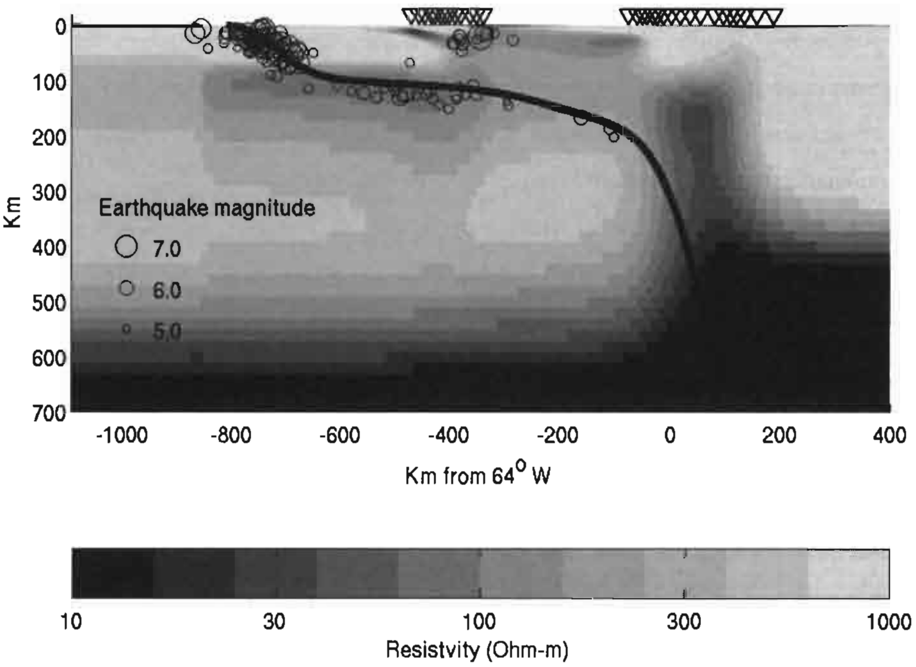

Figure 2. Resistivity model for inversion of Lines 600 and 700. Sites are inverted triangles. Earthquake hypocenters shallower than 200 km are between 30 and 33° S. Deeper, the hypocenters are between 28 and 29° S and the slab position is estimated by extrapolating the well-defined strike of the hypocenters north of 29°.

The main model features described by Booker et al. (2004) remain in Fig. 2. These are the rising conductor just east of the steeply dipping slab and the step in the depth to the top of the deep mantle conductor across the location of the plunging slab. They demonstrate that the rising mantle conductor is a robust feature of the data despite their short MT profile by showing that cutting the vertical electric current flow with a highly resistive layer near 300 km destroys the fit of the predicted TM response to the data. The close correspondance of the sub-vertical conductor to the Nazca slab (deduced completely independently from seismicity) adds considerable confidence. The very resistive root of the Rio de La Plata Craton bounds the rising conductor to the east and may be the mechanical back-stop that forces the flat slab to descend where it does. They also demonstrate that the 150 km step in depth to the top of the deeper mantle conductivity is a robust feature although the absolute depth to this conductive mantle is not well-constrained. The geological significance of this deep assymmetry across the slab depends on what its exact depth is. Their most optimistic model, which is similar to Fig. 2, suggests that the conductive step is the result of the slab forming a boundary bewtween wet and dry regions of the seismic transition zone. A more pessimistic model also presented by Booker, et al. preserves the step but moves it shallower so that its top coincides with the probable base of the Rio de la Plata Craton to the east and the top of the seismic transition zone to the west.

The most interesting new structure is the conductive zone coincident with the flat slab west of -300 km. This coincides with the high seismic activity of the flat part of the slab. Its eastern end also coincides with the drop in slab seismicity and the transference of seismic activity to the crust. It appears thicker and more resistive than it probably is due to viewing the model through the finite resolution of the inversion. The western extent of this flat slab conductor is poorly constrained. However, it definitely does not extend up the very active dipping slab that connects the trench to the flat slab. Adding such a connection to the model significantly degrades the misfit.

The other important new feature is the transition of the lithosphere from resistive in the west to moderately conductive in the east under Line 600. This transition coincides with the eastern end of the slab conductor and the onset of high crustal seismicity. One issue that we could not reliably decide with the data used is the vertical distribution of conductance in the lithosphere between the 600 and 700 lines.

A simple explanation unifies the new structures seen in Fig. 2: The very high seismic activity of the slab after its initial subduction is in the brittle regime and has little or no free fluid to provide an electrical pathway. At about 100 km depth, the slab releases enough fluid to result in high pore pressure and interconnected electrical pathways. High fluid pore pressure triggers the earthquakes in the Nazca flat slab. Eventually these fluids leak upward, pore pressure drops, electrical pathways close and the flat slab seismicity nearly terminates. The fluids transferred upward weaken the overlying lithosphere, concentrating strain and seismic energy release near the surface and lowering the resistivity.

Although fluids leaking from the slab into the overlying lithosphere appear to have important tectonic consequences today, they can be expected to have even more dramatic consequences if the slab subsequently becomes steeper. The lower lithosphere above the present flat slab is undoubtedly much too cool to melt, but this would change if it loses contact with the slab and is heated by re-formation of an asthenospheric wedge. Thus the process that is controlling seismicity today is setting the stage for massive volcanic flare-up in the future.

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References

Booker, J., Favetto, A. and Pomposiello C., 2004. Low electrical resistivity associated with plunging of the Nazca flat slab beneath Argentina. *Nature* 429, 399-403.

Cahill, T. & Isacks, B. 1992 Seismicity and shape of the subducted Nazca Plate. *J. Geophys. Res.* **97**, 17503-17529.

Chave, A.D. and Smith, J.T, 1994. On electric and magnetic galvanic distortion tensor decompositions. *J. Geophys. Res.*, 99, 4669-4682

Egbert, G.D., 1997. Robust multiple station magnetotelluric data processing. Geophys. J. Int 130, 475-496.

Kay and Abbruzzi 1996, Magmatic evidence for Neogene lithospheric evolution of the central Andean "flat-slab" between 30 °S and 32 °S. Tectonophysics, 259, 15-28.

Rodi, W. and Mackie, R., 2001. Non-linear conjugated gradient algorithm for 2-D magnetotelluric inversion. Geophysics, 66, 174-178.