# AEMIP Inversion Applied for Gold Exploration Using Maximum Phase Angle Re- Parameterization of The Cole-Cole Model: A Case in Quadrilátero Ferrífero Area, MG, Brazil

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**AEMIP Inversion Applied for Gold Exploration Using Maximum Phase Angle Re-Parameterization of The Cole-Cole Model: A Case in Quadrilátero Ferrífero Area, MG, Brazil**

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**SUMMARY**

This paper presents the results of the Airborne Electromagnetic Induced Polarization (AEMIP) 1D Laterally Constrained Inversion (LCI) using the Maximum Phase Angle (MPA) re-parameterization of the Cole-Cole model for an AeroTEM$^{HD}$ survey in Quadrilátero Ferrífero area, MG, Brazil. The MPA LCI's were conducted using a robust inversion scheme and its results were compared with the usual Resisitivity-Only (RO) LCI's for gold mineralization zone in Lamego Mine structure. The MPA results seems to present a better recovery of the resistivity model in comparison with the RO usual approach, better agreement with the borehole lithological data and good correlation with previous conductive sheet modeling. An important chargeable body was identified in the MPA model, suggesting the definition of the carbonaceous units in Lamego Mine, an important chemical trap and structural control for gold mineralization in this area.

***Keywords:*** AEMIP, MPA, Mineral Exploration, Quadrilátero Ferrífero, Brazil

## Introduction

The importance of the Airborne Electromagnetic Induced Polarization (AEMIP) phenomenon has increased during the last decade due to its highly potential to be used to map chargeable bodies in large areas covered by Airborne Transient Electromagnetic (ATEM) data. The covering of such large areas could be logistically impracticable for usual ground galvanic Induced Polarization (IP) measurements. Thankfully to the technological improvements in the Helicopter-borne Transient Electromagnetic (HTEM) systems during the 2000's, there was an increase in the occurrence of number of negative transients and steep dB/dt decays, mostly motivated by applications in mineral exploration, groundwater and environmental studies. Specifically for mineral exploration, the AEMIP information can contribute to map disseminated metallic sulfide zones associated with mineralized lithologies or identify chemical traps, like carbonaceous units in highly hydrothermal altered environments in mineral provinces, decreasing ambiguities to differentiate the host rocks from the mineralization itself and providing better understanding to its structural control.
In this work, we present the results of the 1D Laterally Constrained Inversion (Auken et al., 2015) using the Maximum Phase Angle (MPA) re-parameterization of the Cole-Cole model for the IP inversions, proposed by Fiandaca et al. (2018) and using the robust scheme presented in Lin et al. (2018), in the Quadrilátero Ferrífero (QF) area, Minas Gerais (MG) State, Brazil. An AeroTEM$^{HD}$ survey contracted by CPRM – Geological Survey of Brazil covered the study area over the units of the Rio das Velhas Greenstone Belt (RVGB) in the Lamego Mine structure – Figure 1.
The RVGB presents high resistivity values for the mafic and ultramafic units (greater than 2000-3000 Ohm.m) according to petrophysical data, a very urbanized environment due the presence of mining facilities and cities and given that, the AeroTEM$^{HD}$ is a low moment system. These characteristics contributed to a poor signal-to-noise ratio in many parts of the data, which hindered the identification of IP signals. However, over some important mineralizations, like the result presented in this work for Lamego Gold Mine area (Figure 1), it is expected a polarizable signal related to the carbonaceous units associated with the Au-mineralized sulfide zones. The carbonaceous schist present a highly polarizable response, accordingly to petrophysical data and it works as a layered chemical trap for the mineralization. The Au mineralization occurs in the boundary between these carbonaceous units and the banded iron formations (BIFs) – Martins et al. (2016). In fact, over the areas where this units occur, we were able to identify steep dB/dt decays and negatives transients in the late times, besides the poor quality of the data, suggesting a strong IP effect in such parts of the survey.
We choose to use the MPA parameterization seeking to reduce the correlation between the Cole-Cole parameters in the inversion process, as discussed in Fiandaca et al. (2018). The results were compared with the usual Resistivity-Only (RO) parameterization inversion, in order to understand the differences between these two approaches. The comparison seems to show that the MPA approach recovered more reliable resistivity models accordingly to borehole data, than the RO resistivity sections, which seems to distort geometrically and physically the resistive bodies associated with the mafic and metasedimentary units in Lamego Mine area, which presented higher resistivity values for RO results in comparison with MPA results. Also, a strong polarizable body was identified by MPA which could be associated with the carbonaceous schist in Lamego and previous conductive sheet modelling.

## Methodology

In this work, we used the 1D LCI (Auken and Chirstiansen, 2004) with the MPA re-parameterization of the complex resistivity function from the Cole-Cole model (Pelton et al., 1978), introduced by Fiandaca et al. (2018). The data were processed in the Aarhus Workbench and inverted using the AarhusInv inversion code. For MPA, the model parameters are defined by:

$$\boldsymbol{m}_{MPA} = \{\rho_0, \phi_{max}, \tau_\varphi, C\} \quad (1)$$

where $\rho_0$ is the resistivity for the zero frequency, $\varphi_{max}$ is the maximum phase angle of the Cole-Cole complex resistivity model, $\tau_\varphi$ is the inverse of the frequency where $\varphi_{max}$ is reached and $C$ is the frequency dependency parameter.

In addition to MPA re-parameterization, we also used the robust inversion scheme suggested by Lin et al. (2018), which is summarized by:

- Model re-parameterization using the Cole-Cole MPA approach;
- Define a robust initial resistivity model through inversions of positive-only data using very tight spatial constraints;
- Locking of $\tau_\varphi$ and $C$ for the first few (here five) iterations, to build structure in the resistivity and chargeability domains first;
- Increasing the data standard deviation around the sign change in the $dB/dt$ decay curve; and
- Modification of the damping scheme allowing for individual damping of the different parameters, which improves the balance of the multi-parameter model space.

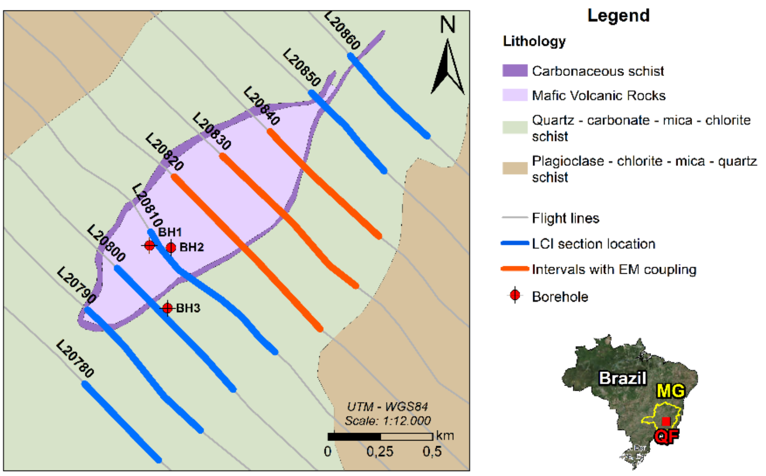


***Figure 1**: Location of study area. Geological map of Lamego Mine with AeroTEM$^{HD}$ flight-lines positions. The blue line intervals indicate the LCI sections for MPA and RO parameterizations and the orange lines the EM coupling intervals due the mine infrastructure. The borehole positions presented in this work are indicated by the red markers.*

**Results**

Figures 2 and 3 present the results for the RO and MPA LCI's for the flight line L20810 presented in Figure 1. The RO inversion were carried out using positive-only data when there are negative transients in the late times, excluding the last positive gate before the first negative. It is possible to note a substantial difference between RO and MPA resistivity models (Figures 2-a and 3-a, respectively). In the RO results, the conductor that might be associated with the carbonaceous/graphite schist in Lamego Mine seems to be more conductive and shallower in comparison with MPA results and with the borehole data. Also, the shallower resistive layer associated with the metamafic units in Lamego structure agrees better in thickness and depth with the boreholes for the MPA resistivity model than the RO model.
The MPA $\phi_{max}$ model also presents an important polarizable body diping to SE, with good agreement with the position of the carbonaceous schist occurrence in the borehole data (dark grey layers in borehole sections of Figure 3-b). This polarizable body also presents a good structural agreement with the model retrieved from conductive sheet modelling, conducted for this data by CPRM and presented in Couto et al. (2017) - Figure 4. The mapping of this polarizable body is an important contribution to understand the structural control of the gold mineralization in Lamego, as it occurs in the boundary between the carbonaceous units and the BIFs layers.

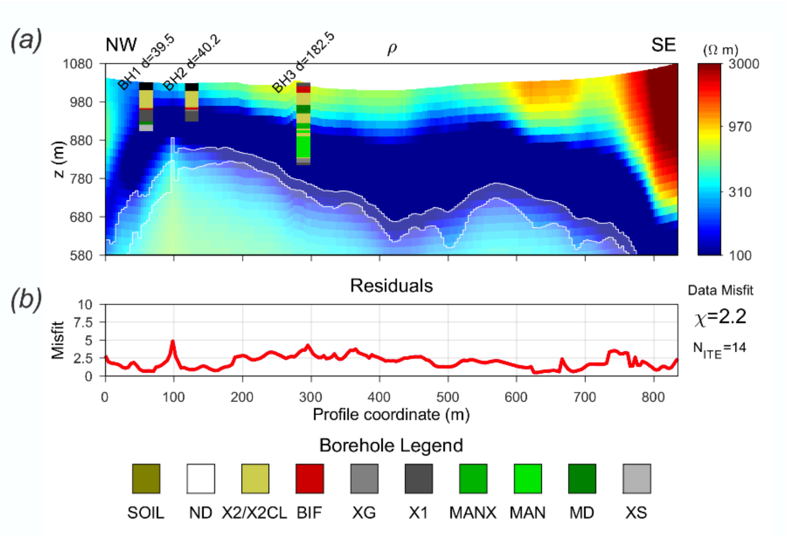


***Figure 2**: Resistivity-only LCI section for line L20810 over the Lamego structure, indicated in Figure 1, integrated with the boreholes sections. The borehole nomenclature is the same presented in Figure 1 and the numbers over the boreholes indicate the distance to the flight-line. (a) Resistivity section - $\rho$. (b) Data misfit along the section. Borehole lithological legend: SOIL - soil layer, ND - non-descripted interval, X2/X2CL - micaceous metapelite, BIF - banded iron formation layers, XG - carbonaceous-graphite schists, X1 - metapelite enriched with carbonaceous material, MAN - metabasalt/metandesite, MANX - MAN interval with chloritization alteration, MD - metadiabase layer and XS - altered felsic metavulcanoclastic layer.*

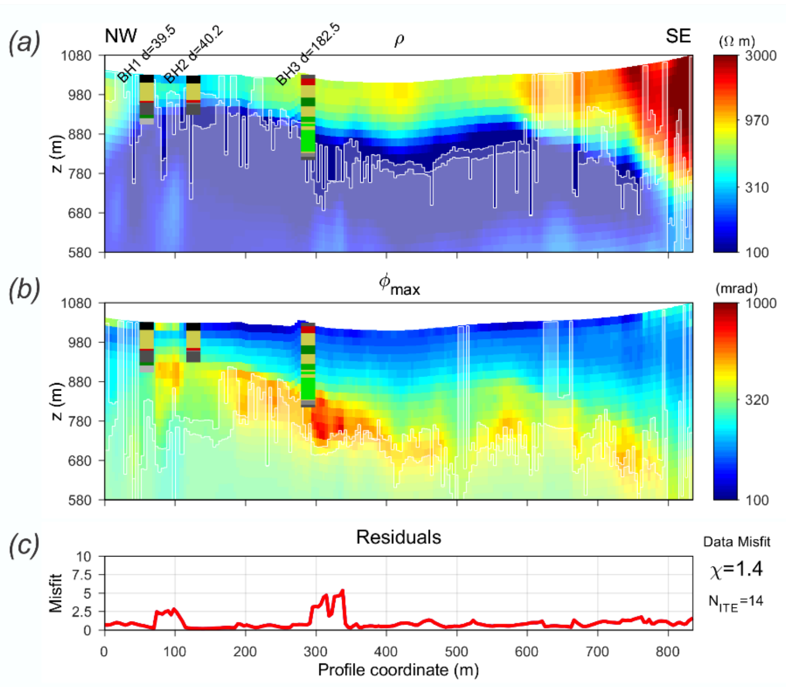


***Figure 3**: Resistivity-only LCI section for line L20810 over the Lamego structure, indicated in Figure 1, integrated with the boreholes sections. (a) Resistivity section - $\rho$. (b) Maximum phase angle section - $\phi_{max}$. (c) Data misfit along the section. The borehole colour representation and distance to flight-line L20810 are the same from Figure 2.*

## Conclusions

We have used two different approaches to invert an AeroTEM$^{HD}$ survey over Lamego Mine strucuture using the LCI technique: the usual RO parameterization and the MPA re-parameterization of the Cole-

Cole model. The MPA re-parameterization seems to present a better recovery of the resistivity model in comparison with the RO results for Lamego Mine region. In addition, the maximum phase model presents an important polarizable body with good structural agreement with borehole data and previous conductive sheet modelling. The understanding of these carbonaceous unit is important for the gold mineralization in Lamego Mine, once its structural control is strongly dependent of the occurrence of this carbonaceous schist, working as a chemical trap. This case indicates that the MPA approach might be an important tool for mineral exploration in the context of metallic sulfide mineralization.

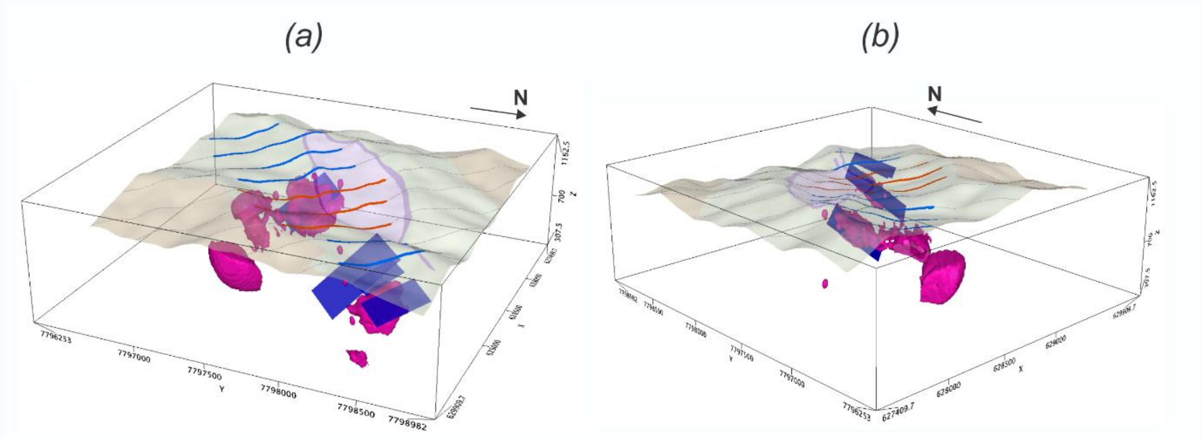


***Figure 4**: Schematic 3D visualization of the polarizable body (in magenta), integrated with previous sheet modelling, presented in Couto et al. (2017). (a) View to Southwest. (b View to Northeast.*

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