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Geophysical Conceptual Model of San Vicente Geothermal Area, El Salvador

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Keywords

Thermal potential, Bouguer anomaly, producer reservoir

ABSTRACT

With the purpose of evaluating the thermal potential of the San Vicente geothermal area, the Geophysics Area of Studies Management carried out from February to April, 2005, geophysical prospecting studies of Standard Gravity, Magnetic and Magneto Telluric (MT) combined with Electromagnetic Method in the Time Domain (TDEM). The study area for Gravity was 250 Km², for MT-TDEM 80 Km², and 40 Km² for Magnetic. The concession area is 100 Km². As a result, a geophysical conceptual model was created. The interpreted geophysical reservoir is distinguished by a high resistive basement and a positive gravity anomaly with an estimated area of 12 to 14 Km² and 800 to 1000m of thickness. The seal cap is associated with a very conductive layer with resistivity values less than 10 ohm-m.

Introduction

In 1993, CEL carried out gravity and resistivity studies in the San Vicente geothermal area (ELC, 1995). These surveys consisted of 233 measure points of gravity in an area of 220 km² and 37 vertical electric soundings (Schlumberger) in an area of 24 km². Most of the sounding identified in a clear manner, two geoelectric layers, a superficial resistive layer with a thickness between 250 and 450 m and resistivity of 100 - 1000 ohm-m; and a conductive layer with resistivity ranging from 5 - 50 ohm-m and an estimated thickness of 600 m. Due to the penetration limited capacity of the DC electric resistivity method, very few sounding were able to identify the resistive basement. From the results above geophysical prospecting studies were recommended with more penetration capacity, with the intention of a campaign of MT sounding.

With the purpose of evaluating the thermal potential of the San Vicente geothermal area, geophysical prospecting studies,

from February to April, 2005, were carried out. The techniques applied were the Standard Gravity, Magnetic and Magneto Telluric (MT) combined with Electromagnetic Method in the Time Domain (TDEM). The area covered for Gravity was 250 Km², for MT-TDEM 80 km², and 40 km² for Magnetic. The concession area is 100 km² (Figure 1).

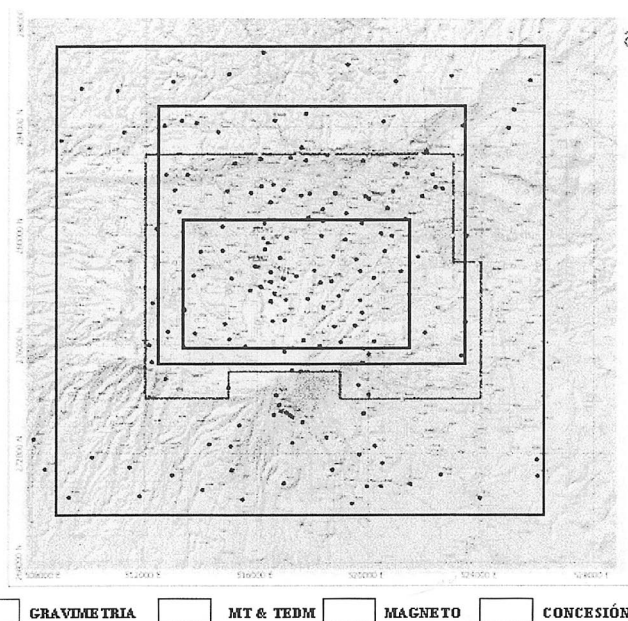


Figure 1. Concession and surveys areas.

Qualitative analysis of the gravity and MT-TDEM data allowed delineating relevant structures in E-W and NW – SE. A geophysical conceptual model was prepared to proposals sites and objectives for exploratory wells.

Gravity Survey

Around 480 gravity stations in an area of 250 Km² were analysed. The data set was processed with a density value of 2.2 gr/cm³ (Handal, 1994), which is one of the values averaged

from the analysis of three profiles Nettleton carried out in 1993. For the density selected, Bouguer and residuals anomaly maps were prepared. 2D quantitative analysis was carried out over several profiles.

The Bouguer anomaly map (Figure 2), reproduces the regional structural features as the central graben with E-W direction. The strong isocontours gradient in this direction, with values ranging from 5 to -9 milligals to the north of Verapaz and Tepetitán towns, suggests a sudden sinking of the central graben in this area. Another structural system, suggested by the behaviour of the Bouguer anomalies, is the gradient of the isocontours observed in NW-SE direction, which could constitute a preferential direction in the circulation pattern of geothermal fluids.

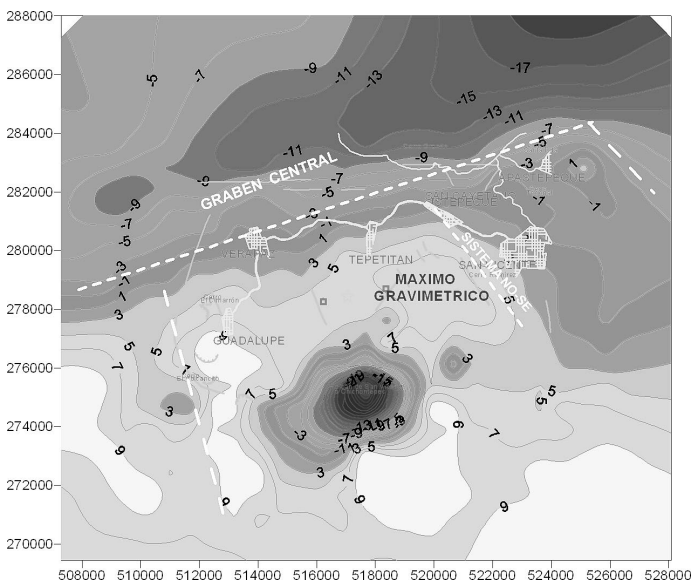


Figure 2. Inferred structural alignments from the Bouguer anomaly map.

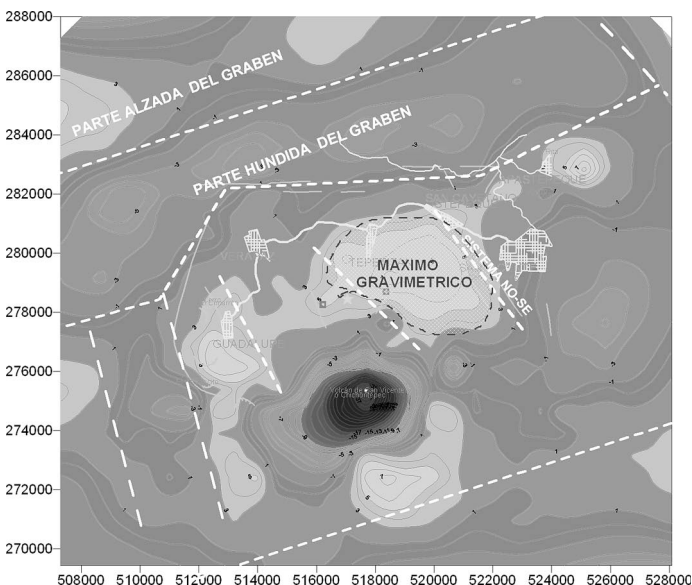


Figure 3. Structural limits inferred from the Bouguer residual anomaly map.

The residual anomaly map (Figure 3) associated to the central graben is observed clearly in the north and south edges of the study area. To the north, a fringe of negative values is observed, three kilometres wide (in blue colour), that is interpreted as the down thrown part of the central graben. In the north edge of the area, positive values of residual anomaly have been observed; interpreted as the uplift part of the graben. These evidences suggest a system of HORST-GRABEN-HORST in the north part of the study area. The coincidence between the verified structures and the structural alignments related to the central graben from the behaviour of Bouguer residual anomalies (Geosystem, 2005), is very important.

Another structural feature that is clearly evident in the Bouguer residual anomaly map is the one associated to a local system in NW-SE direction. Some of the faults are supported by the field structural measurements carried out by LaGeo's geologist (See Figure 4).

The presence of a gravity maximum to the east of the SV-1 well could be reflective of the appearing of a densified stratum for sealing the pores, due to the deposit of secondary minerals of chlorite or epidote type during the circulation of geothermal fluids. In the volcanic environment of geothermal fields, the abundant presence of these minerals is an indicator to identify the geothermal reservoir.

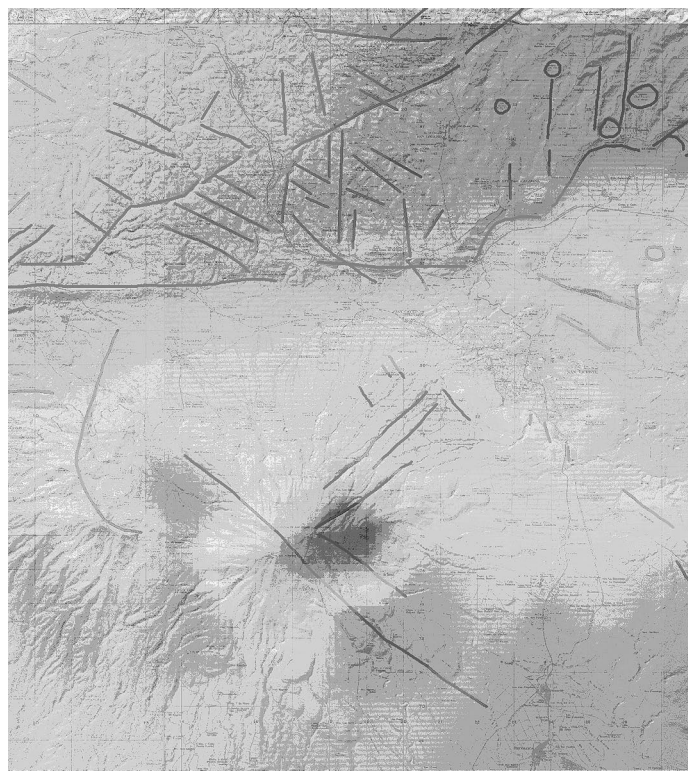


Figure 4. Correlation with structural limits and gravimetric anomalies.

Magnetic Survey

The main objective of the magnetic study is to contribute information to the relationship between the geothermal activity, tectonics and stratigraphy of the San Vicente geothermal area. (Escobar, 2005). Most of the rocks are not magnetic;

however, certain types of rocks contain minerals to originate significant magnetic anomalies. The data interpretation that reflects differences in local abundance of magnetization is especially useful to locate faults and geologic contacts (Blakely and Simpson, 1995).

The magnetic study was focused on the north flank of the Chichontepec volcano from the East of Verapaz to the West of San Vicente. About 2000 stations were measured every 50 meters, along 21 lines spaced 250 metres in E-W direction.

It is more important, at the beginning, to detect the presence of a fault or intrusive body, than to determine their form or depth. Although, in some magnetic anomalies, such determination cannot be made in a unique manner, the magnetic data has been useful because the intrusive is more magnetic than the underlying lava flows. The faulting creates spaces where the hot fluids displace and therefore alter the guest rocks.

From the results obtained with the terrestrial magnetism, it was possible to detect two anomalies of low magnetic susceptibility coinciding with the areas where Infiernillos Ciegos and Agua Agria are located (Figure 5). These anomalies are considered to be possible candidates for a geothermal development. Among the two anomalies, an area of relatively high magnetic susceptibility was detected. This area probably indicates the contrast of lava flows with bigger susceptibility values and probably high magnetism remainder of the present minerals. The potential areas in the two anomalies appear to be low due to magnetic materials, which are usually altered during the faulting, destroying the magnetism.

probably representing a discharge area. This area of unclear nature is limited to the West by values relatively bigger than the susceptibility which represents borders that define the geothermal system. Additionally, in the NE part of the area an anomaly of high susceptibility is located, probably being the hydrothermal area limit. The Infiernillos Ciegos anomaly seems to extend even more towards the SE of the studied area. To confirm and to clarify their extension, the magnetic survey could be extended around 1 km.

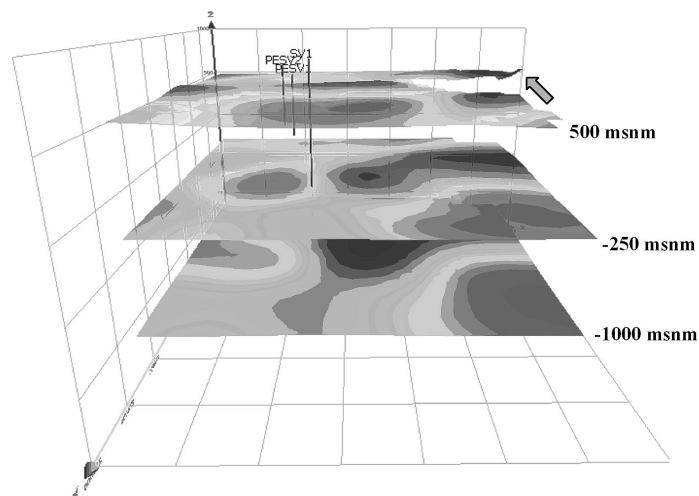


Figure 6. 3D view resistivity maps at constant elevation. Vertical lines: SV-1 and exploratory wells.



Figure 5. Upward continuation (0.5 km) magnetic anomaly map.

In the West part of the studied area (between Verapaz and the wells PESV-1 and PSEV-2), there is an area of relatively low anomaly in north-south direction that extends from Agua Agria towards the North highlighting low depths and

Magneto Teluric Survey

A MT-TDEM survey was carried out. This consisted of 58 soundings at the North flank of the Chichontepec volcano. The remote reference station was located five kilometres South-east, in the area of Obrajuelo in a place geologically stable and with minimum influence of cultural noise.

The quality of the data in most of the places was good, except for some soundings located near towns, where the influence of the residential electric net was inevitable. Maps for constant elevation of values of 500, 0, -500, -1000, -1500 and -2000 m.a.s.l. were created. Figure 6 shows the maps at 500, -250 and -1000 m.

To 500 m.a.s.l, a superficial resistive body is observed in the Central and North part of the study area. The conductive one, smaller at 10 ohm-m appears in the South part, where there are superficial evidences of hydrothermal alterations, the areas of Agua Agria and Infiernillos Ciegos fumaroles being the most representatives. The West resistive presents values between 10 and 20 ohm-m,

suggesting a conductive stratum with smaller alteration; due to its distance from the area of more hydrothermal alteration or system fluids ascent. To the Southeast of Apastepeque, a small resistive spot appears with values of 10 - 12 ohm-m that interrupts the isocontours of 6 ohm-m predominant in the study area.

The maps at -250 and -1000 m.a.s.l. present similar characteristics. In both of them, the small resistive island observed at sea level extends in a Southeast direction covering 30% of the study area with maximum values of resistivity of 60 ohm-m to -1000 m.a.s.l. Deeper soundings have mapped the resistive basement. Figure 6, shows the exploratory wells of San Vicente's geothermal area. They were not able to intercept the resistive basement (blue colour area), since they are located in the West border of this basement.

The underground geoelectric information of the San Vicente geothermal area was analysed in profiles from the results of the 3D modelling. Several geoelectric sections were developed. The resistive behaviour at depth corresponds to a clear sequence of superficial resistive stratum, medium conductive and resistive basement, which is typical of a geothermal system in volcanic environment.

The second stratum observed is a conductive layer smaller than 15 ohm-m, which is a reflection of an altered clay layer of argillitic, argillitic filitic type, as the well SV-1 mineralogy confirms. Its thickness varies drastically in E-W direction, mainly in the central part of the study area near well SV-1, reaches values up to 1000 m and in the central part it decreases at 500 m, where the resistive basement reaches its highest elevation. In N-S direction, the thickness variation is minimal.

The third stratum constitutes the resistive basement with values from 20 to 100 ohm-m. It presents a form of wrapped up bell for the conductive layer, The transition between the conductive cap and the resistive basement can be the reflection of the horizon between the argillitized area and a propilitized stratum with minerals such as chlorites and epidote that thermal temperatures from 230 to 250°C.

The geothermal fluids circulation to lower temperature at shallower levels is responsible for the intermediate layer argillitic alteration, whose resistivities vary from 1 to 10 Ohm-m. The smallest conductive layer at 10 Ohm-m depends on the type and alteration intensity, as well as on the stratum temperature. At still shallower levels, a resistive stratum associated with young material prevails with little alteration, influenced by superficial aquifer, and the content and degree of clay alteration.

The geothermal field of Berlin presents similar geoelectric behaviour at depth. The reservoir is associated with the resistive basement with values ranging from 20 to 50 Ohm-m. Most of producing wells are located inside the resistive basement. The seal cap is associated with the conductive stratum composed of Argillitic -filitic clays alteration and smaller resistivity values at 10 Ohm-m. San Vicente's geothermal area presents similar features as Berlin. ..

Taking into account that the values of the conductive layer are smaller in Berlin and that the upper boundary of this layer comes closer to the surface, it can be inferred that this system has a strong hydrothermal activity and a higher temperature,

as it is confirmed. The temperature range estimated by geothermometers in the case of San Vicente is from 240 to 280 °C and for Berlin is from 280 to 320 °C.

The reservoir volume would be inside the resistive basement, if it is considered a resistivity range between 15 and 50 Ohm-m, a thickness can be inferred from 600 to 800 m.

MT and Gravity Integrated Interpretation

The quantitative interpretation of gravity data supports the pattern suggested by the MT results. In summary, the reservoir according to MT, is associated with a resistive layer at depth with values within 15 and 40 ohm-m, a thickness of 600 to 800 m and a probable extension of 12 km² are estimated (See Figure 7). The SV-1 exploratory well is located at the west flank of this resistive, and it does not reach at depth this layer interpreted as the inferred producer reservoir.

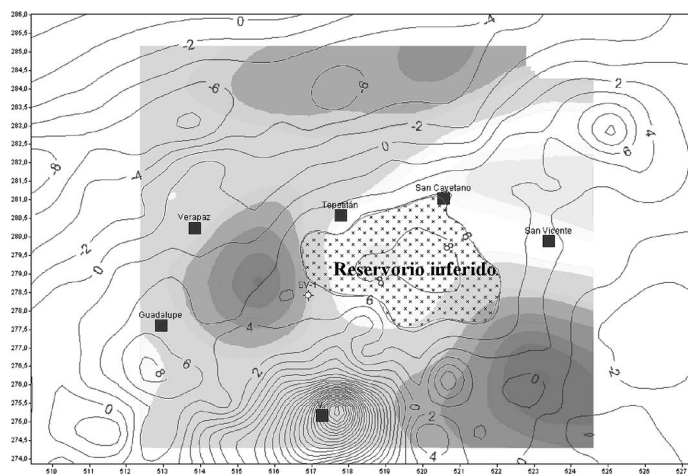


Figure 7. Inferred extension of the resource based on the correlation of the gravimetric maximum (contours map) and the resistive basement (colours map).

The 2D gravity modelling results agree well with observation. The discrepancy between the calculated curve (shown in green) and the interpolated field curve (shown in red) is smaller than 10% (Figure 8). The good agreement between model and data support a conceptual model where the reservoir is associated with maximum gravimetric and a resistive basement.

The density of 2.2 gr/cm³ was assigned to the superficial stratum, associated with the volcanic material inserted with clays with different alteration degrees and/or saturation of fluids coming from shallow aquifer. A density of 2.0 gr/cm³ was assigned to the conductive stratum, associated to altered clays (seal cap). The temperature range inferred for this layer is from 150 to 180 °C. For the MT resistive basement associated with fractured andesite lavas with propilitic alteration, a density of 2.4 gr/cm³ was assigned.

The modelling result of the gravimetric profiles show a maximum gravity decline within the South of the study area, near the exploratory wells. The models suggest that the well SV-1 didn't intercept the high gravimetric; and its termination

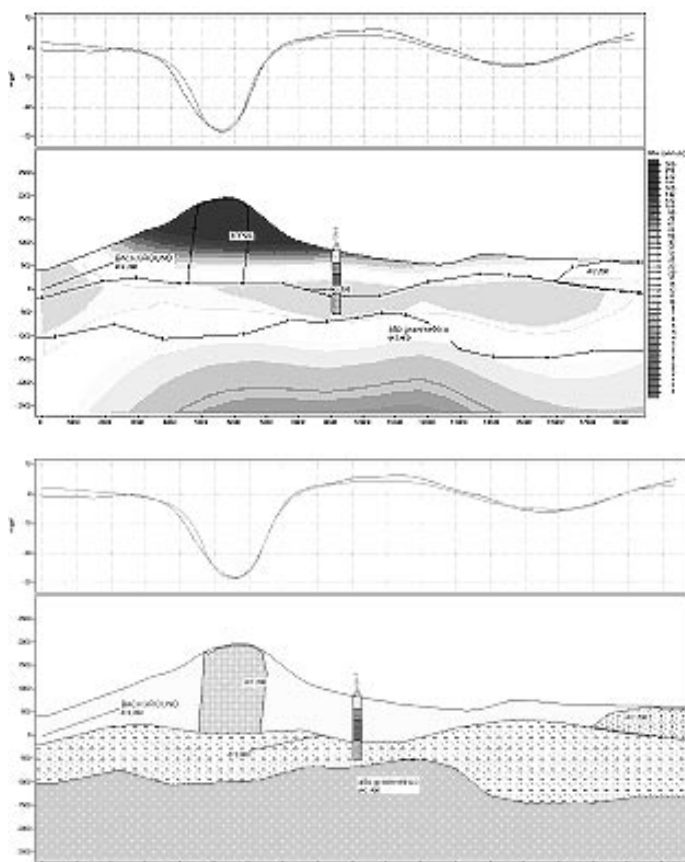


Figure 8. Correlation between gravity and MT models.

was in the intermediate stratum with density of 2.0 gr/cm^3 associated with the seal cap, as is shown in Figure 8. The correlation among both techniques is evidenced in the 3D image of MT results and in the superposition of a gravimetric 2D model shown in Figure 9, in which the correlation of the resistive basement with the gravimetric basement is seen; as well as between the MT conductive layer and the intermediate gravimetric stratum with an estimated density of 2.0 gr/cm^3 .

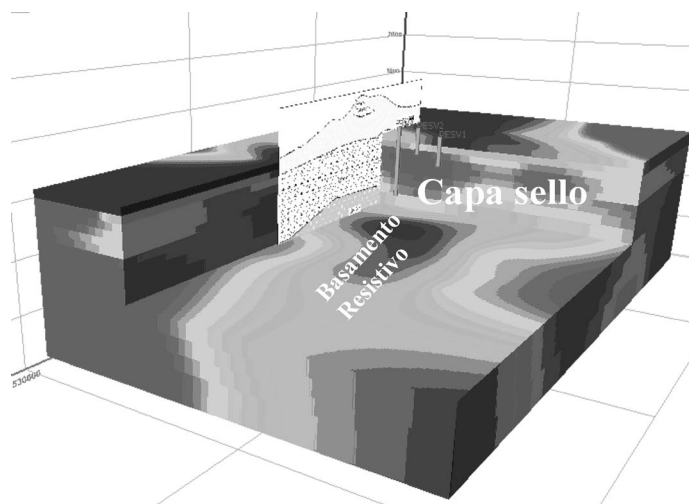


Figure 9. 3D model from MT and 2D gravimetric profile.

Acknowledgments

The authors thank Ricardo Medrano for the preparation of the maps and models. They also thank the technical group for carrying out the data gathering with high level of dedication. They are grateful as well with Julio Guidos, Engineer, for supporting all the field campaign.

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