Airborne IP driven exploration for a green-field research project

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SUMMARY

When collected over a chargeable ground, the inductive measurements are sensitive to Induced Polarization (IP) effects. Given this, using a frequency-dependent resistivity for modelling the EM data allows to retrieve the ground chargeability and to avoid artifacts in the inverted model-space. With this contribute we propose a case study for which the airborne chargeability has been actively used to drive the exploration in a green-field environment and to design the ground follow-up for geophysical measurements.
For this project, two airborne surveys with different base frequencies have been designed to maximize the AIP content in the EM signal and a modelling approach that aims to increase the airborne chargeability sensitivity in depth has been applied to the data. Based on the retrieved models and on their integration with the ancillary information, two ground DCIP lines has been acquired and then overlapped by four ground TEM and two Loupe EM lines.
With this contribute we thus have a twofold intent: we aim to increase the targeting efficacy (and to reduce risks) of the exploration effectively using the large-scale airborne chargeability information and to explore the IP effects in inductive measurements from a multi-frequencies and multi-instrument perspectives.

Key words: Airborne IP, Ground DCIP, Inductive Induced Polarization, Mineral Exploration in Europe

INTRODUCTION

The critical raw materials (CRMs) exploration and supply is crucial to achieve the objectives defined by the European Critical Raw Materials Act to reach the green energy transition. In order to reduce the social and environmental impact of the exploration, innovative indirect techniques have to be adopted for the mineral targeting.
Among the various geophysical methods, two of the most common techniques for exploration are the Induced Polarization (DCIP) and the Electromagnetic (EM) to map, respectively, chargeable and conductive bodies in depth. Although these techniques have been considered sensitive to different physical properties for a long time, it has been recognized that the effects of a polarizable ground can be measurable by inductive EM measurements (Smith et al., 1996), both airborne and ground. It has then been shown that is possible to model the inductive IP (Viezzoli et al., 2013) to retrieve the ground chargeability distribution and how novel modelling approaches (Dauti et al., 2024) can increase the inductive chargeability sensitivity in depth with good relationships with known mineralized bodies.
In this context, with this contribute we propose a case study for which the retrieved inductive chargeability models has been actively used to define the next steps of the exploration workflow for a real green-field exploration research project (the HORIZON SEMACRET European project) with chargeable targets.
First, two Airborne EM surveys have been flown with different base frequencies (12.5 Hz and 25 Hz) to increase the data sensitivity to IP effects and to improve the near surface resolution. Then, a modelling approach that points to reduce the equivalencies among the parameters of the “IP-expanded” modelspace has been applied to the data to define where to follow-up on the ground. In this optic, the benefits of an effective AIP mapping are many, spanning from risk reduction to logistic simplification and increasing the mineral system understanding through the a large-scale mapping of the ground resistivity and chargeability.
With this work we also aim to investigate the inductive IP effects from a multi-frequency range prospective: we acquired on the ground different inductive data with different instruments and base frequencies over the AIP localized anomalies and compared the data among them and with overlapping DCIP galvanic lines. With this we aim to improve the understanding of IP effects at different scales of investigation and for different instrumental spectral contents among galvanic and inductive measurements.

STUDY AREA, GEOLOGICAL CONTEXT, SURVEY PREPARATION

The study area is localized around Beja, in the Alentejo region, in southern Portugal in Europe. In figure 1 the airborne EM survey blocks are visible.

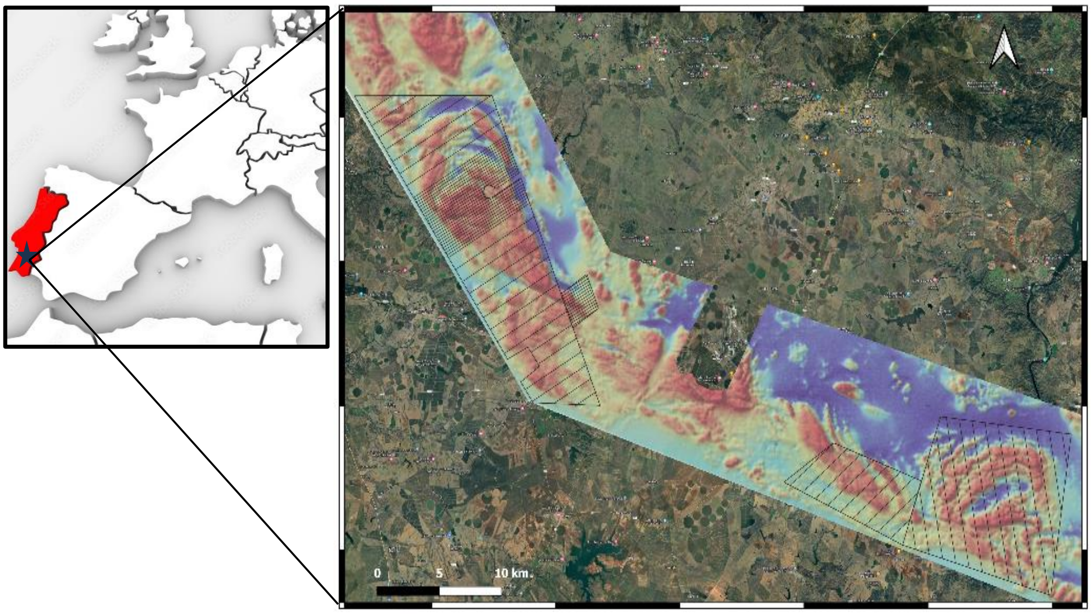

Figure 1. Survey location and zoom of the investigation area. The black lines are the AEM survey lines over the aeromagnetic map.

Geologically, the study area is located in the Ossa Morena Zone, a Variscan terrane containing numerous mafic-ultramafic intrusive bodies. The belt hosts here a large mafic layered intrusion constituted by the 260 km2 Beja layered sequence (Jesus et al., 2014). Petrogenetic and exploration-oriented research have located massive V-Ti oxide masses identified at shallow depths, with TiO2 up to 10 wt% and V2O5 up to 1 wt% (Jesus et al., 2003). In geophysical terms, the Fe-Ti-V oxides shows magnetic response and are hosted in the resistive layered gabbro sequence. Electrically, the oxides are chargeable and resistive when disseminate and can give moderate conductivities (<100 Ω·m) when massive.

The AEM survey has been designed and flown with two different base frequencies (12.5Hz and 25Hz) of the HeliTem (Smiarowski et al., 2019) system by Xcalibur Smart Mapping. A lower base frequency expands the bandwidth of the system allowing to increase the sensitivity to a wider IP spectral range. At the same time, the waveform turn-off gets slower and the near surface resolution decreases. The 25Hz base frequency is an experimental configuration with only 1 turn in the transmitter loop in order to provide a faster turn-off and improve the near surface resolution. For both, a detailed feasibility study considering the geological configuration of the area has been done in order to reduce the noise contamination during acquisition. In figure 2 an example of the feasibility study is provided. The forward responses are computed over a three-layers model where, from the top, a first shallow weakly conductive layer (100 Ω·m) represents the cover; below, a second layer represents the target and then, finally, a deep resistive (1000 Ω·m) layer represents the geological basement. For the feasibility, only the second target layer is parametrized as chargeable with a quick polarization (time constant of 1e-02s) and a phase of 10 mrad. The parametrization has been chosen according with the geological model of the area.

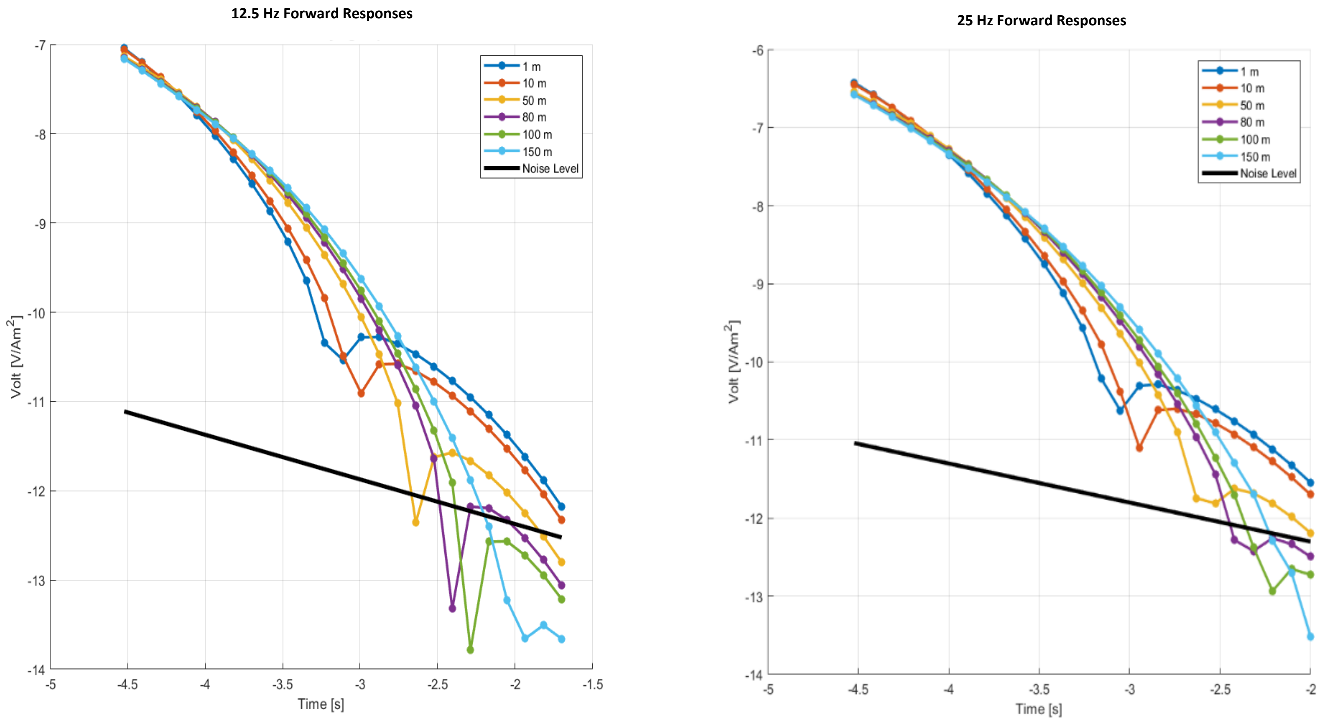

Figure 2. Forward responses for the 12.5Hz (left) and 25Hz system configuration (right). The forwards are computed changing the depth of the chargeable target. The black line represents the noise level.

In the example of feasibility in the figure the forward responses have been computed increasing the depth of the target as indicated in the legend. It is visible from figure how reducing the base frequency the bandwidth of the system is extended and the late time change of sign given by the IP effects is detectable above the noise level also for higher depths.

METHODS AND RESULTS

Regarding the modelling, the model-space have been parametrized with a Maximum Phase Angle (MPA) model (Fiandaca et al., 2018) instead of the classical Cole & Cole model re-arranged by Pelton (1978). The MPA Cole-Cole model is a re-parametrized form of the classic Cole-Cole, where instead of m_0 and τ_ρ we used the maximum phase φ_{max} and the phase relaxation time τ_φ.
This parametrisation allows to minimize the correlations between the Cole&Cole m_0 and C using the poorly correlated φ_{max} and C, and to improve the resolution retrieved from inversion IP data of the classical Cole-Cole model
The inversions have been performed with the EEMverter inversion scheme proposed by Fiandaca et al. (2024) that uses separate model and forward meshes to carry out the inversion and compute the forward responses, respectively. The decoupling of the model mesh and the forward mesh allows to work with more flexible and manageable spaces (forward and model) to perform joint inversions and time lapse inversions. In our inversion procedure, in order to increase the parametrical resolution and the phase sensitivity in depth, we parametrized the spectral parameters (τ_φ, C) on an independent meshes respect to resistivity and phase with different lateral constraints and vertically fixed.
The results of this modelling approach for the 12.5Hz AIP chargeability are presented in figure 3, together with the layout of the ground follow-up and the aeromagnetic responseof the area acquired by Finnish Geological Survey of Finland (GTK) in 2003. In the figure, the two ground DCIP lines (in continous black line) overlap the airborne EM (black points) flight lines and, for the southern line, a 200x200 ground TEM (in green) and three 40x40 TEM (in white) have been acquired over the AEM. The DCIP/AEM lines have been also overlapped by two Loupe EM (Street et al., 2018) surveys, one with a base frequency of 75Hz and one with a 375 Hz base frequency. The follow up area has been selected following an chargeability anomaly modelled from the airborne at a consistent depth with the conceptual model of the mineralization and showing a strong magnetic response in the aeromagnetic map.

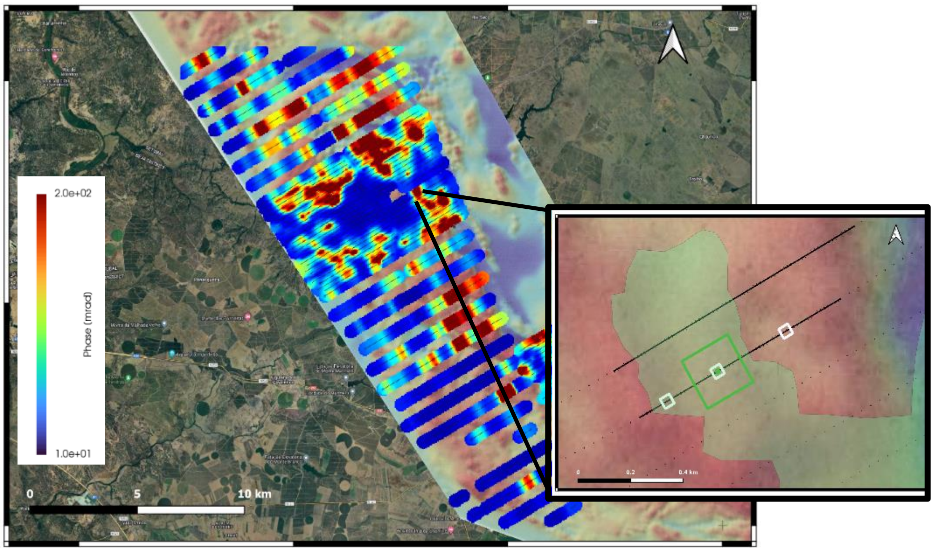

Figure 3., In the main figure, the results of the AEM IP modelling are shown for the 12.5Hz base frequency survey at a slice depth of 80m. In the zoom, the chargeability anomaly outline over the aeromagnetic map is shown. The continous black line indicate the location of the Loupe and ground DCIP lines, the green square the 400x400 loupe and the white squares the 40x40 loupes locations.

The ground DCIP lines have been acquired with the ABEM Terrameter LS2 with an electrode distance of 10m; the 40x40 TEM loupes with an ABEM Walktem 2 with a Tx20 transmitter and the 200x200 TEM with the Tx60 transmitter, reaching a dipole moment higher than 1.000.000.000 NIA.
The ground DCIP have been here modelled using the same approach used for the AEM data, modelling the full voltage decay instead of the integral chargeability, the time gates, the transmitter waveform and the receiver transfer function as proposed by Fiandaca in (2013). The modelled ground DCIP for the northernmost line is shown in figure 4.

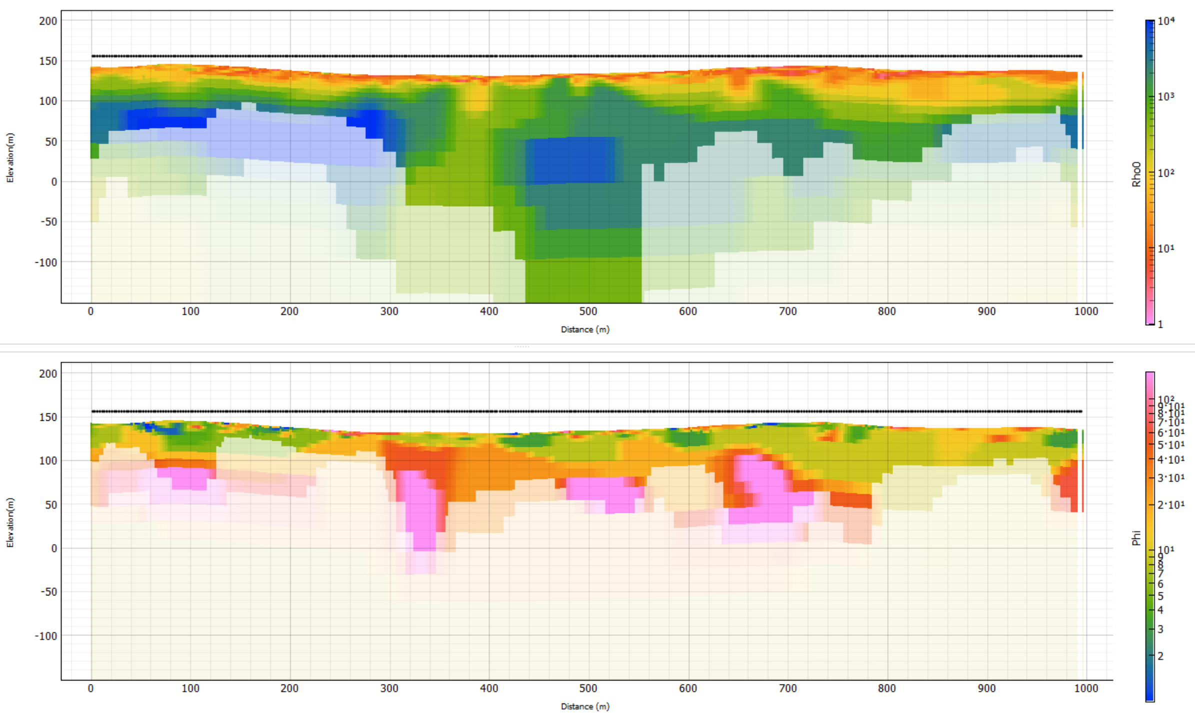

Figure 4. On the top: resistivity model of the acquired northern DCIP line. On the bottom the chargeability model.

As visible from the figure, a resistive and chargeable body has been retrieved as targeted from the airborne EM IP model. As mentioned, according with the mineral system model for the area, chargeable, magnetic and resistive bodies at a depth of around 100m could be associated with the Ti-V oxides contained in the layered gabbroic sequence. In the ground DCIP cross section no resistivity contrast between the chargeable bodies and main resistive in depth (that can be associated to the gabbroic intrusion) is shown.
In figure 5, a comparison between the ground DCIP chargeability and the Airborne chargeability model is shown.

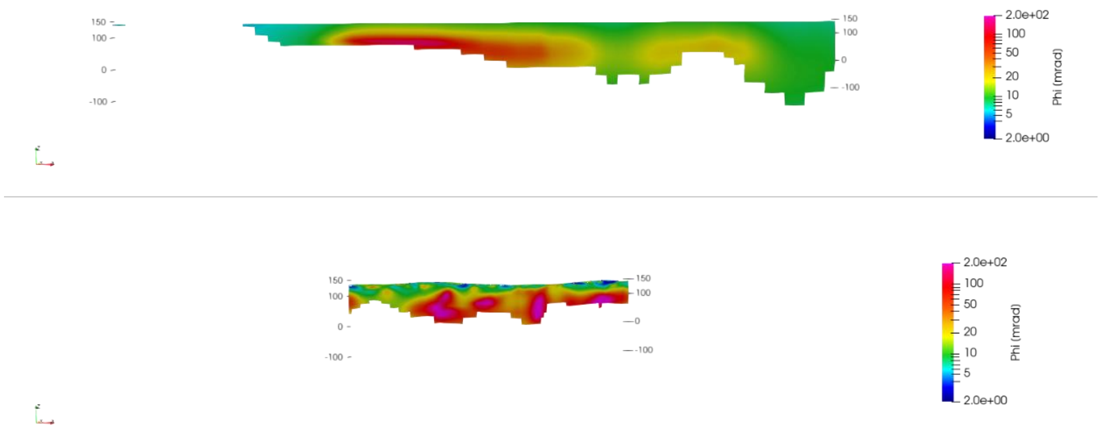

Figure 5. Comparison between Airborne Chargeability model (on the top) and ground DCIP chargeability model (on the bottom).

As visible from figure, a good correlation between the airborne and the ground chargeability model is visible. As expectable, the resolution is improved with the ground DCIP. It is important to highlight how the two chargeabilities match not only in the spatial distribution but also in the value.

CONCLUSIONS

The airborne chargeability model obtained with our approach shows consistency with the available ancillary geophysical and geological information. Integrating these features allows to develop a robust mineral system overview on which develop an exploration model for targeting chargeable bodies in a resistive environment. In this work, the ground follow-up survey has been successfully designed and acquired as consequence of the airborne chargeability model showing consistent results.

ACKNOWLEDGEMENTS

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