Anomalous induction vectors at the Chilean continental margin – an indication of widespread electrical anisotropy in the forearc crust?

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1 Introduction

At the Chilean continental margin the oceanic Nazca plate (and further south the Antarctic plate) subducts beneath the South American plate in quasi eastern direction. The subduction zone is characterized by an up to 8 km deep, N-S oriented trench and the Andes mountain range with maximum heights of nearly 7 km. The Andes form a classical volcanic chain in Northern and Southern Chile (and bordering Argentina and Bolivia, respectively), intercepted by a volcanic gap north of the city of Santiago which is believed to be due to a flattening of the downgoing slab.

In such a setting one would intuitively assume a very strong coast effect on the time-varying magnetic fields and a large ratio of vertical to horizontal components (tipper); if plotted as induction vectors their real parts would point eastwards, away from the trench in so-called Wiese convention. This is, however, not the case. Instead they deviate significantly from W-E, even parallel to the coast over large areas in Northern Chile (Brasse and Eydam, 2008; Araya et al., 2019). In Southern Chile, the deviation is again different with directions of roughly SW-NE (Brasse et al., 2009; Segovia et al., 2021). This highly anomalous behavior is observed over many hundreds of kilometers which in turn makes it difficult to perform 3-D modeling.

2 Anisotropic modeling

Kapinos et al. (2015) and Araya et al. (2019) could successfully demonstrate that 3-D modeling is in fact possible (in terms of data fit) for measuring areas under consideration in South-Central as well as Northern Chile. There remains an unsolved problem, however: Outside the specific measuring or model area the deviation of tippers simply continues and this would require an unrealistic expansion of model space. It is obvious that there exists another overlying effect which cannot be treated with 3-D inversion. Note that this is a zero-order effect.

Brasse and Eydam (2008) and Brasse et al. (2009) showed that an anisotropic approach could at least principally solve this enigma for both study areas. Electrical anisotropy may either be microscopic with graphite as a classical example or macroscopic or structural due to an arrangement of geological layers. In the anisotropic case, scalar isotropic conductivity expands into a 3x3 tensor which can be reduced to a 6-valued quantity by rotation into the main axis: 3 conductivities in x,y,z (in rotated coordinates), anisotropy strike, dip and slant (Pek and Verner, 1997). In practice, it will be nearly impossible to resolve all 6 values with dip and particularly slant being the most insensitive. Furthermore, for geological reasoning it can be assumed that 2 conductivities have equal values - this would resemble a pattern of conductive planes both on microscopic and macroscopic scales. Although a pipe model is not impossible (think of lava tubes), we discard this option for vast areas.

In South Chile, the deflection of induction vectors might be due to a NE oriented system of deep-reaching faults in the crust in accordance with the regional stress field. In North Chile, the deflection of induction vectors into a southward orientation (see Figure 1 at the end of the text) might be caused by deep-reaching faults associated with the west-vergent fault system in the Precordillera. However, Brasse and Eydam (2008) only attempted to fit the real parts while the imaginary vectors remained unclear. This was successfully modeled later by Galindo (2010); his model and the resulting responses are displayed in Figure 2 and Figure 3. The 2-D anisotropic forward codes of Pek and Verner (1997) and Li (2002) were employed, both yielding similar results.

The model consists of an anisotropic layer in the upper-mid crust with resistivities $\rho_x = \rho_z = 1\,\Omega m$, $\rho_y = 3000\,\Omega m$, thus simulating a fault system with an anisotropy strike of $\alpha = -13°$, i.e. N13°W. Major isotropic features include the conductive Pacific Ocean, the resistive subducted Nazca plate and the resistive overriding South American plate. Additional features are sedimentary basins (particularly on the Altiplano plateau) and a tentative deep conductor beneath the plateau. The preference direction of anisotropy corresponds roughly with the west-vergent fault system in this part of the Andes. The anisotropic layer extends far under the plateau, but the actual extent would require further studies.

3 Discussion

The dominant anisotropic layer underpins the importance of large faults systems in the orogen and its development as a response to subduction. The conductive phase may either be fluids (perhaps rising from the subducting slab) or an enrichment of metallic phases - the forearc of the Andes hosts the largest mines of copper and other metallic minerals in the world.

The presented model gives rise to a number of questions, however.

- Note that the anisotropic models only explain the induction vectors, *not* the impedances. Anisotropic 2-D forward modeling incorporating all transfer functions is a cumbersome affair and would require resources beyond realistic options; inversion codes are not (yet?) available.
- The earth is not 2-D and not isotropic, so one day one might achieve a 3-D model with anisotropy included. But this would require even more time and computational costs.
- Why are the induction vectors and thus the anisotropy so different in Southern and Northern Chile? Does this reflect fundamental differences in the genesis of the continental margin? Where would the transition be located between the two

regimes, near the Juan Fernandez Ridge? Without further measurements along the whole extent of the country this remains pure speculation.

Summarizing, this exercise can only be regarded as a first-order approach to geological reality. But the observation must be kept in mind whenever we try to understand the electrical structure in the Chilean forearc.

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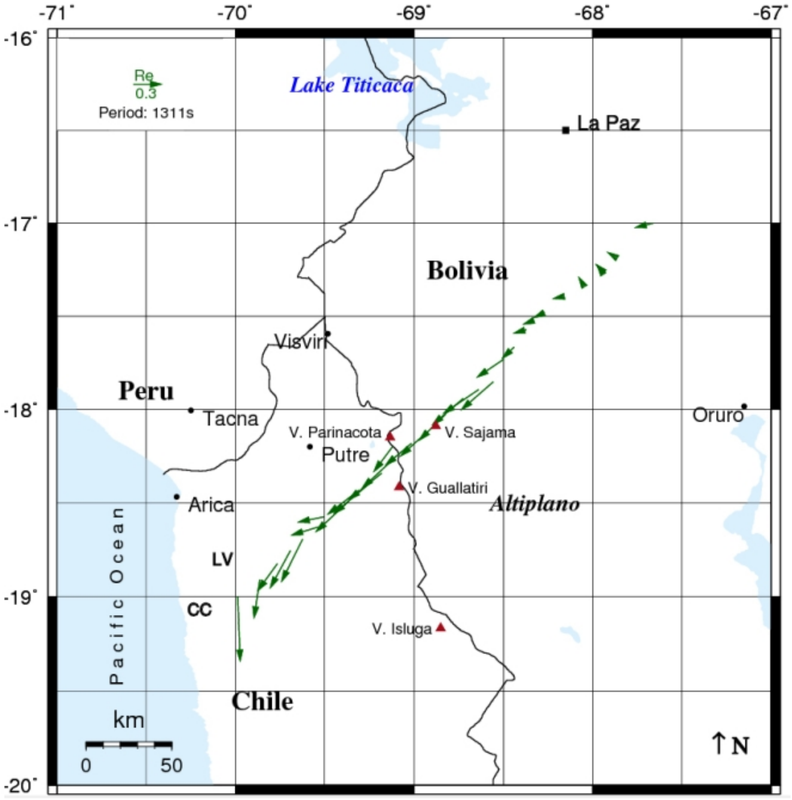

Figure 1: Real induction vectors plotted in Wiese convention at 1311s in Northern Chile and Central Bolivia after Galindo (2010) and Brasse and Eydam (2008). While vectors behave "nicely" (i.e. point in profile direction and are thus suitable for 2-D modeling) for most northeastern sites, they are strongly deflected into a direction parallel to coast line and trench near the Pacific Ocean.

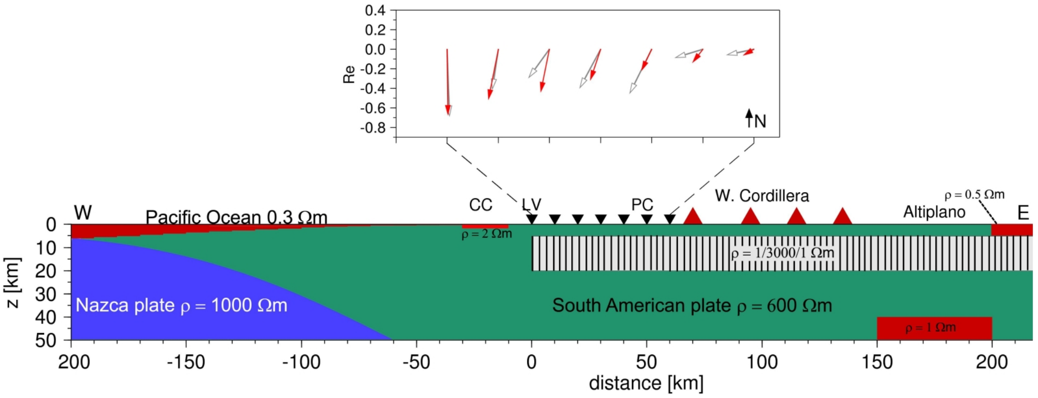

Figure 2: Anisotropic 2-D resistivity model for Northern Chile after Galindo (2010). The model encompasses poorly conducting Nazca and South American Plates, the highly-conductive Pacific Ocean and an anisotropic layer in the upper-mid crust. Above: Measured and modeled induction vectors (real parts)at 1311 s.

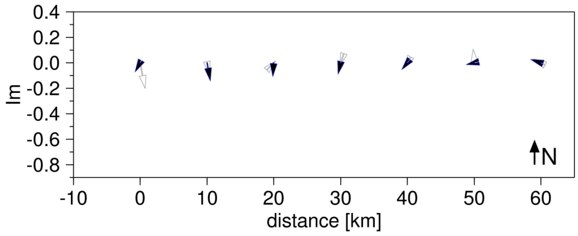

Figure 3: Measured and modeled induction vectors (imaginary parts) for the same period as in Figure 2.