# Continuous Electromagnetic Monitoring Network in the Mexicali Rift, Mexico

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## ABSTRACT

The use of electromagnetic exploration methods as a monitoring tool for the evaluation of geothermal fields is relatively new. However, the first results have generated promising results. In México we are starting the installation of electromagnetic monitoring stations to register the natural electromagnetic field in the Mexicali rift. Our plan is to have a network consisting of 15 continuous monitoring stations, installed in strategic locations of the Mexicali valley around the Cerro Prieto geothermal field. The aim is to improve our understanding of permeability changes and fluid dynamics in the area. Natural variations in electromagnetic fields may provide information about temporal variations of the electrical properties of the ground, likely linked to changes in permeability and geothermal fluid flow. With this concept, long period magnetotelluric stations were designed and built in CICESE. They use electrical dipoles 25 m long to measure the variation of the horizontal electric field (Ex, Ey) and a triaxial fluxgate magnetometer to register the variation of the natural magnetic field (Hx, Hy, Hz). The first station was installed in May 2013, and data were registered and processed in a regular time basis. In this paper we show preliminary results in terms of sounding curves for different times.

## 1. INTRODUCTION

The Cerro Prieto geothermal field is located 30 km south of the city of Mexicali, on the Baja California peninsula, near the Mexico/USA international border (Figure 1). The Cerro Prieto power plant has been operating since 1973 and is the most important geothermal field in the country, with an installed capacity of 720 MW. In recent years the field has experienced a reduction in pressure, enthalpy and temperature, related to the overexploitation of the reservoir (Aguilar-Dumas, 2010). The application of new technologies and methods may provide new and more detailed information about the conditions of the reservoir, allowing a better understanding of the system as well as some clues about the future development of the field.

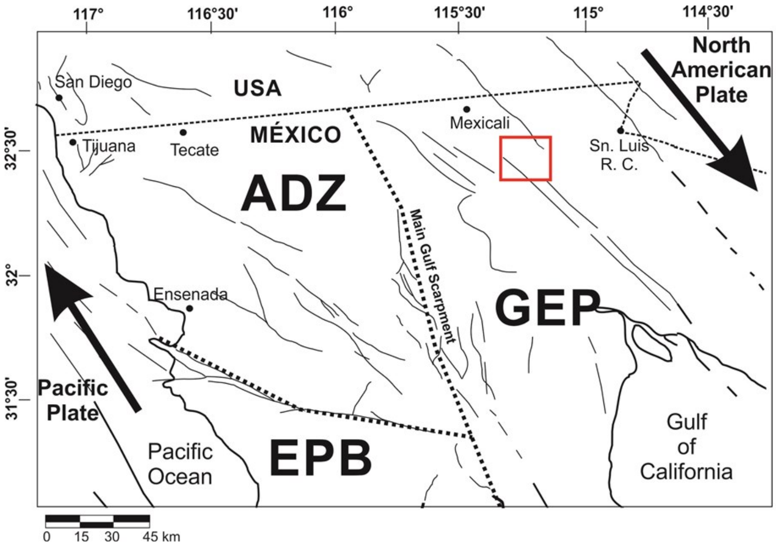


**Figure 1: Location of the Cerro Prieto geothermal field is indicated by the red square. The main active faults are shown as black lines. Tectonic provinces are also indicated: GEP stands for Gulf of California Extensional Province, ADZ stands for Active Deformation Zone and EPB means Extensional Peninsular Block (Stock et al., 1991). The arrows show the relative motion of the Pacific and North American tectonic plates.**

## 2. RATIONALE

In March 2010, a profile with eight magnetotelluric stations was occupied south of the Cerro Prieto Geothermal field as part of a survey conducted to study the electrical conductivity of the crust in northern Baja California (Figure 2). On April 4th, a strong earthquake M=7.2 occurred in the Mexicali valley, distressing the entire area, and causing considerable ground displacements, mud volcanoes and liquefaction phenomena in several places. In May 2010, the same sites were occupied using the same equipment and data acquisition parameters (Cortés-Arroyo, 2011) expecting to detect possible changes in the ground electrical conductivity caused by fluid redistribution and/or permeability changes associated with micro-fracturing close to the active faults.

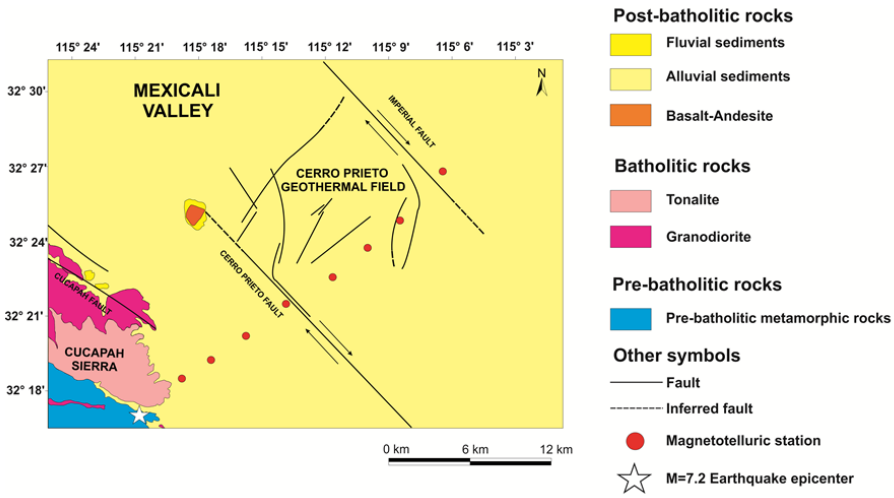


**Figure 2: Location of the magnetotelluric sites, earthquake epicenter, Cerro Prieto production zone, and location of the Imperial and Cerro Prieto Faults.**

Apparent resistivity and phase curves show small changes in all curves except at one site close to the Cerro Prieto geothermal field. Both data sets were interpreted using a 2D inversion algorithm designed to produce ground resistivity models with minima structure, i.e. Occam's razor optimization algorithm (deGroot-Hedlin & Constable, 1990). The resulting models are shown in Figure 3. The conductive anomalies are in red while resistive zones are blue. The main change can be observed at the NE end of the profile close to the Imperial Fault, the assumed eastern limit of the geothermal field. In this zone the after-earthquake model shows an enhancement of the electrical conductivity possibly due to redistribution of fluids caused by the earthquake and/or its multiple aftershocks. A more subtle increase of conductivity can be noticed between km 5 and 10 in the horizontal scale.

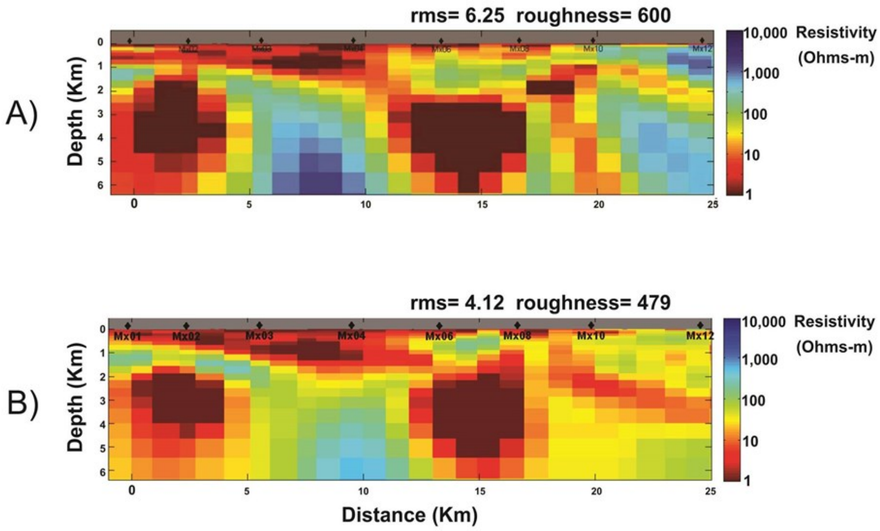


**Figure 3: Comparison of ground resistivity models. A) Resistivity model based on pre-earthquake data (March 2010 data). B) Resistivity model based on post-earthquake data (May 2010).**

These results motivated the idea of implementing a network of electromagnetic stations in the area, with the aim of monitoring temporal changes in electrical properties around the geothermal reservoir. The idea of electromagnetic monitoring is relatively new. In recent years, a couple of projects started to experiment with the magnetotelluric method with continuum measurements in volcanic areas (Aizawa et al., 2011; Aizawa et al., 2013), or in time lapse measurements in a geothermal area (Peacock et al., 2013). In our work, the goal is to install a network of 15 permanent magnetotelluric stations with continuous registering.

## 3. EQUIPMENT

For this new work, equipment that fulfills the specific requirements of the study was needed. Instead of acquiring expensive, commercial equipment, the magnetotelluric continuous recording stations used here were designed and built in the Applied Geophysics Department at CICESE (Figure 4). They have a 5 Hz frequency registering capacity, and there are two different versions: the first version can register both magnetic (Hx, Hy, Hz) and electric (Ex, Ey) fields and the second version can only register electric field components. This makes use of the regional uniformity of the magnetic field. For the magnetic field a triaxial

Scintrex fluxgate magnetometer is used, and for the electric field, two 25 m dipoles are implemented using lead-lead chloride electrodes, built at CICESE according to the instructions of Booker and Burd (2006). The electrodes are installed with a plastic bucket and local soil to help maintain the humidity up to 2 months with very high temperatures (up to 50 °C in the area).

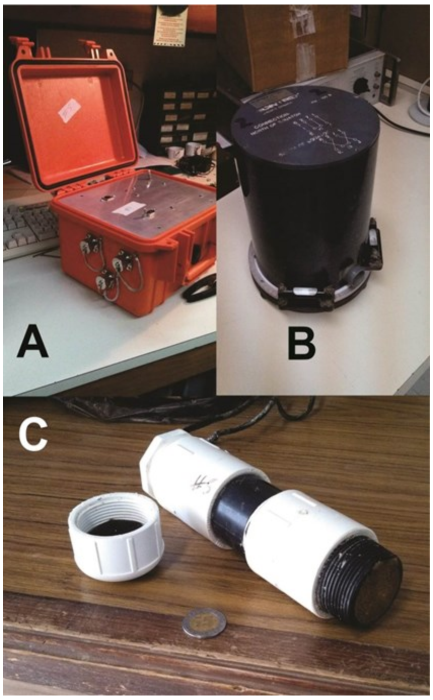


**Figure 4: A) Registering equipment designed and manufactured at CICESE. B) Triaxial fluxgate magnetometer. C) Lead-lead chloride electrode.**

At present two stations are already installe

d in the area (Figure 5), while the rest are being manufactured. The first one was installed in May, 2013 and the second in August, 2013. These stations have been used to test the equipment in the challenging climatic conditions of the area, and to evaluate the data quality that can be obtained.

The stations are visited approximately every 20 days, for revision, maintenance, battery changes and to obtain the registered data.

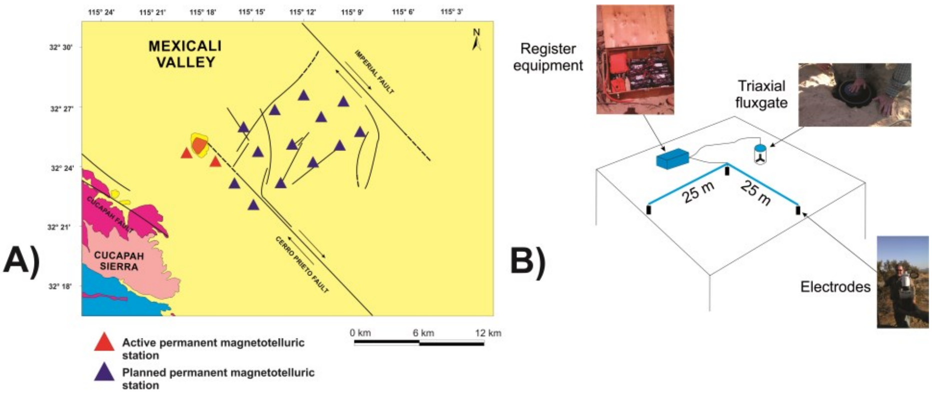


**Figure 5: A) Location of the permanent magnetotelluric stations. B) Installation scheme of the equipment.**

The data is processed by removing the tendencies in the time series, and then a robust processing software is used (Chave and Thomson, 1989) to obtain the apparent resistivity and phase curves. Data from the Tucson magnetic observatory, obtained through the INTERMAGNET network, are used as a remote reference to improve the quality of the results.

### 3.1 First results

Two examples of the processed data are shown in Figure 6. The curves below 50 s periods seem to be affected by some odd effect. Several tests have been performed to detect the origin of this effect, including theoretical and practical reevaluation of transfer functions and measuring in the higher frequencies band with a Metronix ADU-07 to evaluate a possible site effect. After all the evaluations, the main possibility is that our fluxgate magnetometer cannot provide quality data below 50 s. Although the fluxgate magnetometer is able to measure at higher frequencies (up to 5 Hz), the signal to noise ratio at the instrument is too low to provide good quality data in the higher frequency band. Because of this, an implementation of induction coils and a higher sample frequency (15 Hz) are to be made in the next few months. In a first stage the curves estimated with our homemade instruments will be contrasted with data obtained by the Metronix ADU-07 equipment to evaluate the results.

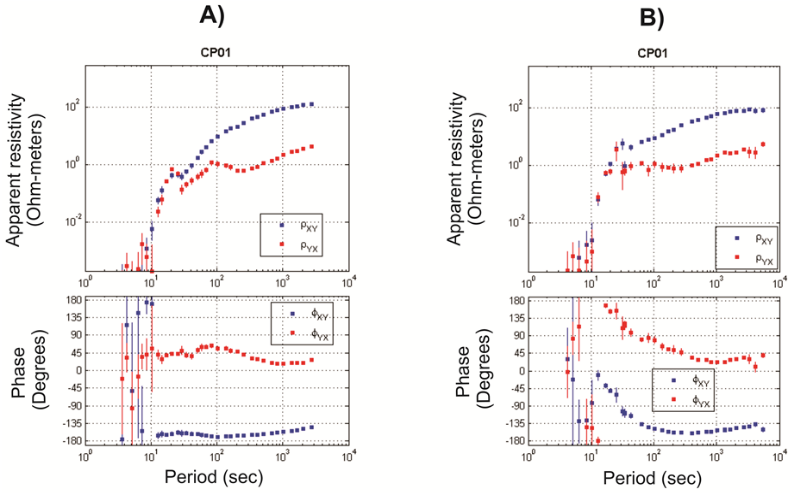


**Figure 6: A) Apparent resistivity and phase curves for May, 2013; B) Apparent resistivity and phase curves for February, 2014.**

## 4. CONCLUSIONS

We expect that the difficulties to obtain reliable data can be surpassed by replacing the magnetometers with induction coils, and that this will bring a considerable improvement. Above periods of 50s, the data has shown good repeatability through the recorded months, which gives us confidence that future variations that might show up can be identified as regional or local variations in electrical conductivity. Although the climatic challenges of the area (typically above 40 °C, sandstorms, etc.) the equipment has behaved better than expected and improved ways to protect the stations have been implemented throughout all this time. The small size and low cost of the equipment promise fast construction and easy installation for future stations.

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