Presented at “Short Course on Surface Exploration for Geothermal Resources”,
organized by UNU-GTP and LaGeo, in Ahuachapan and Santa Tecla, El Salvador, 17-30 October, 2009.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

GEOPHYSICAL CONCEPTUAL MODEL OF THE CHINAMECA GEOTHERMAL AREA, SAN MIGUEL, EL SALVADOR

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ABSTRACT

The concession of the Chinameca geothermal area is about 100 km^2. From August 2005 to March 2006, geophysical prospecting studies of standard gravity, magnetic and magneto telluric (MT) combined with electromagnetic method in the time domain (TDEM) were carried out. As a result, a geophysical conceptual model was elaborated. The interpreted geophysical reservoir is characterized by a high resistive basement. The seal cap is associated to a conductive layer with resistivity values less than 12 Ohm-m. The probable reservoir area is estimated at 7 km^2 while the possible extension is 15 km^2. Geophysical methods applied coincides that the most promising area is the north flank of the El Limbo hill near to the upflow zone.

1. INTRODUCTION

The Chinameca geothermal area was catalogued as a high-enthalpy resource by the PNUD in the 1960’s . In 1980 two exploratory wells were drilled by CEL (Government Electricity Company). The well CHI-1 was located near to the La Viejona and the well CHI-2 near the Los Hervideros fumaroles. A maximum temperature of 190°C was found. This resulted in encouraging complementary surveys in the southern part of the geothermal area (CEL, 1996). In 1997, CEL began these complementary studies consisting of standard gravity and DC Schlumberger resistivity surveys. A total of 225 gravity stations were measured over an area of 250 km^2 as well as 20 DC resistivity soundings.

From August 2005 to March 2006, LaGeo carried out new geophysical surveys, which included gravity, magnetic and magnetotelluric surveys. The main results are discussed and presented in this paper.

2. GRAVITY SURVEY

A total of 243 new gravity stations (GST) were measured. This data was processed together with the previous 225 GST. Both surveys covered an area of 280 km^2 with a total of 468 GST (see Figure 1). A CG-3 digital Autograv from Scintrex was used for this survey. The elevation was measured using high precision GPS from TRIMBLE, model 4700. The density value used for processing the gravity data was 2.3 gr/cm^3, which is the average of the density measurements taken from samples in wells in the Berlin geothermal field (Larios and Henriquez, 1987).

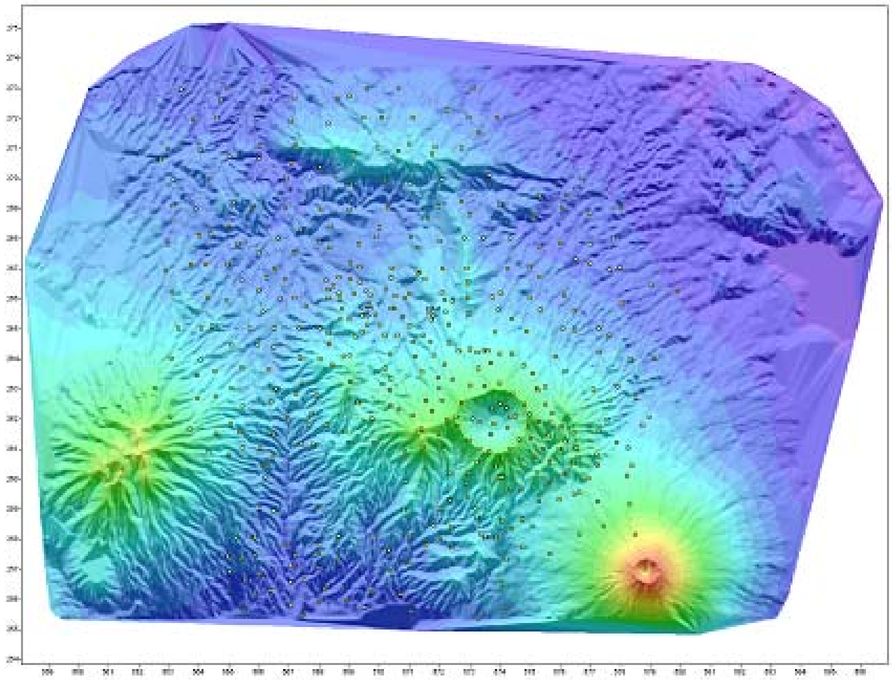

FIGURE 1: Gravity station locations (dots). Background colours are related to topography

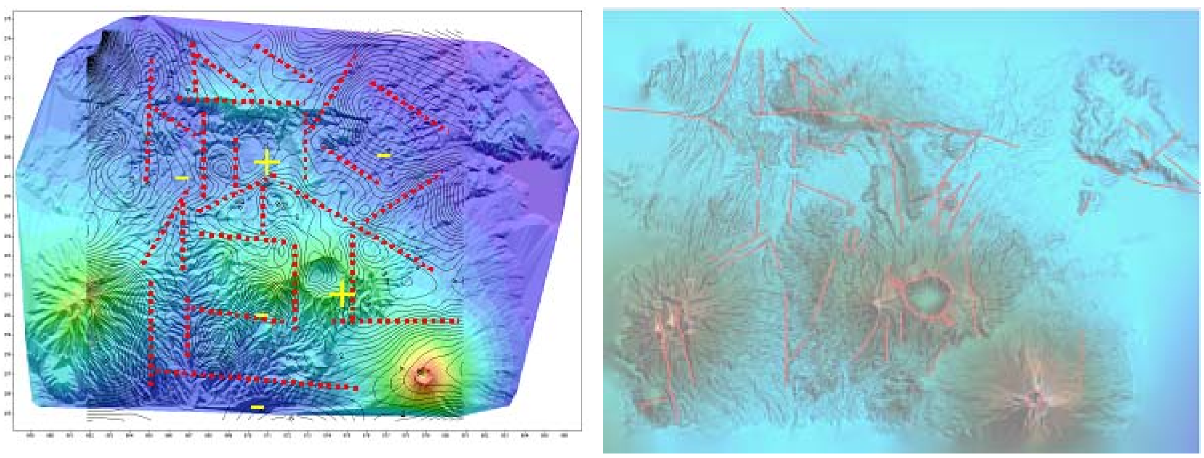

FIGURE 2: Alignments drawn on a Bouguer residual anomaly map compared with a structural map

The structural features suggested by the Bouguer residual anomaly map are: A north-south trend fault system, which is observed in a predominant way. This trend is in good correlation with fault systems defined by LaGeo's geologists, as shown in Figure 2.

Another important fault system observed in the residual anomaly map is the east-west regional trend, belonging to the central graven system. This trend is evident in both, north and south extremes of the geothermal area and can be a limit of this system. A less evident local NW-SE fault system is also suggested by this anomaly map; despite that this system is not visible on the surface, it can be an important channel for the conduction of the geothermal fluid. This hypothesis is supported by the presence of several hot springs at the north-western part of the Chinameca geothermal area.

3. MT/TDEM SURVEY

The field data was collected by Geosystem, between February and March, 2006. A total of 65 MT/TDEM stations were measured. A remote reference station was used and was located about 20 km west of the surveyed are. The quality of the data was good enough, except some polls close to populated towns where the influence of the domestic electric network was inevitable.

Data processing, analysis 3D, was carried out by Geosystem. The horizontal input grille (grid) used was 250 x 250 m. A total of 50 iterations were performed and the final rms was 1.58. The output file from this process was imported to Wing Link (Geosystem software) for generating maps and sections.

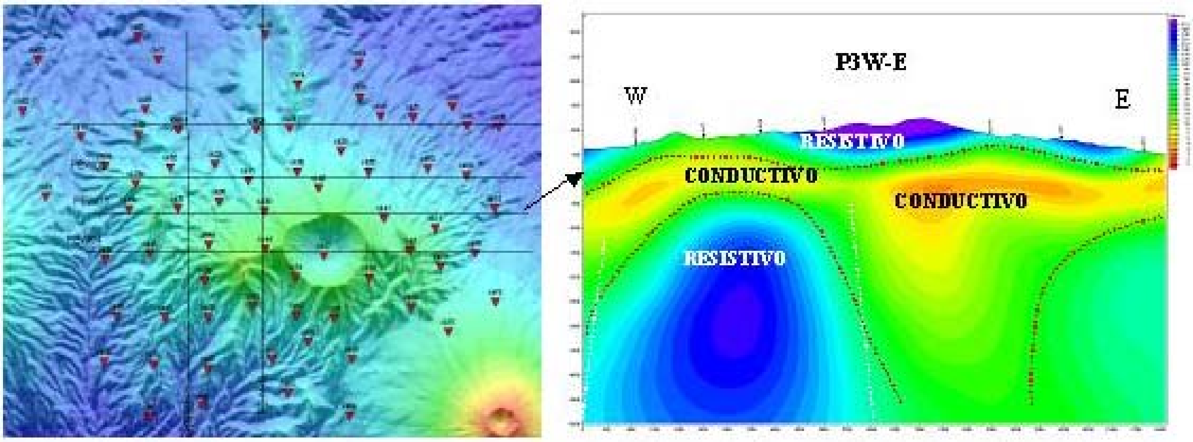

FIGURE 3: MT site locations and the profile P3W-E showing an E-W resistive image crossing the area.

Figure 3 (left) shows the MT site locations. The 3D resistivity correlation layer over the Chinameca geothermal area is shown on profile P3W-E presented in Figure 3 (right). The subsurface geoelectric stratigraphy presents two main features. The first one, from the central part of the profile toward the west, corresponds to the resistive-conductive-resistive sequence typical of a high temperature volcanic system. From the centre to the east of this profile, the first two layers are clearly observed. The lateral resistive discontinuity at the central part of the P3W-E profile suggests the possible presence of a geological fault; this is supported by the good correlation with a N-S fault located between El Limbo Hill and the crater of El Pacayal.

For the analysis distribution of resistivity at depth, several maps at different elevations were elaborated. These maps can provide the information about the size and geometry of the main resistive anomaly associated to the producer reservoir. Figure 4 shows resistivity maps at different constant elevations from +250 to -2,500 m s.n.n. The blue colour represents a resistive body and the red the most conductive areas. The existing shallow well CHI-1 is also shown.

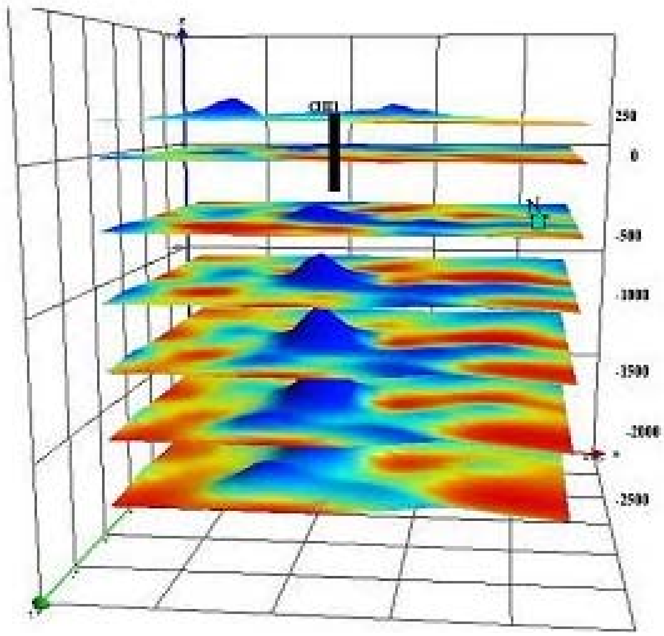

FIGURE 4: Resistivity maps at constant elevations from +250 to -2500 m s.n.n. The blue colour represents a resistive body and the red the most conductive areas. The existing shallow well CHI-1 is also shown

3.1 Interpretation of the resistive sequence

The sequence resistive-conductive-resistive observed in the subsurface of the Chinameca area is very well adjusted to a typical resistive behaviour (model) in an andesitic geothermal volcanic system as is shown in Figure 5. Figure 5 shows the model (left) compared with the result of Chinameca (centre) and the example from Berlín (right).

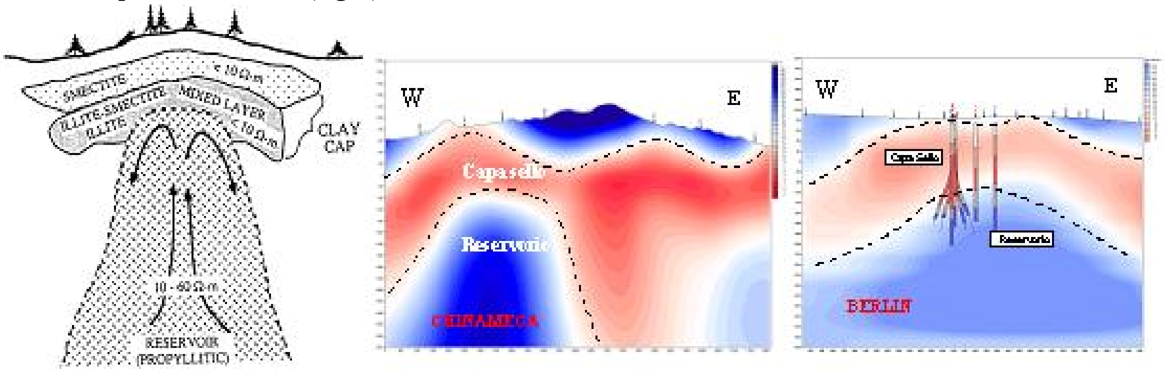

FIGURE 5: Comparison of a theoretical model of MT resistivities in an andesitic geothermal volcanic system (Left) and the resistive sequence in the area of Chinameca (centre). The example from Berlín (right) is also shown

The resistive stratum at the surface corresponds to the soil cap and the very low altered rock, its values and thickness are increased in the northern extreme of the area and over the high part of the volcanic complex Limbo-Pacayal, where the thickness reaches values of 500 m. This layer is interrupted in the zones where the hydrothermal alteration is intense due to the presence of thermal fluids.

The conductive layer, the seal cap, shown in red, corresponds to altered rocks. This cap is very shallow in the west part of the profile of Chinameca (centre Figure 5) but at the centre this layer goes down. The conductive cap, with resistive values between 2 and 12 ohm-m, corresponds to the altered clays of the Argilitic and Argilitic - Filitic facie. The thickness varies from 400 to 700 m in the western part while reaching 2,000 m in the eastern part.

The deep resistor (blue, Figure 5, centre) is associated with the high-temperature reservoir zone (convective) characterized by prophylitic alteration mineralogy, and is electrically resistive compared to the overlying lower temperature cap zone, characterized instead by an electrically-conductive argillic alteration. The change to exploitable reservoir conditions, therefore, is marked by the transition from conductive to resistive conditions.

A 3D view of the sequence resistive-conductive-resistive is very well observed in Figure 6. In Figure 6, the view from the south shows that the resistor resides below the El Limbo hill and the deepening of the conductive layer below the crater of El Pacayal. To the right is shown the Chaparrastique volcano.

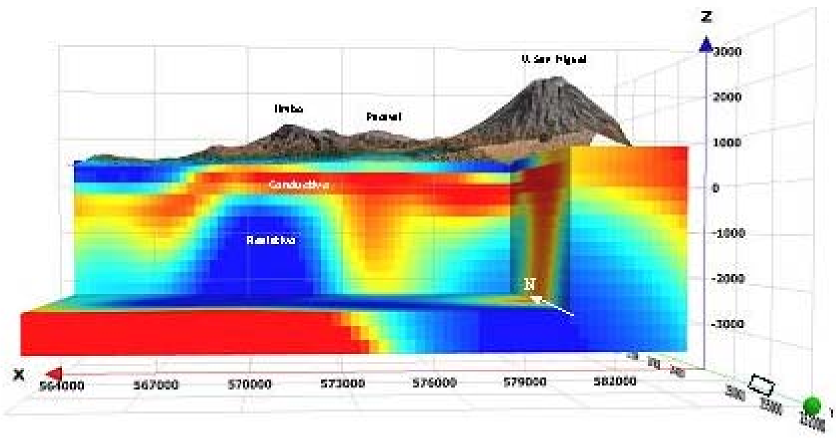

FIGURE 6: A 3D view of the sequence resistive-conductive-resistive in the Chinameca geothermal area (view from the south)

Theoretically, the prophylitic reservoir may have resistive values in the range of 10-60 ohm-m, but it depends on the local conditions for each geothermal system. In the case of Chinameca (See Figure 7), the 16 ohm-m iso-contour has been taken as the possible top of the prophylitic reservoir. The reason is because this value marks the change of the conductive layer to the deep resistive cap. What turns out to be difficult to determine is the value of the iso contour associated at the base of the reservoir, this is due to the constraints in the resolution of the method at these depths. If in a subjective way it is assumed that the 100 Ohm-m iso contour is the base of the prophylitic reservoir, its thickness would be in a rank from 500 to 700 m. This transition constitutes one of the objectives of the deep exploration.

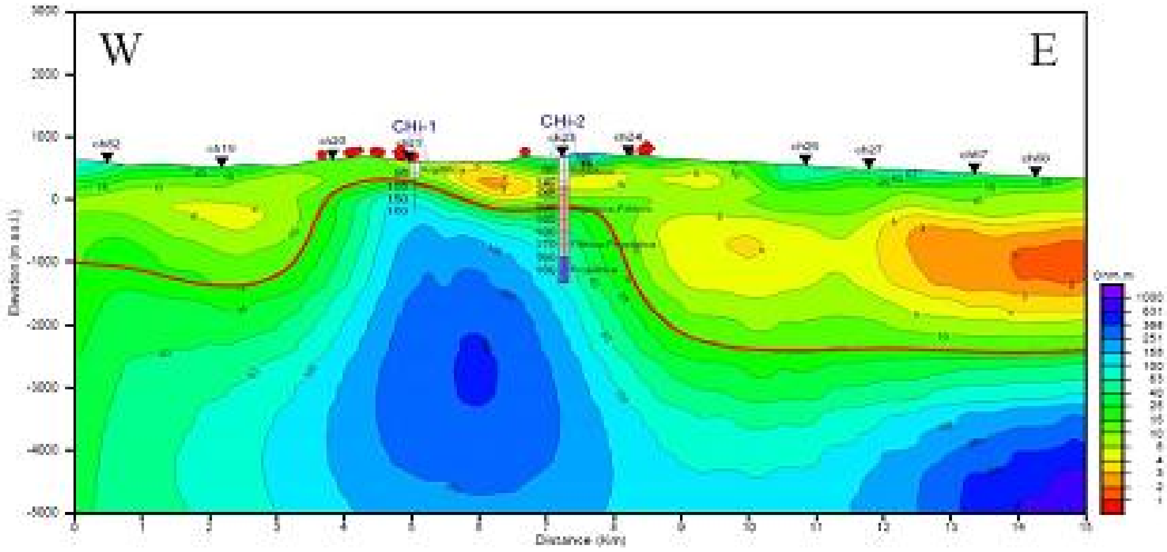

FIGURE 7: Correlation of the mineralogy and temperature of the wells CHI-1 and CHI-2 with the geoelectric layers of the profile PWE-2 (from Geosystem, 2006).

The correlation between the resistivity and the mineralogy is maintained to the depth reached by the well CHI-2 (2,200 m). The appearance of the deep resistor is in correspondence with the presence of the alteration facie prophylitic - phylitic and phylitic. The variable that loses consistency is the measured temperature in the well, since the existing correlation between the deep resistor and the prophylitic – phylitic facie, the corresponding temperature at the bottom of the well should be over 230°C, nevertheless, the measured temperature in the bottom is 160°C. This weakness suggests phenomena of cooling in the northern part of the area where the wells have been drilled. This cooling is due to two reasons: a lateral invasion of cold water to the formation producing the investment of temperature, or the reflection of a fossil system in process of cooling off.

Figure 8 is a N-S 3D view of the deep resistor, seen from the west, the conductive layer has been removed in order to visualize the resistor. The shallow well CHI-1 is over and CHI-2 is behind the resistor, as was shown on Figure 7 on an E-W profile. The raised part of the resistive basement coincides with the values of the conductive layer greater than 5 Ohm-m, while in the zone of greater interest, in the south, the iso-contours of the conductive zone are lower than 3 ohm-m (Figure 9, from Geosystem, 2006).

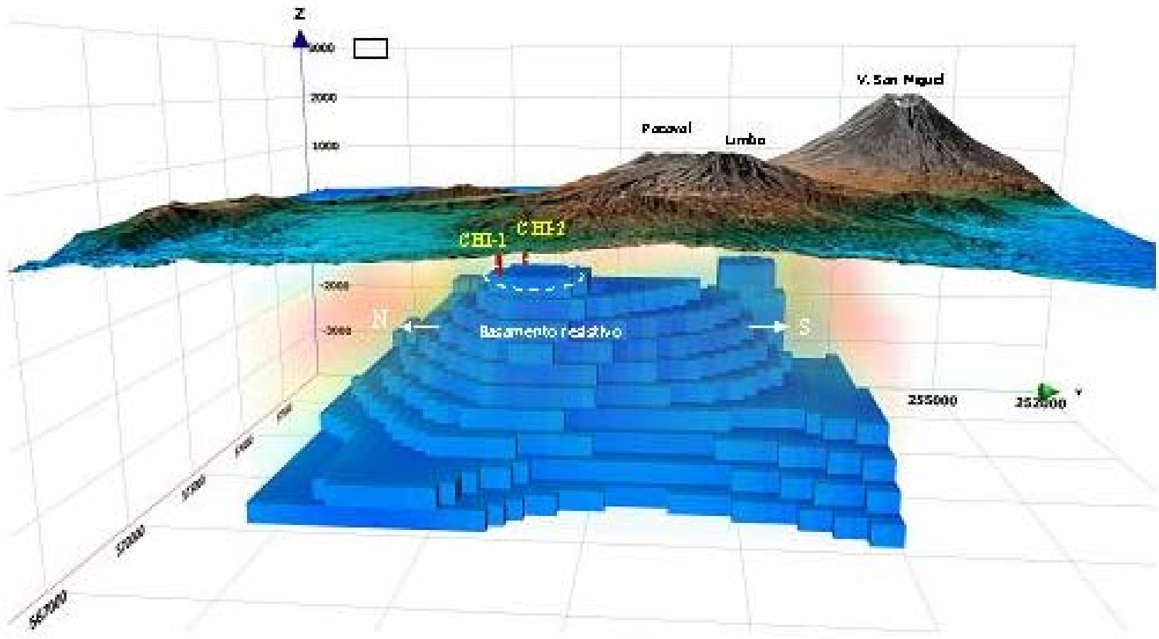

FIGURE 8: A N-S 3D view of the deep resistor, seen from the west.
Wells CHI-1 and CHI-2 are also shown.

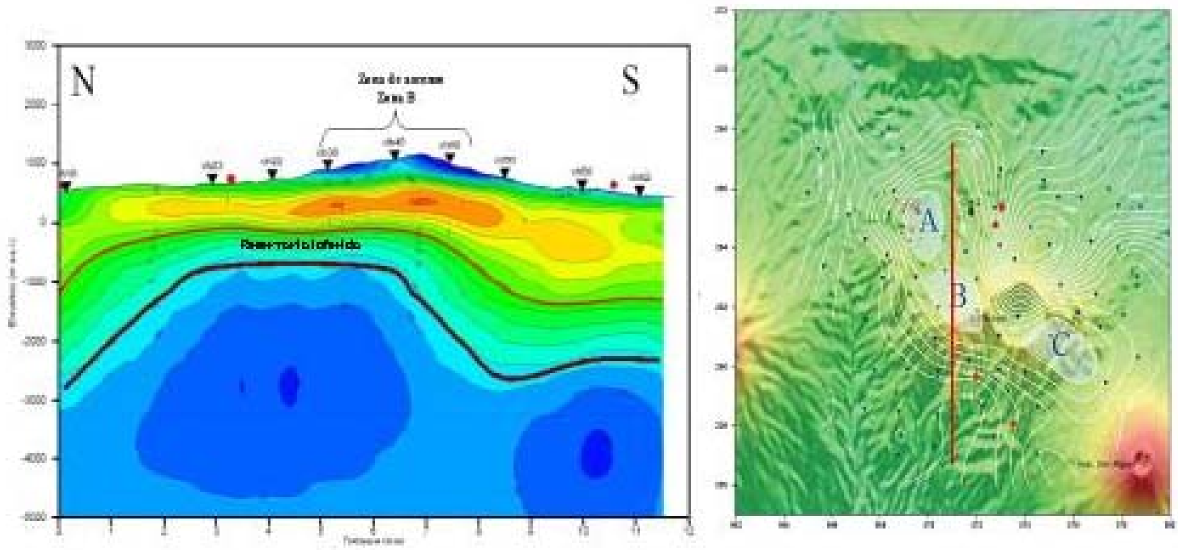

FIGURE 9: MT interpreted reservoir, and the upflow zone

4. MAGNETIC SURVEY

The main goal of a magnetic survey is to get information about anomalies based on magnetic properties of rocks related to geothermal activity. The survey was carried out from September 5th, to December 1st, 2005. About 1,100 stations located every 50 m were measured. In total 13 lines in the E-W direction were measured with a separation of 500 m. The total area covered by the survey was about 50 km^2 (Figure 10). The survey was located mainly in the southern part of the town of Chinameca, the Limbo - Pacayal volcanic complex is included.

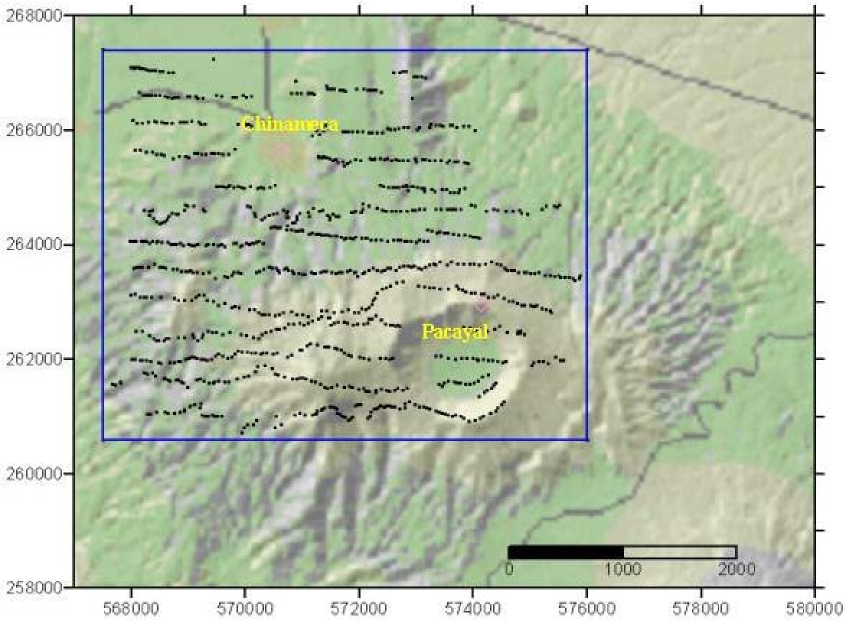

FIGURE 10: Map showing the location of the survey and the measured stations

The main results of the magnetic survey are summarized in Figure 11. This figure shows the magnetic results in correlation with the structural geological map. This figure reveals two main zones of low values of magnetism: the south-eastern and western parts of the area studied. The south-eastern part coincides with the El Pacayal crater. The western zone, located to the south of the town of Chinameca, is related to a N-S fault system bordered by two major faults.

The low values of magnetic susceptibility are related to a decrease in magnetism due the hydrothermal alteration process. This aspect may be interpreted as the presence of a geothermal reservoir. It is possible to observe a very good correlation between low magnetic values (blue colour) and the N-S trend of the fault system. The anomalies have a N-S direction in agreement with structural alignments and the most known altered zone (specially fumaroles) as La Viejona and Los Hervideros. Most of the fumaroles are distributed at the western part of the studied area.

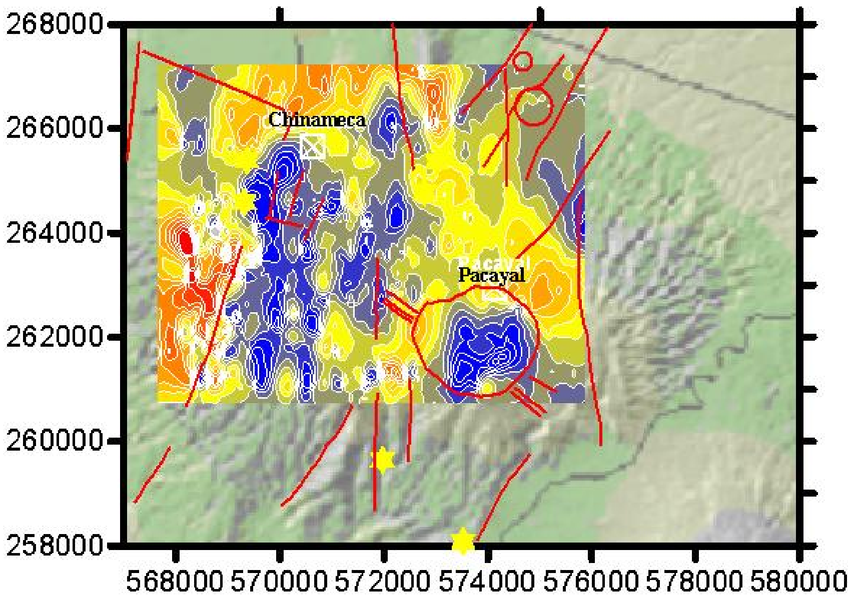

FIGURE 11: Map of magnetic susceptibility and the structural geology

5. CONCEPTUAL GEOPHYSICAL MODEL

Despite the geophysical techniques applied in the geothermal area (magnetic, gravity and magneto telluric) there is no evidence of the heat source of this system. It is assumed to be a magmatic chamber underlying and in the high part of the Limbo-Pacayal volcanic complex. The geophysical methods applied coincide to show that the most promising area is the north flank of the El Limbo hill.

Upflow zone. The fluids upflow zone is found under the Limbo volcano and is associated with the deep uplifting resistor, particularly where the overlaying conductive cap has values less than 3 Ohm-m. This zone becomes of great interest for deep exploration and covers an area of 4 km2, as is shown in Figure 9, zone B.

The reservoir is characterized by the uplifting deep resistor with values between 16 and 100 Ohm-m overlaying a conductive layer of less than 12 Ohm-m. The thickness varies between 500 and 800 m. The probable area of the reservoir is estimated to be 7 km^2 but its possible extension could be closer to 15 km^2.

Circulation patterns. Based on the structural features suggested by the Bouguer residual anomaly map, the main fluids circulation direction is through the N-S fault system, and in a smaller scale towards the south, north-east and north-west directions.

Discharge zone. From the proposal of the circulation pattern, the discharge zones are found in the north-eastern, north-west, and north extremes and south of the fluids upflow zone.

A proposal of a circulation pattern is presented in Figure 12 and a conceptual geophysical model in Figure 13.

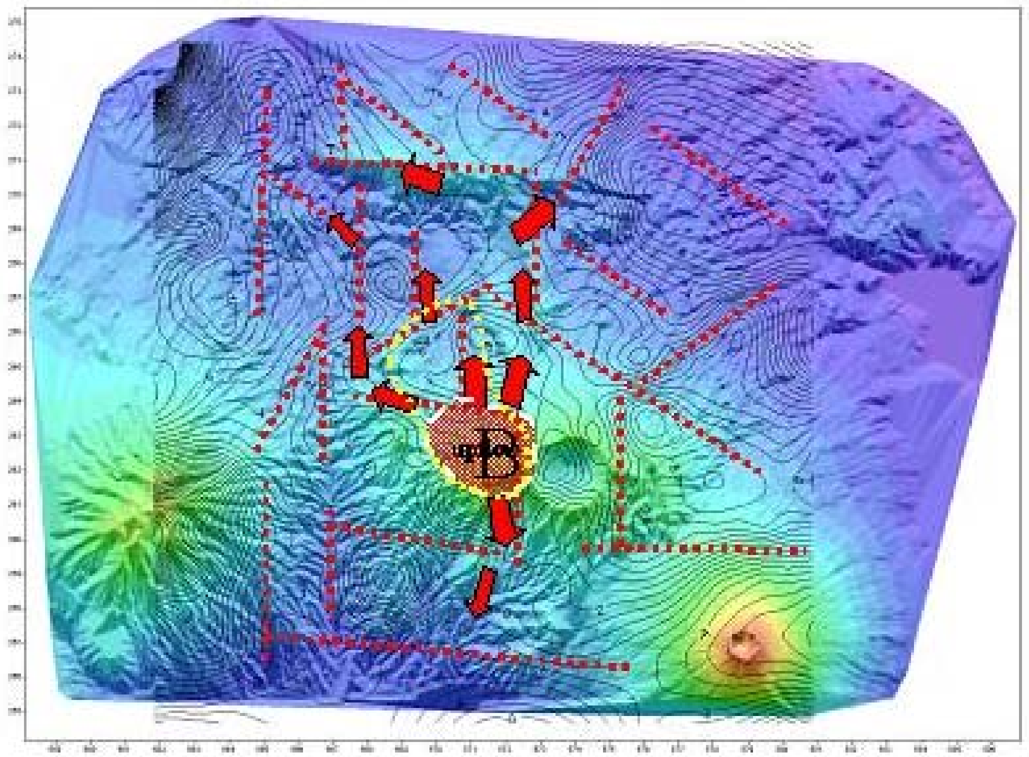

FIGURE 12: Fluid circulation pattern based on the structural features suggested by the Bouguer residual anomaly map.

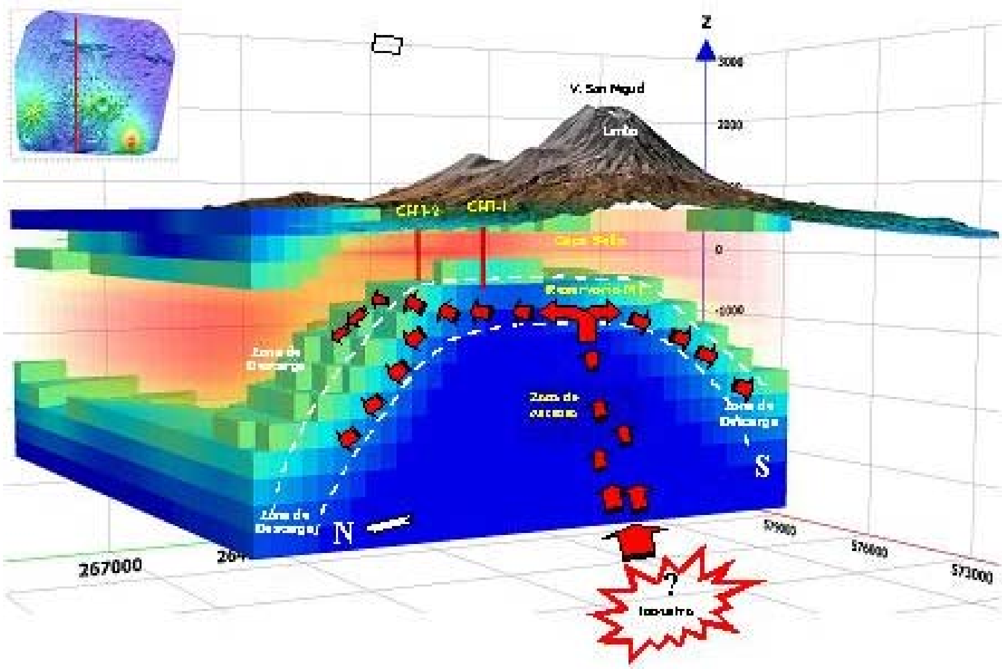

FIGURE 13: Conceptual geophysical model of the Chinameca geothermal area.

6. CONCLUSIONS

Based on the geophysical results the conceptual model is summarized in the following aspects:

- The reservoir is characterized by the uplifting deep resistor with values between 16 and 100 Ohm-m overlaying a conductive layer of less than 12 Ohm-m. The thickness varies between 500 and 800 m. The probable area of the reservoir is estimated to be 7 km^2 but its possible extension could be closer to 15 km^2.

- The up flow zone is found under the volcanic axis from the El Limbo hill and is associated with the uprising of the resistor in the southern part, particularly in the zone where the conductive layer (cap rock) presents values smaller than 3 Ohm-m. This conductive layer represents a zone of greater hydrothermal alteration and becomes of great interest for deep exploration. This covers an area of 4 km^2.

- The model does not have sufficient data to determine the position and type of the heat source but it is assumed to be the magmatic chamber of the Limbo - Pacayal volcanic complex.

- Based on the structural features suggested by the Bouguer residual anomaly map, a fluids circulation pattern is proposed from the up flow zone to the north, through the north-south fault system, and in a smaller scale to the NW and NE and south of the studied area.

- The most important characteristic in the agreement of the geological and geophysical maps is in the north-south fault system, in the central part as in the western sector, which suggests that the fluids displacement take place in this system, from the central part, where it is assumed that they rise and move toward the south and north extremes.

- The well CHI-1, located in the north with a depth of 750 m does not reach the resistive basement. The measured temperature at this depth is 160°C, which is in agreement with the type of clay alteration minerals found by the well.

ACKNOWLEDGEMENTS

The authors want to thank the technical personnel of the Geophysical Area for their great contribution during the field work, as well as the processing of the data. Also, we want to express our gratitude to Ricardo Medrano for the excellent 3D maps and views. Also thanks to Ing. Julio Guidos for the support in all the field campaign.

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