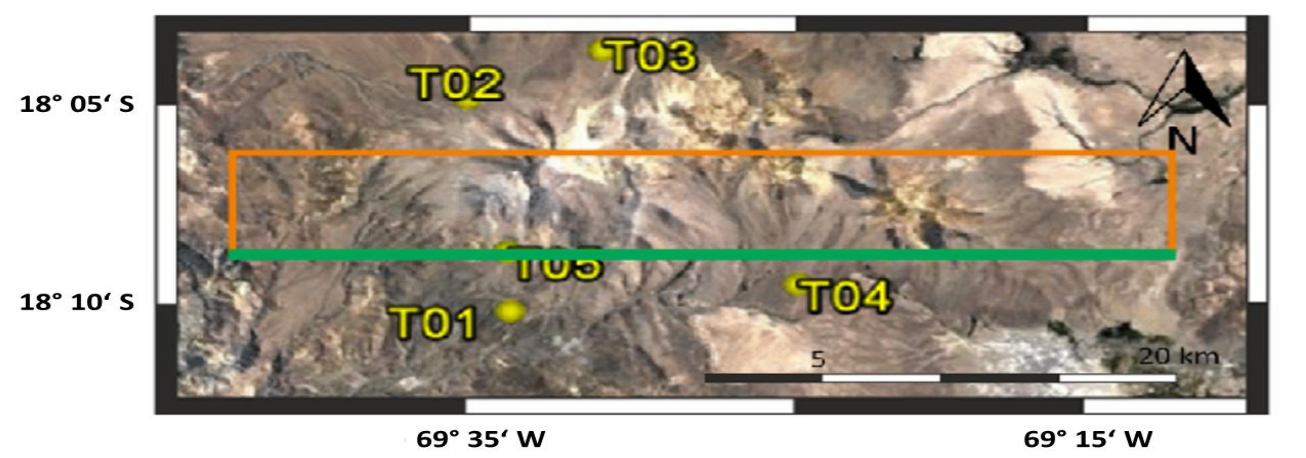
3-D reinterpretation of early magnetotelluric data in the Central Volcanic Zone in Northern Chile

Maximilian Buchner, Christine Kühn, Heinrich Brasse
FR Geophysik, FU Berlin, Malteserstr. 74 – 100, 12249 Berlin, Email: max@geophysik.fu-berlin.de

Abstract

Long-period magnetotelluric (LMT) and audio-magnetotelluric (AMT) experiments have been conducted in the Central Volcanic Zone of the Andes since the late 1980's to study the electrical conductivity distribution in the lithosphere and subduction related processes at the South American continental margin, where the oceanic Nazca plate plunges beneath the continental South American plate. Owing to the computational efforts most of the data were interpreted based on 2-D models. Goal of this work is to extend the existing 2-D results by using three-dimensional modeling techniques at least for the volcanic arc and fore-arc region for two specific investigation areas at around 18°S and 22°S in northern Chile. Dimensionality analysis in both areas indicate strong 3-D effects along the volcanic arc, at the transition zones to the Altiplano, in the Preandean Depression and partly along the Precordillerean Fault System. New 3-D models – employing the ModEM code of Kelbert et al. (2014) – corroborate previous findings, but also enable a more detailed image of lateral resistivity variations in the study areas. North, at around 18°S a shallow conductors are detected at a depth of 5-10 km beneath the stratovolcanoes Parinacota and Taapaca and can be associated with magma chambers belonging to these volcanoes. This shallow conductor was not resolved in previous MT approaches. At 22°S, the magmatic arc conductor emerges now as a trench-parallel, N-S elongated structure slightly shifted to the east of the volcanic front. The most prominent conductor in the whole Central Andes beneath the Altiplano and Puna plateau is also modeled.

Investigation area A1



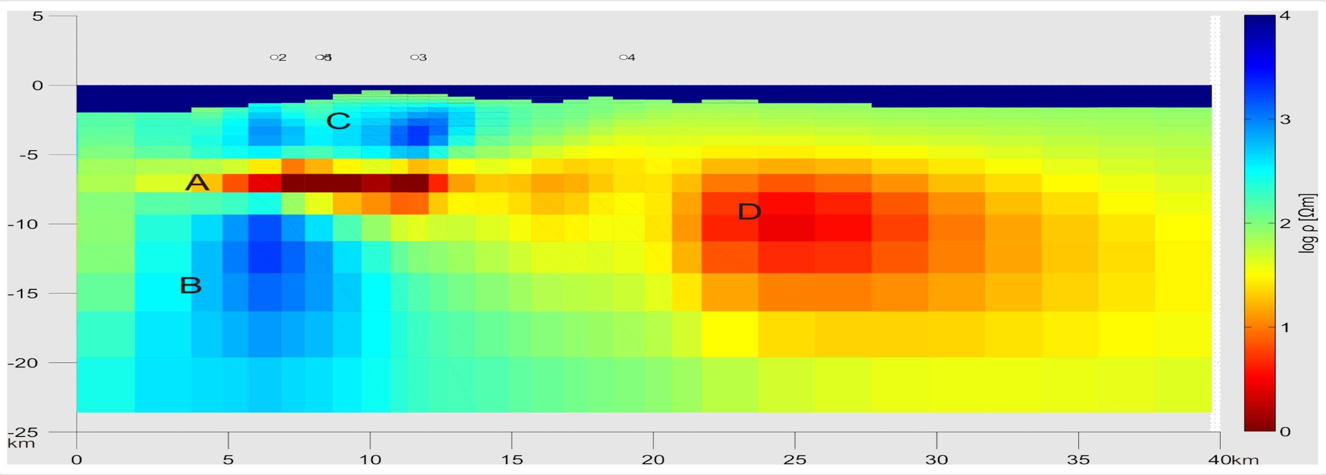


Fig. 2: **3-D inversion model of volcano Taapaca (RMS = 1.043)** after 109 iteration with a background resistivity of 100 Ωm. Important feature (A) may indicate the magma chamber of Taapaca volcano at a depth of 6-8 kilometer, as a possible good conductor is found. The topography of the area is observable, the air is illustrated in dark blue cells and separates from the conductive features of the subsurface. Two resistive feature are resolved at (B) and (C). Feature (D) remains uncertain and requires a sensitivity study to confirm its existence. Satellite image taken from Google Earth shows the area of the profile with stations. The orange line illustrates the array of the inversion model cut. It is a result of the cell size of the initial model. The green line indicates the front-side of the profile shown.

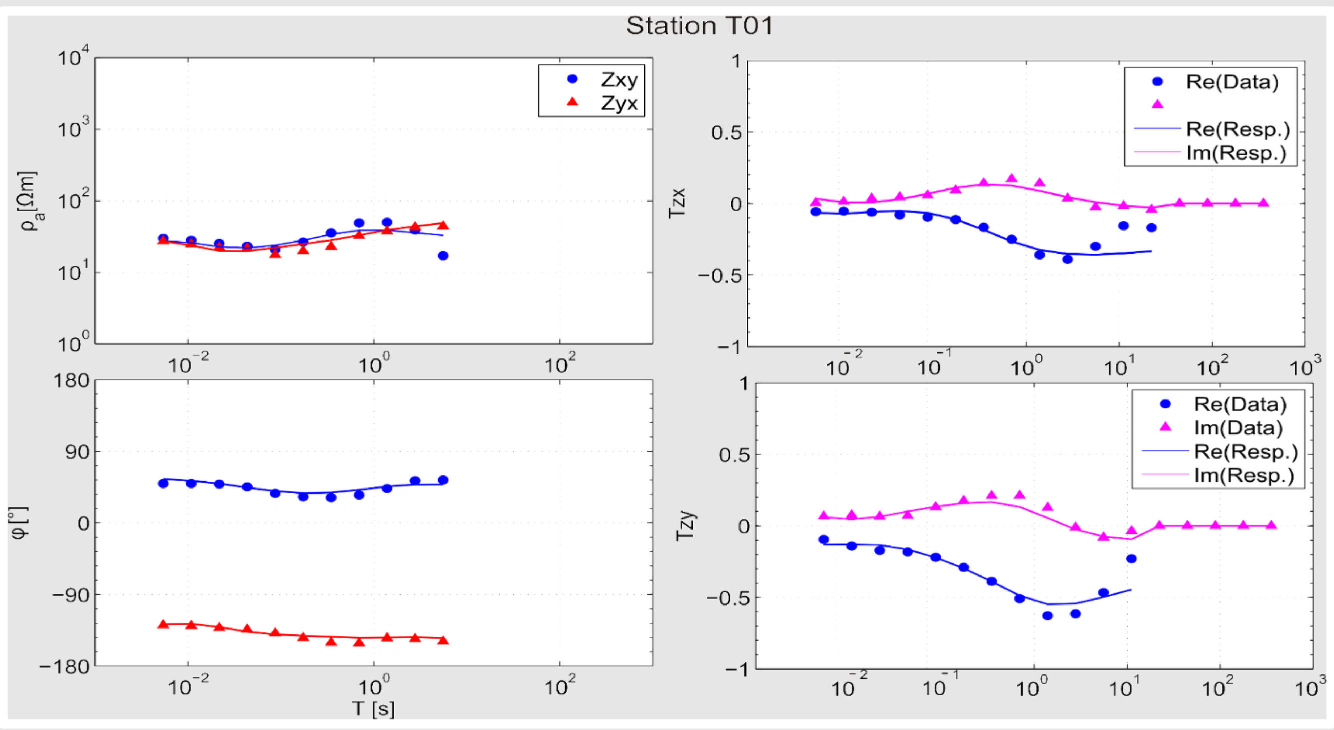


Fig. 3 : **Apparent resistivity and phase curves for off-diagonal impedances at site T01 and tipper function for volcano Taapaca**. The AMT site shows fitting problems at 'longer' periods. Apparent resistivity and vertical transfer function have been calculated really well, beside some small non-fits at longer periods. This may be a result of a topography effect or the cell distribution .

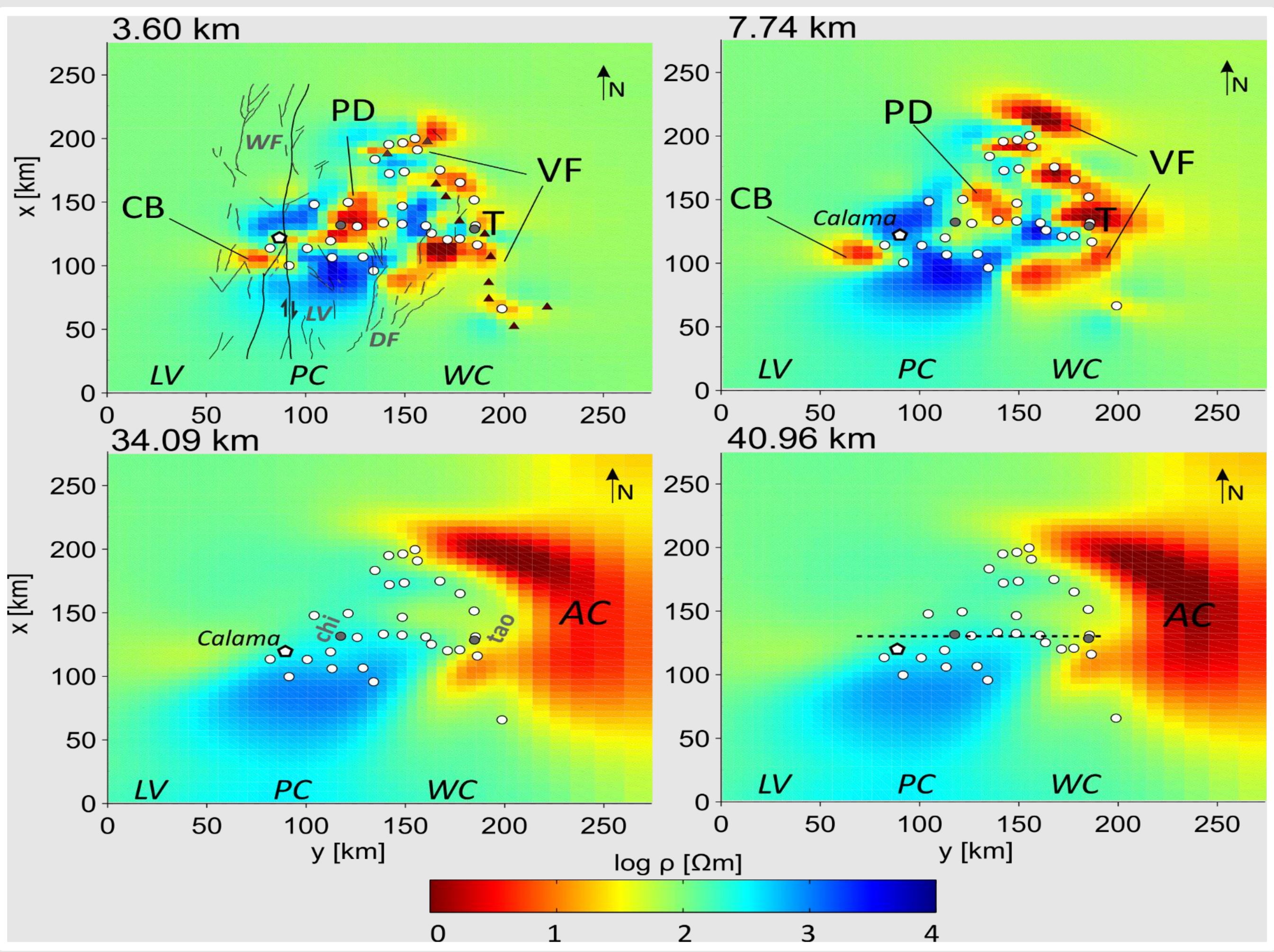


Fig. 7: **Preferred 3-D model (RMS=2.09, 132 Iterations) of investigation area B in plan view at different depth.** The final data set consist of 32 sites located in the Precordillera (PC), the Western Cordillera (WC) and the Preandean Depression (PD). For the 3D inversion with the ModEM 3-D algorithm, the impedance tensor and vertical transfer function elements were smoothed and interpolated using an Akima function. Background resistivity was set to 100 Ωm. AC-Altiplano Conductivity Anomaly; VF-Conductor that belongs to the volcanic arc; T-conductor correlating with the El Tatio Geysers; CB-conductive sediments of the Calama Basin. Grey dots: Data example. Triangles represent the location of the volcanoes. Upper left: solid lines indicate main faults of the study area (WF-West Fissure; LV-Limon Verde; DF DF-Domeyko Fault). Lower right: dotted line illustrates cross section of the resistivity distribution along depth.

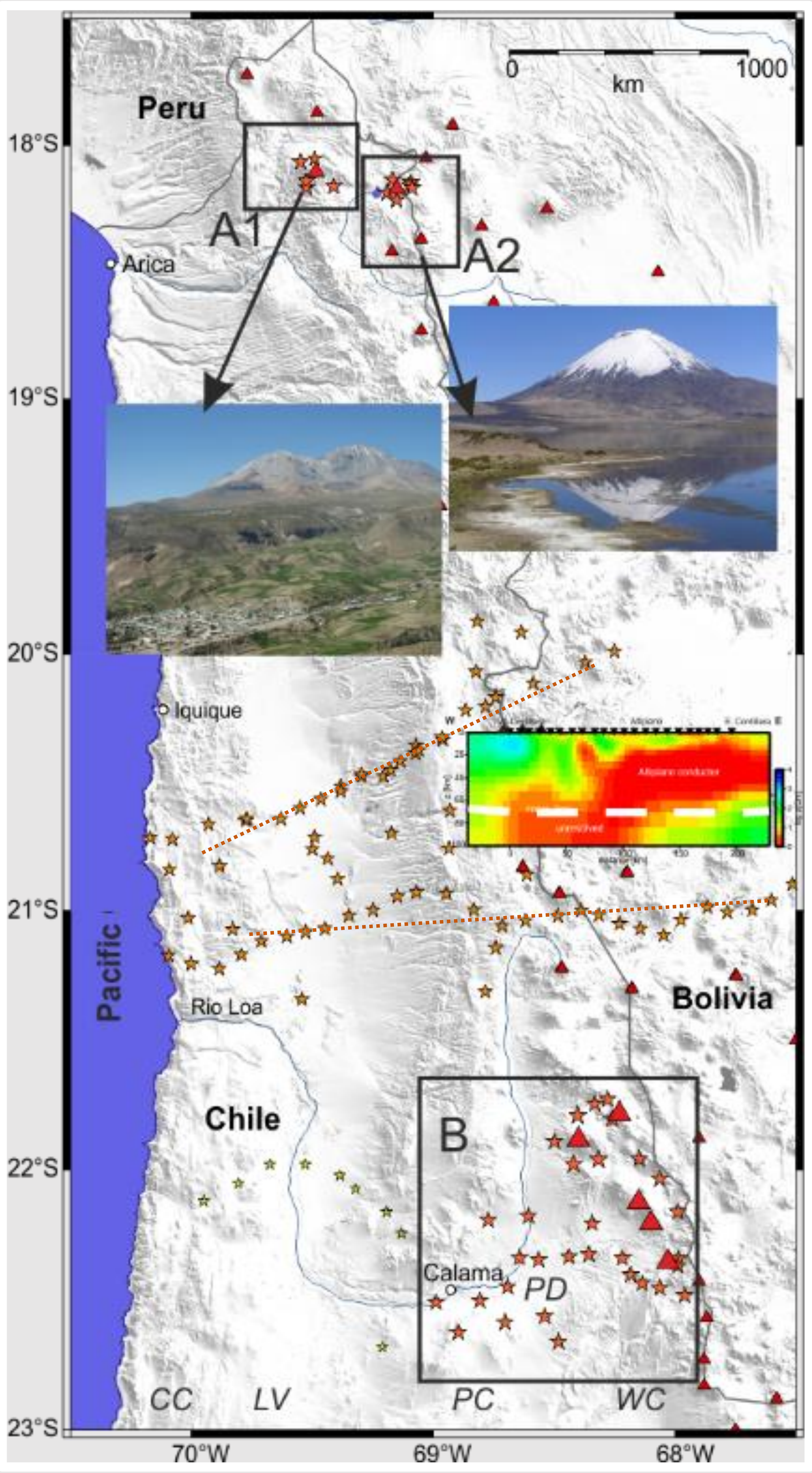


Fig. 1: Map of the investigation areas in Northern Chile. Stars mark the magnetotelluric (MT) sites in this area. Rectangles A1 and A2 (at ~18°S) and B (at ~22.5°S) are areas for which 3-D modeling with the ModEM 3D inversion algorithm was performed. The dotted lines indicates the location of the MT profiles Pica (north) and ANCORP (south). The electrical resistivity distribution of the Altiplano-Puna Magma Body (APMB) are shown in the middle part of the map. The 2-D inversion model at 21°S along the ANCORP line is by Brasse (2011). The image represent the most prominent conductor in this part Andes. CC-Coastal Cordillera; LV-Longitudinal Valley; PC-Precordillera; PD-Preandean Depression; WC-Western Cordillera; triangles show the location of the volcanoes.

Conclusions Area A1 and A2

The AMT study confirms the existence of both magmatic structures.. However, the layer of Taapaca volcano is located southward of the peak, it seems reliable as volcanoes tend to have a trending side for the magmatic chamber based on their torispherical structure. Additional geochemical researches go along with the MT results concerning the depth of the magmatic reservoir. We performed sensitivity studies on both volcanoes to confirm the existence of each feature. The results were positive.

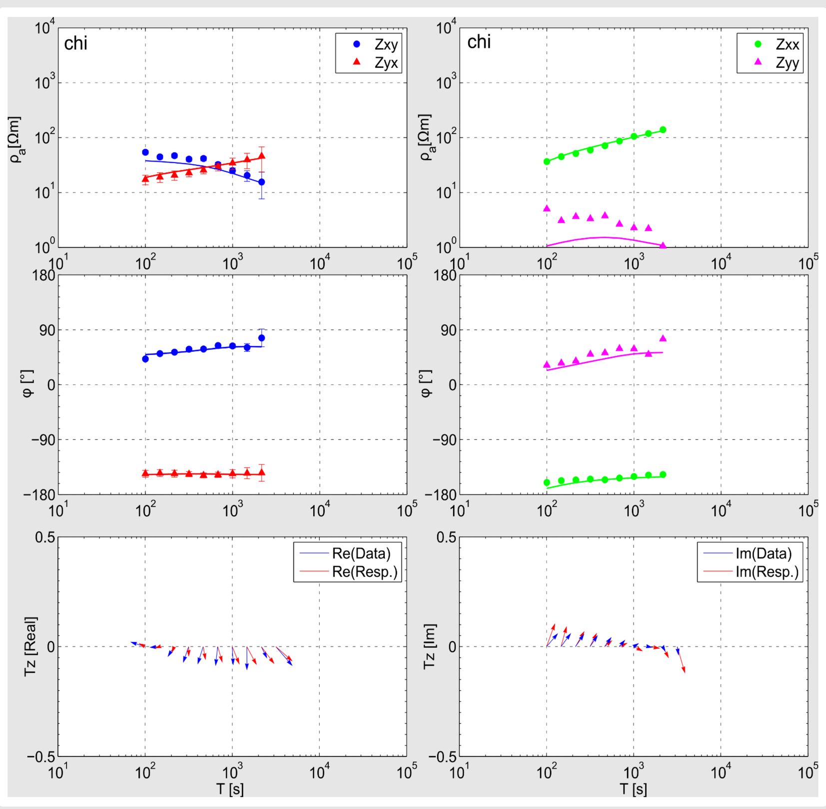


Fig. 6: Apparent resistivity, and phase and tipper at sites tao and chi with an RMS= 2.09. Derived from the off-diagonal (left) and the main diagonal (right) elements of the impedance tensor Z and tipper. Solid lines represent the response after the inversion with ModEM. It turned out that the 3-D model with a covariance set to 0.2 and tipper set to an error floor of 0.03 (impedance tensor set to an error floor of 0.05) fits the data best.

Acknowledgements

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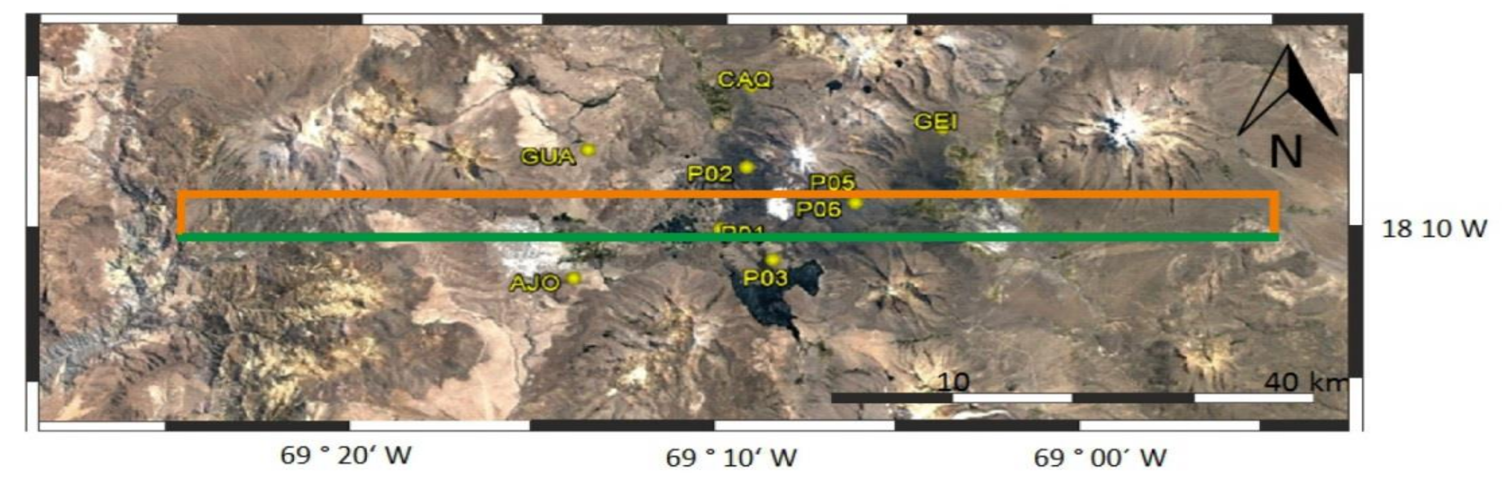
3-D inversion study on two stratovolcanoes in the Central Andes (Area A1 and A2)

In autumn 2007, an MT survey was conducted in the Central Andes at 18°S. Among others, a detailed study on two stratovolcanoes Parinacota and Taapaca was part of the field campaign. Previous studies indicated three-dimensional effects beneath two stratovolcanoes Parinacota and Taapaca, but 3-D forward modeling could not resolve any conductor in the upper crust. A new 3-D MT inversion study of AMT data was carried out and could resolve a good conductor at shallow depths for each volcano, respectively. The estimated depth of the magmatic layer of Parinacota is located in 8 – 10 km and for Taapaca in 6 – 8 km.

Investigation area A2



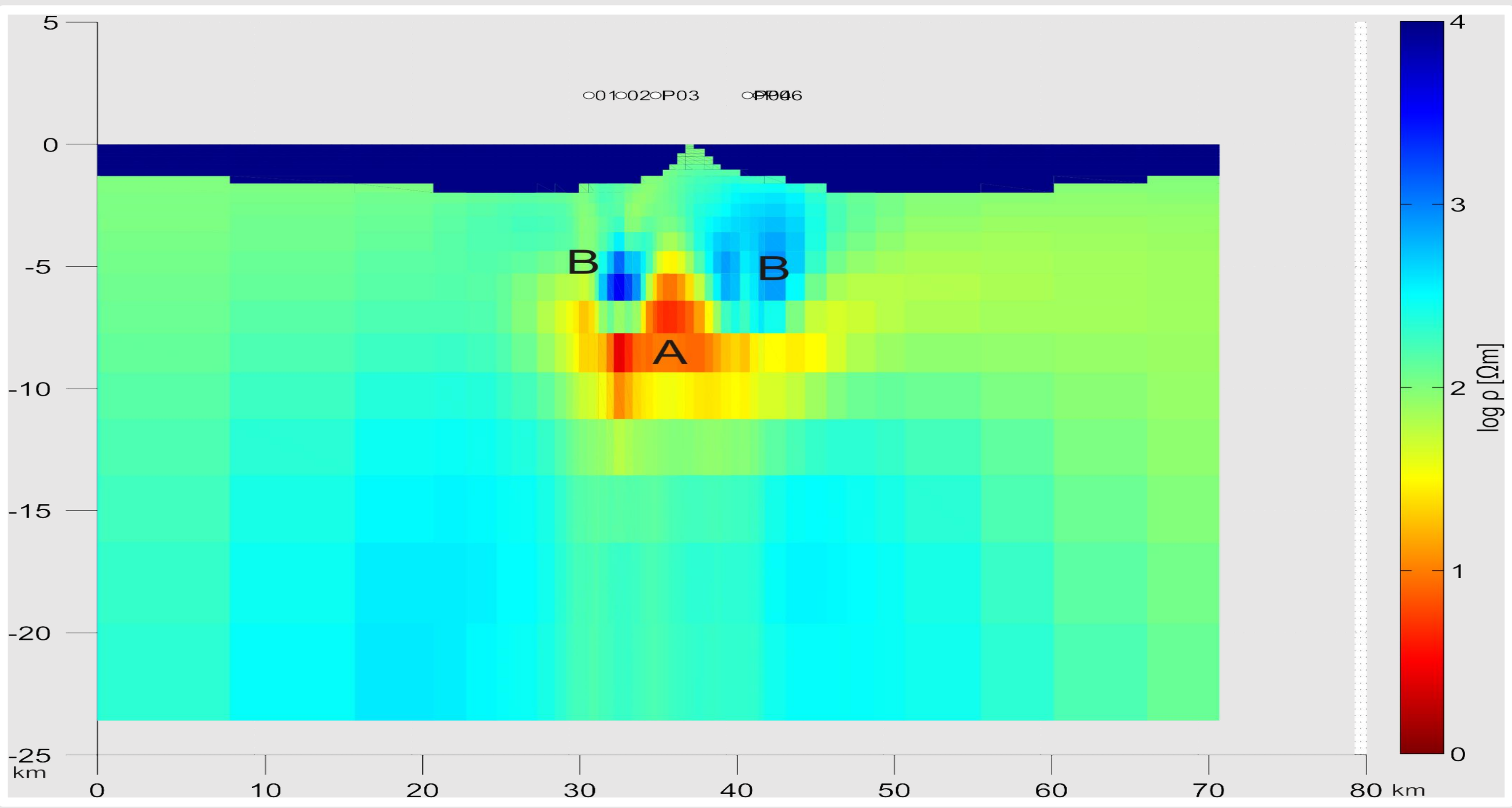


Fig. 4: **3-D inversion model of volcano Parinacota (RMS = 1.43)** after 134 iteration with a background resistivity of 100 Ωm. Well conductive feature (A) with an apparent resistivity of 1 Ωm beneath volcano Parinacota. Higher resistivity structure (B) in the subsurface around the volcano complex. The green array delimits the profile which illustrates in the image above

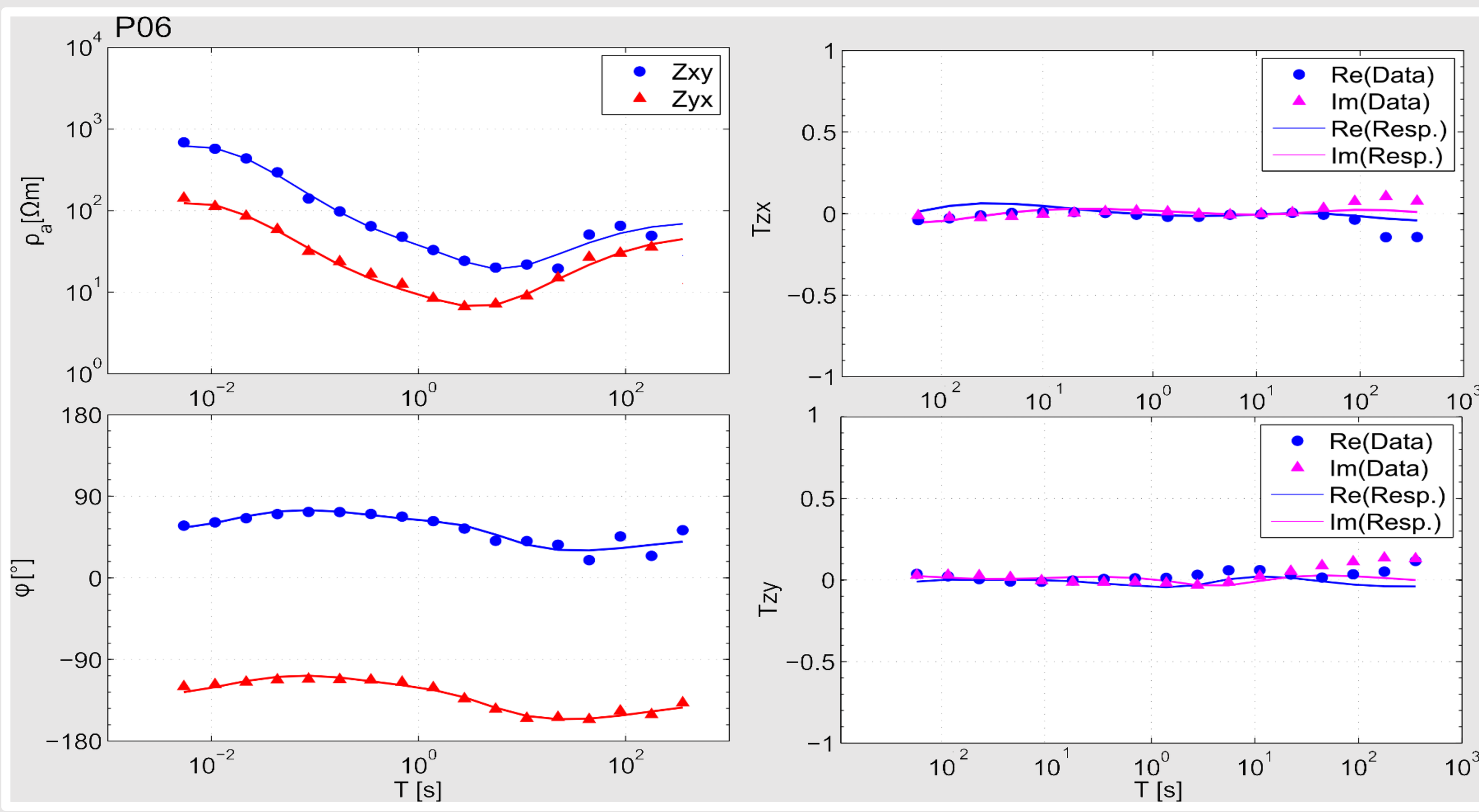


Fig. 5: **Apparent resistivity and phase curves for off-diagonal impedances at site P06 and tipper function for volcano Parinacota**. The general fit is satisfying, although 'longer' periods face problems with the fit.

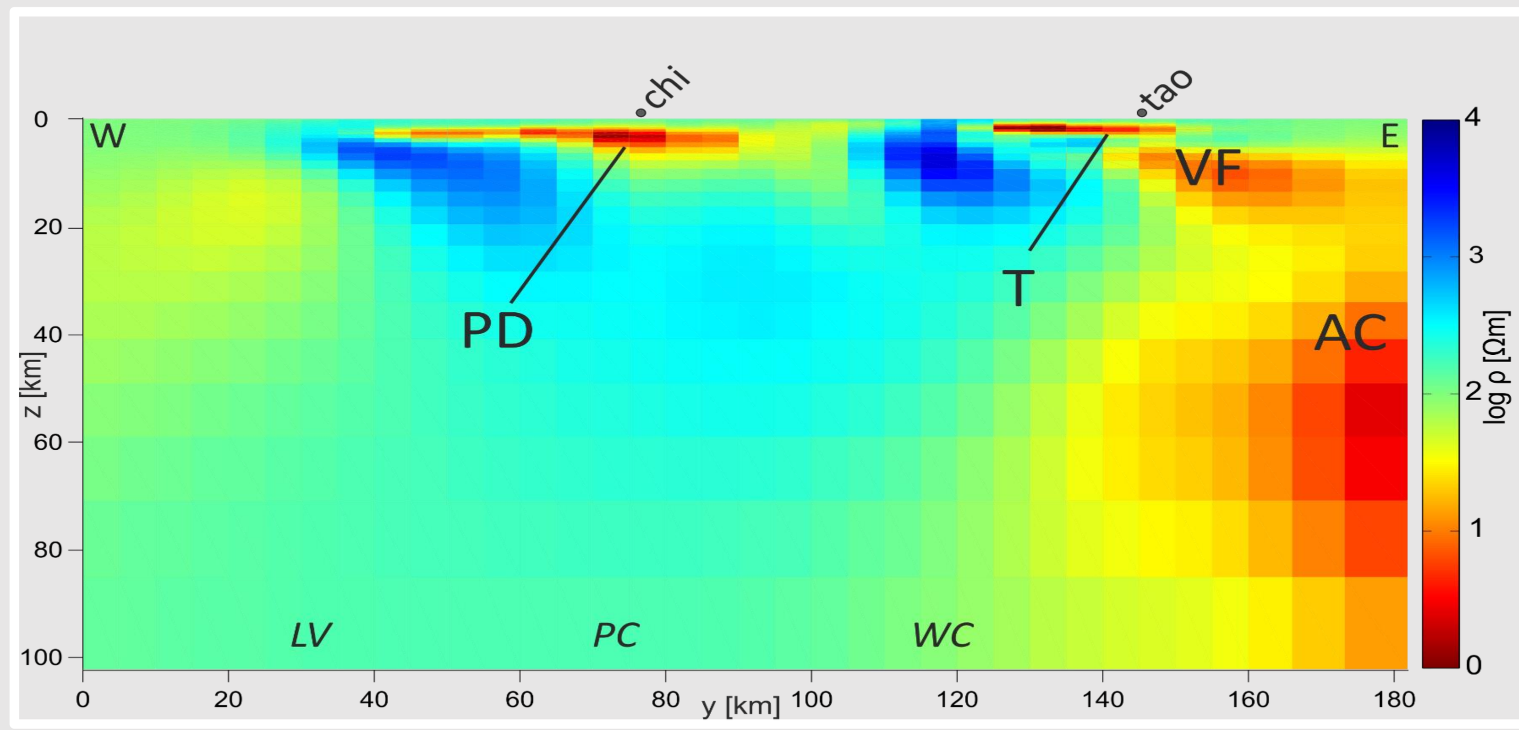


Fig. 5: **Resistivity distribution along depth (RMS=2.09) of the preferred model at around 22.5°S in study area A.** AC-Altiplano conductor; VF-Conductor that belongs to the Volcanic arc; T-conductor correlating with the El Tatio Geysers. Grey dots: MT sites closest to the selected section and shown in Fig. 4.

Conclusion Area B

Resistivity distribution beneath the volcanic front suggest the presence of partial melts in the crust, which is also reported by other geophysical investigations e.g. Haberland and Rietbrock (2001); Schurr and Rietbrock (2004). The less conductive structure associated with the West Fissure supports the assumption by Kühn et al. (2014) and Brasse et al. (2002) that its conductivity increases towards the north. Conductive spots correlate with upper crustal magma chambers of the volcanoes along the Bolivian border. The highly conductive structures extend to one more less trench-parallel conductive structure. Owing to limited resolution and the insufficient site spacing, it stays unclear it this structures merge into one continuous lineament. The Altiplano Conductor is naturally only imaged at its western margin, but its location is consistent with previously obtained results of Schwarz and Krüger (1997) and closes at least partly the gap between ANCORP and Pica investigations between 20°S-22°S.

References

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