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Interpolations from Vertical Electrical Soundings for the Characterization of the Geothermal System of the Municipality of Paipa, Colombia

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Keywords

Vertical Electrical Soundings, Geothermal System, Paipa, Interpolations

ABSTRACT

As a complementary study to the geothermal system of the municipality of Paipa, the geophysical method of Vertical Electrical Soundings (VES) was applied, with the objective of identifying the spatial distribution in the subsoil of the hydrothermal fluids and understanding their possible relationship with the geological structures mapped on the surface, from its electrical variations. For this, 152 stations were acquired, which were processed for the construction of one-dimensional models (1D) of layers reaching an average research depth of 350 m throughout the work area, and then the interpolation methods were applied based on Simple Kriging and Kernel smoothed at different depths for the construction of resistive prediction models of the subsoil. The results showed very conductive layers less than 10 Ωm, possibly associated with evaporite deposits from the Salpa sector east of Sochagota Lake, where the inclination of the terrain would favor their accumulation or perhaps this electrical response is due to the contribution of the fluids from thermal springs that present sulfated and sulphated sodium chemical compositions. It was also possible to identify areas with high values of resistivities of the order of 2000 Ωm probably associated with the Tibasosa-Toledo anticline to the SE of the area, and a conductive corridor in the NW direction possibly associated with hydrothermal fluids transported through the basement Fault of Cerro Plateado. Regarding the SE sector (vulcanitas) of the study area, the identified conductive anomalies could be due to the weathering and the presence of arcillolites from the volcanic deposits.

1. Introduction

As part of the activities of the Geothermal Resources Research and Exploration Group of the Colombian Geological Survey, and as the main stage of pre-feasibility studies for the exploration of geothermal resources, work was carried out to acquire Vertical Electric Soundings (VES) for the geothermal area of the municipality of Paipa in Boyacá department (Franco (2016)). The objective of implementing this geophysical method consisted in identifying the spatial distribution of hydrothermal fluids and understanding their relationship with geological structures, for which a total of 152 VES were recorded (Figure 1), which were processed by constructing models 1D for each station and from these models were created interpolation of the electrical resistivity in depth.

The geothermal area of Paipa, was classified by OLADE, ICEL & GEOTERMICA ITALIANA, 1982, as an area of interest with high-medium priority, based on surface geological information. Subsequently, from the review of the previous study and a visit to the area, the Japan Consulting Institute (1983) conceptualized that it is possible to find a promising geothermal reservoir for the exploitation of the resource in power generation. Alfaro et al. (2016).

The main recharge of the reservoir of the geothermal system occurs from the south and southeast (Tibasosa – Toledo Anticline) through the Une Formation. The deep recharge to a possible reservoir lodged in the basement, would occur through extensive structures such as faults, crosses between faults and planes of contact between the igneous intrusions and the rocks of the basement and the sedimentary coverture. The upward flow of fluid from the deep reservoir accumulates in the Une formation, forming a sedimentary reservoir, between igneous intrusions, south of the Cerro Plateado fault, through which it initiates a lateral flow to the main discharge zone, in the ITP sector (Institute of Tourism of Paipa) – Lanceros. Alfaro et al. (2016).

In the geothermal area of Paipa there discharge zones (sources of interest are El Hervidero, Olitas and SALPA named after the name of the sodium sulfate benefit factory in these are located) characterized by the occurrence of thermal springs which are presented in figure 1. The main discharge area of the geothermal system, the ITP-Lanceros sector, is located southeast of Sochagota Lake at the junction between the El Hornito and El Bizcocho Faults, near the Labor and Tierna outcrop, which is highly permeable (Alfaro, 2002). In this sector at least eleven springs are located, most of which are used for the swimming pools of the hotels of the municipality. The maximum temperature registered by these springs is 70 ° C. These are sulphated sodium waters with a neutral pH and high electrical conductivity (up to 56 mS / cm), with maximum SiO_2 concentrations of around 60 mg / L and abundant gas discharge. Alfaro et al. (2016).

A series of longitudinal faults have also been identified that allow knowing the local behavior of the Boyacá and Soápaga faults considered as the regional structures of the study area. From the west to the east lies the NNE El Bizcocho Fault, considered to be riding with vergence to the east, where the contact between the Guaduas and Labor and Tierna formation is observed, El Batán Fault has its takeoff at the base of the Plaeners formation and has occurrences of thrusts with vergence to the east, Rancho Grande Fault is oblique its vertical component has a vergence towards the west, this structure affects the deposits of the Tilatá Formation, Buenavista Fault acts as a thrust structure with vergence to the northwest and takeoff in the Churuvita group, Agua Tibia Fault is a rectilinear line, discontinuous and interrupted by NW Faults, it is assumed as a inverse Fault inclined to the west, which in turn generates thrusts with vergence to the NorthWest, Lanceros Fault is of the inverse type and considered as retrocabalgamiento fault. Now the NW transversal Faults are observed especially to the southeast of the area where the Cerro Plates and Paipa-Iza Faults were identified that are located through the volcanic deposits and are interpreted as basement Faults that preserve the character of open fractures facilitating the passage of hydrothermal fluids, rise of magmas giving rise to the volcanism of the area. While between the NE Fults, El Hornito Fault can be distinguished, Canocas Fault with dextral direction component and the Santa Rita Fault that affects the Guaduas formation and displaces the sandstones of the Labor y Tierna formation in a dextral form. Velandia (2003).

Paipa geothermal area (Figure 1) is located in the 5 ° 38 ' N and the 5 ° 45' N of latitude and the 73 ° 08 'W and the 73 ° 10' W of longitude the eastern part of Colombia on the Eastern Cordillera in the Sogamoso Valley (Boyacá department), It has an average height of 2525 -3150 meters above sea level.

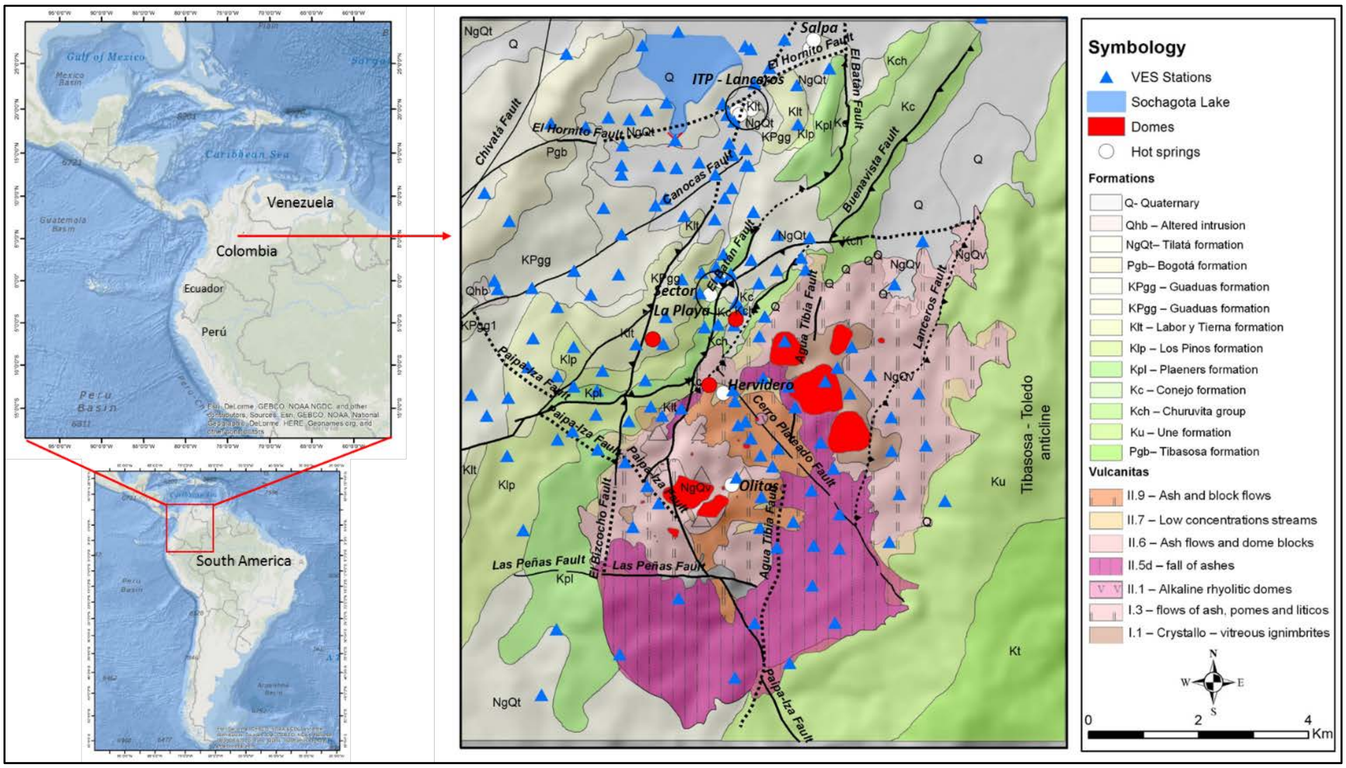


Figure 1. Location map of VES stations. Geological mapping: Velandia (2003). Vulcanite mapping: Cepeda y Pardo (2004). Domes mapping: Rueda (2016). VES: Franco (2016).

2. Methodology

For the approach of the Vertical Electric Soundings processing methodology, acquisition campaigns were proposed, 1D layer models were proposed and the interpolation methods for the construction of the prediction resistive models were applied.

2.1 Acquisition of Electrical Sounding

For acquisitions, the Schlumberger electric method was considered, with openings of the current electrodes of 1400 m and located mainly on areas of intersections between geological Faults and proximity to surface hydrothermal manifestations (Lozano (1990), Hidroceron Ltda. (1998), Moyano (2010), Franco (2016)).

2.2 1D models

To define the number of layers in the one-dimensional models in each of the Vertical Electric Sounding, it was taken into account that the apparent resistivity curves did not show abrupt changes in the resistivity value in the plot of the curve and the adjustment of the experimental curve with the theoretical one will not exceed an error of 8% (Figure 2).

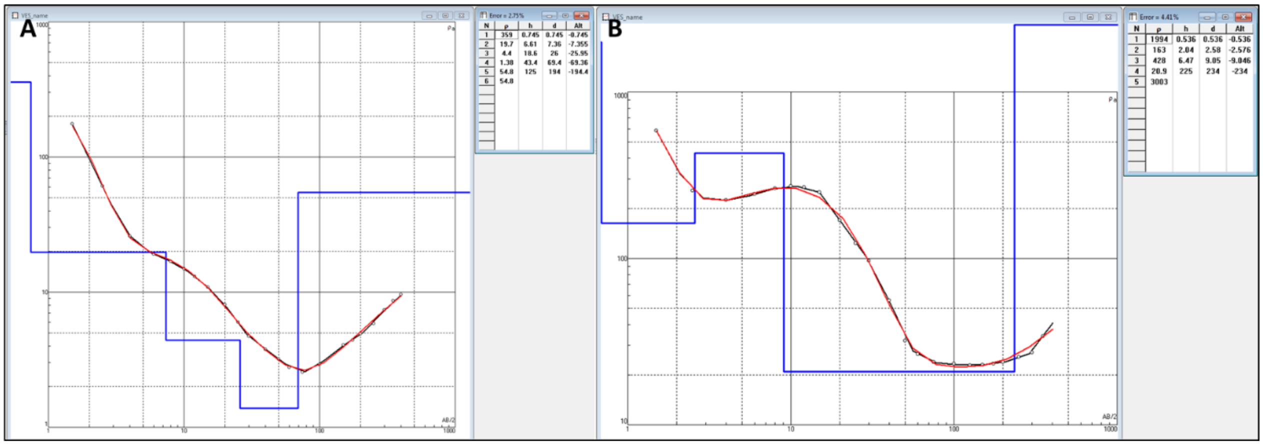


Figure 2. The A and B image represent 1D models of layers from the interpretation of the VES.

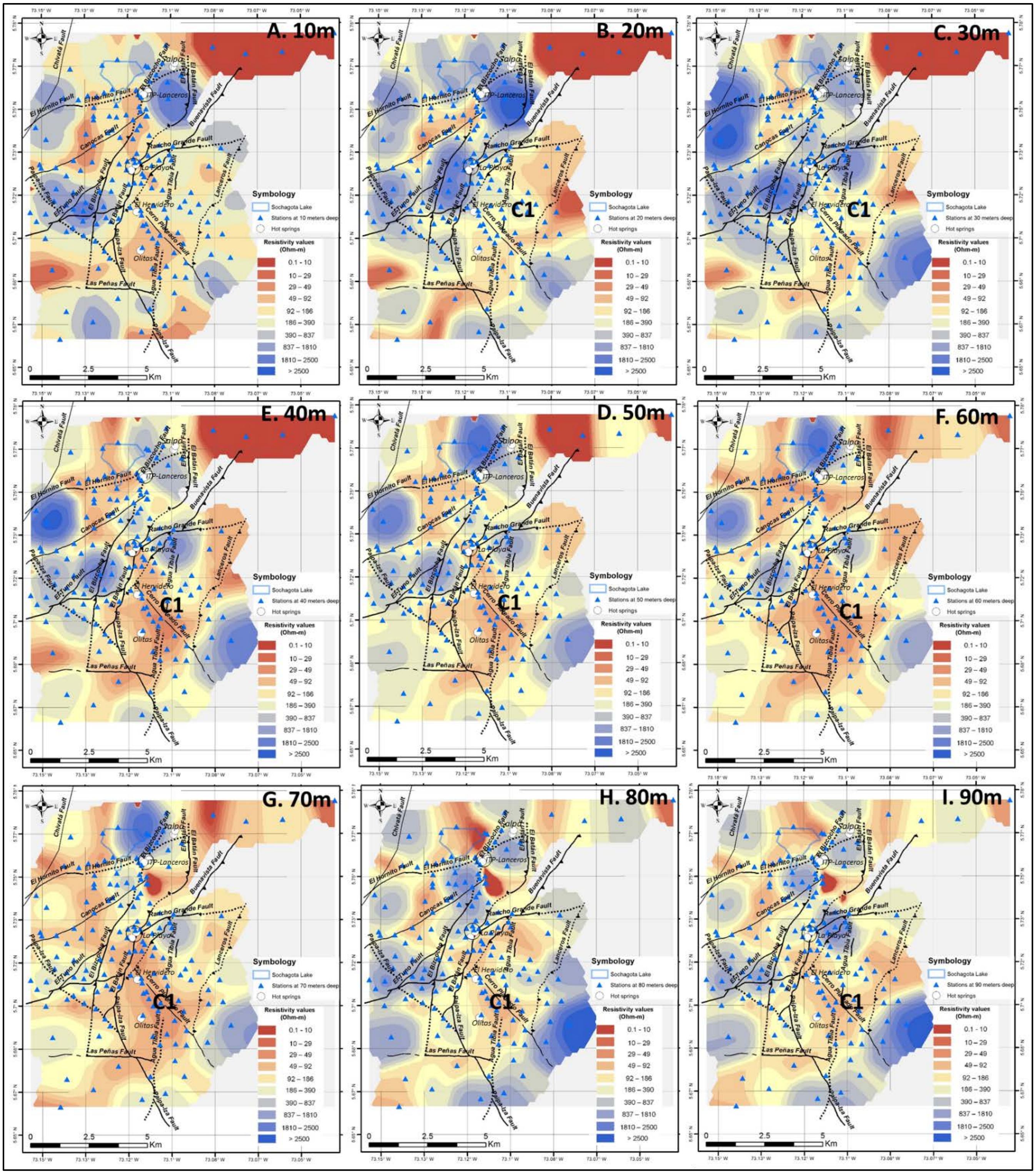
2.3 Interpolation method

Different interpolation models based on the Simple Kriging method were proposed. In each of them, variations were made in the semivariogram models (experimental) calculating for each case the parameters of range, sill, and nugget in addition to considering the size of the space lag with values of 100 m, 400 m, 600 m and 1000 m without exceeding the maximum distance between stations. From this information, we took into account the values obtained from the mean and the root mean squared (RMS) between the theoretical and experimental semivariograms to choose the model that best fits the resistivity data.

As a final step, the Kernel Smoothing interpolation method was used to better constrict the resulting model, mainly to avoid edge effects in areas that were discovered by electrical soundings. In each of the models at different depths, the Gaussian Kernel function was applied with a 650 meters bandwidth (average separation distance between stations).

3. Results

Using the Kernel interpolation method, we used the Gaussian kernel function with a bandwidth of 1000 m which corresponds to the average separation distance of the stations and a smoothing factor with value of 1. In the results interpolations were made according to different depths, which in turn were linked with the layers models that had been previously constructed. According to this, different cuts were proposed beginning with Figure 3A (10 meters deep) and later increasing the depth of investigation as seen in Figures 3B, C, D, E, F, G, H, I, J, K, L, M, N, O, P and Q.


A. 10m
B. 20m
C. 30m
E. 40m
D. 50m
F. 60m
G. 70m
H. 80m
I. 90m
C1
Chivatá Fault
El Hornito Fault
Canocas Fault
El Bizcocho Fault
El Batán Fault
Buenavista Fault
Rancho Grande Fault
Lanceros Fault
Agua Tibia Fault
Las Peñas Fault
Salpa
ITP-Lanceros
La Playa
El Hervidero
Olitas
Symbology
Sochagota Lake
Stations at 10 meters deep
Hot springs
Resistivity values (Ohm-m)
0.1 - 10
10 – 29
29 – 49
49 – 92
92 – 186
186 – 390
390 – 837
837 – 1810
1810 – 2500
> 2500
0
2.5
5
Km

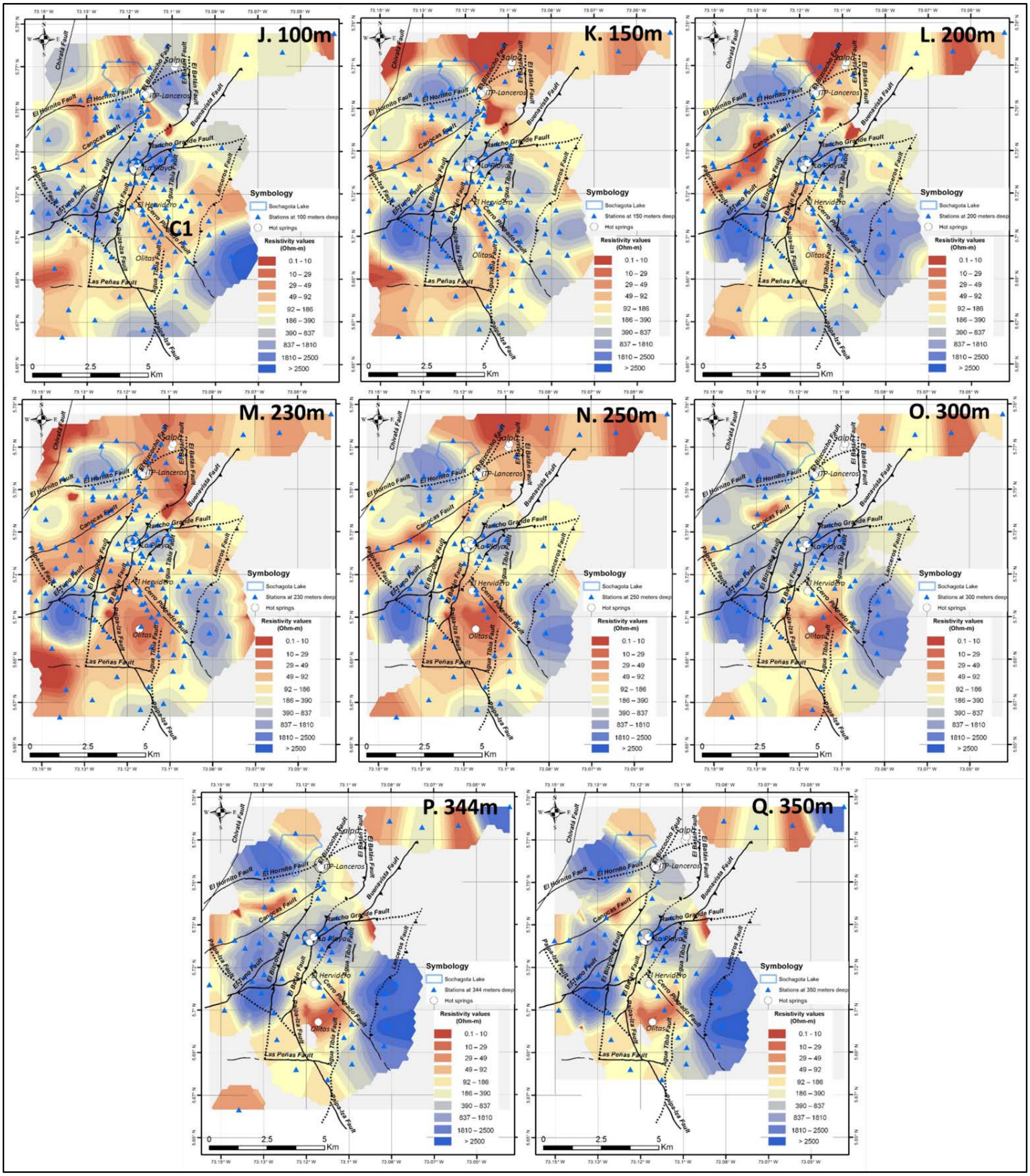


Figure 3. Interpolation models from left to right from 10 to 350 meters deep.

As it went deeper into the subsoil, the information was becoming limited, because not all the surveys that were conducted in the area reached the same depths of investigation. Therefore, it is considered that the uncertainty in the models presented, allows to have confidence up to approximately 350 m.

4. Discussion of Results

In the models it was observed that in the first 50 m depth anomalies of very low resistivity are maintained east of Lake Sochagota associating this behavior to the presence of evaporite deposits in the Salpa sector and to the chemical contribution of the sulphated and sulfated springs sodium present in this area, these anomalies are also marked on the sector of volcanic deposits which could be associated with the level of arcillolitas and weathering in this area. While at a depth of 150 m and with a thickness of approximately 100 m, an area of conductive anomaly is maintained to the east of Sochagota with values below 20 Ωm reaching up to the order of 0.1 Ωm, which would be also related to mainly to the contribution of Salpa salts (Figure 5 A). A conductive corridor **C2** extends in a NW direction through the basement Fault of Cerro Plateado and then goes north until it reaches Sochagota Lake at a depth of approximately 90 m, which could be due to the transit of hydrothermal fluids heated by a source of water deeper and whose ancestry would be through this basement Fault (Figure 4).

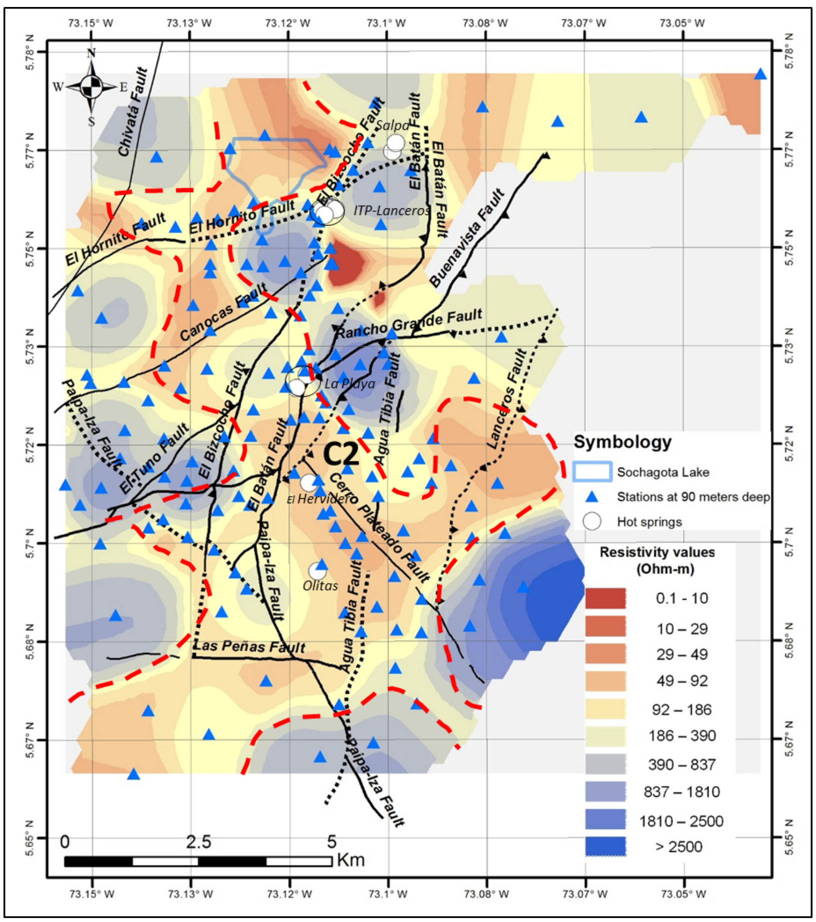


Figure 4. Demarcated area at 90 meter deep where the conductive responses with lateral continuity are concentrated.

Starting at 200 m depth, it begins to mark very clearly the appearance of areas with high values of apparent resistivity **R1** in NW and too the NE directions and conductive zones located on the Canocas Fault, which could be associated with fluids hydrothermal. However, on the vulcanitas sector, a conductive anomaly in the NS direction is still being maintained, with resistivity values of around 30 Ωm. The presence of the highly resistive anomaly **R2** in the SE zone of the area may also be associated with the Tibasosa-Toledo anticline (Figure 5).

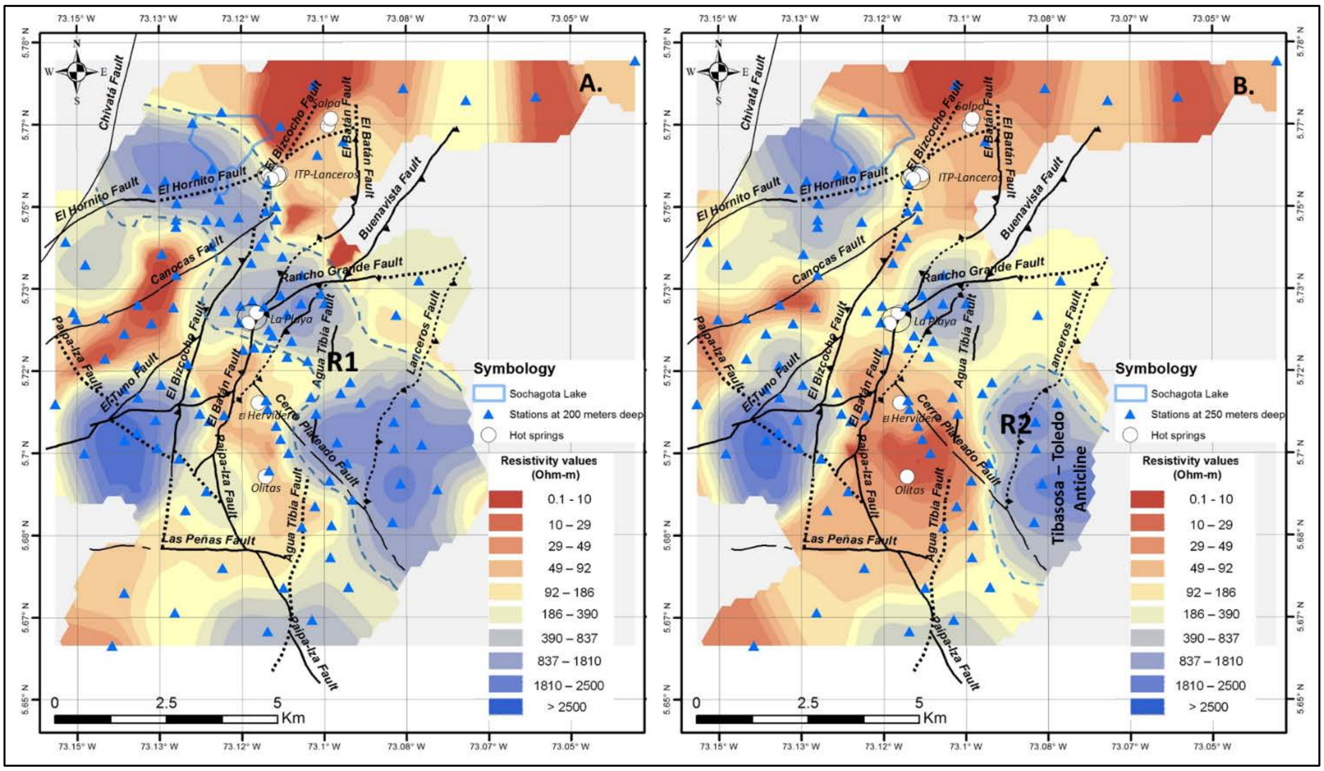


Figure 5. Interpolation models highlighting highly resistive zones with dotted lines. A. interpolation at 200 meters deep; B. Interpolation at 250 meters deep.

5. Conclusions

Conductive areas **C1** figure 3B - 3J between 20 to 100 meters deep with values below 10 Ωm to SE of the area may owe their electrical response to the weathering of volcanic deposits or also to arcillolite levels according to the lithology of this zone. While that the conductivity anomaly C2 would represent maybe with the circulation of the hydrothermal fluids near to the surface.

Conductive zones are structurally controlled by the basement Fault of Cerro Plateado in the NW direction that preserve the character of open fractures deep and between the Canocas and El Hornito inverse Fault both with dextral direction component, associating this electrical response to the possible transit of hydrothermal fluids.

The areas with highly conductive anomalies east of Lake Sochagota have been associated with the presence of evaporite deposits from the Salpa sector and the contribution of fluids coming from the thermal springs with sulphated chemical and sodium sulphates compositions.

In the SE sector of the study area, the resistive anomaly **R2** with values of 2000 Ωm is associated with the Tibasosa - Toledo anticline considered the main recharge zone of the geothermal system.

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