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Geophysical Responses of Hydrothermal Rocks Associated with Copper Gold Mineralization in the Neoproterozoic Mara Rosa Magmatic Arc, Central Brazil

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ABSTRACT

Gold and gold-copper deposits of the Mara Rosa Magmatic Arc, Central Brazil, occur in four main associations: Au-Ag-Ba; Cu-Au; Au only and Au-Cu-Bi. Mining companies have been investigating the region since the beginning of the 1970's. Between 1970 and the present, investment in exploration was discontinued several times. New regional airborne geophysics have been undertaken to assist in geological mapping and indicates the presence of many distinct geotectonic environments, such as oceanic arc, back arc basin, and accreted terrains. These environments are favourable to gold and copper-gold deposit formation because of their depth, magmatic association and structural framework. The airborne geophysical results are compared with the distribution of known hydrothermal host rocks and outcrops where Au, Au-Ag-Ba and Cu mineralization occurs. Analysis of the data indicates high positive correlation between magnetic and gamma ray anomalies. Our study is focused on characterizing the geophysical properties of the hydrothermal rocks and associated mineralization that can host gold and copper. Two new geological targets for copper minerals have been identified in the Mara Rosa Magmatic arc. The new copper-gold targets have clear physical property contrasts with their host rocks and therefore lend themselves to detection and mapping by airborne geophysical methods.

INTRODUCTION

The history of mineral exploration in the Neoproterozoic Goiás Magmatic Arc, Central Brazil, especially in the Chapada and Bom Jardim areas, dates back to the early beginning of the 1970´s. At that time, the exploration work aimed at the discovery of volcanogenic massive sulfide deposits, since the volcanic/plutonic rock associations of the Goiás Magmatic Arc were correlated with Archaean greenstone-belts of the Crixás-Hidrolina region. In the beginning of the 1990´s, however, the volcano-sedimentary sequences and associated plutonic units hosting the Cu-Au mineralizations in Chapada and Bom Jardim were re-interpreted as representative of Neoproterozoic juvenile associations, formed between ca. 0.9 and 0.64 Ga in geotectonic settings similar to modern magmatic arcs (Pimentel and Fuck, 1992; Pimentel et al.,1997).

This study applies a simple predictive methodology that has established the airborne geophysical characteristics of host rocks of Cu-Au mineralization. The airborne geophysical signatures of known deposits are compared with analogous ones and available geological data. Goals of this study are to (1) provide useful mineral information for other studies by determining the signature of host rock within the magnetic and gamma-ray data and (2) locate target areas for field verification of potentially unmapped or shallowly buried Cu-Au host rocks. The airborne geophysical datasets provide the necessary input for a regional analysis. Furthermore, airborne magnetic and gamma-ray data are available for the entire Mara Rosa Magmatic Arc and as such, we believe that this study demonstrates a simple approach that can be used to map hydrothermal zones in areas of restricted access, limited outcrop, and thick alluvium, soil, or vegetation cover.

GEOLOGICAL SETTING

The Tocantins Structural Province corresponds to a large Neoproterozoic (Brasiliano/Pan-Africano) orogenic zone developed between two major continental blocks: The Amazon Craton in the west and the São Francisco Craton in the east. The eastern part of the Province is occupied by the Brasilia Belt, which includes mainly a thick metasedimentary sequence and a large area where juvenile Neoproterozoic arc rocks are exposed (The Goiás Magmatic Arc). In the northern part of the Goiás Magmatic Arc, the main tectonic features are: (i) large-scale high-angle thrust to reverse shear zones (Rio dos Bois Fault) developed during the Brasiliano orogeny, separating the Neoproterozoic sequence from the Archaean granite-greenstone terrains of the Crixás-Hidrolina area in the south and from the

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Mesoproterozoic Serra da Mesa metasedimentary sequence in the east (Figure 1); and (ii) extensive NNE-trending, vertical dextral strike-slipe shear zones constituting the so-called Transbrasiliano lineaments.

The Goiás Magmatic Arc extends for more than 1000 km in the western and northern parts of Goiás state, into Tocantins state, and disappears under the Phanerozoic Parnaíba Basin (Figure 1). Two main areas of Neoproterozoic juvenile crust have been identified, and are known in greater detail; these are hereafter referred to as the Arenópolis and Mara Rosa arcs, respectively in the southern and northern sections of the Goiás arc (Pimentel & Fuck, 1992, Pimentel et al., 1997).

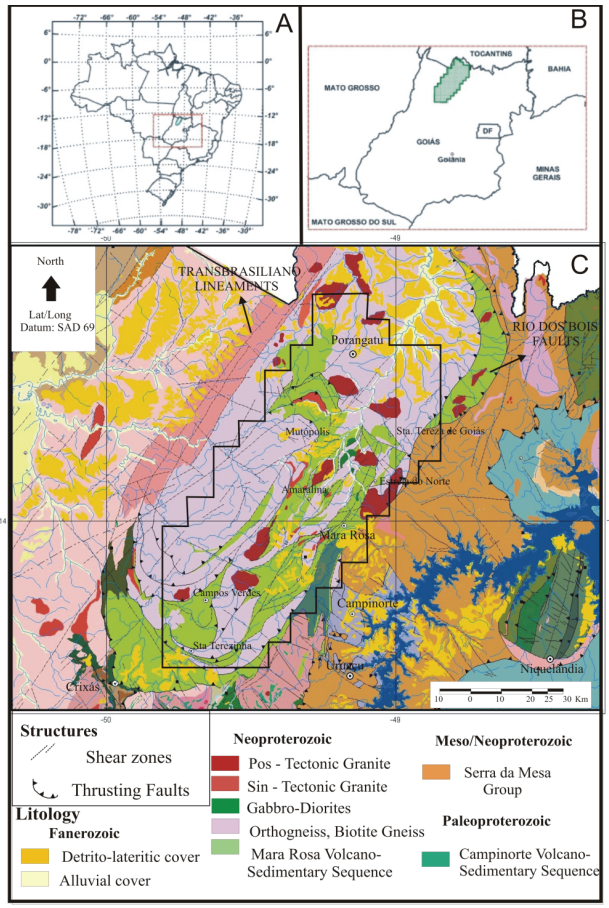

Figure 1: Geological map of Mara Rosa Magmatic arc with the airborne geophysical coverage (black polygon). The figure 1.A shows the position of the studied area in Brazil and in B a detail position of the airborne survey in the state of Góias.

MINERALIZATION

The Mara Rosa arc contains important Au (Posse, Zacarias, Mundinho) and Cu-Au (Chapada) deposits (Figure 2). Mining companies have been investigating the region since the beginning of the 1970's. During the period between 1970 and the present, investment in exploration was discontinued several times due to gold price fluctuations in the international market.

Gold and gold-copper deposits of the Mara Rosa Arc occur in four main associations: *i)* Au-Ag-Ba (e.g. Zacarias Deposit), which is interpreted as a stratiform volcanogenic-type deposit (Poll, 1994); *ii)* Cu-Au (e.g. Chapada Deposit), which has been interpreted either as volcanogenic (Kuyumjian, 1989), or as a porphyry-type deposit (Richardson et al., 1986); *iii)* Au-only deposit (e.g. Posse Deposit), which has been interpreted as an epigenetic disseminated deposit controlled by a mesozonal shear zone (Palermo et al., 2000); and *iv)* Au-Cu-Bi (e.g. Mundinho occurrence), which are considered as vein-type deposits controlled by magnetite-rich diorites.

AIRBORNE GEOPHYSICAL DATA

The Goiás state airborne geophysical data were acquired using 500 m spaced north-south flight lines with orthogonal tie lines flown every 5,000 meters at 100 meters of constant ground clearance. The magnetic system used was an optically pumped (cesium vapour) G822-A magnetometer. The output from the magnetometer was sampled at 0.1s to a resolution of 0.001 nT with a noise envelope less than 0.01 nT. The EXPLORANIUM spectrometer, model GR-820, employed 256 spectral channels and consisted of two downward looking groups of crystals (Thallium-doped NaI) of 1024 cubic inches each (for a total of 2048 cubic inches of detector volume), and two upward looking crystals of 256 cubic inches each (for a total of 512 cubic inches).

The magnetic data was expressed as the anomalous magnetic field, or in other words, as the total measured field corrected for the diurnal variation, the main geomagnetic field (IGRF), and levelling errors. The gamma spectrometry data were discriminated into energy channels with reference to the total energy (total count channel, which was expressed in µR/h), while the potassium channels were expressed in percentage. The uranium and thorium channels were expressed as micro-equivalents and corrected for dead-time; energy variations (spectral stabilization) of the respective background levels of radiation; altitude variations relative to the nominal value for the project; and for scattering due to the Compton effect.

METHOD

The magnetic and gamma-spectrometric data (channels TC, K, U, and Th) data were interpolated in a regular grid with 125m cells using the appropriate algorithms to maintain data fidelity at the original sample locations. The algorithm was based on a linear interpolation along the direction of the flight lines, and on the Akima spline perpendicular to the flight lines. Microlleveling and decorrugation techniques were further applied to the data, producing several geophysical products (individual and composite thematic maps) for geologic analysis and interpretation.

The analysis of the variation of the anomalous magnetic field was aided by its linear transformations principally that dealing with the amplitude of the analytic signal, which are a critical products to locate the spatial distribution of magnetic sources in low latitudes. The use of derivatives, principally the

first vertical derivative, helped to determine the spatial positions of these sources, and were also extremely useful to characterize linear features. The horizontal derivatives further allowed the mapping of lateral limits of these same sources. All of these steps were guided by the analysis of the radial power spectra of the anomalous magnetic field.

The methodology used in the interpretation of the gamma-spectrometric data involved: a) comparison of each micro-levelled grid with digital terrain data, verifying zones where topography influenced the gamma-spectrometry response; b) analysis of the total count channel and other individual channels to define major gamma-spectrometric domains; c) K, Th, and U channels displayed as RBG and CMY false-color maps (ternary images), optionally merged with digital terrain data; and d) computation of U/Th, Th/K, and U/K ratios and analysis of their correlation with gamma-spectrometric domains.

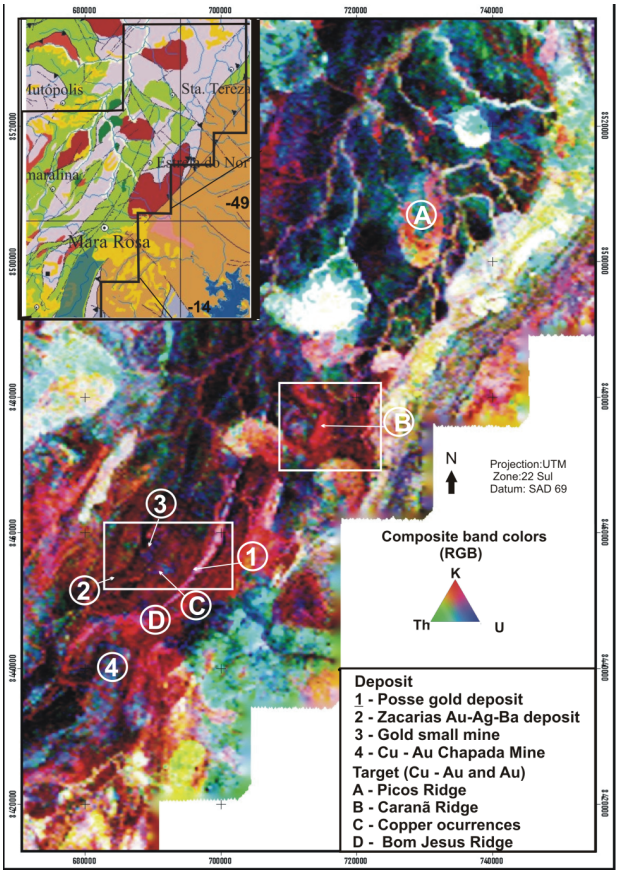

Figure 2: Gamma-ray spectrometric image RGB (KThU) of Mara Rosa Magmatic Arc illustrating the geophysical signature of the main hydrothermal alteration zones and associated mineralization. The white square polygon covers the Caranã ridge and is presented in detail in figure 4. Another one covers the new Cu-Au gold targets (Figure 5).

THE GEOPHYSICAL SIGNATURE OF THE MAIN HYDROTHERMAL HOST ROCKS

The integration of information generated by the interpretation of the magnetic and gamma-spectrometric data allowed the discrimination of several litho-structural domains and hydrothermal zones. The ability of these products to predict regions favourable for economic copper-gold mineralization was verified by comparing them with the occurrences of Cu-Au (Chapada) deposits and host rocks. The best interpretations of the Mara Rosa Magmatic arc were achieved from visual analysis of the ternary radioelement map (Figure 2) and the analytical signal amplitude map (Figure 3). These maps highlighted key host rocks in the area: epidote-rich rocks, epidosite, magnetite-pyrite-quartz-muscovite schist, massive kyanite and kyanite-bearing rocks (Figure 2). They represent narrow ridges associated with thrust faults that are responsible for regional foliation and structural framework of the area. Late deformations are represented by open folds and strike-slip faults with sinistral movement.

The best examples are related with the Picos, Morro do Caranã and Bom Jesus ridges (A, B and C in Figures 2 and 3). They have anomalous potassium signatures that represent the

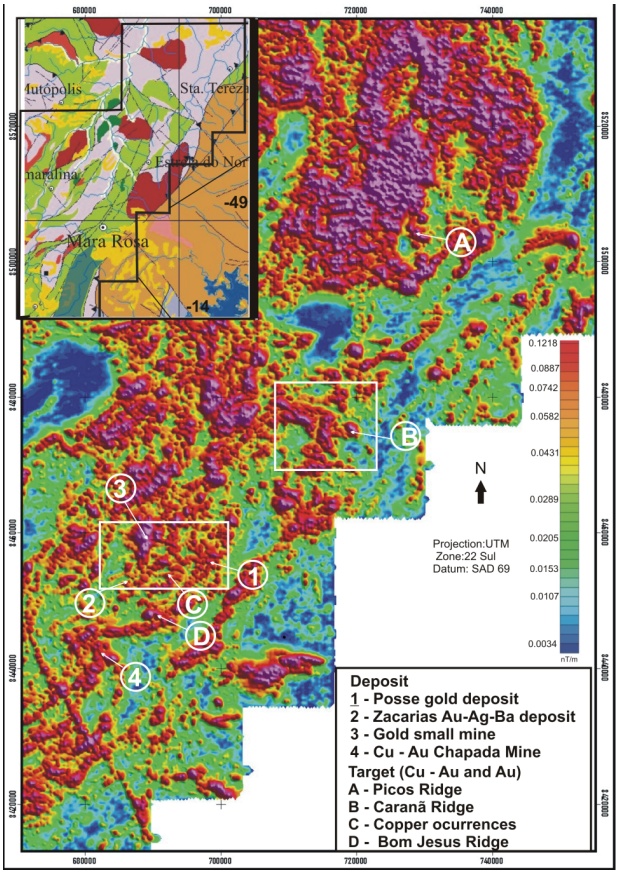

Figure 3: Analytical Signal Amplitude of Mara Rosa Magmatic Arc. The most significant hydrothermal alteration zones in this area are correlated with high analytical signal amplitudes.

phyllic/argillic alteration of orthogneisses. The propylitic alteration (epidosites, quartz-epidosites) is recognizable as two cyan colored areas on the KThU image and medium (red) on the K image (Figure 4). This area was ground-truthed with a geological mapping at 1:25.000. In the Bom Jesus ridge, the known mineralized zone extends for almost 1 km in a NNE direction hosted by the leucocratic orthogneiss near the contact with the amphibolites, where the late hydrothermal event produced an intense alteration with the development of muscovite, epidote, quartz, albite, sericite and carbonate (Palermo et. al. 2000).

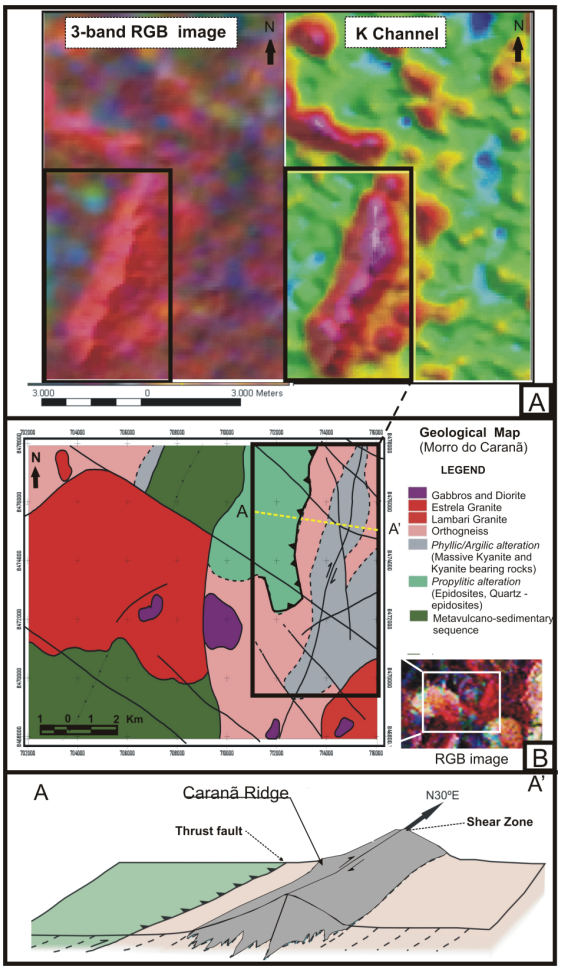

Figure 4: The RGB (KThU) and K images of the Morro do Caranã showing the high K signature that illustrate the main mineralization process in this area. This region was ground thruthed with a geological mapping in 1:25.000 scale.

The Gold Mineralization

The Zacarias Au-Ag-Ba deposit is characterized by a discrete anomaly controlled by a NE trend with low amount of Th and U, intermediate values of K and high gradient in the analytical signal amplitude. Sorongo, Filó and Vendinha are small mines (*garimpos*) and are mapped in the airborne geophysical data by magenta anomalies (medium values of K and U) in RGB ternary and high amplitude in the analytical signal images corresponding with a medium grade of U and K. The anomalies have a strong NE trend enhancing the regional trend related to the gold mineralization (Figure 5).

The New Copper-Gold Targets

Two new geological targets for copper-gold have been identified in the Mara Rosa Magmatic Arc. The new copper-gold targets have clear physical property contrasts with their host rocks and lend themselves to detection and mapping by airborne geophysical methods (Figure 5). Halos of potassic alteration which accompany the mineralization occur in a zone controlled by transcurrent-NS deformation, which clearly post-date the alterations which previously affected the wallrock (Figure 5).

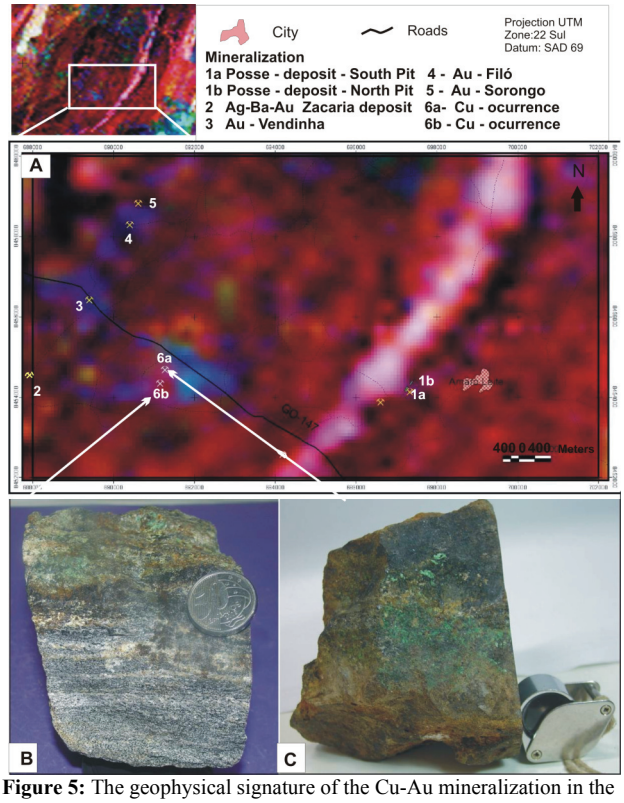

Figure 5: The geophysical signature of the Cu-Au mineralization in the RGB (KThU) image. There are two types of signature: a high uranium associated with the gold only mineralization and the another type with halos of potassic alteration that also maps two new targets (6a and 6b) for copper minerals in the Mara Rosa Magmatic arc. Malachite (B and C) was found in the field and confirms the potential of the area.

CONCLUSIONS AND FUTURE TRENDS

Several geophysical maps that delineate highly prospective areas were derived. From the regional perspective, the geophysical products convincingly map important host rock units. Most importantly, they predict new prospective areas in each of the

different mineralized environments, outside the known mines. These areas have the potential to contain similar mineralization.

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REFERENCES

Arantes, D., Osbourne, G.A., Buck, P.S., Porto, C.G., 1991. The Mara Rosa volcano-sedimentary sequence and associated gold mineralization. In : E. A. Ladeira (ed.) Brazil Gold'91. Anais. p. 221-229.

Kuyumjian, R.M. & Araújo Filho, J.O., 1994. Controle estrutural das mineralizações auríferas no Maciço de Goiás. In: SBG, Simp. Geol. Centro-Oeste, 4. Brasília. Anais, 1:40-42.

Kuyumjian R.M.I., 1989. The geochemistry and tectonic significance of amphibolites fromthe Chapada sequence, Central Brazil, Imperial College, England, PhD. Thesis, 289.

Machado, E.C., 1981. Novas considerações e integração geológica na região de Pilar-Crixás/Mara Rosa-Porangatu. In: Simpósio de Geologia do Centro-Oeste, 1. Goiania, Ata, p.300-318

Oliveira, C.G., Queiroz, C.L., Pimentel, M.M., 2000. The Arenópolis-Mara Rosa gold-copper belt, Neoproterozoic Goiás Magmatic Arc. Revista Brasileira de Geociências, 30:219-221

Palermo, N., Porto, C.G., Costa Jr., C.N., 2000. The Mara Rosa gold district, central Brazil. Rev. Bras. Geoc., 30(2):256-260.

Pimentel, M.M., Heaman, L., Fuck, R.A., 1991. U-Pb zircon and sphene geochronology of late Proterozoic volcanic arc rock units from southwestern Goiás, central Brazil. Journal of South American Earth Sciences, 4:329-339.

Pimentel M.M. & Fuck R.A., 1992. Neoproterozoic Crustal Accretion in Central Brazil.Geology, 20:375-379.

Pimentel, M.M., Whitehouse, M.J., Viana, M.G., Fuck, R.A., Machado, N., 1997. The Mara Rosa Arc in the Tocantins Province : further evidence for Neoproterozoic crustal acretion in central Brazil. Precambrian Research, 81. p.299-310.

Poll N.J.I., 1994. The geology of the Zacarias gold-silver harite deposit, Goiás State, Brazil.Colorado School of Mines, USA, Master thesis, 124p.

Richardson J.V., Jones J.P., Essene E.J., Kesler S.E., 1986. Origin and geochemistry of theChapada Cu-Au deposit, Goiás, Brazil: a metamorphosed wall-rock porphyryCopper deposit. Econ. Geol., 81:1884-1898.