Closing the gap between Airborne EM and Ground Galvanic Induced Polarization for Mineral Exploration

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Summary

It is demonstrated and nowadays accepted that the Induced Polarization effects can affect inductive measurements and can be a source of artifacts if not proper modelled during inversion process. At the same time, using a dispersive resistivity to model EM data largely expands the model space and expose the inversion procedure to strong equivalencies and ambiguities. These limitations have often brought to over-precautionary modelling approaches of AIP and leaded to the impossibility in interpretation of the airborne-retrieved chargeability models.
With this contribution a novel modelling approach to extract inductive induced polarization from Airborne EM data is proposed. The AEM data are acquired in Spain, for VMS and polymetallic exploration and overlap 17 ground DCIP lines. The modelling approach we propose concerns a re-parametrization of the Cole-Cole model to an equivalent less-correlated parametrization and a split of the spectral parameters during the inversion procedure. To prove the modelling, a comparison with the ground DCIP lines will be shown. This latter one has been modelled with the same parametrization and inversion scheme of the AEM data to provide a robust comparison between the two and reduce ambiguities in the interpretation. Then, to evaluate the AIP sensitivity to ground chargeable bodies, a joint inversion between the two entire datasets will follow and a vertical and lateral resolution-improved chargeability model is retrieved. This shows the AIP information content and contribute in the enhance of data sensitivity during the modelling procedure.

Introduction

The Iberian Pyrite Belt (IPB), located in southern Spain, is one of the oldest and still active mining districts in the world. In the last decade, a renewed mining activity and scientific research have led into a wealth of new data and new geological hints for explorers and for the academic community, making the IPB one of the most important and dynamic mining districts in Europe (Inverno et al, 2015). In this region, the great number of different signatures related to the ore body and to its vectors call for an integrated use of complementary geophysical methods. The sulfides targets show contrast in both density and electrical properties, and historically gravity has played a crucial role for exploring in the IPB. These methods have been later accompanied by EM methodologies, both airborne and ground, given their high sensitivity to conductive targets (Menghini et al, 2022).
For this work, we focused on a case study of integration between two different techniques: the ground DCIP and the airborne Induced Polarization extracted from the airborne EM measurements. The integration between these two, although the same physical phenomena is recorded, is not a given and is object of many open questions. The different base frequencies, the expanse model-space for AIP modelling with its poor spectral content and a lack in translation of physical properties into geology, constitute crucial unknowns for the application of this technique to the targeting. Beside these problems, another major issue, not always recognized, is the difference in the modelling approach. Ground IP data is usually modelled dropping the spectral information, e.g., turning a full secondary voltage decay into a single value of integral chargeability (e.g. Oldenburg and Li, 1994), complicating comparisons and understandings.
Regarding the AIP, a robust synthetic study on its physics and phenomenology (Viezzoli et al, 2019) have demonstrated its sensitivity to large domains of geological features, possible mineral targets or orebodies vectors. From a theoretical standpoint, if the sensitivity of AIP to geological targets is demonstrated, the challenge lies into the inversion procedure and in the management of the equivalencies in a large model-space to effectively map the chargeability from inductive data.
For this contribute, we worked with data acquired by a mining company; these are constituted by 17 ground DCIP lines overlapped by an airborne EM survey, as visible in *figure 1*. These surveys represent a good configuration to make experiments on the airborne IP nature and on the integration with the ground.

Figure 1. Survey area. In black the Airborne EM survey is represented, in red the 17 ground DCIP lines.

With this work we aim to investigate the AIP capabilities for exploration. First, we apply a novel modelling technique to AEM data with a dispersive resistivity that aims to reduce the equivalencies in the inversion procedure. Then, a comparison of the airborne chargeability models with the ground DCIP models will be conducted, to evaluate and ground prove the modelling done. In conclusion, to robustly evaluate the AIP sensitivity, a joint inversion between the two datasets will be done modelling the capacitive phenomena.

Theory and/or Method

For this work, the datasets have been modelled with a consistent modelling procedure, with a 2D forward response formulation for the DCIP data (Fiandaca 2013) and 1D for the TDEM (Fiandaca 2012). The modelling approach proposed by Fiandaca allows to model the full-voltage decay (instead of the integral chargeability), the transmitter waveform and the receiver transfer function, increasing the procedure accuracy in recovering the spectral parameters. These features have been modelled both for the Airborne EM than for the Ground DCIP.

Regarding the model-space parametrisation, we used the Maximum Phase Angle (MPA) Cole-Cole re-parametrisation (Fiandaca et al., 2018; Madsen 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. The phase of the complex conductivity can be defined in terms of both equations 1 and 2 as:

$$\varphi(\omega) = atan\left(\frac{\sigma''(\omega)}{\sigma'(\omega)}\right) = atan\left(\frac{\rho''(\omega)}{\rho'(\omega)}\right) \qquad \text{(eq. 1)}$$

The phase reaches his maximum φ_{max} at an angular frequency $\omega_\varphi \equiv 1/\tau_\varphi$ as:

$$\varphi_{max} = atan\left(\frac{\sigma''(1/\tau_\varphi)}{\sigma'(1/\tau_\varphi)}\right) = atan\left(\frac{\rho''(1/\tau_\varphi))}{\rho'(1/\tau_\varphi)}\right) \qquad \text{(eq. 2)}$$

Furthermore, the model space of the MPA Cole-Cole model can be written as:

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

The MPA 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 inversion scheme proposed by Fiandaca et al., 2023 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 laps 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 mesh respect to resistivity and phase, with different lateral constraints and vertically fixed (as proposed by Viezzoli and Fiandaca in 2021).

Results

In figure 2a and 2b the results are shown, with a comparison between a portion of the airborne and the ground DCIP modelled chargeability (phase) with our modelling approach.

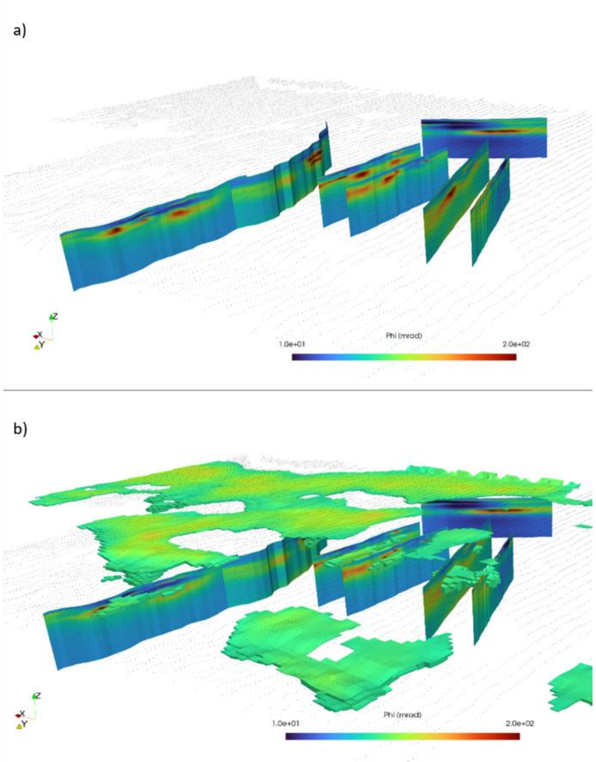

Figure 2. a) Example of ground DCIP phase results and, in dashed line, the AEM survey flown above; b) Ground DCIP and Airborne chargeability results.

As visible from the figures, a great correlation between the airborne and ground is obtained when modelling with the presented approach. The airborne chargeability model shows a consistent structure with the ground model in depth and a geology-controlled behaviour in the shallower near surface. A known mineralization has also been mapped with the AIP. The differences in the near surface are consequence of the big electric dipoles dimension used for the ground DCIP (100m). For this dataset, all the airborne IP chargeability anomalies have been confirmed from the ground IP and a ground prove of a known mineralization has been modelled also by the airborne, as visible in *figure 3*.

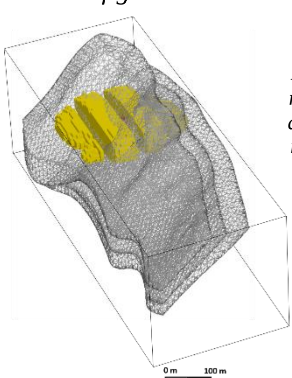

Figure 3. Known mineralization (in grey) and airborne chargeability model retrieved by the AEM data modelling.

After this, we performed a joint inversion between all the ground DCIP lines (17) and the entire AEM survey. For the joint inversion we used the AEM model (for all the parameters) as starting model for the joint inversion. In figure 4 and 5 the results are shown.

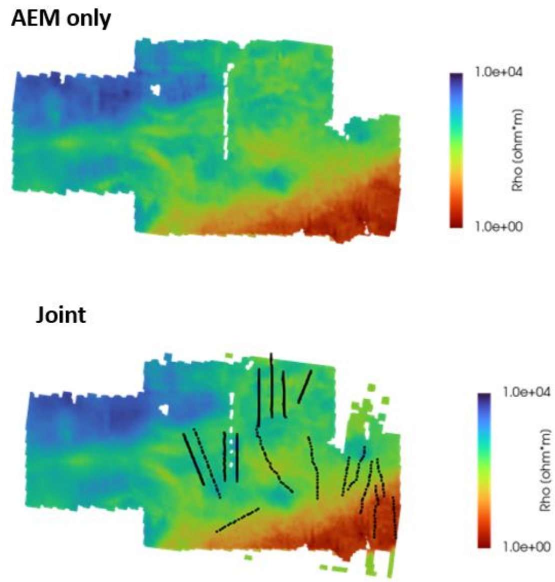

Figure 4. Comparison between AEM only model (on the top) and Joint Inversion model (on the bottom) for a resistivity slice at 60 m of depth.

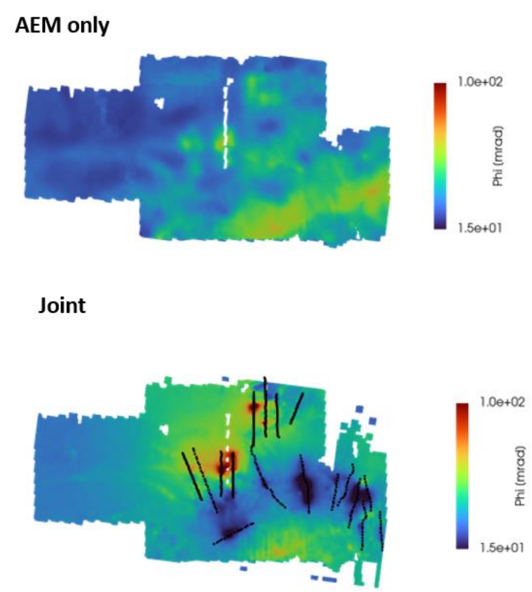

Figure 5. Comparison between AEM only model (on the top) and Joint Inversion model (on the bottom) for a chargeability slice at 60 m of depth.

In figure 4 a comparison between the AEM only and joint inversion resistivity is presented. As visible, the main structural are mantained in the inversions.

Differently, in figure 5, it appears that introducing the ground DCIP lines in the inversion add structure in the chargeability model for the entire survey area. In terms of misfit, the general misfit of the AEM only inversion is 1.6 while the misfit for the joint inversion is 1.7, confirming how the AEM data accept the jointly obtained chargeability model obtained together with the ground IP.

Conclusions

This study shows encouraging results in the using of the Airborne Induced Polarization for chargeability mapping for airborne-scale areas. In particular it results that:

1. Reducing the equivalences in the AEM-IP modelling is a key to unlock the understanding of the AIP sensitivity to geological and mineral targets.
2. For this case study, the airborne chargeability shown sensitivity to deep chargeable bodies.
3. All of the airborne chargeability anomalies have been confirmed from the ground DCIP models, demonstrating an overlapping field of sensitivity between the methods.
4. Known mineralizations have been mapped with the AIP.
5. The joint inversion between the DCIP and the AIP is possible and shows how the AEM data not only is compatible with the joint model, but also contribute in the chargeability mapping.

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