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MT, CSEM and Gravity Joint Interpretation for a Geothermal Study the Vallès Basin (Catalan Costal Range, NE Spain)

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ABSTRACT

In the frame of the GEO-URBAN project, two low-enthalpy deep geothermal reservoirs in urban areas, Dublin basin (Ireland) and Vallès Basin (Spain), will be evaluated using novel geophysical exploration techniques. In particular, in the Vallès Basin (Catalan Coastal Ranges, NE Spain) the geothermal reservoir corresponds to a fractured granite bedrock. In its NE part (La Garriga-Samalús) significant geothermal anomalies were detected from geophysical surveys a few years ago. New gravity data shows a strong gravity gradient in the NE-SW VallèsVallès half-graben system and recent magnetotelluric (MT) profiles have imaged, with high resolution, the main fault (Vallès fault) of that system. To complete these data and to test novel geophysical techniques to be used in the GEO-URBAN project, a control source electromagnetic (CSEM) profile coinciding with one of the MT profiles were acquired. For the CSEM measurements, different configurations were tested (single-Long Electrode Mise À La Masse (LEMAM), double LEMAM, etc.) to explore how the source signal and/or the recorded signal could increase the signal/noise ratio in noisy environments. In this works we will present the results of these tests as well as the 2D MT-CSEM joint inversion and the MT and gravity joint interpretation.

1. INTRODUCTION

Nowadays, low-enthalpy deep geothermal reservoirs are targeted as resources to generate heat in urban areas. Different geophysical surveys have determined the presence of geothermal anomalies in La Garriga - Samalús area, in the Vallès Basin (Catalan Coastal Ranges, NE Spain) (fig. 1). However, the setting remains poorly understood and largely untapped, and the fractured nature of the granite bedrock represents a geological challenge.

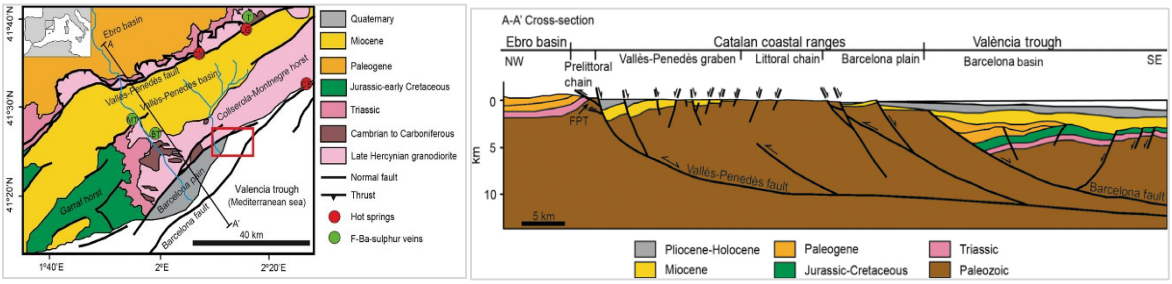


Figure 1: Left: Geology map of the central Catalan Coast Range. Right: Cross-section A-A' through the Catalan Coastal Range (Santanach et al., 2011)

The Catalan Coastal Ranges display a well-developed horst and graben structure limited by NE-SW and ENE-WSW striking normal faults developed during the opening of the Valencia Trough (NW Mediterranean). The Vallès-Penedès belongs to the outermost graben of this extensional system. It is filled with marine and continental Miocene sediments and its internal structure is characterized by the presence of longitudinal (ENE– WSW) faults that compartmentalize a NW - tilted block (Roca et al. 1999). The Garriga hot springs are located at the NW edge of this basin close to the main bounding fault (the Vallès-Penedès Fault).

The Vallès half-graben (fig. 1) could allow the study of a complex and multiphase tectonic/fluid history encompassed by four tectonic events.

Every tectonic event has conditioned the characteristics of the fractures system and, therefore, the fluid circulation regime. Since the Neogene, hydrothermal fluids up to 190^{0}C have ascended through the faults and characterized the Vallès fault by hydrothermal conditions, which remain active until nowadays. Forced convection seems to be the most plausible model to explain the La Garriga-Samalús geothermal anomaly (Fernández & Banda, 1988), having the recharge zone in the Montseny Massif with a water circulation pattern through the Paleozoic on its way down (fig. 2).

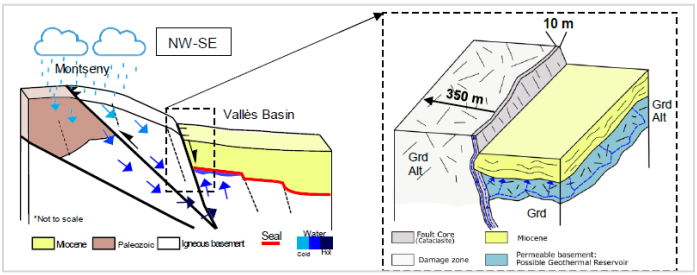


Figure 2. Proposed water circulation model in the study area after multiscale characterization of the fracture zone, by Mitjanas 2018.

2. GEOPHYSICAL CHARACTERIZATION

Several geophysical campaigns were carried out in the area in the last five years; in particular MT and gravity and CSEM tests. As a first approach, with the aim to correlate the results obtained with these techniques, here we show the results from the three collocated profiles.

2.1 Magnetotelluric surveys

A profile with 14 MT sites perpendicular to the fault was carried out in 2016 (fig.3). In order to obtain a high resolution resistivity model, some vintage SEV and the information of two boreholes were taken into account to construct a 2D model using the RLM2DI inversion code (Rodi and Mackie, 2001). The resulting model clearly delineated the subvertical fault (see figure 6c in the next section).

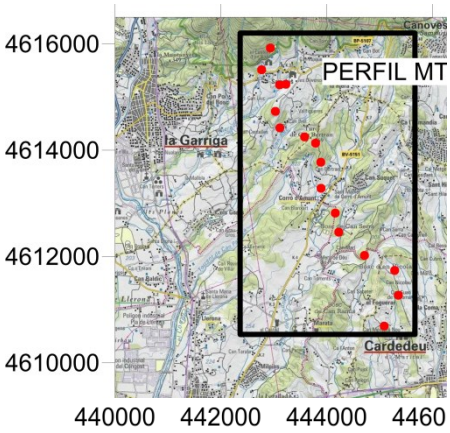


Figure 3. MT profile perpendicular to the trend of the main fault.

2.2 CSEM experiment

CSEM measurements are good complementary data for MT characterization although its methodology on land is not sufficiently developed and tested as it is in marine environments. Acquiring expertise in CSEM is crucial for future studies in places where MT cannot be performed due to high levels of cultural noise. As the MT results to image the Vallès fault were good, we decided to carry out two CSEM profiles (fig. 4) to be jointly interpreted with MT.

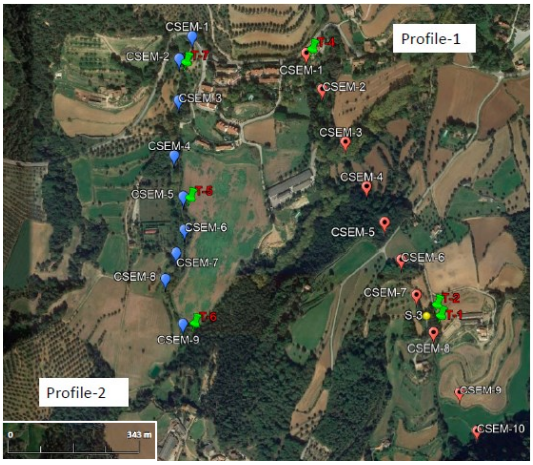


Figure 4: CSEM profiles. NW-SE Profile-1 coincides with MT but it is shorter, covering only the first 1400m. Profile-2 is a NS 800m long.

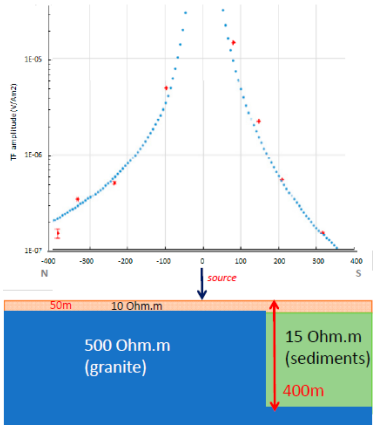


Figure 5. Preliminary interpretation of CSEM profile-2 based on 1D inversion using DIPOLE1D. Red points measured data, blue points model responses

Different modeling and inversions have been attempted for the surface-surface configuration profiles: Figure 5 shows the results of the 1D model obtained from the DIPOLE1D code (Key, 2009) to fit the CSEM data of profile-2. Red crosses are the experimental data and the blue dotted line are the 1D responses: (a two layer case at the left and three layers model at the right, as it can be seen in the fig. 5. This simple test proves that CSEM is sensitive to the presence of a fault.

More information was obtained from 2D inversion. Figure 6d shows the result of the 2D MT-CSEM joint inversion for profile-1, using MARE2DEM code (Key, 2016).

So far, in addition to surface-surface configuration, additional configurations were also tested to improve the resolution and signal/noise ratio, not shown here. The metallic casing of wells close to the profile can be used as receiver to increase the recorded signal, or it can be used as a long electrode transmitter to inject the electrical current deeper. However, the quantitative interpretation or the inversion of these data is still a challenge that needs new numerical approaches.

2.3 Gravity data

A 2D gravity profile was build using data from the Gravity Map of Catalonia (Casas et al., 1981) with new data acquired during the winter of 2019.

Considering the great variety of lithologies present, each with particular densities, it was decided to employ a single reduction density corresponding to the mean density of the upper crust. Thus, the Bouguer anomalies were computed using a reduction density of 2.67

g/cm³. The ellipsoid adopted for the calculation of theoretical gravity was the WRS-84, which includes corrections caused by attraction produced by atmospheric mass.

The terrain correction was made using OASIS MONTAJ software (by GEOSOFT), which allows the calculation of the regional terrain correction from a coarse regional DEM draped over a more finely sampled local DEM model that covers the survey area. This produces a regional correction grid which represents terrain corrections beyond a local correction distance and this can be re-used to calculate detailed corrections at each observed gravity location. This process uses a combination of the methods described by Nagy (1966) and Kane (1962).

Figure 6a (black dots) shows the residual anomaly obtained from the Bouguer anomaly map and considering a regional first-degree polynomial surface. A high negative slope from the NW is the signature of the subvertical Vallès fault. Figure 6b shows a preliminary 2D density model obtained from the inversion of the experimental data using OASIS MONTAJ, and the fitting of the model responses (black solid line) and data is shown in fig. 6a

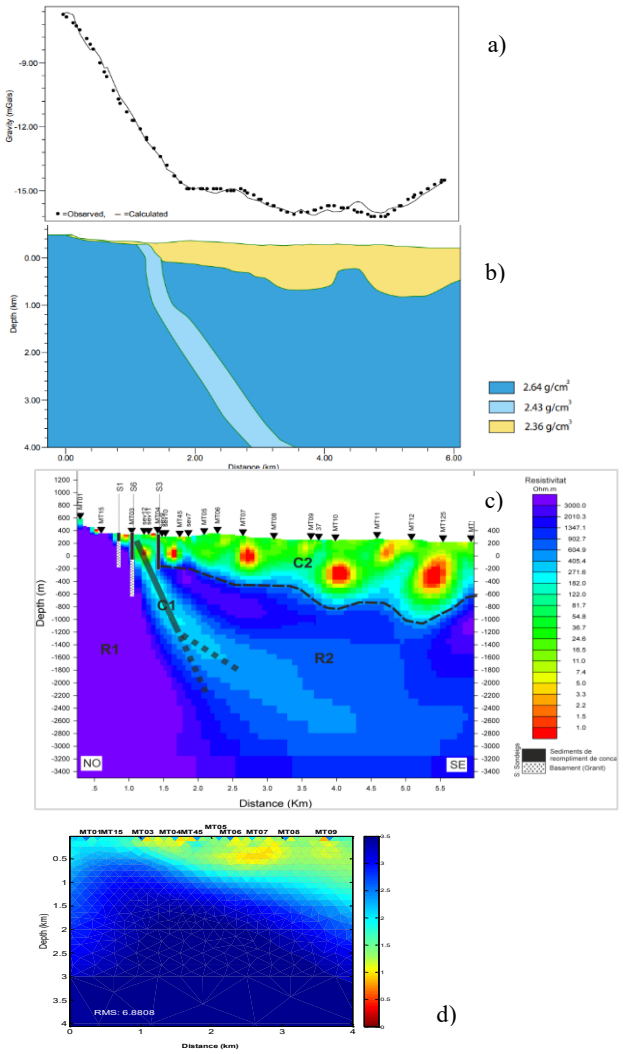


Fig. 6. Comparison of 2D preliminary models: a) residual gravity, b) density model, c) MT and d) joint inversion CSEM and MT (a subset)

3. RESULTS AND CONCLUSION

Figure 6 shows a good agreement between the three geophysical 2D models. Figure 6b corresponds to the density model that fits the residual gravity anomaly (figure 6a). The density model (figure 6b) shows, in blue colours, the denser materials (2.64 g/cm^3) that can be correlated with the granodiorite and Paleozoic materials of the Prelitoral chain. Within it, the fault is characterized by less dense materials (2.43 g/cm^3), necessary to fit the strong negative gradient of the anomaly. In brown, the low-density value (2.36 g/cm^3) corresponds to the Miocene deposits Figure 6c shows the 2D MT resistivity model that images the normal vertical fault (C1) as a relatively conductive zone in contrast with the resistive basements: R1 and R2. R1 corresponds to the granodiorite of the Coastal Range and R2 to the basement of the Vallès basin (Paleozoic granodiorite and filling materials as conglomerates). C2 corresponds to Miocene sediments with presence of fluids. Figure 6d corresponds to a 2D resistivity model inverting CSEM surface-surface measurement of profile 1 (8 sites) jointly with MT (9 sites). The RMS for that model must be reduced and more tests must be done to check the sensitivity of CSEM to C1 (see figure 6c).

These results suggest a good starting point for a joint interpretation. Moreover, a seismic tomography profile, collocated with the previous ones, as well as passive seismic techniques will be carried out, with the aims of adding a new physical constraint to the models.

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