Three-dimensional modeling of magnetotelluric data in El Tatio - La Torta Geothermal system, North Chile

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SUMMARY

During 2017, 19 magnetotellurics stations in the El Tatio-La Torta geothermal system were measured (Figure 1). Although there are several studies in this zone, the geothermal system characterization is not clear. Therefore, this work pretends to help to perform a three-dimensional modeling of magnetotelluric data through ModEM algorithm. The last inversion results in Figure 2, where there are differents structures associated with La Torta dome (R1), Copacoya dome (R2), Laguna Colorada caldera complex (C1), San Pedro formation (C2) and shallows conductors interpreted as hidrothermal alteration.

Keywords: Geothermal system, Magnetotellurics

INTRODUCTION

Chile is in a convergent margin where, as a consequence of the subduction of the Nazca plate under the South American, the volcanic arc of the Andes has been developed. It hosts more than 200 potentially active volcanoes and at least 12 giant caldera systems (Siebert et al, 2011) These volcanoes have magma at the crustal scale that could serve as sources of heat for the development of local geothermal systems that have the potential to generate clean and sustainable energy (Lahsen, 1986).

El Tatio Geyser field, which has over 100 erupting springs, is the largest geyser field in the southern hemisphere. It is located within the Andes Mountain of northern Chile at 4200 meter above mean sea level (Glennon and Pfaff, 2003). It is in the Altiplano-Puna Volcanic Complex (APVC), which through seismic evidence (Chmielowski et al, 1999), it is proposed to host a regional magma body. The volcanic history on El Tatio, according to Lucchi et al (2009), began in the Miocene and, during inactivity periods begins to act erosives and structurals processes, in addition to the deposit of ignimbrites from external sources.

The exploration in this zone began in 1921 and there has been several surveys (Lahsen and Trujillo, 1976; Cusicanqui et al, 1975; Cumming et al, 2002; Lucchi et al, 2009) in differents periods. Nonetheless, it is not clear the characterization of El Tatio-La Torta geothermal system. Moreover, the computational performance has advanced and today it is possible to perform a 3D inversion through MT data. This work does characterization through depth electrical conductivity structures.

METHODOLOGY

During March and October 2017, 19 magnetotelluric (MT) stations in El Tatio - La Torta geothermal system were installed, they are approximately 1 km apart. Between El Tatio and La Torta wasn't possible install stations due to the inaccessibility part (Figure 1).

The MT method measures natural time-varying electromagnetic waves on the surface to probe the subsurface electrical conductivity (σ , the inverse of resistivity $\rho = 1/\sigma$) (Chave and Jones, 2012). We process the MT data through robust method Egbert and Booker (1986) and we also determinated the strike using algorithm Smith (1995) and phase tensor Caldwell et al (2004) to realize dimensional analysis.

Finally, we modeled MT data with ModEM algorithm (Kelbert et al, 2014) that it is based on Non-Linear Conjugate Gradients (NLCG) and parallelized using MPI, allowing to work with the computational capacity of vatious multi-core PCs, in this case, we worked with Leftraru cluster from Center for Mathematical Modeling (CMM) at Universidad de Chile.

To do the inversion, we applied 3D-Grid program to data mask to smothed curves and delete poor data quality. Also, we performed the grids testing differents cells sizes in x-y-z direction to reduce RMS. We used full impedance, tipper and topography. The preferred model was model with a covariance 0.2, cell number 78-43-144 in x-y-z directions, the tipper error floor 2 %, the impedance error floor 3% for Z_{xy}-Z_{yx}, and 5 % for Z_{xx}-Z_{yy}, using data error 20 % for Z_{xx} -Z_{yy}, and 5 % for Z_{xy}-Z_{yx}. In the last model got, after 149 iterations, an RMS of 2.89.

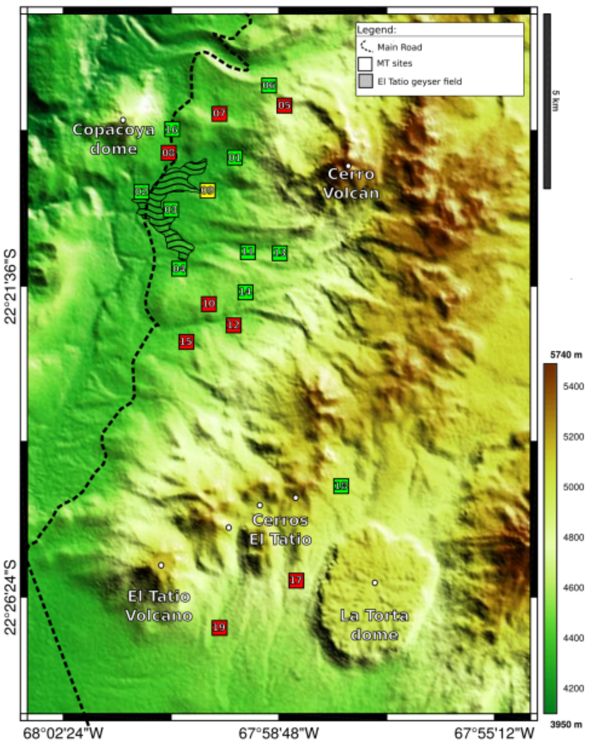

Figure 1: Study zone and location sites. In red stations measured without tipper, in yellow station with problems due to wire cut of N-S dipole and in green stations without problems.

Results and Discussion

Several sensitivity tests were done, replacing the condutors with original background resistivity (100 Ωm) and run forward model. The results for these tests increased the RMS.

The last model is shown in Figure 2 with two fit curves for stations T04 and T10. Due to wells correlations (Lahsen and Trujillo, 1976), the shallows conductors in El Tatio geyser field are interpreted as hidrothermal alteration, possibly clays. Moreover, the principal aquifer is in Puripicar ignimbrite with a resistivity betwen 40-75 Ωm due to different levels of fracturing and irregular permeability.

The resistor R1, which is under of La Torta dome, it is a rhyolite dome and the last volcanic event in the zone. According to Cumming et al (2002), it is the up-flow zone of the geothermal system and we had similar results with differents scales, possibly due to the method used, where they derived from 2D smooth inversions supplemented by a 3D smooth inversion. The high resistivities would be due to porosity, which tends to decrease with depth and this reduces the effect of bore fluid conditions, thus reinforcing the resistivity increase, countering to some extent the effect of higher salinity that is commonly inferred to lie in deeper parts of most systems (Ussher et al, 2000). Moreveover, this has been seen in others geothermal systems as Darajat, Indonesia (Rejeki et al, 2010) and Glass Mountain, California (Cumming and Mackie, 2010), where the hotter parts of geothermal systems are characterised by higher resistivity. The resistor R2, is associated with Copacoya dome, which is a dacitic dome, that serves as a geologic barrier, don't permiting that fluids pass to the west, rising to the surface through geothermal manifestations.

The conductor C1, is asocciated with Laguna Colorada that is a caldera complex and produced the Laguna Colorada ignimbrite 1.98 Ma (Salisbury et al, 2011) and results of Comeau et al (2015) show a conductor in this zone too. Moreover, Fernandez-Turiel et al (2005) said that it is where likely that the water become heated. The conductor C2, is in thermal inversion zone (according to wells data Lahsen and Trujillo (1976)) and could be due to San Pedro Formation, that is the basament of the zone and is compost of red gypsum clays secuences, red and gray sandstones, gray conglomerates and mantles of salt and gypsum (Marinovic and Lahsen, 1984) and it is possibly altered.

CONCLUSIONS

The current computational performance allows better results in MT data inversions. This work could be improved by including more MT stations to better delimit some structures, but it have a good correlation with previous studies (Lahsen and Trujillo, 1976; Cusicanqui et al, 1975; Cumming et al, 2002; Lucchi et al, 2009). It was shown in Figure 2:

- Shallows conductors due to hidrothermal alteration.
- R1 is under of La Torta dome, and likely the hotter part of geothermal system.
- R2 associated with Copacoya dome that act as a geologic barrier to fluids.
- C1 associeted with Laguna Colorada caldera complex.
- C2 associated possibly with San Pedro Formation.

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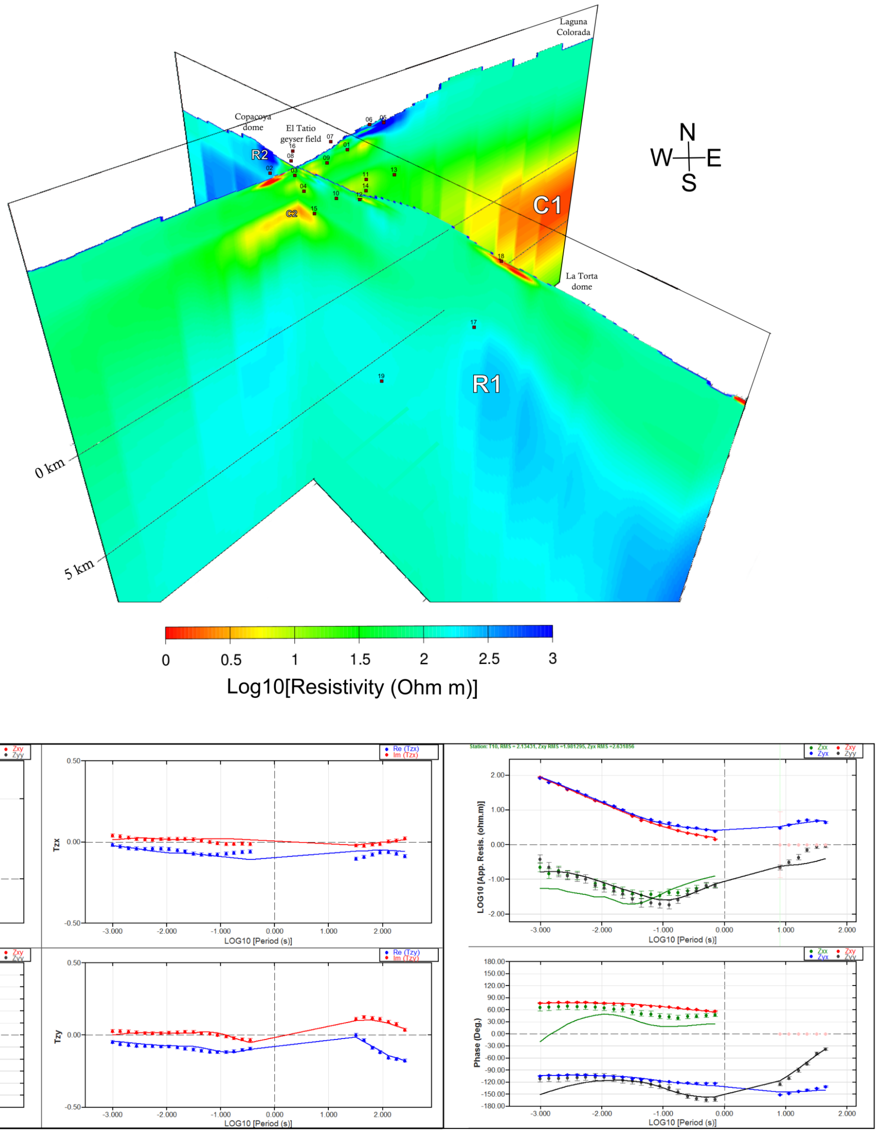

Figure 2: Upper: Electrical resisitivity image from the last model inversion and main conductors and resistors structures. Botton: Examples of two fit stations T04 and T10.