VTEM and Aeromagnetic Data Modeling Applied to Cu, Zn and Pb Prospection in Palmeirópolis Project, TO, Brazil

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Abstract

This paper presents the results of forward sheet modeling for conductors bodies and Magnetization Vector Inversion (MVI) technique applied for an airborne geophysical survey located over Palmeirópolis region, TO State, Brazil. The airborne geophysical survey was provided by Votorantim Metais and Lara do Brasil LTDA. It is composed by Versatile Transient Electromagnetic (VTEM) and aeromagnetometric data. The region is characterized by Cu, Zn and Pb mineralization associated with Volcanic Hosted Massive Sulfide (VHMS) environment. The modeling was focused in four known ore bodies (C1, C2, C3 and C4) and presents significant results associated with the mineralizationm, its structural control and spatial extension. Also, to minimize the inherent ambiguities of each method, a Spectral Induced Polarization (SIP) and geochemical follow-up and regional CPRM surveys were integrated to the results.

Introduction

The Palmeirópolis Project is located in the Southern portion of Tocantins State, Central Brazil. The high mineral potential was discovered and evaluated by CPRM – Brazilian Geological Survey in the lates 1970's. At that time, CPRM mapped four orebodies in the area: C1, C2, C3 and C4. A total of 165 drill holes were performed by CPRM at the area, totalizing approximately 32500 m, distributed in the four orebodies.

The project area is 520 km from Goiânia, capital of Goiás State, and is easily reached by highways GO-080 and BR-153, both paved (Figure 1). The property consists of six mineral rights with final exploration reports already approved by the National Mineral Research Department (DNPM, in Portuguese), for a total of 6050 ha.

Geologically, the project area is located in the North-Central portions of the 300 km long Tocantins Province (Figure 2), which comprises the volcano-sedimentary rocks of Palmeirópolis (which hosts VHMS bodies), Indianápolis and Juscelândia (Araújo *et al.*, 1995). The polymetallic (Cu, Zn, Pb, Cd, Ag, and Au) VHMS deposits are stratiform and stratabound, divided into two volcanic successions.

The four orebodies are located in the Northern part of the Palmeirópolis Sequence, associated to gabbroic rocks overlaid by amphibolitic rocks derived from MORB type basalts. There is also a restricted occurrence of iron formation, and intercalations of cherts and silicic-graphitic sediments (Oliveira, 2000).

Main ore minerals are represented, in order of abundance, by pyrrhotite, pyrite, spharelite, chalcopyrite and galena. Massive orebodies occur in two types of structures: breccias, which is characterized by host rock fragments of different sizes surrounded by massive sulfides; and banded ores (restricted to the C3 body), that is characterized by intercallations of brownish bands of pyrite/sphalerite and yellow bands of pyrite/chalcopyrite. Disseminated ores are the predominant types and occurs following the schistosity of the host rocks, disseminated in the rock matrix and in veins filling fractures.

The sulfide bodies C1, C2 and C3 are located in the contact of amphibolites and intermediate/acid volcanic rocks. The length and width of the orebodies area: C1 – 1100x45 m, C2 – 300x130 m, C3 – 500x180 m. The C4 orebody is ring-shaped and occurs mostly as disseminated ore in the rhyolitic rocks.

The airborne geophysical survey was performed over all CPRM areas by Votorantim Metais and Lara do Brasil LTDA. (Votorantim, 2008). Figure 3 presents the location of the airborne geophysical survey and the four orebodies positions in the CPRM areas. This survey consists of VTEM and airborne magnetic data, which were modeled with forward and inversion modeling techniques. The flight lines have E-W direction and are separated by 250 m. The VTEM data provides conductive anomalies responses (picked along flight lines), which was forward and inverse modeled as conductive plate/prism bodies. These models could be correlated with the sufides concentrations in the region of the orebodies, possibly indicating the geometry, structural geology and positions of mineralized zones.

The airborne magnetic data was inverted by the MVI technique. The magnetic modeling could indicate zones of high concentration of magnetic minerals and, sometimes, pyrrhotite zones, which could be correlated with the conductive mineralized zones indicated by VTEM data. This is why the integration of these methodologies is very important in this work. Both of them are discussed in the next sections.

Method

The methodology applied in this work focus on the modeling of VEM and airborne magnetic data. The VTEM survey allows identifying conductive zones which could be correlated with sufide zones, possibly associated with mineralized bodies. These data was modeled with EMIT Maxwell software algorithm (version 6.0.75.29549). This algorithm solve the forward and inverse problems for VTEM conductive anomalies (picked along the flight lines), considering the physical response of conductive plates or prisms. This kind of modeling allows extracting important structural, geometric and electrical conductivity parameters of the conductive bodies. Furthermore, the models could be correlated with sufidation zones and possibly with mineralized bodies.

The magnetic modeling approach was based in the MVI technique. The VOXI MVI algorithm (Ellis *et al.*, 2012) for the Geosoft Oasis Montaj (version 9.1) was used in this work. This algorithm solves the inverse problem to find the underground vector magnetization spatial distribution and its magnetic susceptibility associated values. The MVI algorithm avoids the problem with remanent magnetization, because it solves the direction and amplitude of the effective vector magnetization (Aisengart, 2015).

The resulting geophysical models were integrated with the orebodies models for four areas: C1, C2, C3 and C4, to compare their structural and geometric relations. These orebodies models were based on the Pb+Zn grades measured in the boreholes CPRM campaigns. Also, the geophysical anomalies were integrated with the follow up and regional sampling geochemical surveys, to compare their spatial geometry with distribution of Cu, Pb and Zn anomalous zones.

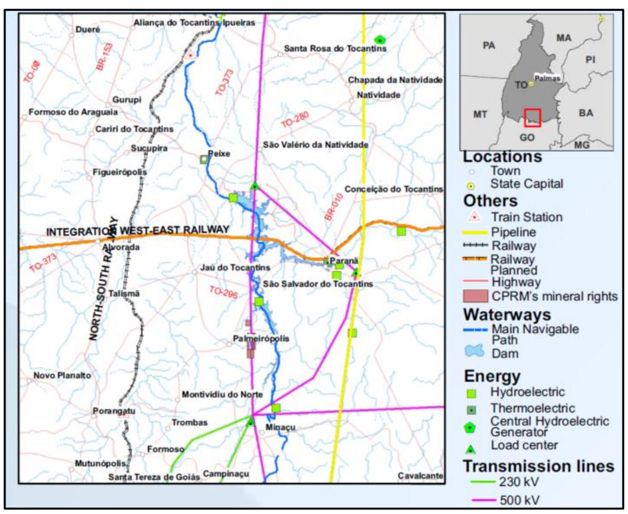

Figure 1: Map of location and infrastructure.

Examples

This work was focused in the four orebodies located in Palmeirópolis project area (Figure 3): C1, C2, C3 and C4.

Regionally, the VTEM data presents a huge (> 10 km) linear off times B Field anomaly for channel 25 (late times interval) of VTEM data in the CPRM areas, associated with conductive zones. It has North-South direction, as could be seen in Figure 4. This conductive trend could be associated with the contact zone between the aluminous metalpelite, gabbroic and acid metavolanic rocks (Figure 2) and, apparently, presents a conductive connection between C2 and C3 orebodies areas. Also, the VTEM conductors picking follows this conductive anomaly and the pickings at C3 area are well aligned with the linear anomalous trend. These results could demonstrate a high metallogenic potential for the region between C2 and C3.

The next subsections present the detailed geophysical and geochemical aspects for each orebody area.

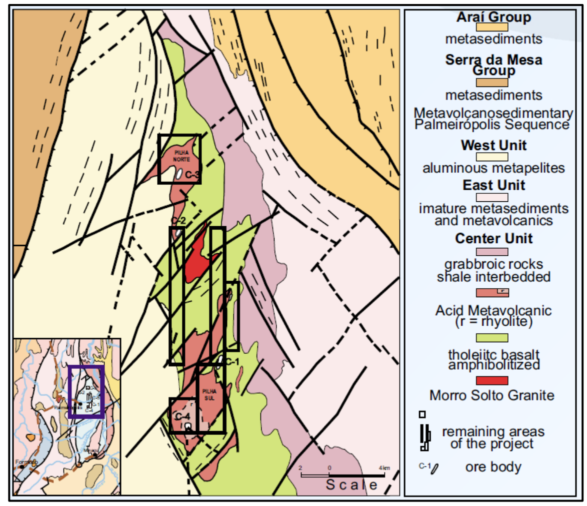

Figure 2: Geological map of Central-Northern portion of Palmeirópolis Sequence and CPRM areas location.

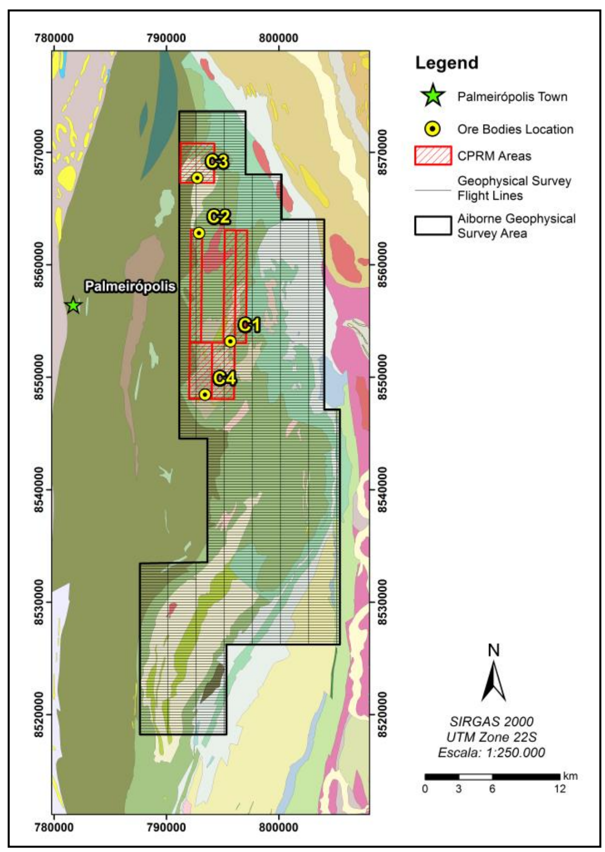

Figure 3: Location of the four orebodies (C1, C2, C3 and C4) and airborne geophysical survey flight lines position over CPRM areas.

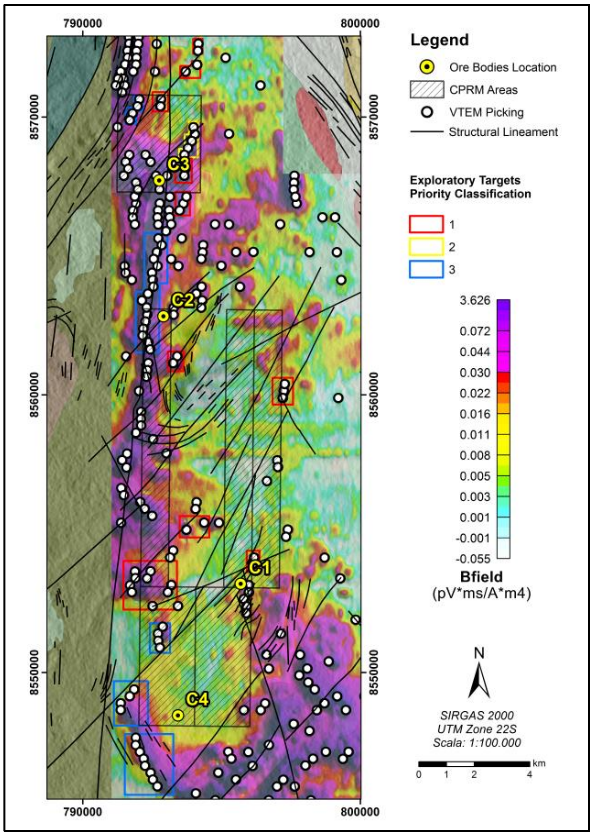

Figure 4: B Field anomaly map and VTEM conductors anomalies positions. The map also shows favorabilty areas for prospection activities.

C1 Orebody

Figure 5 shows the detailed geophysical and geochemical map for C1 orebody area. The map presents an Analytic Signal Amplitude background, integrated with the VTEM conductors picking, Percent Frequency Effect (PFE) from SIP data and soil geochemical anomalies and the favorability zones for Cu, Zn and Pb. Also, the outcrop part of the orebody is shown on the map.

It can be seen a good alignment of all these anomalies to North-NE direction, which helps to support the high mineral potential of the C1 orebody. This alignment is located over a magnetic zone ($ASA > 0.15\, nT/m^2$). An important issue presented in this figure is the continuity of PFE anomalies ($> 2\%$) to the Southern part of the orebody, which could indicates the continuity of the orebody to this area. However, more drillholes campaigns have to be performed to confirm this hypothesis.

C2 Orebody

Similarly to the case of C1 orebody, the VTEM conductors pickings, geochemical anomalies and the known modeled orebody have good spatial position correlation and follows North-South trend (Figure 6). In this area there is no SIP survey data. Some second order Cu anomalies are exactly over the orebody position, which supports the good mineral potential for this orebody.

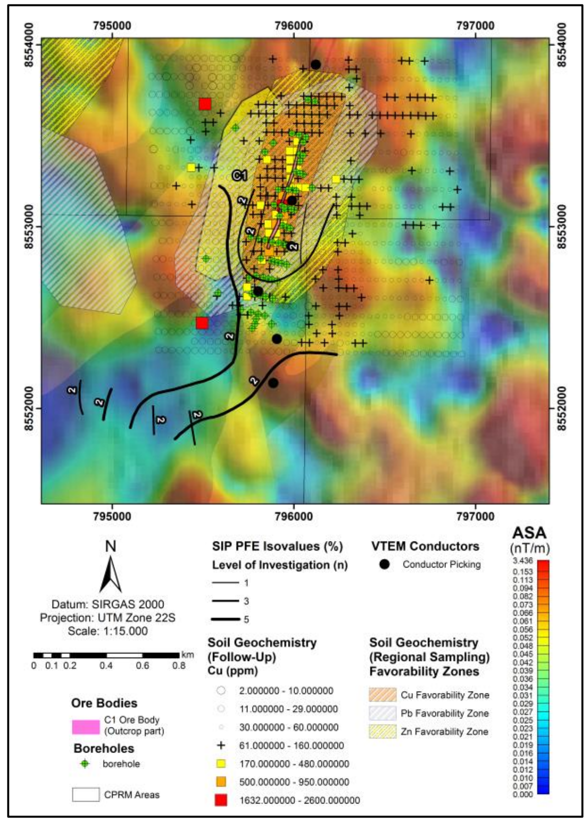

Figure 5: Geophysical and geochemical detailed map for C1 orebody área.

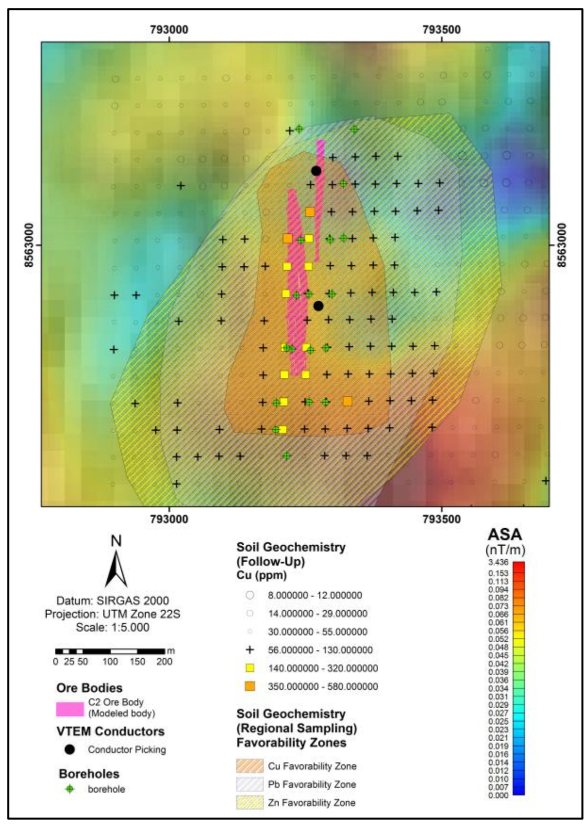

Figure 6: Geophysical and geochemical detailed map for C2 orebody área.

C3 Orebody

C3 orebody is located at northern portion of CPRM areas. In the C3 orebody area (Figure 7), there is no geochemical soil follow up survey data and SIP survey in this area. The only geochemical data concerns about the regional survey. However, the geophysical data provides important information for the mineral potential.

This region presents important magnetic trends and structural trends as can be seen in the Figure 7, which has a first order horizontal derivative of the magnetic field intensity (dx1) background. The lineaments have NE and NW trends. The VTEM data indicates good alignments of the conductors pickings with this lineaments. Two of them are located over C3 orebody position and are nearby from Cu and Pb favorability zones. Also, the VTEM conductors trend in the eastern part of the area is well aligned with an important Zn favorability zone. These features improve the mineral potential of this part of CPRM areas. As can be seen in the next section, the MVI and conductors modeling agree with these results.

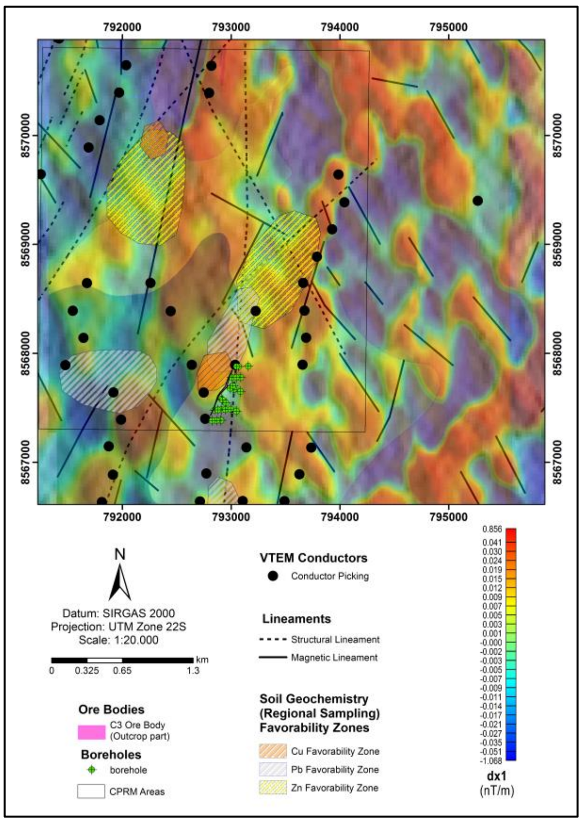

Figure 7: Geophysical and geochemical detailed map for C3 orebody área.

C4 Orebody

In the C4 orebody area (Figure 8), the VTEM conductors are well correlated with the contact zone between the West and Central Units (Figure 2), and are not nearby from the orebody position. However, there are circular PFE (3-4%) and ASA anomalies coincident with the position of the modeled orebody (purple body in Figure 8). Also, the Western part of this area has many PFE anomalies coincident with Zn and Pb favorability zones. These results could suggest a good exploratory potential in this part of the area.

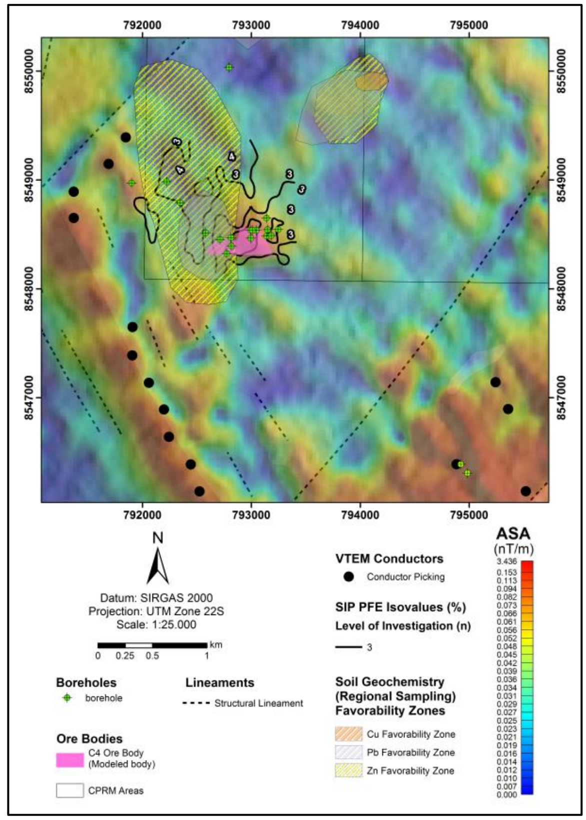

Figure 8: Geophysical and geochemical detailed map for C4 orebody área.

Results

C1 Orebody

Figure 9 presents the results for MVI and conductors modeling at C1 area. It can be seen the good association of the conductors model (blue plates) with the modeled orebody (yellow body) and the magnetic body (purple body). The conductive bodies dip 30-40º toward to SE, compatible with the dip values of the modeled orebody. The depth of base of these conductors are around 150 m and the adjusted conductance values are in the interval $40\,S < G < 120\,S$.

The magnetic bodies envelop the orebody and the modeled conductors. They apparently achieve depth of base values about 400 m and the inverted magnetic susceptibility values are in the interval $(0.01 < k < 0.15SI)$. Some parts of them have coincident positions with the conductors plate models and the modeled orebody. In this case, the plate models could indicate pyrrhotite zones and its correlation with mineralized bodies associated with this kind of sulfidation and/or possible other sulfides kinds, such as chalcopyrite or pyrite. More borehole investigation is demanded to better understand these relations.

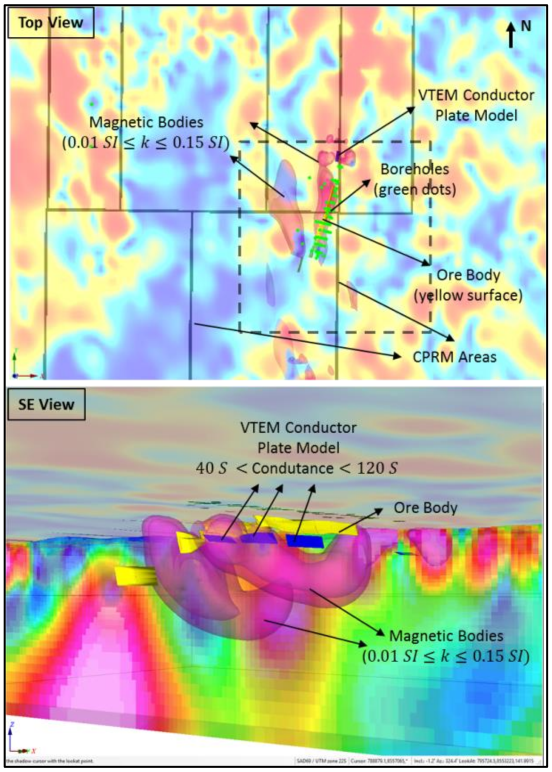

Figure 9: Geophysical modeling results (MVI and conductors plate modeling) for C1 orebody. The dashed square indicates the area presented in Figure 5.

C2 Orebody

The geophysical modeling results for C2 orebody is presented in Figure 10. They indicate a magnetic body associated with the VTEM conductors and the modeled orebody. The conductors models present conductance values between ($70\,S < G < 130\,S$) and magnetic bodies have magnetic susceptibilities in the interval ($0.01\,SI < k < 0.29\,SI$). The extension of this magnetic body and conductor plate model could indicate the depth continuity of the ore body until 300-350 m depth and could be correlated with enriched pyrrhotite zones. More borehole investigations are recommended to investigate these results.

C3 Orebody

The geophysical modeling for C3 orebody (Figure 11) shows that conductors plate models ($25\,S < G < 43\,S$) intercept the modeled orebodies with different angle values: the orebodie has a subvertical (~90°) dip, while the conductors dip 15-30° towards to East. They have 350-450 m along depth extension. These results could suggest a more extensive orebody, possibly with other kinds of sulfides along the conductors direction. Which possibly improve the economic and prospective potential of the orebody area.

MVI results indicate a strong magnetic body ($0.005\,SI < k < 0.12\,SI$) associated with the southern part of C3 orebody and the VTEM conductors in this region. Probably, it could indicate pyrrhotite zones. However, more geophysical investigation and borehole soundings could improve this interpretation.

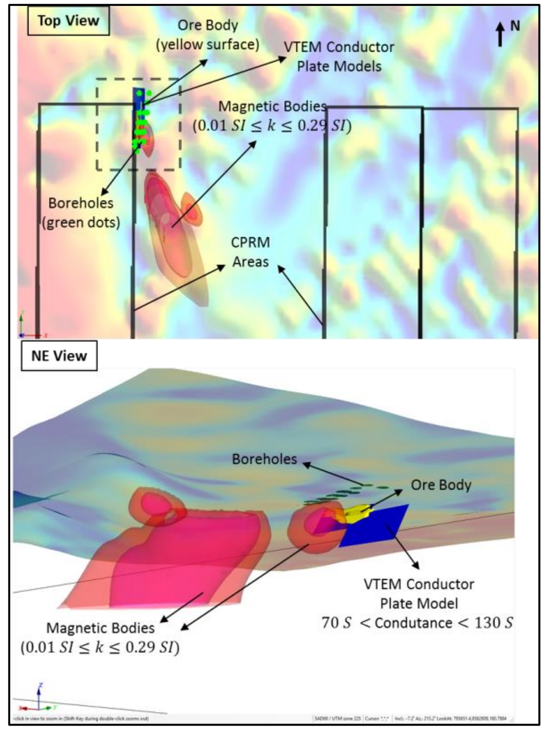

Figure 10: Geophysical modeling results (MVI and conductors plate modeling) for C2 orebody. The dashed square indicates the area presented in Figure 6.

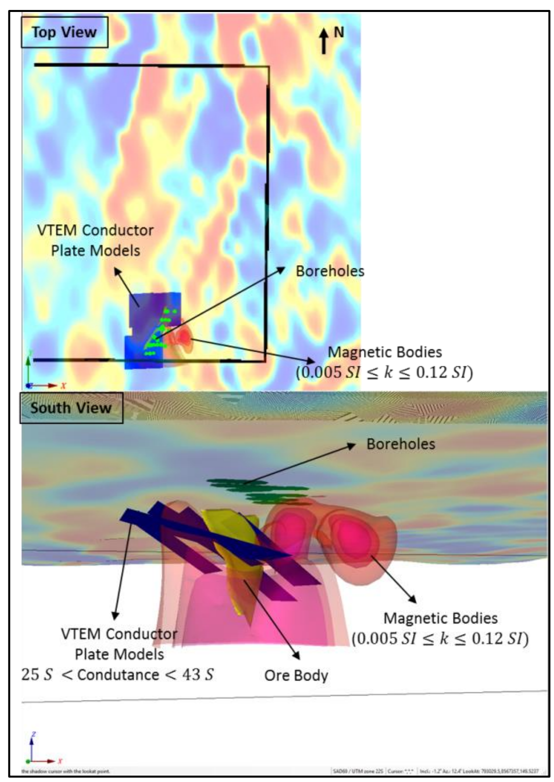

Figure 11: Geophysical modeling results (MVI and conductors plate modeling) for C3 orebody.

C4 Orebody

The conductors plate modeling for C4 orebody area is presented in Figure 12. As discussed in the previous section, apparently, they are correlated with the contact zone between the West and Central Units and seem to be not associated with C4 orebody. However, the modeled orebody are well coincident with the magnetic body solved by MVI technique ($0.002\,SI < k < 0.06\,SI$) bellow the circular ASA anomaly in the C4 position. This magnetic body is part of a set of three linear magnetic bodies with North-NE direction. These results could indicate zones of disseminated pyrrhotite (magnetic susceptibility values are smaller in comparison with the other ore bodies) and could suggest the continuity of the ore body to SE.

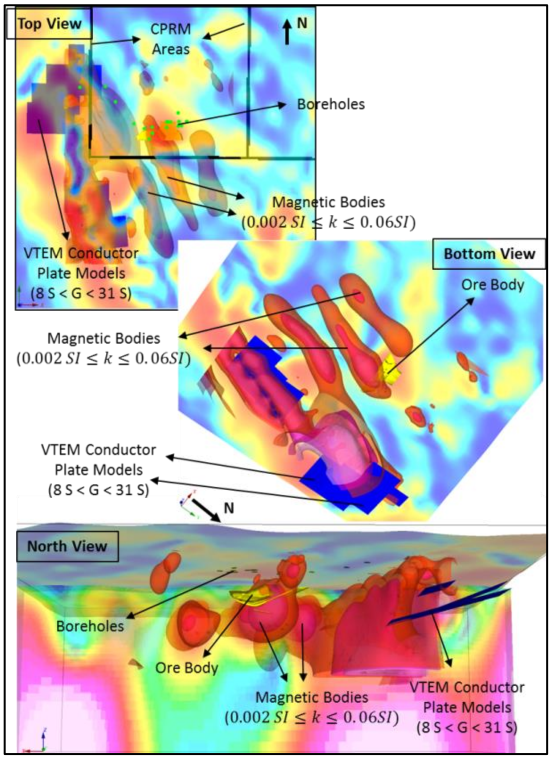

Figure 12: Geophysical modeling results (MVI and conductors plate modeling) for C4 orebody.

Conclusions

The MVI and conductors plate models presented in this work provide important results to improve the prospective potential in the orebodies areas of the Palmeirópolis Project.

In the C1 and C2 areas, the VTEM, magnetic data, SIP anomalies and geochemical anomalies present an excellent correlation with the known mineralized body, which enhance the metallogenic potential. The geophysical modeling (MVI and plate conductors modeling) supports the structural framework of the modeled orebody and also improve the prospective potential in depth extension, possibly indicating enriched pyrrhotite zones.

The results for C3 orebody indicate a good potential for the Northen part of CPRM areas, where a high association of magnetic and structural lineaments with VTEM conductors and some Cu, Pb and Zn anomalies is presented. The geophysical modeling could indicate an spatial improvement of the modeled orebody, possibly indicating its extension to West portion.

The most important results for C4 orebody area concern about the linear extension (to South-SE) of the magnetic bodies solved by MVI. Also, the SIP anomalies agree with many magnetic and geochemical anomalies (Zn and Pb), which could significantly improve the economic potential of this area.

It is highly recommended more borehole and terrestrial geophysical surveys to confirm the geophysical modeled bodies positions presented in this work. For the terrestrial geophysical surveys, it is indicated to perform electromagnetic (TEM and/or FDEM), Induced Polarization over C2 and C3, resistivity and magnetic surveys.

Acknowledgments

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