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Geophysical Signature of the Salobo IOCG Deposit and Implications for Mineral Exploration

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Abstract Summary

Geophysics plays an important role in mineral exploration and has become even more relevant with recent advances in technology and the need to explore deeper targets. It helps reduce the uncertainty and cost associated with drilling. The Salobo deposit, located in the Carajás Mineral Province, is a large iron oxide copper-gold (IOCG) system found along secondary structures linked to the main Cinzento shear zone. Because of their high sulphide and iron oxide content, IOCG deposits are often suitable for geophysical surveys. However, the IOCG group includes a variety of deposit types with different characteristics. These differences, including variations in physical rock properties, affect their geophysical responses and require tailored exploration approaches. At Salobo, various geophysical methods—including magnetic, gravity, gamma spectrometry, time-domain electromagnetics (TDEM), and direct current resistivity and induced polarization (DCIP)—were used to study alteration zones and mineralization. The results underline the value of combining different data types. Based on Salobo's geophysical patterns, a set of exploration guidelines was developed to support drilling in similar geological context.

Introduction

Geophysics is used in mineral exploration to help identify zones of alteration and understand the footprint of mineral deposits. Its role has grown in recent years due to advances in technology, the need to explore deeper targets, and the growing availability of geophysical data. Using geophysics to reduce drilling risks is now often considered a necessary part of exploration planning. The Salobo deposit, located in the Carajás Mineral Province, is one of the largest known iron oxide copper-gold (IOCG) systems. It is one of the few IOCG deposits found in Archean rocks. The deposit lies in secondary structures linked to the Cinzento shear zone, which formed around 2.55 billion years ago and separates the Itacaiúnas Supergroup from the Igarapé Gelado metagranite. The mineralization includes bornite, chalcocite, magnetite, and smaller amounts of chalcopyrite and gold, along with other elements like Co, Ni, As, Ag, Mo, and rare earth elements. To design effective exploration programs, it is important to understand what controls these geophysical signals. In Carajás, geophysics has been used extensively to search for mineral deposits, especially with magnetic, electromagnetic, and induced polarization methods. This paper examines Salobo's geophysical characteristics by analyzing and integrating different types of data collected at different scales. The goal is to better understand how each method contributes to identifying IOCG targets and to outline a set of exploration guidelines based on these results.

Method and/or Theory

The mineral systems approach focuses on understanding the geological processes and settings that control mineral deposit formation. Geophysics and petrophysics improve exploration by helping prioritize targets based on broader geological context. Surveys at multiple scales are important: regional data reveal large structures, while deposit-scale data help define mineralization controls. At Salobo, geophysical data were analyzed at regional (1:50,000), district (1:25,000), and deposit (1:10,000) scales using magnetic, radiometric, gravity, electromagnetic, and DCIP methods. Data from the Geological Survey of Brazil and Vale S.A. were processed and reanalyzed using industry-standard software (Oasis Montaj, Geoscience Analyst Pro). Processing included corrections, map transformations, and inversion techniques such as Magnetic Vector Inversion and VOXI modelling. For time-domain EM data, the SPIKER

algorithm was used to improve depth resolution by adjusting for smoothing in apparent conductivity data, producing clearer subsurface images to support exploration decisions.

Results

Magnetic data at all scales shows a clear link between magnetic anomalies and zones with magnetite, as well as areas with potassium and iron alteration. These are closely associated with sulphide zones, making magnetics a key method for exploration. Regional and district-scale magnetic data already provide enough detail for exploration purposes at Salobo. While deposit-scale magnetic data added some value, its impact was limited due to the large size of the deposit. For smaller deposits, deposit-scale data could offer more useful insights (Figure 1A).

Gravity data shows a relationship between density and copper content, due to dense potassium-iron and iron-rich zones occurring within less dense granite (Figure 1B). Gamma spectrometry also provides a clear signal at Salobo. Alteration zones with varying potassium, calcium, sodium, and uranium content stand out from the granitic background. The uranium/thorium (U/Th) ratio is especially helpful for distinguishing IOCG-style alteration zones from the host rock (Figure 1C).

Time-domain electromagnetic (TDEM) models consistently identify Salobo as a weak conductor in early and mid-time windows, similar to other deposits in the region like Furnas. Conductivity patterns are mainly influenced by the type of sulphide minerals present, with stronger signals in areas rich in bornite and chalcocite, and weak or no signal in areas without them (Figure 1D and 1E).

DCIP results show that resistivity better outlines the deposit than chargeability. While chargeability extends over a broader area, likely due to later-stage hydrothermal changes, resistivity more accurately maps the core alteration zone. Overall, magnetic, gravity, TDEM, gamma spectrometry, and IP data all highlight the deposit, although each is influenced by different geological features and minerals (Figure 1F).

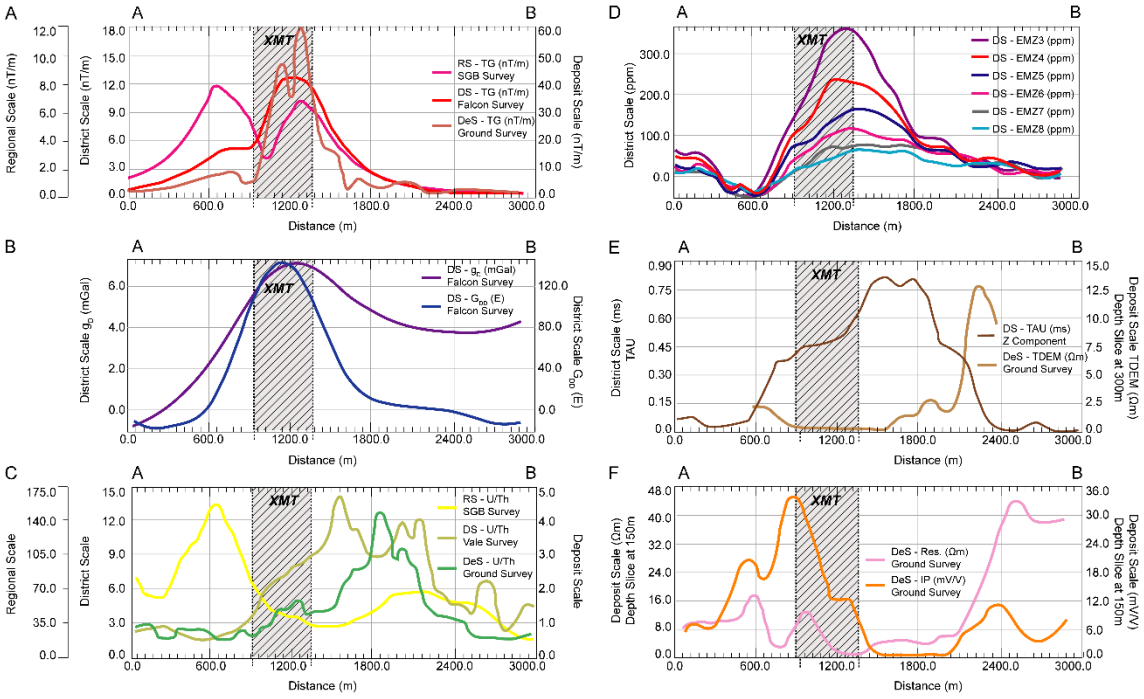

Figure 1: Multiscale and multisource geophysical footprint of Salobo. A) Multiscale magnetic data. B) Multiscale gravity data. C) Multiscale gamma spectrometric data. D) District-scale airborne

TDEM data. E) Multiscale TDEM data. F) Profile of modelled resistivity and chargeability at 150m depth. XMT - Magnetite Schist, RS – Regional Scale, DS – District Scale, DeS – Deposit Scale, gD and GDD Falcon component, EM – Electromagnetic, TDEM - Time-Domain Electromagnetic, TAU - Time Constant, DCIP – Direct Current resistivity and Induced Polarization and SGB - Geological Survey of Brazil.

Conclusions

Iron oxide copper-gold (IOCG) deposits are complex in terms of their physical properties and geophysical responses. While early discoveries were often made using basic exploration approaches, more detailed models will be needed going forward. In the Carajás Mineral Province, the varied characteristics of IOCG deposits make it difficult to define a single geophysical model. This study shows that Salobo's geophysical signature, observed using multiple data types at different scales, is influenced by its mineral content, texture, and structural features. Each geophysical method offers different information, and their combined use helps in understanding the geological features of the deposit. The different minerals and alteration zones affect the geophysical data in specific ways that need to be linked to geological processes. Based on Salobo's data, a set of priorities for IOCG exploration surveys was developed. These can help identify new targets and guide exploration in similar areas, improving drilling efficiency. Understanding how geological and alteration features influence geophysical responses is important for building accurate exploration models. Because of the complexity of IOCG deposits, detailed geological, petrographic, and petrophysical studies are needed to better characterize targets and improve exploration success.

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