Numerical simulation of electromagnetic induction responses of 2D resistive structures as an aid for interpretation of archaeological data

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Summary

A Frequency-domain Electromagnetic Induction System was used to characterize an archaeological site in South Patagonia. This method involves the measurement of the change in mutual impedance between a pair of moving coils. The data are usually interpreted directly from the In-Phase and Quadrature components, and sometimes also by performing a 1D or in some particular cases 2D inversions. Most of the applications of this method point to the detection of metals and other conductive bodies. Notwithstanding, we have found in a previous paper that good resolution can be obtained for detecting also resistive structures. In the present paper, we analyzed the sensitivity of the method to characterize a structural feature that was present at the archaeological site: two adobe walls with tile deposits between them, both with a clear resistive electrical signature. Using the 2D forward modeling code introduced in that paper, we performed numerical simulations of the In-Phase and Quadrature components of the response of the above mentioned buried structure. The results were then used to interpret the data acquired at the site. The archaeological structure and the soil environment were modeled using information from excavations as well as from geoelectrical data; then, we calculated the synthetic responses using the 2D forward code and these results were compared to data. The good correlation obtained confirmed us that these resistive structures present a characteristic signature, which can be distinguished in the response patterns.

Introduction

Within the last three years we have been performing geophysical studies to characterize the archaeological remains of a XVIII century-Spanish fortress situated on the Atlantic coast in Patagonia (Argentina). The site has an area of 10000m^2 and the topography presents elevations, which may be associated to the location of buried structures. Archaeological excavations showed that these structures were mostly adobe walls; also, tiles probably due to roof collapse were found within the zone of interest (Senatore *et al.*, 2000). A preliminary geophysical study indicated that those buried structures appeared in data as resistive anomalies (Lascano et al., 2003).

Our first objective was to survey two sectors of the total area, which includes a presumably set of houses, in order to obtain a preliminary map of the site. To improve the fieldwork, we planned to use GPR to localize the anomalous zones and after that, the geoelectrical method to get a high-resolution local electrical image of the subsoil. But the presence of vegetation produced very distorted radargrams, so we decided to use instead a Frequency-domain Electromagnetic Induction (EMI) system to delimit the anomalous zones because this system does not require direct contact with the ground.

These equipments are generally used as detectors of conductive buried structures since they are very sensitive to the presence of this kind of electrical anomalies (e.g., Witten et al., 2003). Many studies have been done to analyze and characterize the electromagnetic responses of conductive bodies (e.g., Won et al., 2001; Shubitidze et al., 2004) and also 1D and 2D inversion methods have been developed to re-construct the conductivity profiles from EMI data (see e.g., Huang and Won, 2000; Zhang and Liu, 2001; Farquharson *et al*. 2003). Notwithstanding, in a previous paper (Martinelli et al., 2004), where we reported an alternative forward modeling technique based on a Rayleigh-Fourier approach for 2D multi-layer structures, we showed that EMI method can be successfully applied to detect also resistive structures.

In the present paper, we analyzed EMI data acquired along a line which presumibly crosses the remains of two adobe walls with a tile deposit between them, in order to determine if these structures can be recognized from data. We used information from a geoelectrical dipole-dipole profile, obtained along the same line, together with results from excavations, as starting points for modeling the soil together with the buried structure. Then, we numerically simulated the In-Phase and Quadrature responses to the resulting model, applying the 2D forward code previously developed. Finally, these results were compared to data in order to look for evidences that allow identifying the resistive structures in the response patterns.

Modeling the selected profile

The electrical profile was acquired using the multielectrode resistivimeter Saris 500. We deployed dipole-dipole arrays with apertures of 0.5 m. In order to obtain the electrical tomography, data were inverted applying the DCIP2D inversion code (2001) developed by the University of British Columbia (UBC) and based on the work of Oldenburg *et al*. (1993) and

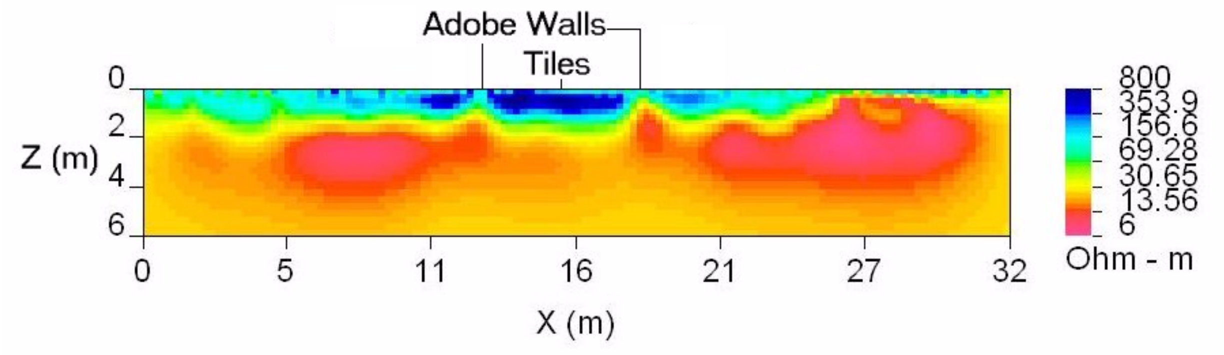

Figure 1: Structure of the sub-soil below the studied profile, obtained through 2D inversion of geoelectrical data.

Oldenburg and Li (1994). The resulting model of the subsoil is shown in figure 1. A resistive zone can be appreciated coincident with the expected location of our target structure, which is centered at approximately 14-16m. The resistive anomaly would correspond to a tile deposit delimited by two resistive adobe walls (Osella et al., 2004).

EMI data was also acquired along this line, using a multi-frequency electromagnetic profiler GEM-300 (Won *et al*., 1996). These data were collected with a step of 1 m, for a frequency range 330-19325 Hz, for four different configurations. Dipole axis are parallel to the ground in configurations H1 and H2, and are perpendicular to it in configurations V1 and V2; instrument axis is coincident with the x-direction in configurations V1 and H1, and is perpendicular to it in configurations V2 and H2.

We constructed a simplified multi-layer version of the model shown in figure 1 (see figure 2) and calculated its synthetic EMI responses using our algorithm. These responses at 19325 Hz are compared to EMI field-data in figure 3.

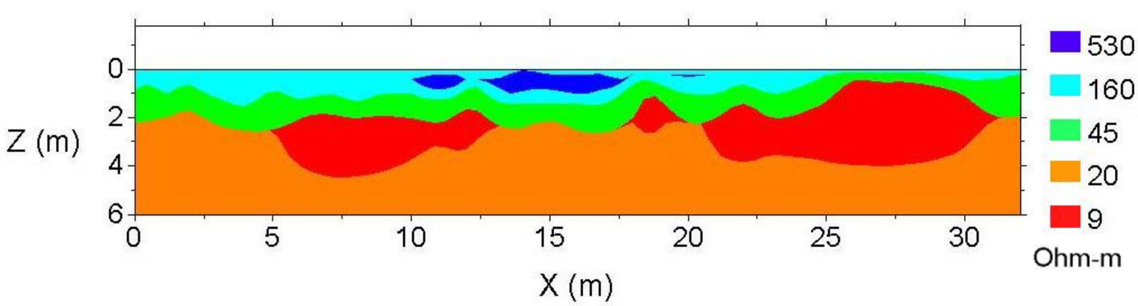

Figure 2: Multi-layer representation of the structure shown in figure 1

We only show the Quadrature components because, according to the results obtained in Martinelli et al. (2004), they are the only ones expected to be sensitive to the target structure. As we used a simplified model of the sub-soil, it is not expected that our synthetic responses can reproduce the finest details of the anomalies observed in data. Nevertheless, they should follow their general behavior. As it can be seen from figure 3, this happens for the H1 and H2 Quadrature components. The V1 component follows the behavior of data only for values of x between 4 and 18m, approximately. Clearly, there is no agreement between the synthetic V2 component and the corresponding data. In cases V1 and V2 the responses for x>18m are greatly overestimated. This may be attributed to an overestimation of the actual conductivity of the sub-soil in the geoelectrical model.

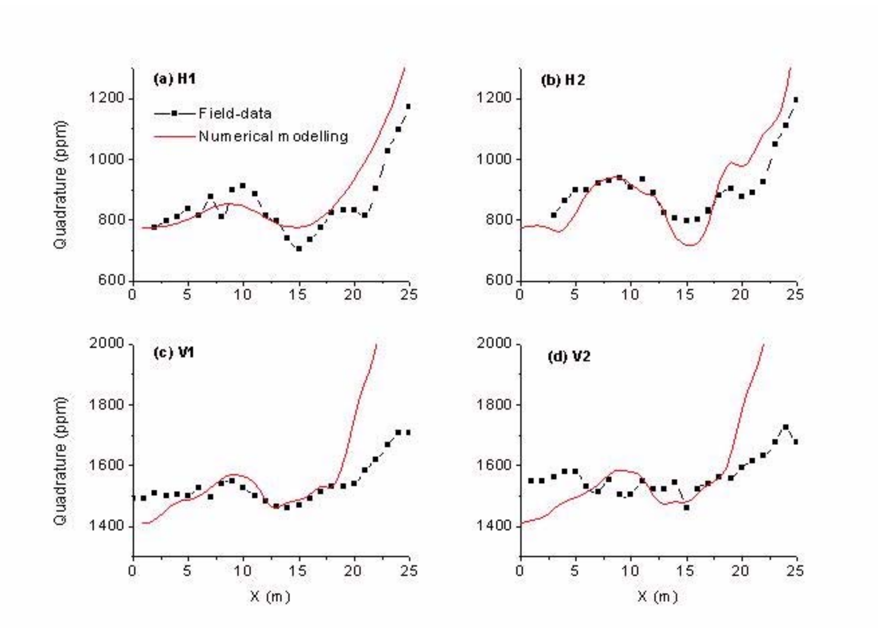

Figure 3: Synthetic EMI responses of the model shown in figure 2 compared to the corresponding field-data

Modeling the localized target

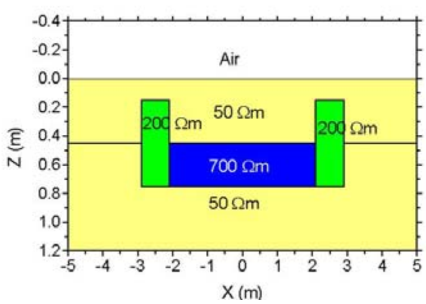

Figure 4: Schematic structure

To investigate if the anomalies observed in data, centered at 14-15m, can be attributed to the presence of the target structure, we designed the model shown in figure 4, taking into account information from excavations as well as from the geoelectrical prospection. The 200 ohm-m resistivity bodies correspond to the adobe walls and the 700 ohm-m resistivity body represents the collapsed roof, composed mainly by tiles. We calculated the synthetic EMI response of this model at the frequency 19950 Hz, along a profile coincident with the x-direction, for the four configurations previously described. The resulting Quadrature components are shown in figures 5 (a) and (b). Although the anomalies produced by this resistive structure are much lower than the ones usually produced by conductive bodies, they are still clearly detectable. H2 gives the best delimitation of the lateral extension of the structure. As we expected, In Phase responses exhibit very low anomalies, they differ from the corresponding responses of a 50 Ohm-m half space in less than 1.7% for V1, V2 and H1, and in less than 3.8% for H2.

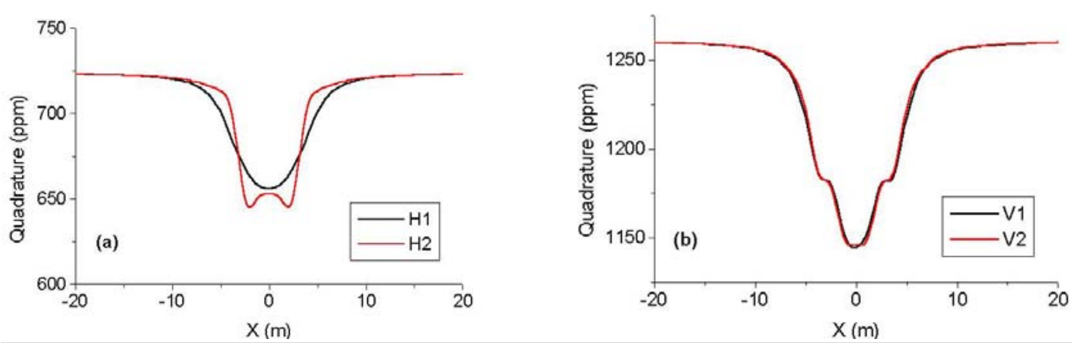

Figure 5: Synthetic Quadrature responses of the schematic model for configurations: a) H1 and H2 ; b)V1 and V2

Finally, we can compare the predictions of this numerical simulation to the actual behavior of data in the zone over the target. The structure of the sub-soil below the studied profile is not as simple as in this schematic model where the host medium is uniform. Nevertheless, the magnitude and lateral extension of the anomalies observed in data in the Quadrature components H1, H2 and V1 are in good agreement with those predicted by this modeling. Then, we can conclude that the target effectively generates these anomalies. Although for configuration H2, the anomaly somewhat is less localized than it was expected.

Conclusions

The broadband electromagnetic induction method is usually applied to detect and characterize metallic objects as unexploded ordnance, land mines, embedded pipelines, etc. In this paper we presented an alternative application of this method for resistive targets.

We first applied a 2D numerical simulation and we found that the synthetic response presented similar anomalies as the field data. Even though the model used was a simplified multi-layer version of the result of a geoelectrical inversion, and so the details of the model were smoothed, the general behavior was reproduced.

Then we designed a schematic model of the localized archaeological target. The synthetic response of this model reproduced the anomalies observed in the data both in magnitude and lateral localization and extension. In this way, these results aided to confirm that those anomalies found in the data corresponded to the archaeological structure.

It is important to remark that, at least in this case where the resistivity contrast is high (of approximately one order of magnitude), the tile deposit could be detected, even though it presented a small thickness (aproximatelly 0.4 m).

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