Integrated airborne geophysical and geological studies of the Mundo Novo Greenstone Belt, Bahia, Brazil

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Summary

The Mundo Novo greenstone belt (MNGB) region forms part of the São Francisco Craton, which represents a large crustal segment of the South American Platform, stabilized during the Transamazonian geotectonic cycle. The craton occupies an area over 700,000 km^2 surrounded by Neoproterozoic metasedimentary and metavolcanic fold belts. Archean and Paleoproterozoic granite-greenstone rocks and Paleoproterozoic high to medium grade mobile belts constitute its basement. Greenstone belts are scattered throughout the craton and show evolution from the Archean to the Proterozoic. Among them is the Mundo Novo greenstone belt (MNGB), in the east-central part of the State of Bahia, dated with 3.2 Ga and crosscut by intrusive transamazonian granites (1.8Ga). In 1998 CBPM surveyed 1,530 km^2 in the southern part of the MNGB employing high-resolution airborne transient electromagnetic, magnetic and radiometric geophysical methods. It surveyed E-W lines 200 m apart in a total 8,340 km length survey. The integrated interpretation of the geophysical and of the geological data led to the definition of 46 base metal and gold targets. An important massive sulfide body with a high content in Zn is already delineated in the area. Furthermore the geophysical data improved the definition of the regional tectonic features, and the mapping of the main structural trends. It also mapped lithotypes masked by a 50 m thick overburden. This increased the overall geological knowledge of the MNGB and improved the definition of its extension and metallogenetic potential.

Introduction

The Mundo Novo greenstone belt (MNGB) lies within a large crustal mass, the São Francisco Craton, with an area of 700,000 km^2, which extends mainly into the states of Bahia and Minas Gerais. The craton became stable during the Transamazonian geotectonic cycle. Its basement comprises Archean and Paleoproterozoic low to middle grade granite-greenstone and high to medium grade mobile belts. Thick Meso- and Neoproterozoic detritical and carbonate metassedimentary sequences cover a large part of its basement. Neoproterozoic metassedimentary and metavolcanic sequences enclose the craton and their foliation verges towards it. Greenstone belts are scattered throughout the craton and show evolution from the Archean to the Paleoproterozoic. Among these sequences is placed the MNGB (Mascarenhas & Silva 1994; Mascarenhas et al. 1998) in the east-central part of Bahia State, Brazil (Fig. 1) dated at around 3.2Ga (Peucat et al. 1999, written communication) and crosscut by intrusive transamazonian (1.8Ga) granites (Sabaté et al. 1990).

As a part of its mission the Companhia Baiana de Pesquisa Mineral (CBPM) has been developing integrated investigation programs in several metallogenetic provinces in the State of Bahia, such as greenstone belts, volcanic-sedimentary sequences, and other equivalent prospective environments. One example of these programs comprise the airborne geophysical surveys (EM, GAMA, MAG) associated with geological investigations, ground geophysics (EM, IP, MAG) and geochemical exploration undertaken in the south part of the MNGB. All the geophysical surveys employed modern high-resolution acquisition and processing systems. The emphasis was to investigate the environments where the possibility of the occurrence of ore deposit is very high, and to adequate the methods of work so as to decrease the cost of the subsequent prospecting programs. This paper attempts to outline the process and results of this investigation program.

Fig. 1 - MNGB Localization Map

Geology of the Mundo Novo Greenstone Belt (MNGB)

The MNGB exhibits a trend approximately N-S for about 300 km, with an average width of 22 km, embodied in Archean bimodal TTG's terrenes intruded by granite and granitoide bodies. A thick sequence of siliciclastic rocks of the Jacobina Group (JG) borders the western part of the MNGB (Leo et al. 1964), with fluvial metassediments in the base and coastal to marine sediments in the top (Molinari & Scarpelli 1988). Its basal conglomerate reefs of the Witwaterrand type hosts important gold mineralisations inclusive the world-class gold deposit, the Jacobina Gold Mine owned by Williams Resources Corporation. The minimum age for the JG sedimentation is 2.1 Ga (Mougeot et al. 1995; Mougeot 1996). The MNGB represents a volcanic-sedimentary sequence consisting of komatiitic ultramafic, tholeiitic mafic, and calc-alkaline felsic metavolcanic and intrusive rocks as well as a variety of metasediments, such as metacherts, calc-silicate rocks and BIFs, besides aluminosilicate rich paragneisses, and quartzites (Souza in print).

Petrographical and geochemical studies confirm the komatiitic nature of the ultramafic rocks. The geochemical signature and textural features of these ultramafic rocks are very similar to those proposed by Arndt & Nesbitt (1982) for komatiites associated to Archean greenstone belts. The mafic domain contains locally metabasalts with pillow lavas and amigdaloidal texture. Discriminate diagrams indicate a tholeiitic character for the original magma of these rocks, and the ETR indicates that the chemical behavior of the metabasalts is close to the tholeiitic field of back-arc or MORB. The metamorphism acting on the

MNGB varies from greenschist to high amphibolite (Souza et al. 1996).
The structural evolution was developed in the context of a large process of deformation. It started with a crustal shrinking that yielded recumbent folds with E-W axis, followed by an expressive transport of mass from E to W, that ended with transpressional strike slip sinistral shear zones. The resulting foliation of is subvertical, with a refolding of normal style and axis along the N-S direction. In the high strain zones the folds present vertical axis. The transpressional faults provoke a strong lithological imbrication, placing side-by-side metamorphites of high and low degree. As Souza (in print) suggests, the interaction of the folding has generated domes and basins type 1 and mushrooms type 2 interference figures (Ramsay 1967), as depicted on Figure 2. Mineralization of polimetalic massive sulfides, locally with predominance of Zn, has been found and several targets are under evaluation by CBPM.

Geophysical and Geological Studies
Airborne geophysics is being successfully employed by CBPM for the last years aiming the characterization of tectonic and structural compartments as well as the definition of new prospective areas or specific targets for mineral exploration. The survey of the MNGB area is part of the Project Airborne Geophysical Surveys of Volcanic-sedimentary Domains in the State of Bahia that searches geophysical information to enable the evaluation of the mineral potential of vulcanossedimentary of the State of Bahia. With this objective CBPM contracted an integrated airborne geophysical survey consisting of magnetic, electromagnetic and gamma-spectrometric methods.
The survey was done by the consortium LASA/WORLD GEOSCIENCE (1999) employing a fixed wing aircraft, that contained a digital QUESTEM 450 time domain electromagnetic acquisition system with the following characteristic: triaxial, sampling in 256 channels, basic frequency 25 Hz, and transmitter coil dipole moment of 440,000 Atm^2. It also contained a cesium vapor optically pumped magnetometer, with noise level of 0.1 nT and resolution of 0.01 nT, operating ten samples per second; and a gamma-spectrometer with a detecting crystal with a volume of 2,048 cubic inches, and register of the peaks of thorium, uranium and potassium, besides the total counting and the cosmic radiation, with sampling at intervals of one second.
The survey area has 1,503.94 km^2, corresponding to 8,338 km of E-W production flight lines, spaced of 200 m, and N-S transversal control lines spaced 2,000 m, at an average height of 120 m.
The products of this airborne geophysical program yielded a great scientific and technical advance, considerably increasing both the geological knowledge and the mineral prospectivity in the MNGB domain. The thematic maps derived (Figs. 2a-d) furnished information that strongly contributed for the characterization of the geotectonic-structural framework of the area, that it is known in a fragmented manner, not only because of its complexity, imposed by the superposition of the orogenic events, but also by the extensive tertiary detritical sediments that cover a great part of the area. In these maps, anomalous geophysical domains with complex geometry are signaled. They are either boomerang-shaped in the central part, or dome-shaped and mushroom-shaped in the southern part (Fig. 2e). They also present large linear features with N-S and SW-NE direction that translate the distinct tectonic framework.
The observed electromagnetic panorama for the MNGB area shows the existence of domains with individual geo-electrical characteristics, through the qualitative interpretation of the on time apparent conductivity maps. They express the lithological and structural changes occurring in this area. Two environments with distinct conductivity have been delimited: DE1 e DE2 (Fig. 2c).
DE1 is characterized by a resistive context with values of conductivity lower than 0.8 siemens/m. Geologically correlates to the rocks of the siliciclastic sequence of the Jacobina Group, with the rocks of tonalitic, trondhjemitic, and granodioritic composition (TTG's bimodal) of the Mairi Complex and with the bodies of granite rocks.
DE2 predominates in the area and constitutes a moderate to strong conductive domain, with values of conductivity between 0.8 and 3.0 siemens/m. This domain houses the main conductive zones and EM anomalies of the bedrock-type, related to deep bodies, sometimes associated to magnetic bands. Geologically, there is a predominant association of its segments with the lithotypes of the MNGB of amphibolite and greenschist facies, such as: meta-ultramafites, banded iron formations, metabasalts, calc-silicate rocks, graphitic pelites, metatuffs and aluminous-gneisses.
The magnetic data (Fig. 2b) displays a large amount of anomalous magnetic domains along all the area. This reflects the densification of magnetic lithologies associated to the context of the MNGB. The mapping of these anomalous features shows that the behavior of the geomagnetic field indicates definite variations along the N-S direction. In the northern part predominates an N-S trend, forming large magnetic structures in this direction with inflections to the east and west (5°), deformed by a secondary trend in the SW-NE direction. In the center-south portion the morphology of the magnetic field changes completely. It is characterized by an extremely variable magnetic trend with abrupt variation of direction, from SW-NE to E-W, and with perturbation in the directions SE-NW and N-S. A conspicuous and concentric elliptic-shaped magnetic feature occurs between the UTM 8,660,000 N to the UTM 8,675000 N. It is formed by anomalies of high amplitudes and low frequencies, that translate a dome/basin and/or sheath fold interference patterns generated from the interaction of the represented folding phases and intensive shear zones. In the extreme south of the area, the anomalous magnetic zones follow trends that vary from N-S to SW-NE, formed by lines of magnetic dipoles of large amplitude and strong linearity.
Magnetic trends have been defined associated with faulting along the N-S, NE-SW e NW-SE directions. The transpressional faults of the area are associated to the regional magnetic trends. Besides them secondary fracture systems along the E-W, NE-SW and NW-SE directions have been defined.
Geologically the anomalous magnetic zones that form the described trends map the magnetized lithotypes of the Mairi Complex (TTG's), and especially the lithotypes of the amphibolite and greenschist facies of the MNGB.
The gamma-spectrometer survey data, constituted by the U, Th, and K maps as well as by the ratio of these channels, individualize the radiometric domains characterized by different concentration levels of these radio-elements, allowing the delineation of faciologic and radiometric domains. The definition of these domains contributes, very much, not only to the geological map, pointing to the existing geological diversity,

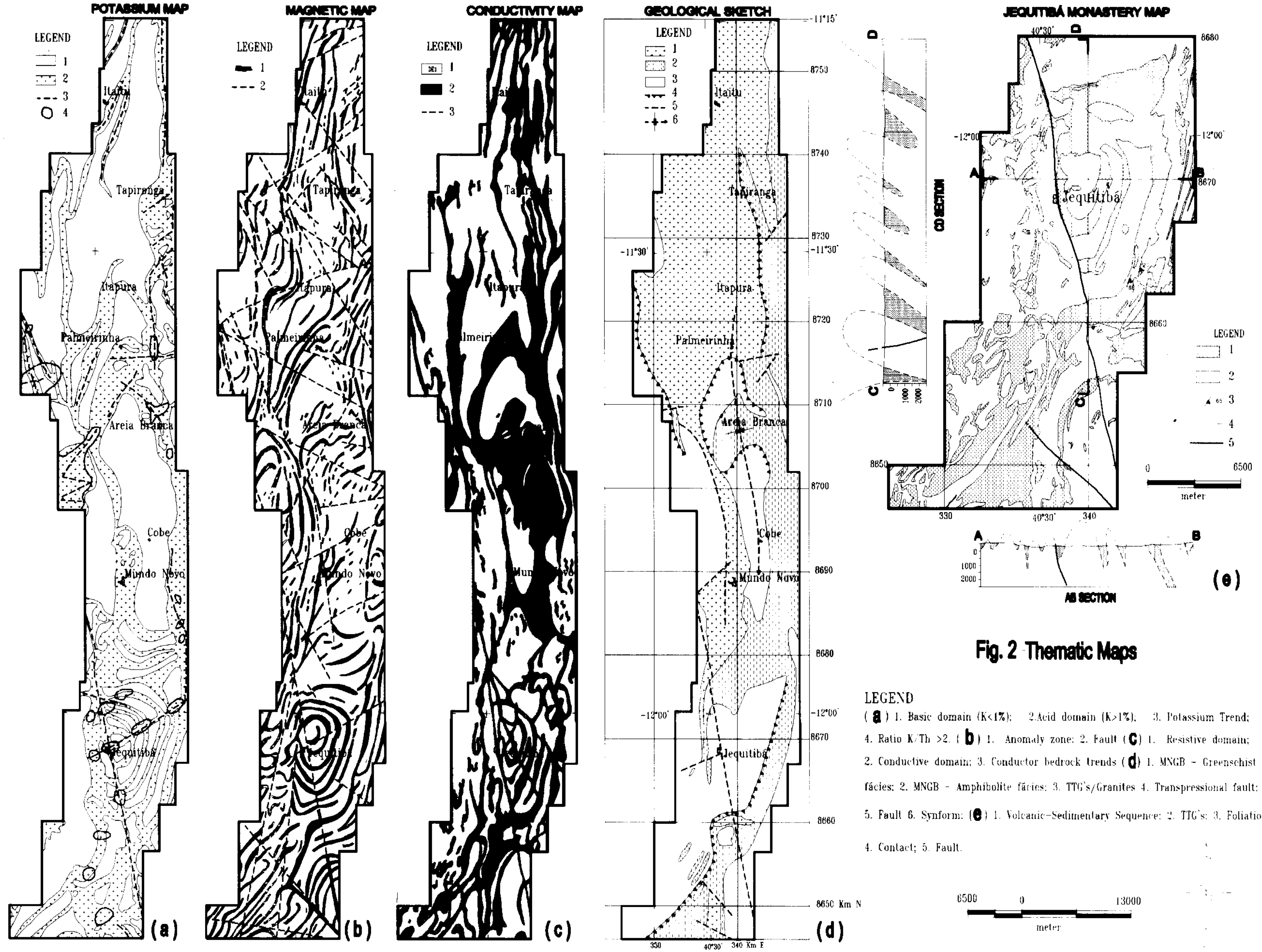

Fig. 2 Thematic Maps

LEGEND

(**a**) 1. Basic domain (K<1%); 2.Acid domain (K>1%); 3. Potassium Trend; 4. Ratio K/Th >2. (**b**) 1. Anomaly zone; 2. Fault (**c**) 1. Resistive domain; 2. Conductive domain; 3. Conductor bedrock trends (**d**) 1. MNGB - Greenschist fácies; 2. MNGB - Amphibolite fácies; 3. TTG's/Granites 4. Transpressional fault; 5. Fault 6. Synform; (**e**) 1. Volcanic-Sedimentary Sequence; 2. TTG's; 3. Foliation; 4. Contact; 5. Fault.

but also helping to define the characterization of hydrothermal alterations and the geochemical signature in terms of K, Th, U of some lithological units, mainly intrusive granites.

Based on the distinct concentrations of K and Th the MNGB has been divided in the following four domains: high Th (>10 ppm) and high K (>1%) associated with granites; low Th (<10 ppm) and low K (<1%) associated with the amphibolite and greenschist facies rocks of the volcanic-sedimentary sequence, such as the meta-ultramafites, metatuffs, banded iron formation, metabasalts, and graphitic pelites; high Th (>10 ppm) and low K (<1%) related to the TTG's bimodal rocks of the Mairi Complex, the siliciclastic rocks of the Jacobina Group and tuffaceous metassediments; high K (>1%) and low Th (<10 ppm) mainly associated with the aluminous paragneisses and secondarily with the felsic metavolcanic.

The trends of larger potassium concentration indicating the stripes that underwent hydrothermal processes are enhanced. They are potential catalysts to contain gold and base metal mineralization in massive sulfide zones within a volcanic environment, and/or gold mineralization in hydrothermal shear zones. They delimited the zones of potassium enrichment relative to thorium (K/Th>2), that historically indicates alteration processes (Fig. 2a).

Conclusions

The geophysical response of the MNGB confirms its high potential for gold and base metal deposits and it is a great incentive to exploration in its environment. The geological environment typical of greenstone belt terrenes is adequate for the use of geophysics as both a basic exploration tool and of support to the geological mapping, especially integrated to the other sensor and to geochemistry.

The result of the magnetic, electromagnetic, and radiometric interpretation gave conditions to improve the knowledge about key crustal-scale features, and also served as a landmark for the definition of target areas, that may contain base metals and gold deposits related to shear zones and/or lithologic features. It also mapped lithotypes masked by a 50 m thick overburden.

The present data show several new features that are not observed on the surface, and were neither displayed nor evident in the geological map obtained prior to the geophysical analysis. (Fig. 2d). Furthermore the geophysical data improved the definition of the regional tectonic features, and the mapping of the main structural trends. This increased the overall geological knowledge of the MNGB and improved the definition of its extension and metallogenetic potential.

The interpretation of these data shows therefore an improvement of the geological map and a better characterization of the environment, resulting in the delineation of the main lithological, structural, and metallogenetic characteristics, and also in the indication of the main targets for the orientation for the prospecting. In the studied area 46 targets have been defined, now under detailed research work. One of them is related to a zinc rich massive sulfide body with minor Cu, Pb, Au and Ag.

All data presented are a demonstration that nowadays airborne geophysical surveys are a convincing, powerful and cost-effective way of obtaining basic information for geological mapping and mineral exploration purposes. Indeed they supplement geochemical surveys and geological investigations, and assist to locate and delineate ore bodies, or define its extent. This points out the need to integrate geology and geophysics. This thinking and methodology has been recognized by CBPM`s geophysicists and geologists teams that are integrating regional and detailed geological mapping with the interpretation of geophysical data. As a result this, realistic geological maps are being produced. The resulting maps will be very useful and assist the CBPM mineral exploration planning.

Acknowledgments

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