1D AEMIP Inversion Using MPA Reparameterization for HTEM Survey at Lamego Gold Mine, Quadrilátero Ferrífero, MG, Brazil

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1D AEMIP Inversion Using MPA Reparameterization for HTEM Survey at Lamego Gold Mine, Quadrilátero Ferrífero, MG, Brazil

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Summary

This paper presents the result of the Airborne Electromagnetic Induced Polarization (AEMIP) 1D inversion using the Maximum Phase Angle (MPA) Cole-Cole model reparameterization for a Helicopter Time Domain (HTEM) survey in Quadrilátero Ferrífero area, MG, Brazil. The inversion was conducted for a set of four soundings points over the mineralized structure of Lamego Gold Mine. The results demonstrate good agreement with the drill-hole lithological description data and indicates two polarizable layers: one thin layer associated with the Au-mineralized banded iron formation (BIF) and the other one associated with a thick graphite schist bellow the Au-mineralization. Additionally, the AEMIP inversion results might suggest improvements in the underground resistivity model, which could not be achieved if the non-complex resistivity model is considered.
Keywords: AEMIP, MPA Reparameterization, HTEM, Quadrilátero Ferrífero, Brazil

Introduction

In the recent years, the interest for the Airborne Electromagnetic Induced Polarization (AEMIP) phenoma has been significantly increased (e.g. Viezzoli et al., 2017, Kang and Oldenburg, 2016, Macnae, 2016). For mineral exploration, its applicability could be a promising tool to map disseminated sulfide zones associated with economic mineralizations in Helicopter Transient Electromagnetic (HTEM) surveys. In particular, AEMIP can help to decrease the ambiguity between conductors and/or resistors which could host mineralizations and to map large areas with chargeability information. Covering such big areas with galvanic induced polarization methods in ground surveys could be a real difficulty in terms of accessibility, logistics, time of data acquisition and costs, which is an important advantage for AEMIP surveys.

In this study we present the IP modelling of AEM signals acquired in areas with disseminated sulfides associated with gold mineralization in the Lamego Gold Mine (AngloGold Ashanti property), in Quadrilatero Ferrífero (QF) area, MG, Brazil. The AEMIP modelling was carried out in terms of Maximum Phase Angle (MPA) reparameterization of the Cole-Cole model introduced by Fiandaca et al. (2018), in order to reduce the correlation of the inversion parameters. The geophyical database consists of an AeroTEM^{HD} survey located in QF area (red polygon in Figure 1-A), in the Belo Horizonte Metropolitan Region, with N45W flight line orientation, spaced by 250 m and with total 3560 line-km coverage. This data was assigned by CPRM – Geological Survey of Brazil for this research. The AeroTEM^{HD} system has a triangular pulse current waveform with 323 A for the peak value, 711000 NIA for peak moment and 17 sampling channels for the vertical component in the off-times. Due to the high flight altitude (90 m in average, needed because of the QF's topography), the signal to noise ratio is low in general. Nevertheless, some clear negative transients were recorded, and in this study they were inverted with the MPA parameterization. We present the results for an interval of one flight line (L20810) located over the mineralized structure in Lamego Gold Mine (Figure 1-B), which presents four sounding points with negative transients.

Methodology

The methodology used in this work is based on the AEMIP inversion through the Cole-Cole MPA reparameterization introduced by Fiandaca et al. (2018), implemented in the software AarhusInv (Auken et al., 2015). The MPA consists of the reparameterization of the complex resistivity Cole-Cole model (Pelton et al., 1978), using the following parameter vector:

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

where ρ_0 is the resistivity for the zero frequency, φ_{max} is the maximum phase angle of the Cole-Cole complex conductivity model (i.e. the minimum of the complex resistivity phase changed of sign), τ_φ is the inverse of the frequency where φ_{max} is reached and C is the frequency dependency parameter. In the MPA reparameterization, a weaker correlation exists between the φ_{max} and C parameters in comparison to the correlations between the m_0 (intrinsic chargeability) and parameters of the classic Cole-Cole model (Fiandaca et al., 2018).

The MPA inversion results presented in this paper were carried using the available drill-hole information for setting the starting model up, but without any prior constraint, in order to let the parameters respond freely according to the physics of the dataset.

Results

Figure 2 presents the result of the Lateral Constrained Inversion (LCI) section clip of flight line L20810 presented as the green line in Figure 1-B, which was inverted considering the resistivity-only (RO) inversion for transient soundings, with the negative data deleted in the processing before inversion. This RO LCI section was ran in the Aarhus Workbench, which also uses the AarhusInv engine (Auken et al., 2015). The locations of the four transient soundings (8 m away from each other) with negative data are indicated in Figure 1-B by the blue crosses. According to AngloGold Ashanti's drill-hole and petrophysical data assigned for CPRM, the area is characterized by a high resistivity environment (with average resistivities values greater than 600 Ω.m). Therefore, a smooth layer model with 30 layers and starting resistivities greater than 600 Ωm were used for the RO LCI. The other parameters were set as the default values in the Workbench LCI environment.

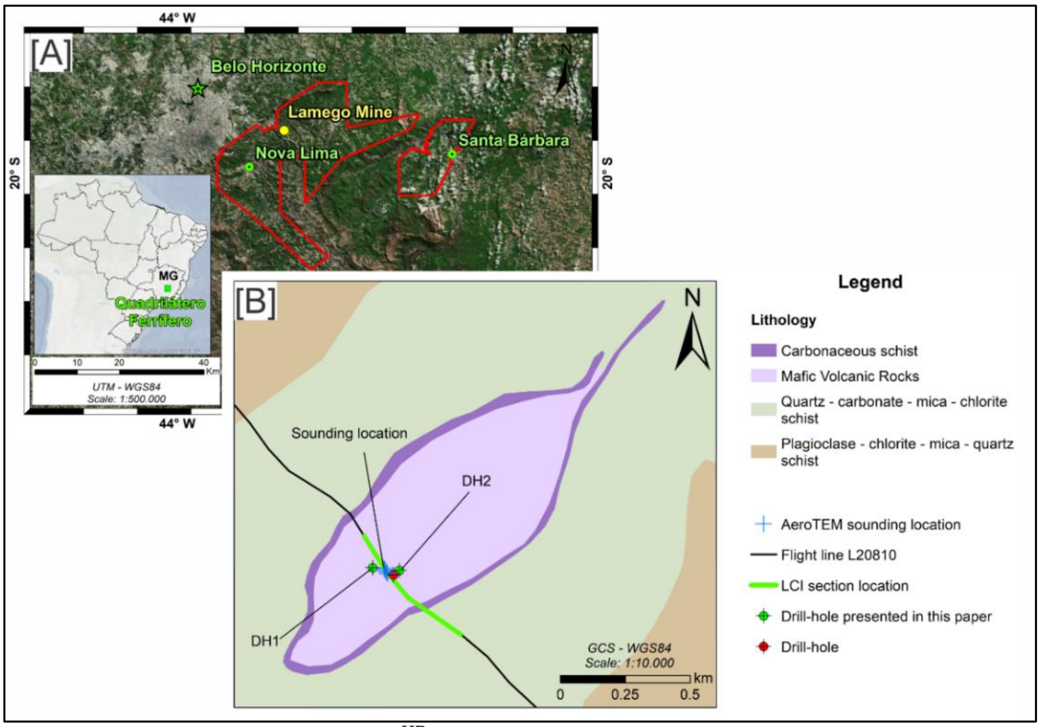

Figure 1: *[A] Location of the AeroTEM^{HD} survey in QF area (red polygon), with the position of the Lamego Gold Mine. [B] Geological map of Lamego Gold Mine area, with the flight line L20810 (black line) over the main structure.*

The location of the four soundings with negative transients are also indicated by the black dashed vertical lines in Figure 2. The RO LCI model suggests a 3-layer model in the interval of the four sounding points, with a conductor starting close to depth values between 50-60 m. Drill-holes log descriptions (there are five drill-holes near the sounding points and their locations are presented in Figure 1-B) indicate that close to this depth value (60-67 m), there is an occurrence of a Au-mineralized banded iron formation (BIF) layer with 5-8 m thickness and Au concentration between 4-6 ppm, followed by a layer of graphite schist down to approximately 130 m. These drill-holes are distant 30-40 m away from the sounding positions. These mineralized intervals hosted in the BIF layers are also reported in Martins et al. (2016), which characterized these occurrences as sulfide dissemination along smoky-milky quartz veins with stockwork structure within the BIFs in mafic volcanic environment.

Based in the RO LCI results and the drill-hole information, we ran the MPA and RO 1D inversions on a representative sounding considering a starting 4-layer model. The starting model considered a resistive non-polarizable background, with polarizable second and third layers (φ_{max} values greater than 100 mrad): a thin second layer with $\boldsymbol{m}_{MPA}^{2} = \{1000\,\Omega \cdot m, 100\,mrad, 0.01\,s, 0.5\}$ and a thick third layer with $\boldsymbol{m}_{MPA}^{3} = \{300\,\Omega \cdot m, 300\,mrad, 0.01\,s, 0.5\}$. Starting layer thichnesses were defined from the variability in the drill-hole logs. The third layer was thought to represent the graphite schist which it is expected to present high polarizability and low resistivities values in comparison to the resistive and expected polarizable second thin layer, due the high graphite content. No difference between the taus values were initially considered. The resistivities values for the initial models were based on the drill-hole petrophysical average data for the unities in this region, which indicates resistivities of the order of 300 Ω.m for the graphite schist and values greater than 600 Ω.m for the other lithologies. For the RO inversion, the same resistivities values were used in the input model and the negative transients data were cutted off.

In Figure 3, the comparison between the RO LCI, RO and MPA 1D inversion models is presented. The Depth of Investigation (DOI) is presented by the colored crosses according to their colors. The resistivity models are really different, both in thickness and resistivity values. However, the MPA model agrees better with the borehole and petrophysical information.

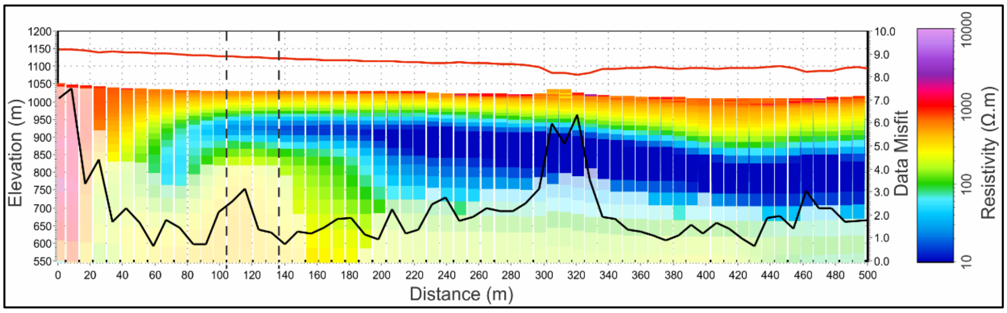

***Figure 2**: RO LCI section for the flight line L20810 clip indicated by the green line in Figure 1-B. The flight line altitude is indicated by the red line, the data misfit by the black solid line and the depth of investigation by the white transparent vertical rectangles. The vertical black dashed lines indicate the position interval of the four soundings with negative data. The first sounding in this interval is presented in this paper.*

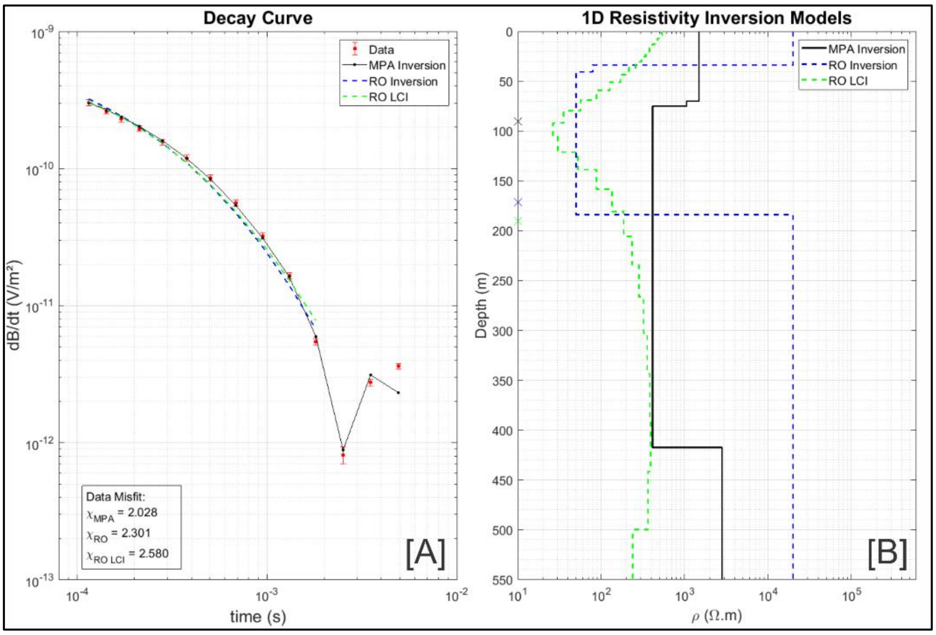

***Figure 3:** Comparison between the MPA, RO and RO LCI (the last two with only the positive values). [A] Decay curve of the transient response. [B] 1D resisitivity model, the colored crosses in the vertical axis indicate the DOI for each resistivity model, according to their colors.*

This is verified in Figure 4, which presents the MPA inversion model of all inversion parameters in comparison to the drill-hole information. The decay curve for the MPA resulting model (black solid line) is presented in Figure 4-A. Figure 4-B presents the resulting MPA model (solid lines) and the starting model (dashed lines) for the four parameters presented in equation (1). The DOI (calculated as presented in Fiandaca et al., 2015) for each parameter is indicated by the colored crosses in the vertical axis, according to their model colors. Figure 4-C presents the log description of the drill-holes DH1 and DH2, indicated in Figure 1-B. The MPA inversion indicates the polarizable contrast between the second thin layer and the third in good agreement with the drill-hole data, suggesting the second layer with 6 m thickness. The insertion of this thin layer decreased the data misfit for a factor of 10%, in comparison to tests with 3-layer model.

Conclusions

AeroTEM^{HD} soundings acquired over the Lamego Gold Mine and showing negative late-time responses were inverted considering the IP effect, in terms of MPA Cole-Cole reparameterization. The data were inverted using the 1D routine of AarhusInv package for HTEM. The results for a set of four soundings, which present negative data, identified chargeable anomalies where drill-hole data indicate Au-mineralized sulfide dissemination within BIF layers and a graphite schists layer. It was also noted that if the data is inverted using only resistivity, culling out the negative data during processing, the resulting models might suggest underestimated resistivities and depth values for the polarizable conductor, which indicates that the IP effect should be taken into account to properly map the underground resistivity distribution. These results will serve as a guide to model other IP anomalies in QF area.

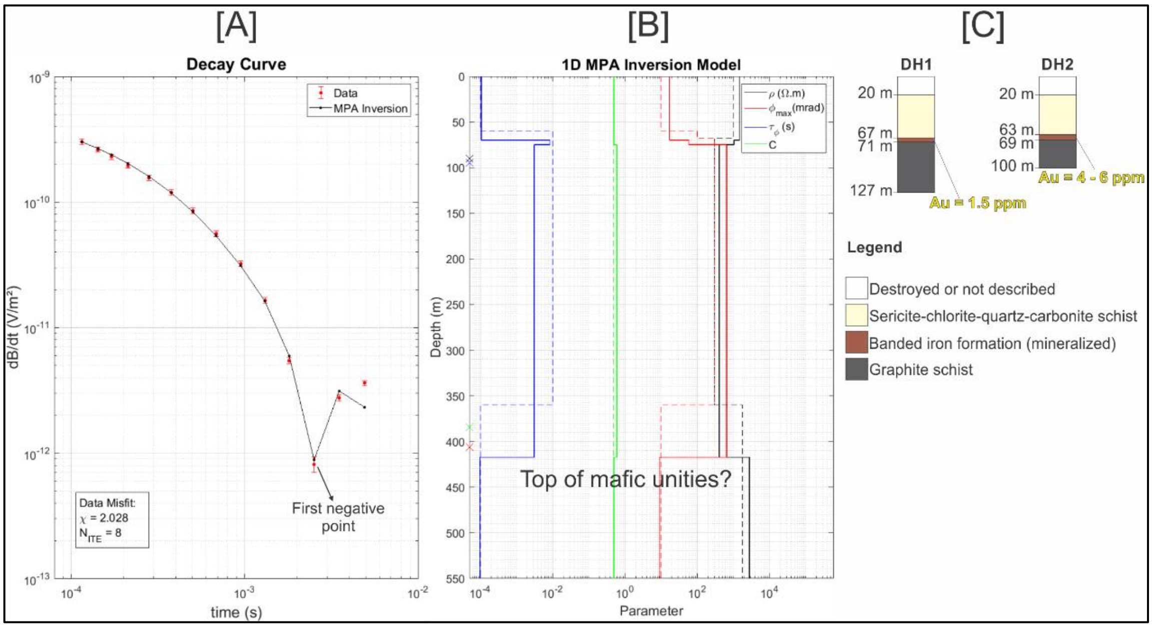

Figure 4: *MPA inversion results. [A] Decay curve for the data (red points) and inverted model (black solid line). [B] 1D MPA models for* $\rho_0, \varphi_{max}, \tau_\varphi$ *and* C *(dashed lines represent the initial models and solid lines the resulting models). The DOI for each parameter is indicated by the colored crosses in the vertical axis, according to their model colors. [C] Lithological description for DH1 and DH2 drill-holes, the gold mineralization interval is indicated in yellow (background values <0.5 ppm).*

Acknowledgments

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