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Geophysical methods applied in mineral exploration: a case study from the Gueroba target, Carajás Mineral Province, Pará, Brazil

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Abstract Summary

This study presents the application of integrated geophysical methods for mineral exploration in the Luanga and Xingu Complexes, located in the Carajás Mineral Province, Pará, Brazil. Airborne gamma spectrometry and magnetometry surveys, covering approximately 5,862 hectares with 150-meter line spacing, enabled the identification of regional geophysical anomalies and definition of exploration targets. Detailed investigations at the Gueroba target (40 ha) employed electrical resistivity and induced polarization (IP) surveys to delineate fractures, faults, and sulfide-rich zones. Ground magnetometry, conducted using a Stop-and-Go method along N45W profiles with an average spatial sampling of one reading every 10 meters, yielded 836 high-quality data points after processing. Magnetometric data revealed anomalies associated with banded iron formations and mafic-ultramafic rocks, indicating potential for copper, nickel, and gold mineralization. Radiometric data showed variations in radiogenic activity, with ultrabasic rocks exhibiting low and gneisses higher activity. IP surveys detected twelve significant chargeability anomalies at depths of 10 to 54 meters, suggesting sulfide mineralization. Advanced data processing using Oasis Montaj software and interpretation based on established methodologies enhanced anomaly characterization. 3D modeling of magnetic anomalies further refined target delineation, highlighting discrete sources at depths up to 280 meters. The integrated geophysical approach effectively mapped subsurface structures and mineralized zones, demonstrating its value for exploration in complex geological settings of the Carajás Province.

Introduction

The study area lies within the Amazonian Craton, composed predominantly of archean rocks subdivided into two main geological domains: the Rio Maria Domain and the Carajás Domain. The Rio Maria Domain is characterized by mesoarchean greenstone belts, while the Carajás Domain comprises granulites, granitoids, banded iron formations, and mafic-ultramafic intrusions (Santos, 2000; Vazquez and Rosa-Costa, 2008). The Carajás Province is well known for its rich iron, manganese, nickel, gold, and copper deposits, especially Iron Oxide-Copper-Gold (IOCG) deposits.

This case study addresses the application of geophysical methods in mineral exploration within the Luanga and Xingu Complexes, located in Curionópolis (PA), part of the Carajás Province, one of Brazil's largest and most significant metallogenetic districts.

Method

Airborne gamma spectrometry and magnetrometry data from the Projeto Aerogeofísico Tucuruí (CPRM/ LASA Prospecções S.A, 2010), with 150-meter line spacing, were used to map geophysical anomalies across an area of 5,862.18 ha, assisting the definition of exploration targets.

At the Gueroba target, which covers an area of 40 ha, electrical resistivity surveys using the dipole-dipole configuration in electrical profiling were conducted to detect fractures and faults with resistivity values below 300 Ohm.m, accompanied by induced-polarization (IP) surveys to identify sulfide-rich zones through chargeability anomalies.

The ground magnetometry survey was primarily conducted along a N45W direction. Data recording time was set to 3 seconds, using the Stop-and-Go method, which involves collecting measurements while walking and pausing at predefined intervals. This approach resulted in an average spatial sampling of one reading every 10 meters. After removing spurious data, a total of 836 high-quality measurement points, represented as yellow dots, were obtained.

All processing operations and enhancement filters were performed using Oasis Montaj software by Seequent/Geosoft. Interpretations were based on the methodologies presented by Reynolds (2011), Gunn and Dentith (1997), and Blakely (1996).

Results

The magnetometric data highlighted anomalies associated with banded iron formations and mafic-ultramafic rocks, suggesting potential for copper, nickel, and gold mineralization. Gamma spectrometry and radiometric surveys revealed variations in radiogenic activity across the study area. Ultrabasic rocks exhibited low radiogenic activity, while the gneisses of the Xingu Complex showed higher levels, contributing additional geophysical contrast useful for interpretation.

At the Gueroba target, electrical resistivity helped to delineate geological structures likely related to mineralization, revealing conductive zones associated with fractures and faults. The induced polarization method identified 12 significant chargeability anomalies, primarily located in Areas 1 and 2, with depths ranging from 10 to 54 meters. Chargeability values varied between 4 and 120 milliseconds, indicative of sulfide-rich mineralized zones.

Ground magnetometry surveys demonstrated its efficacy in identifying zones with high magnetic susceptibility. The survey successfully delimited the areas and estimated the depths of these anomalous zones, further defining the lithological contrasts in depth based on the observed anomalies. Analysis of the radially averaged power spectrum indicated that the magnetic sources exhibited varied depths, reaching up to 300 meters.

The Analytical Signal Amplitude (ASA) (Fig. 1A) proved highly reliable in locating magnetic bodies, identifying key anomalies such as the central circular target. The tilt derivative map (TDR) (Fig. 1B) enhances the edges of anomaly-causing bodies and is particularly effective for identifying lithological contacts and vertical structures. Directional derivatives DX and DY emphasized horizontal gradients, useful for delimiting lateral limits of geological bodies. The vertical derivative (DZ) (Fig. 1C) indicated intensity variations along the Z-axis (depth), with clearer regions suggesting positive gradients (ascending contacts or shallow bodies) and darker areas indicating negative gradients (deeper structures).

The Vertical Integral (IV) emphasized the magnetic response of buried bodies and identified zones of strong accumulated magnetization, potentially linked to mafic-ultramafic intrusions or mineralized concentrations. Anomaly Magnetic Vertical (VIAS) highlighted shallow magnetized sources and strong magnetic contrasts, proving effective for identifying intrusive structures, lithological contacts, and potential mineralized zones. The Analytic Signal of Vertical Integration (ASVI) revealed significant magnetic field variations, indicating high-susceptibility bodies consistent with mafic or ultramafic rocks. The combined application of these filters improved the correlation between positive magnetic anomalies and target geometry, making them suitable for magnetic source modeling without significant distortion from remanence effects.

A subtle but positive correlation was observed between the ASA and VIAS magnetic anomalies and the topographic elevation (Fig. 1D). Specifically, lower magnetic signals were noted at lower elevations in the northern part of the study area, corresponding to a pronounced terrain decline.

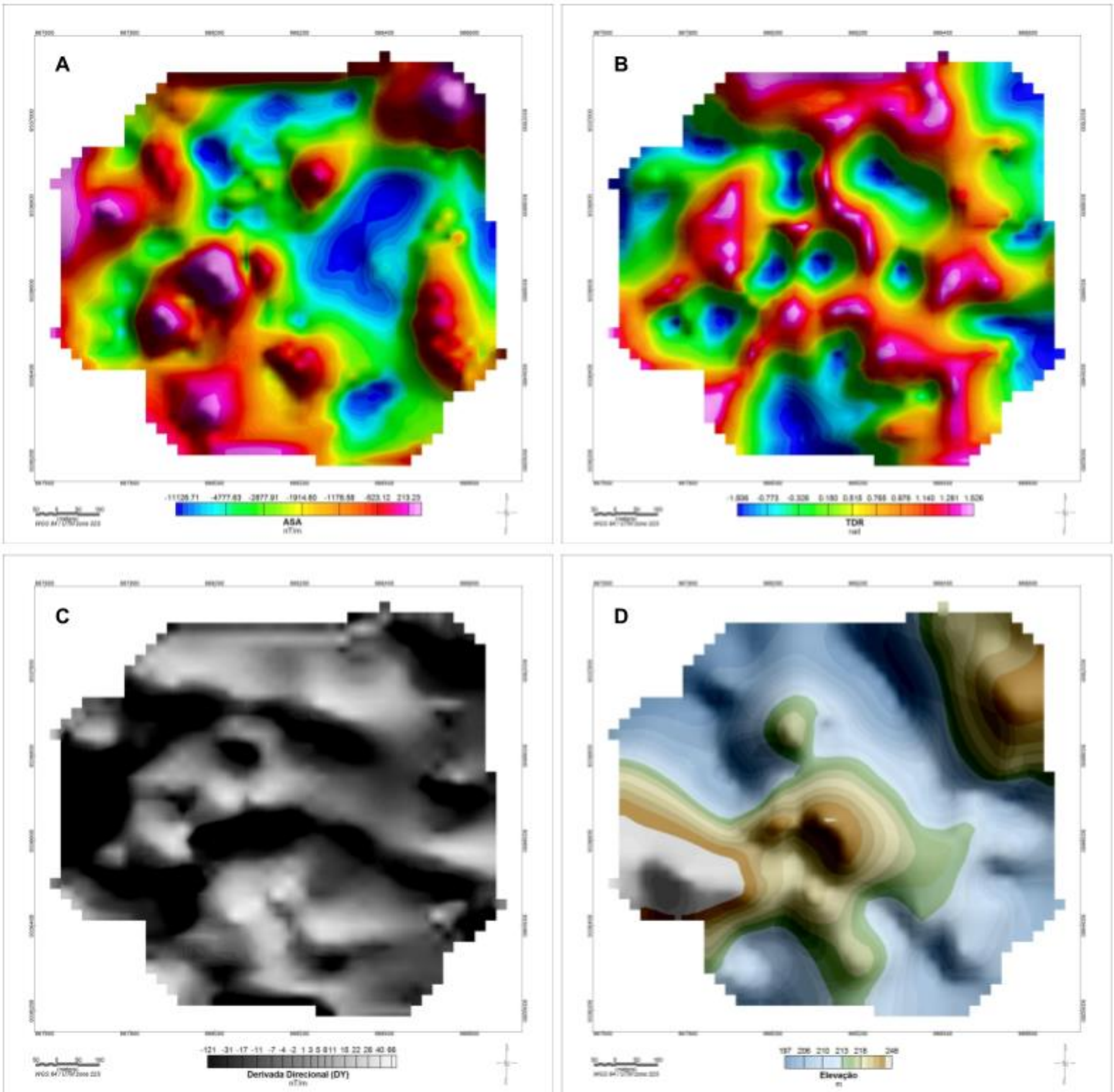

Figure 1: Ground magnetometry maps of the Gueroba target. A) ASA, B) TDR, C) Directional derivative (DY), D) Topography.

To enhance the representation of targeted features, 3D models were generated using ASA data (Fig. 2). This approach proved instrumental in revealing discrete anomalous sources, depicted as colored volumes situated beneath the grid. Notably, filtered values greater than 0.042 nT/m from these inversions pointed to a body at a minimum depth of 280 meters, with further downward extension. These 3D inversions, especially within the subset area, significantly improved the clarity of visualization and depth of analysis for the magnetic anomalies, aligning precisely with the observed grid behavior at depth.

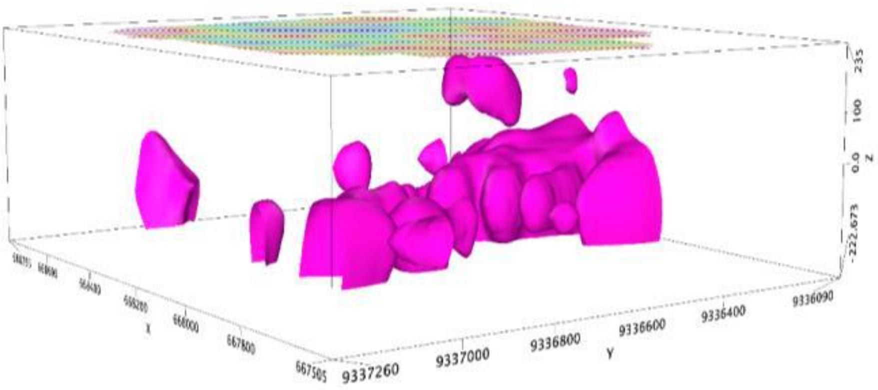

Figure 2: 3D ASA Model.

Conclusions

The methodology applied and processing techniques provided robust insights into the subsurface geology and highlighted potential mineralized bodies.

The ground magnetometry survey successfully identified and characterized significant magnetic anomalies.

The Analytical Signal Amplitude (ASA) map proved highly reliable in locating magnetic bodies, including a central circular target. Maps involving Vertical Integral, such as IV, ASVI, and VIAS, revealed extensive and easily understandable anomalies within the context. It was possible to identify a main SW-NE trend with small, intermittent magnetic bodies along this axis, oriented in the SE-NW direction. Smaller anomalies oriented to NW were also observed, suggesting an absence of well-defined structures within the study area, which is corroborated by the derivative maps.

Geophysical data, combined with geochemical evidence, confirm the presence of the Luanga Complex in the subsurface at an approximate depth of 280 meters.

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