Exploration of Fe-Ti-V oxides in an Orthomagmatic system using the Airborne Induced Polarization

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 retrieve IP parameters from inductive data (e.g. Viezzoli et al.2017, Lin et al., 2019) and that the airborne EM (AEM) systems can be sensitive to IP spectral ranges relatable with mineral bodies and mineralization vectors (Viezzoli et al, in 2019). Nowadays, a challenge to effectively map the airborne chargeability from AEM data is in the improvement of the inversion procedure to reduce the equivalences in the “IP expanded” model-space.
With this contribute we propose a novel approach to model the AEM-IP data, to actively integrate the airborne chargeability models in the interpretation workflow and to design the ground DCIP follow-up based on the large-scale chargeability model. In this optic, the benefits of an effective AIP mapping are many, spanning from risk reduction to logistic simplification, from mineral system overview to an improved targeting.

These developments are applied to the exploration of Ti oxides in an orthomagmatic system located in the Alentejo region, in Portugal, object of study of the HORIZON SEMACRET European project.

Study Area, Geological context, Survey Preparation

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

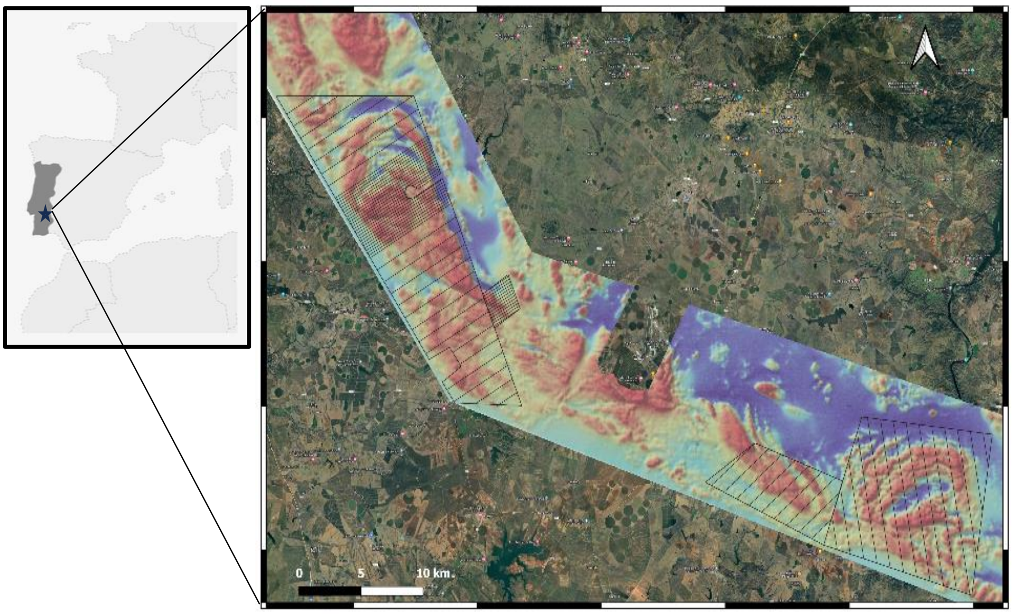

Figure 1. Survey location and zoom of the investigation area. The black lines are the AEM survey lines over the aeromagnetic map.

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 km^2 Beja layered sequence (Jesus et al., 2014). Petrogenetic and exploration-oriented research have located massive V-Ti oxide masses identified at shallow depths, with TiO_2 up to 10 wt% and V_2O_5 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 moderately chargeable and resistive when disseminate and can give high chargeabilities and 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., 2018) system developed 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.
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.

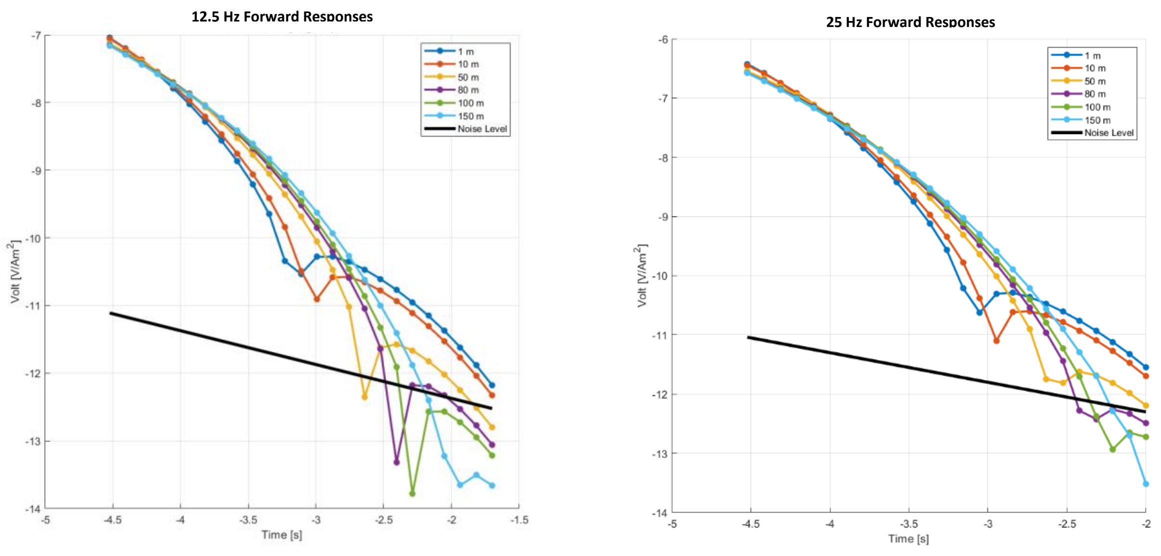

Figure 2. Forward responses for the 12.5Hz (left) and 25Hz system configuration (right). The forwards are computed changing the depth of the chargeable target. The black line represents the noise level.

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 model space of the MPA Cole-Cole model can be described as:

$$m_{MPA\ Cole-Cole} = \{\rho_0, \varphi_{max}, \tau_\varphi, C\}$$

The inversions have been performed with the EEMverter inversion scheme proposed by Fiandaca et al., 2024 that uses voxel model mesh to map the solved parameters via an interpolation of the forward mesh solutions. 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, the spectral parameters (τ_φ, C) are defined on a mesh with vertical variability.
The results of this modelling approach for the 12.5Hz base frequency system's chargeability are presented in figure below.

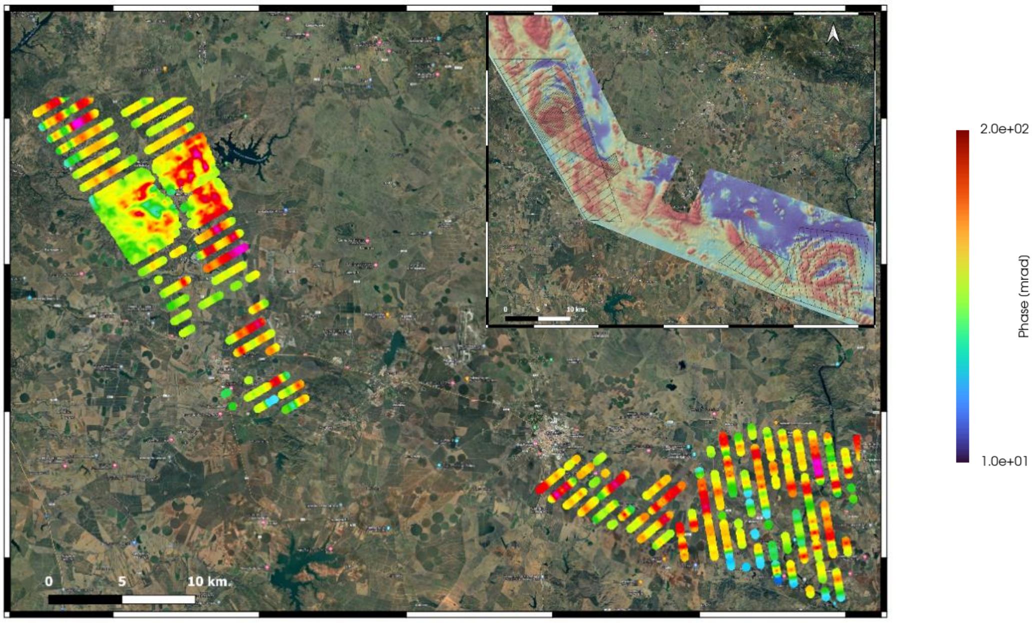

Figure 3. Airborne chargeability slice at 70m of depth.

From the map in figure, a good correlation between the airborne chargeability and the magnetic model of figure 1 is visible. Integrating the airborne chargeability models with the magnetics and the available geological information, the ground DCIP survey has been designed and modelled. In figure 4, a comparison between an acquired ground IP line (top) and a correspondent AIP (bottom) cross section is presented. The ground DCIP data have been here modelled in EEMverter (Fiandaca et al., 2024) using the same approach used for the AEM data, i.e. modelling the full voltage decay instead of the integral chargeability, the time gates, the transmitter waveform and the receiver transfer function.
As visible from figure, a good correlation between the two models is obtained.

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, a ground DCIP survey has been designed and acquired as follow-up of the airborne chargeability model for the first time showing consistent results with the airborne.

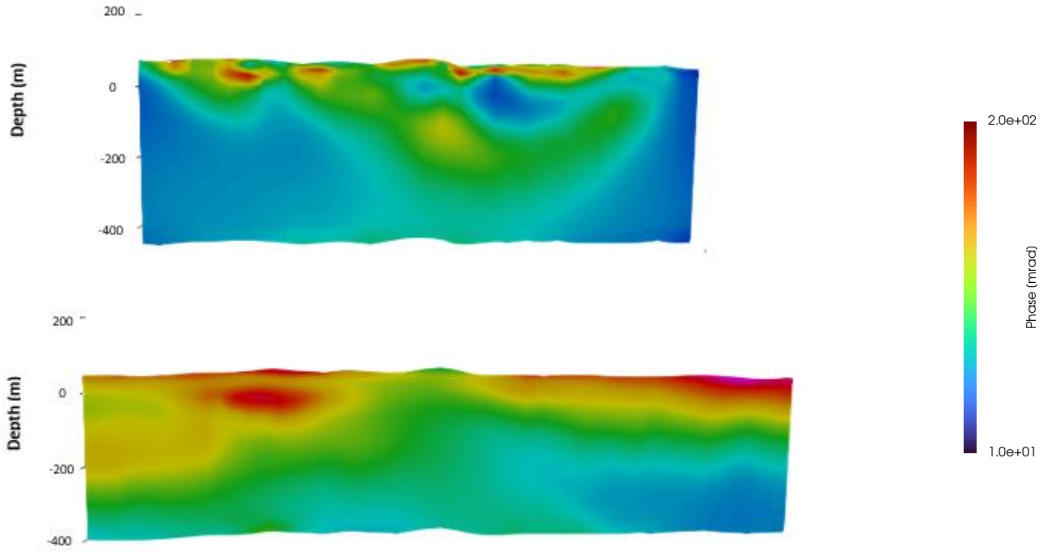

Figure 4. Comparison between a ground DCIP line (top) designed and acquired after the AIP modelling and an Airborne Chargeability cross section (bottom).

Acknowledgements

This work is funded by the EU project Semacret (HORIZON-CL4-2021-RESILIENCE-01-06), which aims to promote sustainable exploration for green transition Critical Raw Materials in the EU securing the continued supply for its industries.

References

- Fiandaca, G., Madsen, L.M. and Maurya, P.K. (2018), Re-parameterisations of the Cole–Cole model for improved spectral inversion of induced polarization data. Near Surface Geophysics, 16: 385-399.
- Fiandaca, G., Zhang, B., Chen, J. (2024). EEMverter, a new modelling tool for Electric and Electromagnetic data with focus on induced polarization. Near Surface Geoscience 2024 – 30th European Meeting of Environmental and Engineering Geophysics, 8-12 September 2024, Helsinki, Finland.
- Jesus, Ana & Mateus, António & Oliveira, Valeska & Munhá, J. (2003). Ore-forming Systems in the Layered Gabbroic Sequence of the Beja Igneous Complex (Ossa-Morena Zone, Portugal); State of the Art and Future Perspectives.
- Jesus A., Mateus A., Munhá J.M., Tassinari C., Telmo M. Bento dos Santos, Benoit M. (2016), Evidence for underplating in the genesis of the Variscan synorogenic Beja Layered Gabbroic Sequence (Portugal) and related mesocratic rocks, Tectonophysics, Volume 683.
- Lin, C., Fiandaca, G., Auken, E., Couto, M. A., & Christiansen, A. V. (2019). A discussion of 2D induced polarization effects in airborne electromagnetic and inversion with a robust 1D laterally constrained inversion scheme. Geophysics, 84(2), E75-E88.
- Viezzoli A., Kaminski V., Fiandaca G., 2017. Modelling IP effects in helicopter TEM data: synthetic case studies, Geophysics, 82 (2), E31-E50. 10.1190/geo2016-0096.1
- Viezzoli A. & Manca G. (2019). On airborne IP effects in standard AEM systems: tightening model space with data space, Exploration Geophysics, 51:1, 155-169, DOI: 10.1080/08123985.2019.1681895
- Smiarowski A., Miles P., Konieczny G., (2018), CGG's New Helitem-C AEM Systems, ASEG Extended abstract, pp.1 – 4.
- Smith, R.S., and J. Klein, 1996, A special circumstance of airborne induced polar-ization measurements, Geophysics, 61, 66–73.