

Joint Inversion of DC and TEM data from a geothermal area in Mexico

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Introduction

San Felipe's area has many evidences of hydrothermal alteration, recent volcanism and hot springs. Also, there are many normal faults nearby the hot springs zone. The chemical composition of these hot springs indicates the presence of adequate temperatures to produce geothermal energy (Barragan et al., 2001). It is expected to obtain a potential between 100 and 120 MW for the geothermal reservoir, assuming a reservoir volume of 1 km³ (Prol-Ledesma et al., 2012). It is feasible to realize a geophysical exploration survey in the area in order to characterize the geothermal system (Fig. 1).



Figure 1. Localization of San Felipe.

Data acquisition

17 TEM and MT soundings were recorded along 4 lines, 1 NW-SE and 3 SW-NE, with 4 km of sounding spacing (Fig. 2). TEM soundings were acquired in the same spots in order to correct the static shift effect of MT data. Also, DC soundings that were found in literature are being used.

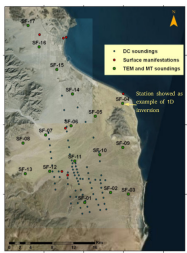


Figure 2. Localization of the soundings recorded.

TEM data

- TerraTEM of Monex Ltd.
- Single loop configuration
- 50 x 50 m loop size
- Four different gains: 1, 32, 100, 1000

Figure 3. TerraTEM device used in the field.

MT data

- Metronix devices
- Dipole length 50 m
- Induction coils
- Non-polarizable electrodes
- Frequency sampling of 4096 and 1 Hz
- Transfer functions in period range of 0.001-100 s

Figure 4. a) Layout of a sounding in the survey area. b) Induction coil. c) Metronix device. d) Field area.

1D Inversion of TEM data

1D inversion of TEM data has been performed with Occam and Marquardt inversion techniques.

Occam inversion was done for 30 layers with logarithmically equidistant layer thicknesses. The thickness of the first layer used is 1 m and the depth of the last layer 200 m.

The number of initial layers for Marquardt inversion was derived from the Occam models. A three-layers model is sufficient to fit the data. Equivalent models and parameter importances were calculated to reflect the model uncertainty and the quality of the inversion. In general, the resistivity and depth of the first layer have the greatest uncertainty. In the figure 7 we present the results of station SF-04, where a good conductive layer can be seen at depth of 90 m. This layer can be correlated to material exposed to hydrothermal alteration. D.C soundings confirm this interpretation. Finally, all the models generated present comparable values of resistivity and depth.

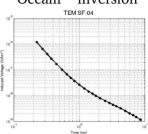


Figure 5. Example of data recorded with gain of 100.

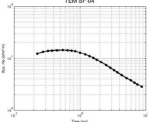


Figure 6. Example of late-time apparent resistivity curves.

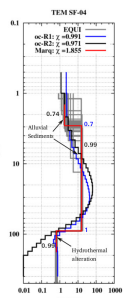


Figure 7. Example of model generated. Parameter importances are marked, in black for resistivities and in blue for depths.

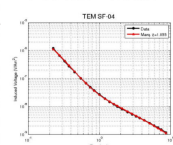


Figure 8. Example of data observed and fitting.

Spatially Constrained Inversion (SCI) of TEM data

Since 1D inversion results are similar for all TEM soundings, we assumed the subsurface is homogenous and decided to perform the Spatially Constrained Inversion scheme.

- SCI constraints are set laterally in two dimensions

1. The first step for constraining the soundings is to perform a Delaunay triangulation (Fig. 10).

2. Second step is to decide how many neighboring soundings each sounding should be constrained to.

3. Final step is setting the strength of the constraint, following the formula:

$$C_{SCI}(d) = 1 + (A - 1) \left(\frac{d}{B} \right)^a$$

Where:
d is the distance between two constrained soundings
B is the reference distance
A the reference constraint value
a determines how the constraints loosen up with distance

Joint DC-TEM Inversion

We could find information about a D.C survey exploration for groundwater purposes realized by the Mexican Commission of Water during the end of the 80's. D.C soundings were acquired with Schlumberger configuration and the maximum AB/2 was of 1000 m. Since some of their D.C soundings are between 300-800 m near from the TEM stations, we decided to perform D.C-TEM Joint inversions to them. In order to be able to do the Joint Inversion, we calculated Forward Modeling to the D.C resulted models that we found in the literature and added 1 % of error to the synthetic data. In the figure 15 we show the 1D results of Occam and Marquardt joint inversion schemes for the stations: SF01-VES216, SF10-VES108 and SF12-VES13. We can see an important conductivity contrast at depths of 90 to 100 m. This conductivity layer can be associated to material that has been exposed to hydrothermal alteration.

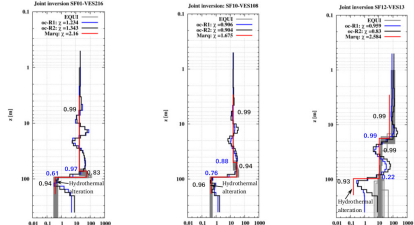


Figure 15. Results of Occam and Marquardt joint inversions. Equivalent models are also showed. Parameter importances are marked, in black for resistivities and in blue for depths.

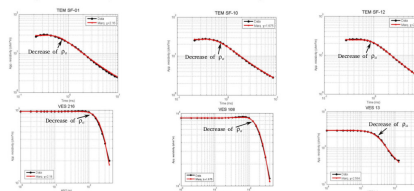


Figure 16. Data observed and data fitting of TEM and D.C soundings.

Conclusion & Outlook

The 1D models generated with TEM data describe the resistivity distribution of the shallow area from the subsurface in the survey area. Spatial Constrained Inversion results are consistent and comparable to the 1D Marquardt and Occam results. Joint inversion results of DC and TEM data are also comparable to the single 1D models obtained. We were able to obtain better results for the resistivity and depth of first layer with the help of D.C data.

Main goal of this project is to generate a 3D model with the Magnetotelluric data. We are going to use the TEM results as constraints for the MT data inversion in order to characterize accurately the geothermal system of San Felipe.

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