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# Electromagnetic exploration for unconventional geothermal systems in Mexico: The GEMex Project

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## The GEMex Project

The GEMex Project is a scientific cooperation by a bilateral consortium formed by European and Mexican experts on the development of superhot and enhanced geothermal systems. The objective is to add their long-term expertise to investigate unconventional geothermal fields in detail. The project started in October 2016 and it will end in 2020. It has been organised into several work packages (WP), grouped by disciplines. Specifically, the WP5 – Detection of Deep Structures – includes the geoelectrical characterisation using both magnetotellurics and time domain electromagnetics.
The ultimate goal is to generate a comprehensive reservoir model by integrating information of the geoelectrical-imaging with results obtained by other geoscientific disciplines (geophysics, geology and geochemistry) in order to study variation of the subsurface physical properties and their role in the reservoir dynamics.

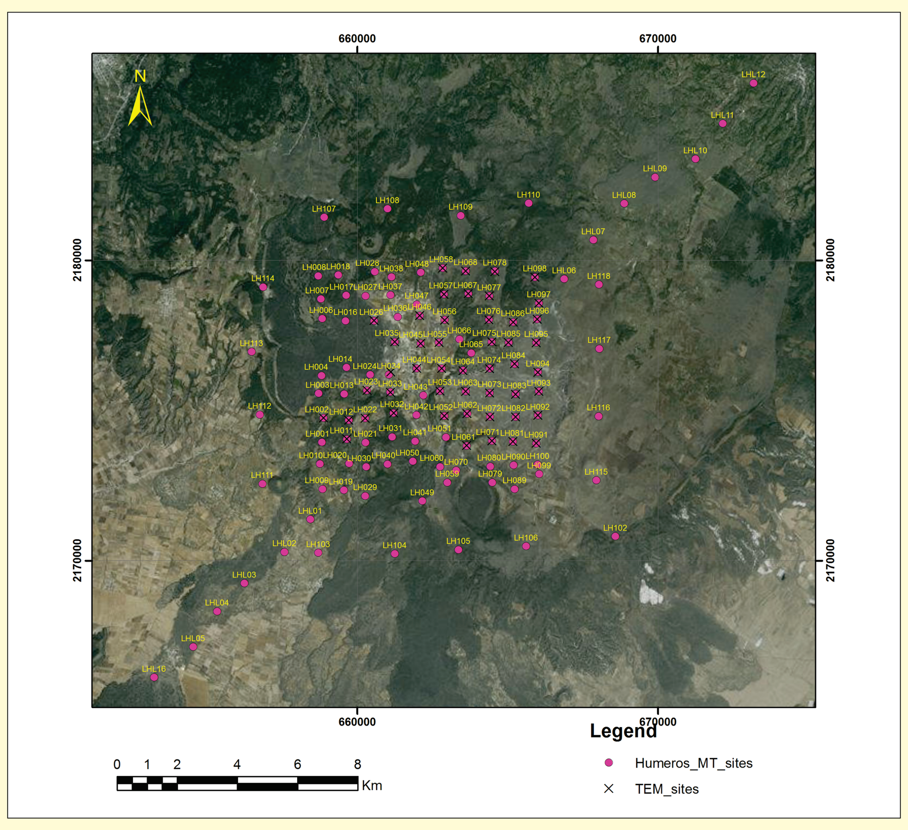



Figure 2. Data acquisition at Los Humeros geothermal field.

## Data processing

Magnetotelluric responses were estimated using the advanced mode of the BIRRP scheme (Bounded Influence Remote Reference Processing; Chave and Thomson, 2004) including the remote reference processing. The apparent resistivity and phase curves were significatively improved since the sites had been influenced by anthropogenic noise. In figure 4, the comparison between BIRRP estimation and a non-robust scheme is shown in order to compare the improvement provided by the robust estimation in noisy sites.

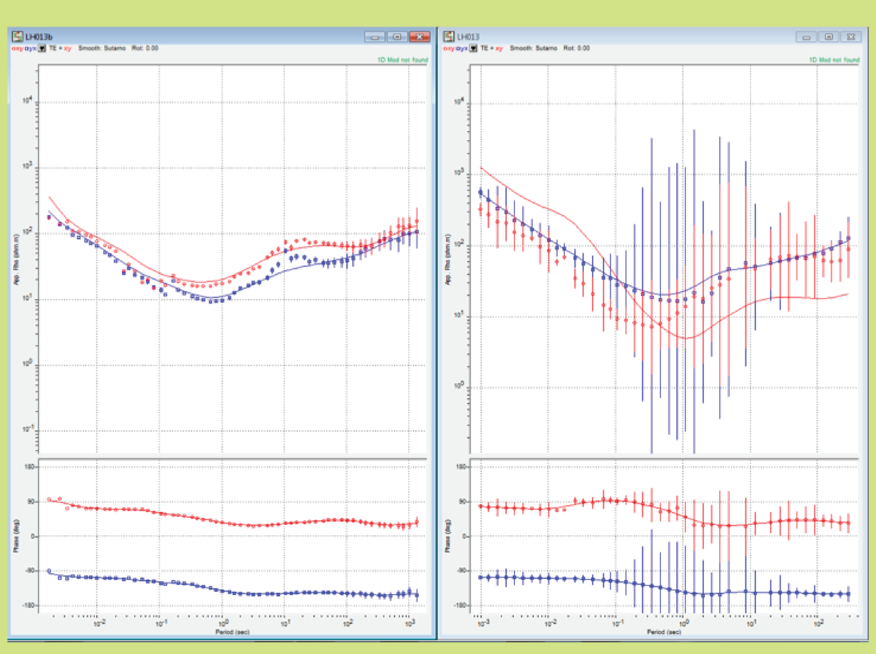


Figure 4. Comparison between BIRRP estimation (left) and a non-robust scheme (right) for site LH013.

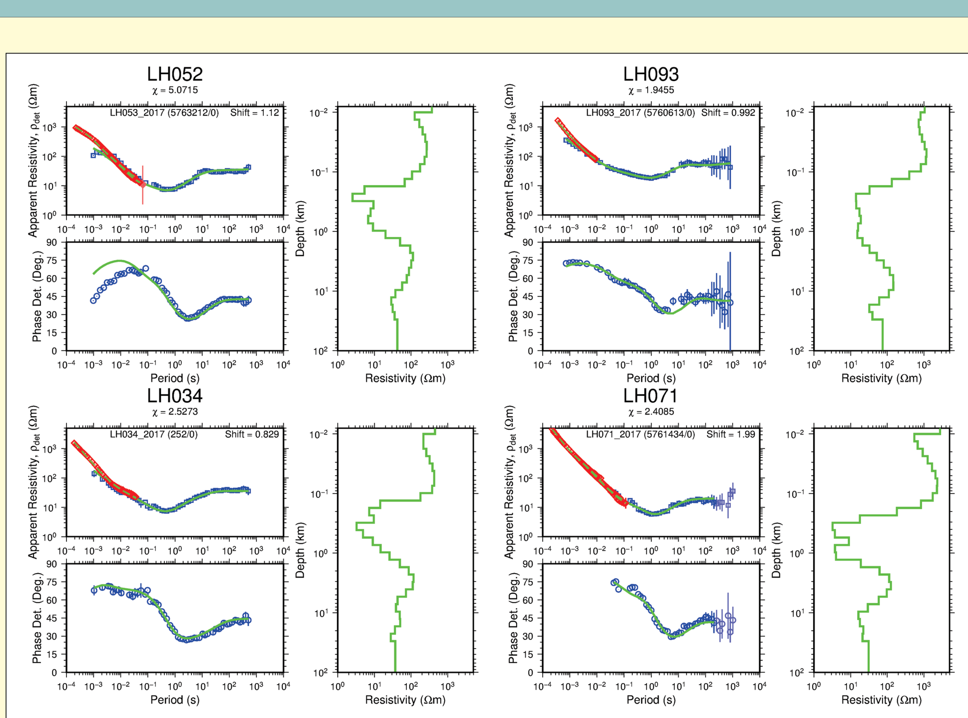



Figure 6. 1D geoelectrical models and adjusments from MT+TEM joint inversion using TEMTD inversion scheme.

## Future work

In addition to the acquisition of electromagnetic data, the activities planned in this project include novel modelling of previous and new geophysical data, the calculation of synthetic models for the optimisation of the three-dimensional inversion, which will be performed using two different schemes for comparative purposes (Siripunvaraporn et al., 2005; Kelbert et al., 2014), 1D-, 2D- and 3D-modelling including joint and advanced constrained inversion schemes (e.g. Árnasson, 2006; Gómez-Treviño et al., 2014; Gallardo-Delgado, 2007) as well as multi-objective joint optimisation (Santilano et al., 2018).

## Study areas

Two different sites have been selected in eastern area of the Trans-Mexican Volcanic Belt (Figure 1), with two different goals. The main objective at the Acoculco caldera is to develop new methodologies for the characterisation and exploitation of a low-permeability field that shall produce energy by utilisation of an EGS. On the other hand, at the currently producing Los Humeros geothermal field, the idea is to apply new developments for characterising and better understanding superhot conditions (>350°C) found in some sectors of the reservoir (SHGS) and enhance future exploitation attempts.

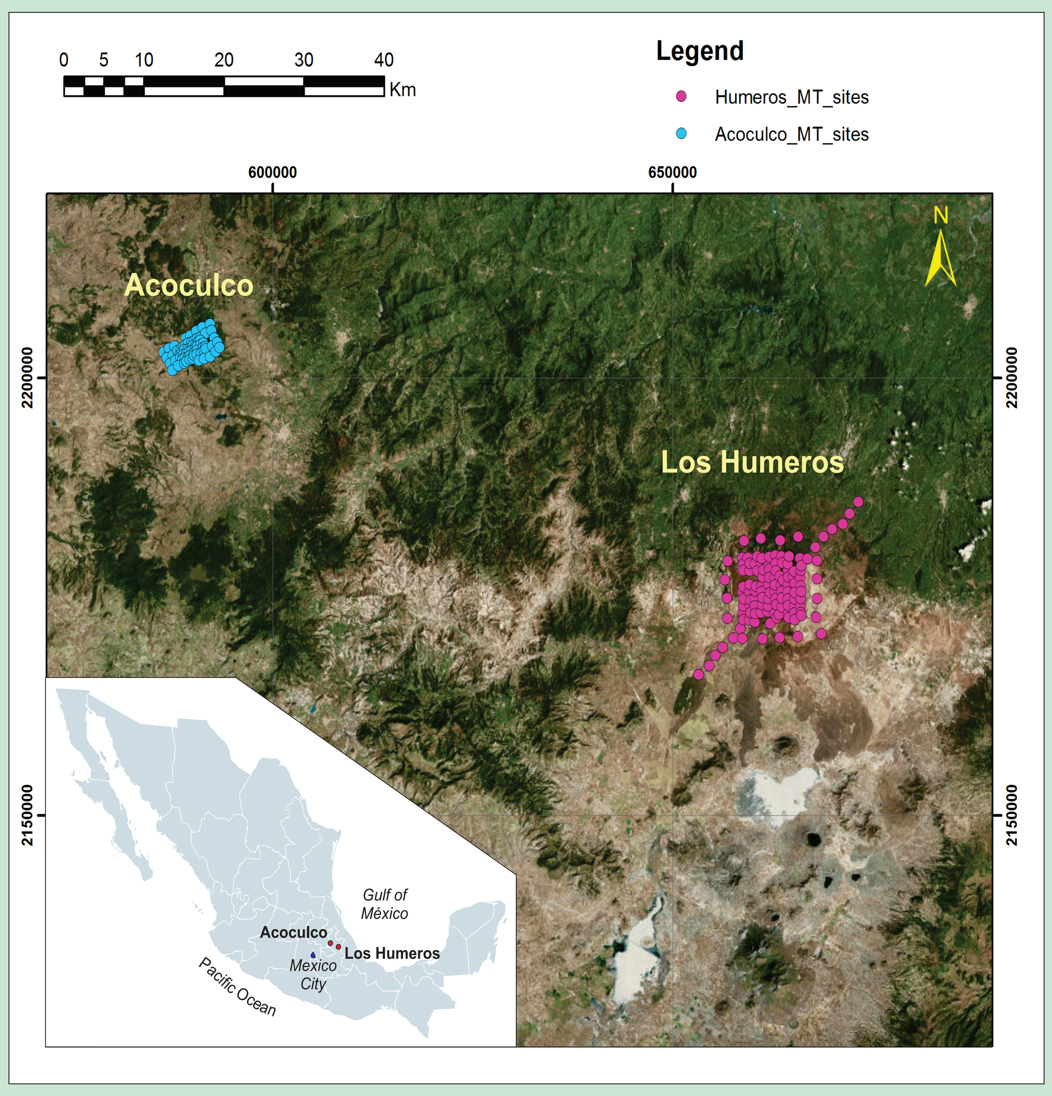



Figure 1. Location of the study areas.

## Preliminary results

Preliminary 1D modelling was performed by the Iceland Geosurvey Group for Los Humeros dataset using TEMTD algorithm (Árnasson, 2006). The scheme involves the joint inversion of MT and TEM soundings. In figure 5, horizontal sections are shown from the interpolation of 1D models generated with TEMTD algorithm (Árnasson, 2006). In figure 6, MT+TEM inverted models and adjustments for four different sites are shown.

## Data acquisition

Geoelectrical characterisation has been performed using both magnetotellurics (MT) and time domain electromagnetics (TEM) to infer subsurface electrical resistivity distribution. A total of 123 MT soundings were acquired at the Los Humeros geothermal field in a cuasi-regular grid and along a NE-SW profile. The soundings were recorded using four ADU-07e devices by Metronix. In order to estimate the impedance tensor with the remote reference technique (Gamble et al., 1978; Goubau et al., 1979) a remote reference station was located in vicinity of the Acoculco area, about 78 km away. Additionally, 44 TEM soundings were acquired using a terraTem device by Monex Geoscope for both static shift correction and joint 1D inversion (Figure 2).
In Acoculco geothermal prospect, 68 MT soundings were carried out with the same acquisition parameters. They were acquired in a regular grid surrounding the already drilled wells where the estimulation test will be performed (Figure 3). The remote reference station was located at Los Humeros geothermal field. In further fieldwork, the rest of the TEM soundings will be measured at both the sites.

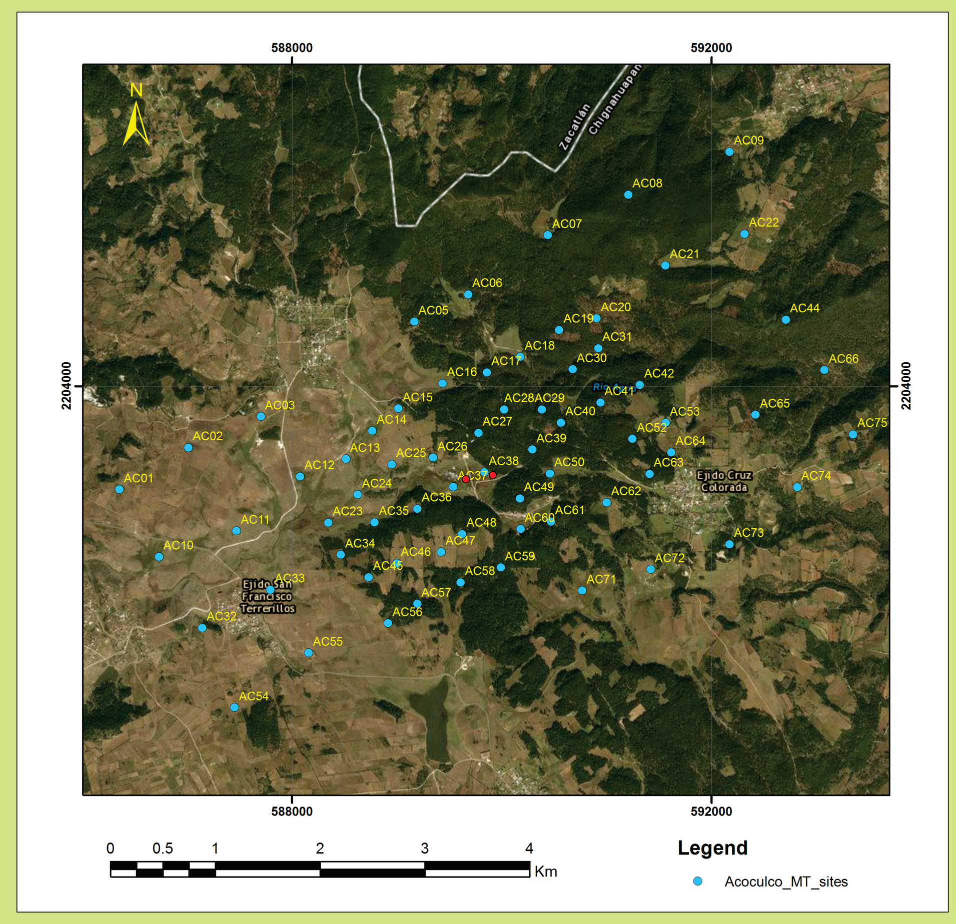
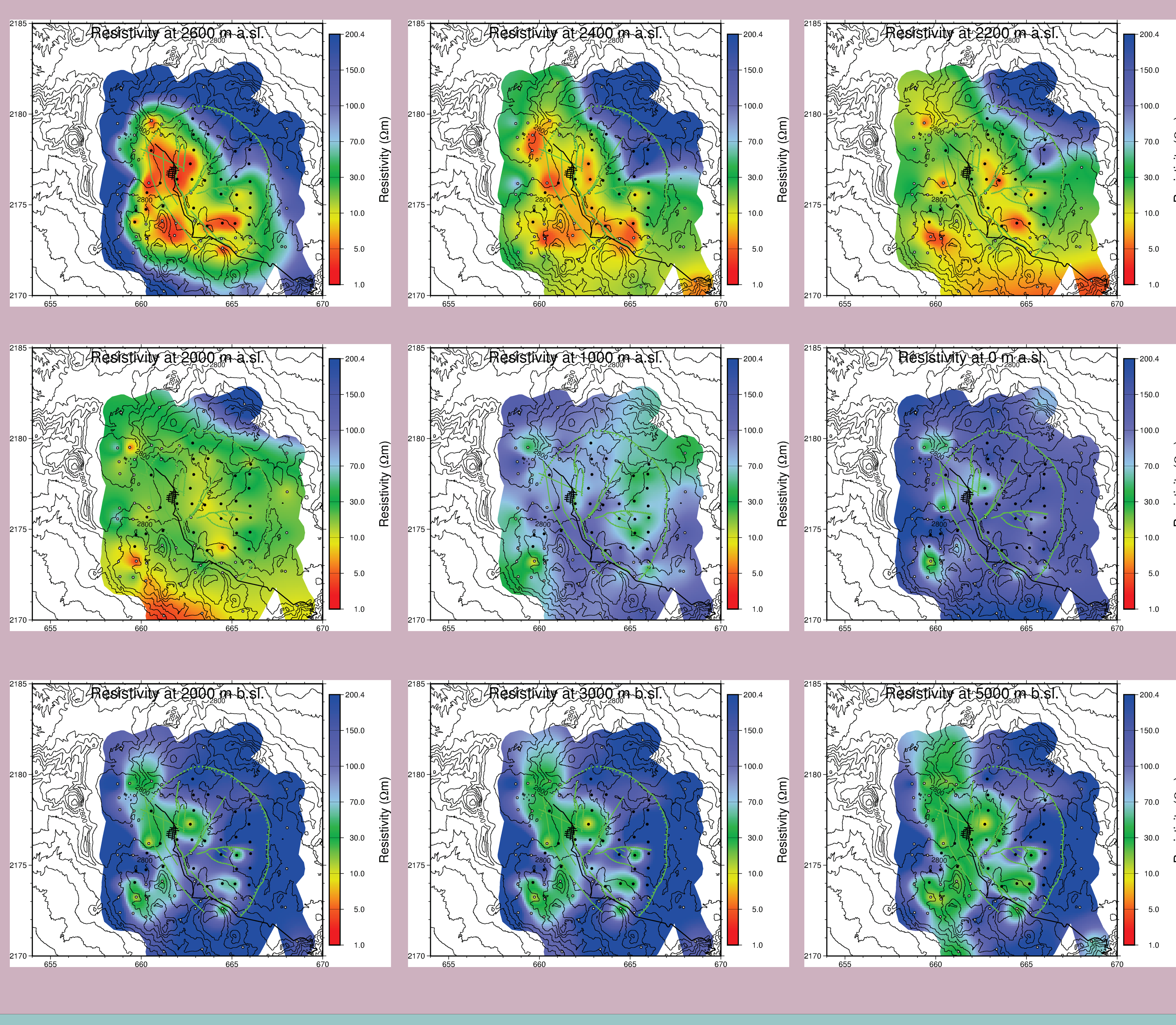



Figure 3. Data acquisition at Acoculco prospect. Wells are shown with red dots.

Figure 5. Preliminary 1D modelling from MT+TEM joint inversion using TEMTD code. Horizontal sections from 2400 m a.s.l. to 5000 m b.s.l. (left to right and top to bottom).




## Acknowlegments

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## References

*Árnason, K., 2006. TEMTD. A program for 1D inversion of central-loop TEM and MT data, a short manual. ÍSOR – Iceland GeoSurvey, Reykjavík, 16 pp.
*Chave, A.D., and Thomson, D.J., 2004. Bounded influence estimation of magnetotelluric response functions, Geophys. J. Int., 157, 988-1006.
*Gallardo-Delgado, L.A., 2007. Multiple cross-gradient joint inversion for geospectral imaging. Geophys. Res. Letters, 34. L19301.
*Gamble, T., Goubau, W.M. and Clarke, J., 1979. Magnetotellurics with a remote magnetic reference, Geophysics, 44(1), 53-68.
*Gómez-Treviño, E., Romo-Jones, J. M. and Esparza-Hernández, F. J., 2014. Quadratic solution for the 2-D magnetotelluric impedance tensor distorted by 3-D electro-galvanic effects. Geophys. J. Int., 198(3), 1795-1804.
*Goubau, W.M., Gamble, T.D. and Clarke, J., 1978. Magnetotelluric data analysis: removal of bias. Geophysics, 43(6), 1157-1166.
*Kelbert, A., Meqbel, N. M., Egbert, G. D. and Tandon, K., 2014. ModEM: A modular system for inversion of electromagnetic geophysical data, Comp. Geosci., 66, 40-53.
*Siripunvaraporn, W., Egbert, G.D. and Uyeshima, M., 2005. Interpretation of two dimensional magnetotelluric profile data with three dimensional inversion: synthetic examples. Geophys. J. Int. , 160, 804–814.
*Santilano, A., Godio, A. and Manzella, A., 2018. Particle swarm optimization for simultaneous analysis of magnetotelluric and time-domain electromagnetic data. Geophysics, 83(3), E151-E159.