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Geothermal prospecting of the Apacheta geothermal field in bolivia using 1d inversion of magnetotelluric data

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ABSTRACT

This report summarizes the findings of resistivity model based on 1D inversion of magnetotelluric data with the information available for Apacheta field which belongs to the Laguna Colorada area in the southwest of Bolivia, located at the foothills of Western Cordillera next to Sol de Mañana geothermal field.

The results show resistivity structure which is characterized by a shallow low-resistivity clay cap oriented approximately east-west along the drilled wells in Sol de Mañana geothermal field. The clay cap extends west to the Apacheta geothermal field. Two up-doming features are observed, under Sol de Mañana and under Apacheta geothermal fields. The mineralogy of the wells is playing a very important role to understand the results of the 1D inversion and correlates somewhat with the results of the 1D resistivity model. More soundings are needed around the Apacheta field to confirm the up-doming feature.

1. Introduction

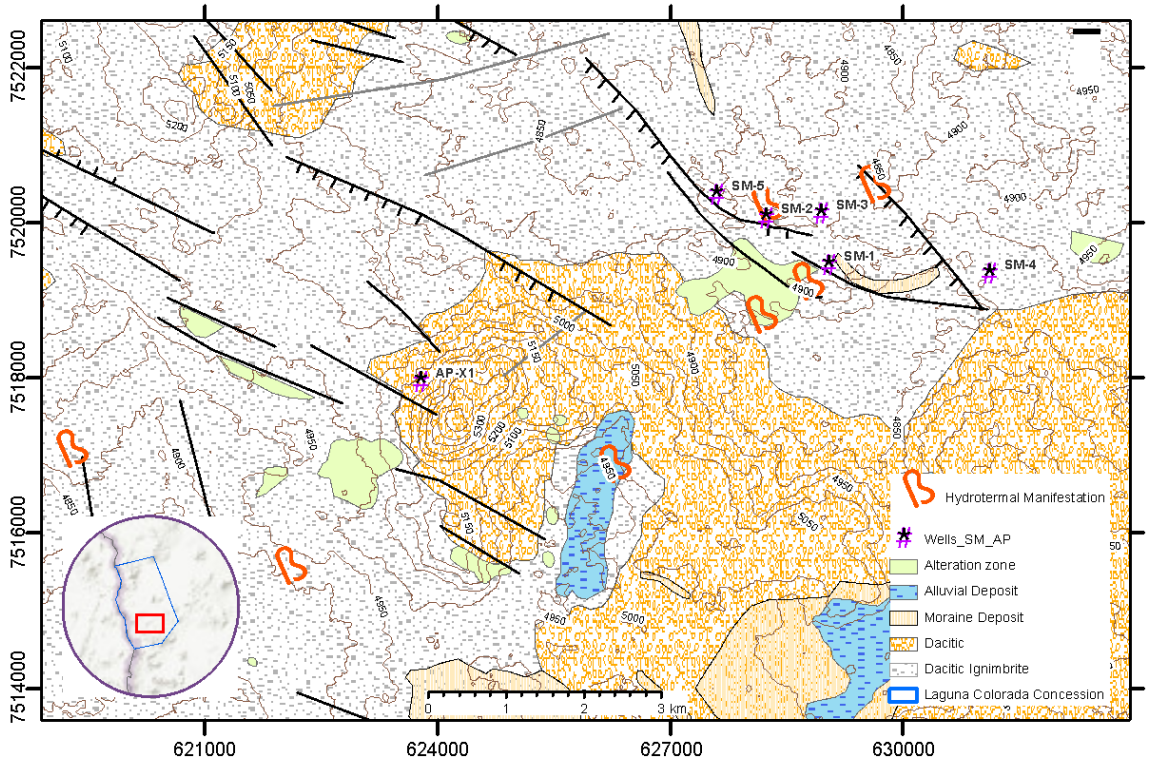
One of the major volcanic areas in the world is the Andean Volcanic Belt (part of the Ring of Fire), hosts four active volcanic zones: Northern, Central, Southern and Austral. The Central Volcanic Zone of the Andes (CVZ) extends from southern Peru in the south, north through western Bolivia, north-western Argentina, and northern Chile. CVZ forms the western boundary of the Altiplano plateau. This volcanic arc developed due to the subduction of the Nazca plate under western South America plate. The concession area of Laguna Colorada is in the Miocene-Pleistocene part of the CVZ, which extends in north-south direction over the Western Cordillera. The volcanic products are overlain by sediments of mesozoic and paleogene age. The mineral products of the volcanic arc have a composition of calcium-alkaline, varying between andesite and hydrocite, consisting of lavas and ignimbrites (JETRO, 2008).

The location of Sol de Mañana and Apacheta fields is between the Western Cordillera and the Altiplano-Puna plateau (this last is most know in Bolivia just as Altiplano). The area has an intense volcanic activity since 23 Ma with a production of acid magma, characterized by powerful ignimbrite and andesitic lava flows. The elevation of the study area is 4900 meters above sea level (m.a.s.l.).

To date, six wells have been drilled in the study area, five in the Sol de Mañana (wells SM

1-5) field and one in the Apacheta field (AP-1 well), which is our study focus. Figure 5 shows two tectonic fault systems, the first is the set of main faults extending in WNW-ESE direction (black lines) and the second set in NE-SW direction (gray lines). Most WNW-ESE faults are over Sol de Mañana wells and some of them close to AP-1 well, most likely control fluid flow and distribution of geothermal fluid.

Figure 1. Geological map of Sol de Mañana and Apacheta geothermal fields. Purple triangles are the wells. Black and gray lines are the faults.



The objective of this report is to examine the resistivity structure within the Apacheta geothermal field which is close to Sol de Mañana geothermal field and explore potential correlations between the outcomes of 1D-inversion using magnetotelluric data and the surface manifestations, as well as the mineralogy observed in the Apacheta-1 well (AP-1).

2. Methodology

The MT data in the Sol de Mañana and Apacheta geothermal fields were collected by company Teranov Geothermal Energy and CGG was subcontracted for final processing. 70 MT soundings were acquired. The stations collected data for 17 hours. A remote station collected data during the project time, located 35 km from the survey area. This site was chosen because the topography is relatively flat, there is not much wind because of mountains in the western part. Also, it is far away from touristic paths, and it has porty vegetation, so the animals have not been considered a problem. The following sources were considered as noise sources in the MT survey: borax factory (it has a power generator working all day), tourist and animal activities, and wind´s effect.

The surveyor for Laguna Colorada project pre-processed the raw data (time-series). Five files were acquired at each site (4096 Hz Low Gain, 4096 Hz High Gain, 2048 Hz y 128 Hz). The on-site surveyor processed the data using Mapros software where the data were

converted from the time domain to the frequency domain (from *.ats to *.edi). The data are of very good quality in most of the stations. 65 out of 70 stations were used in the 1D inversion. A skew angle is a parameter that describes the dimensionality of the MT data. Skew values between 0.1-0.3 are considered 2D distorted and values less than 0.1 are considered for 1D or 2D (Swift, 1967; Bahr 1991). Skew values close to 0 indicate a 1D Earth. Many of the soundings have values of skew close to 0 for periods <10s, making them ideal for 1D inversion. The program TEMTD was used to perform 1D inversion of MT data. TEMTD was written by Árnason (2006b) in ANSI-C programming language and runs under UNIX/LINUX operating systems, it uses the gnuplot graphics program for graphical display during the inversion process. As the inversion is 1D the Earth is assumed to be layered. The program can invert for only TEM or MT data and for joint inversion of TEM and MT data. Laguna Colorada project just has MT.

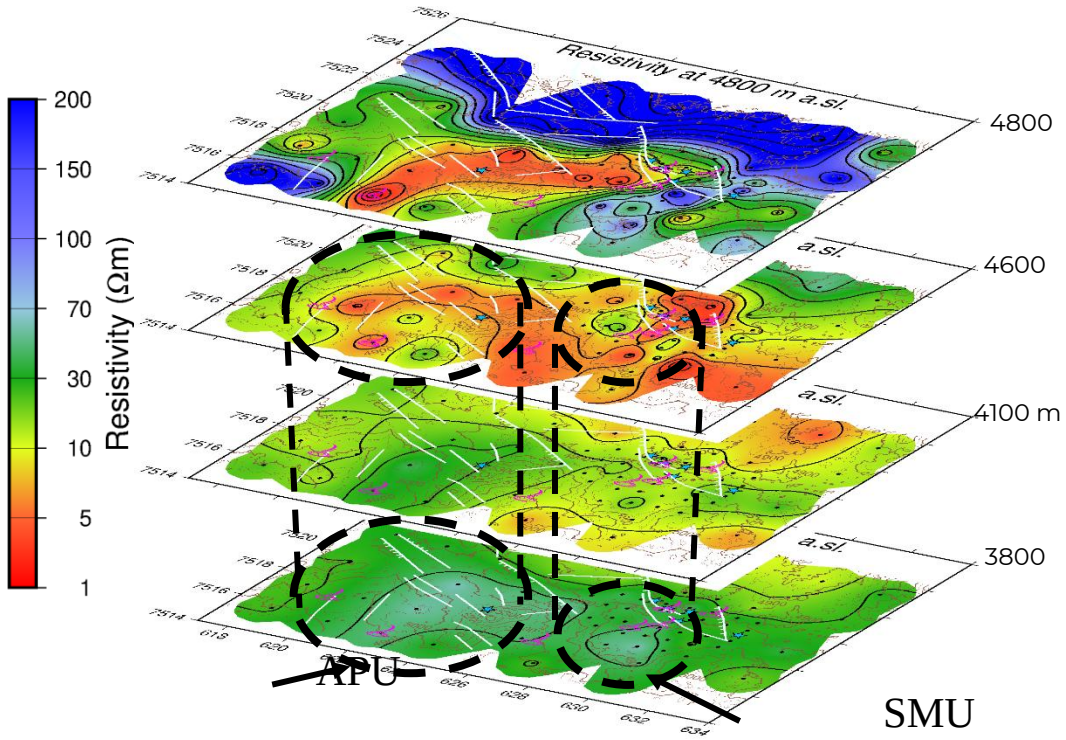
3. Results

Figure 2 shows the resistivity at 4800 m.a.s.l., 4600 m.a.s.l., 4100 m.a.s.l. and 3800 m.a.s.l. At 4800 m.a.s.l. the low-resistivity layer is trending in NE-SW direction, beginning close to the wells in SM field, crossing the location of well AP-1, and farther SW. At 4600 m a high resistivity anomaly appears in the center, just west of the SM wells, and growing larger with increasing depth. Similar resistive anomaly is seen to the southwest below the AP-X1 well. These high-resistivity anomaly could be an up-flow zones. These anomalies are called for this paper as Sol de Mañana upflow (SMU) and Apacheta upflow (APU). At 4100 m.a.s.l. a low-resistivity layer appears with a trend in NE direction. A big uncertainty is associated with it as not many soundings are located there. At 3800 m.a.s.l the survey area is generally becoming more resistive, with two high resistivity anomalies where the possible reservoirs are located (see black dashed lines in Figure 29). By alteration minerology it seems that the argillic and silicified zones in the wells correspond to the clay cap. The clay cap starts at a 0-100 m depth and extends down to roughly 700-1000 m below the surface. This correlates very well with the depth of the bottom of the silicified zone in the wells.

4. Conclusions

- A low-resistivity layer is observed in the results of the 1D inversion of the MT data. The layer is interpreted to be the cap rock in Sol de Mañana field and Apacheta field. The lower resistivity layer reaches 800 m depth below the surface and correlates with the argillic and silicified zones in the wells in Sol de Mañana and Apacheta fields.
- Two upflow zones are identified as up-doming anomalies in the 1D resistivity model, the SMU and APU anomalies. It is not possible to identify if these zones are connected.

- A denser study in the SW and E of Laguna Colorada area will help to understand the conductive anomalies in SMU and APU.
- The static shift must be studied further because it is can greatly influence the results of the 1D inversion. It is unknown how much the static shift problem is present in Sol de Mañana and Apacheta fields and it is therefore recommended to carry out a TEM survey where MT data exist.



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