3-D magnetotelluric inversion for geothermal exploration in Socompa volcanic zone, NW Argentina

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SUMMARY

The Socompa volcano lies in the arid core of the Puna region. It is a stratovolcano whose summit reaches 6,051 m high and it is located between the limit of the Antofagasta region, Chile and the Province of Salta, Argentina. The volcano is located in a sterile environment, and the diversity and abundance of life that has been documented in the region is explained through a geothermal system revealed in the form of fumaroles and hot springs of stable temperatures. These manifestations suggest the importance of a magnetotelluric (MT) research to study a potential geothermal field that has not been explored. The MT method has been widely used in geothermal exploration.
In December 2017, we carried out the first survey in the region. The present work is oriented to determine the top of the layer that could be the reservoir of the geothermal system. According to the literature, thermal manifestations are located in the Socompa Lagoon and in Quebrada del Agua fault. The survey consisted in 34 MT stations that covered the area. A 3D inversion was performed employing the ModEM code using a frequency range from 1 to 1000 Hz. The results showed a highly conductive layer at approximately 450 m depth.

Keywords: Magnetotelluric, Socompa volcano, Geothermal field

INTRODUCTION

Socompa volcano is the most voluminuos stratovolcano of the Central Volcanic Zone in western South America, where volcanism is due to the Nazca plate subduction below the South American plate. The volcano presents on its northwest flank an extensive scar caused by the collapse of a portion of the building that produced a large avalanche of debris (25 Km^2) (see Figure 1). The age of a deposit related to the collapse was estimated about 7200 years ago. There was evident post-avalanche activity, including lava flows and dacitic domes within the scar of the avalanche that has not been dated (Grosse et al, 2017). The southeast flanks present a steep slope towards a basin that is 3400 m above sea level, and that contains the Socompa lagoon (Argentina) where a small stream and a number of seeps bring hydrothermal water from the volcanic system into the lagoon (Farias et al, 2013). The main structural features are Quebrada del Agua fault and to a system faults from the circular lineament of dacitic domes that delimit the low of the lagoon and the low that surrounds the volcano (Seggiaro and Apaza, 2018).

Quebrada del Agua Volcano-sedimentary Complex at 200 m depth is the formation that is expected be acting as seal and reservoir of the geothermal field. It is composed by piroclastites, conglomerates, andesites and dacitic and riodacitic domes and it is assigned to the upper Oligocene-Lower Miocene period (Zapppettini and Blasco, 2001). Three members were identified, lower, middle and upper, with estimated thicknesses of 110 m, 200 m and 230 m, respectively. Above Quebrada del Agua Complex there are andesitic and dacitic lavas (Seggiaro and Apaza, 2018). In the region the formations are mainly resistive and if there is a hydrothermal process the alteration of the clays would lead to a significant decrease in resistivity (Muñoz, 2014).

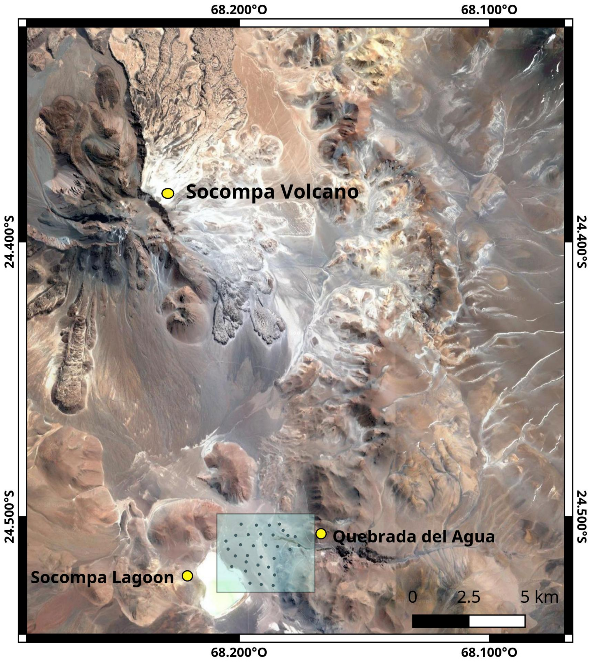

Figure 1: Socompa volcano and main regional features. The light blue area shows the MT sites distribution.

3-D INVERSION

For 3-D inversion we used ModEM code developed by Egbert and Kelbert (2012). The 34 MT sites are separated around 500 m. In total the model has 45x50x105 cells in the X, Y and Z directions, respectively, where the X axis point towards geographic north, the Y axis towards east and the Z axis down. The horizontal cell size is 170 m in X and 150 m in Y direction, consider at list a cell between sites, and out of the area cells increment by a linear factor of 1.2. In vertical, the thickness of the first cell was 5 m and the increment applied was lineal in a factor of 1.05.

To determine the best half-space value for the prior model multiple inversions were carried out, and the value chosen was 30 Ωm since it has the best nrms fit. The inversion was performed using 32 periods from 0.001-1 s, and in this first step we inverted off-diagonal impedance tensor elements. Error floor was set at 5 $\%$ of $|Z_{xy} * Z_{yx}|^{1/2}$ and the covariance in 0.3 in all directions.

RESULTS

After 80 iterations, the final nrms achieved was 1.81.

Previous inversion, 1-D analysis of each site was carried out using the Winlink code. From this analysis it was observed that the resistivity drops drastically from hundreds of Ωm to values close to 1 Ωm for an average depth of 500 m. In order to validate the results a half-space of 30 Ωm with a layer thickness of 200 m of 1 Ωm at 500 m depth covering the region where it is expected was considered as prior model. The parameter that was modified until the discrepancy between the models was negligible was the increase in Z. For a linear increase of 1.15, the greatest difference between the half-space model and the half-space model with the layer is the resolution of the thickness of the conductive layer, being much greater for the first case. As the increase considered decreases, this discrepancy becomes smaller. Finally, for an increment of 1.05 the final nrms of the half-space with the layer was 1.85 and the models do not show considerable differences. For all the increments considered, the depth of the conductive layer did not vary significantly.

Figure 2 and Figure 3 shows the principal structures observed. The model presents:

- A resistive layer (> 500 Ωm) on the surface
- Conductive bodies (< 5 Ωm) near lagoon
- A layer of low resistivity (< 5 Ωm) at a depth about 400-500 m with a thickness of 150 m covering the study area

Under the conductive layer the model can not resolve structures.

The surface layer that covers the area is resistive as expected for volcanic rocks. The conductive bodies observed near surface in the vicinity of the lagoon are associated with seeps which bring hydrothermal water into the lagoon. Finally, the conductive layer is associated with hydrothermal alteration, and since the depth of the Quebrada del Agua Complex is around 200 m is estimated that it is associated with the upper and/or middle member.

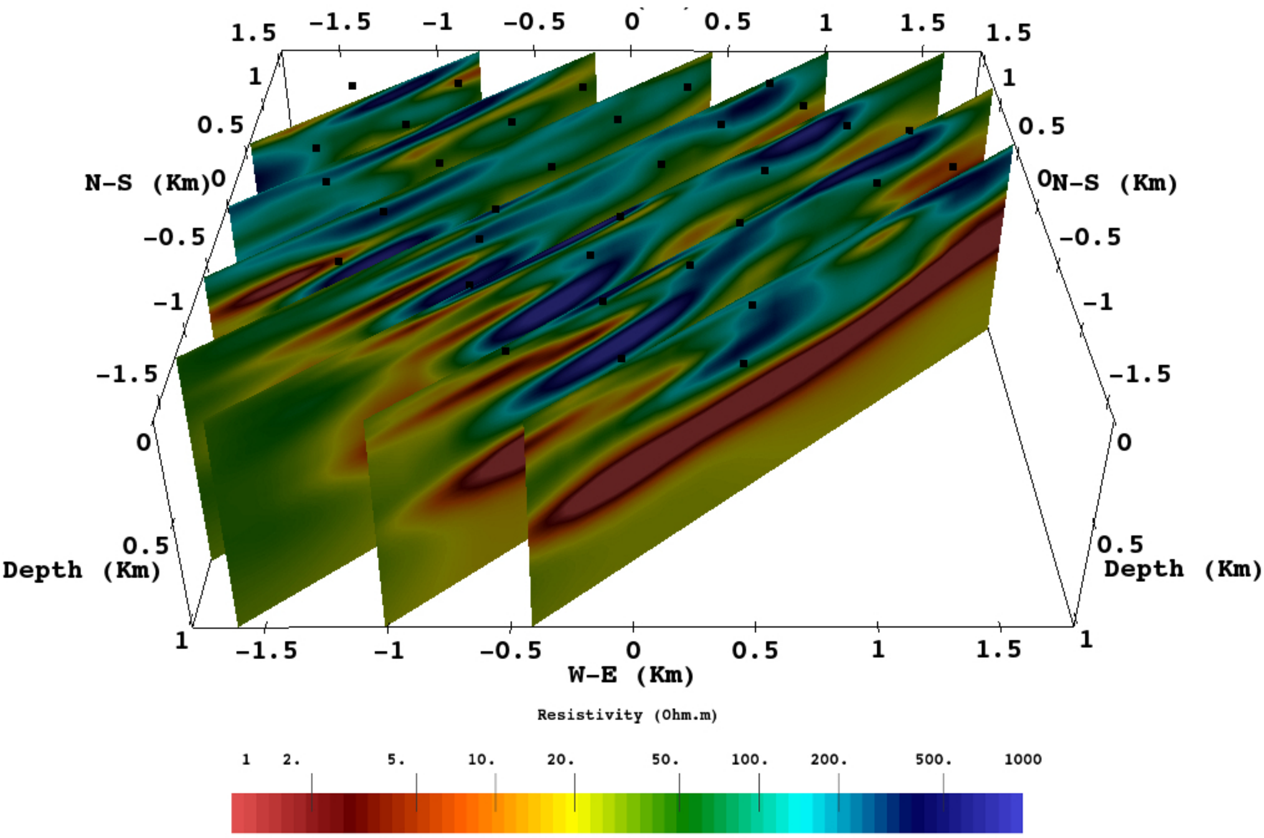

Figure 2: Vertical slices in the direction of Quebrada del Agua-Socompa Lagoon (NE-SW).

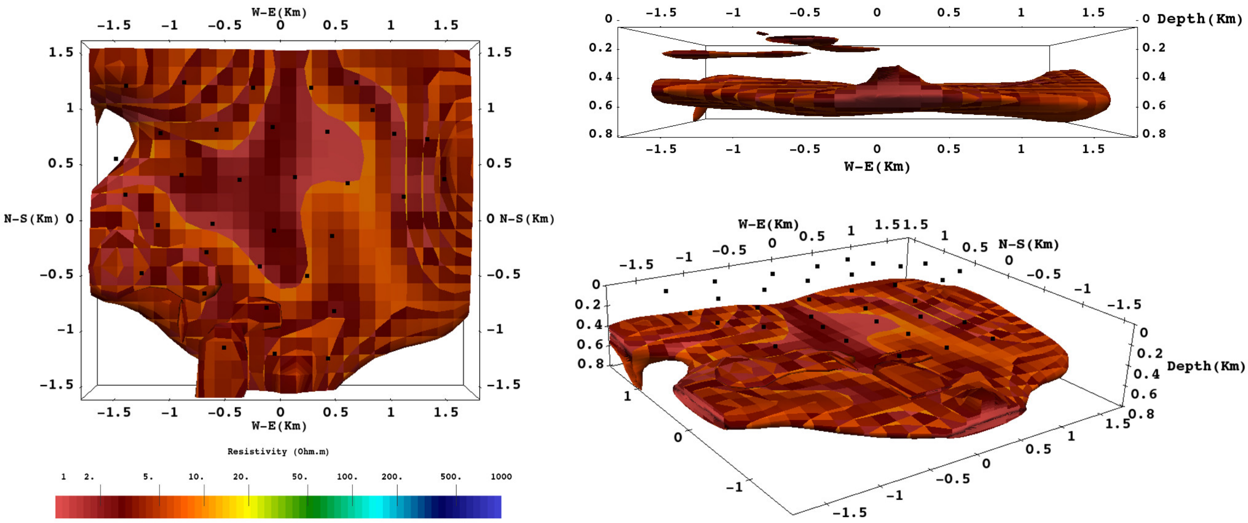

Figure 3: Conductive structures (< 5 Ωm).

CONCLUSION

From 3-D inversion a surface resistive layer (> 500Ωm) associated with volcanic deposits was observed. At 400-500 m depth, a conductive layer (<5 Ωm) of 150 m thickness was detected associated with hydrothermal process that would take place in the upper and / or middle member of Quebrada del Agua Complex. Under the conductive layer a resistive layer associated with the geothermal reservoir is expected but the model can not determine structures below it.

In order to delineate the boundary of the resource field, in October/November 2018 another survey will be carried out to cover the southern region of Socompa lagoon. It will also MT data be registered with other equipment that covers longer periods in order to study the structures below the conductive layer and to try to delimit the heat source of Socompa geothermal field.

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