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ALEMÃO COPPER-GOLD (U-REE) DEPOSIT, CARAJÁS, BRAZIL

Petronilia C. Ronzê, Anselmo D.V. Soares, Marcos Giovanni S. dos Santos and Célio F. Barreira

Rio Doce Geologia e Mineração SA – DOCEGEO

Abstract – The Alemão copper-gold deposit is located within the Carajás Mineral Province of Northern Brazil and was discovered in 1996 by DOCEGEO using geophysical and geological techniques. Alemão is hosted by the Igarapé Bahia Group, which comprises two lithological and stratigraphic domains: a lower metavolcanic unit composed of metavolcanic rocks and acid to intermediate volcaniclastics; and an upper clastic-chemical metasedimentary unit with volcaniclastic rocks. The Alemão ore body is covered by a 250 m thick unconformable siliciclastic unit referred to as the Águas Claras Formation. The ore body, which is 500 m in length and 50 to 200 m wide, strikes northeast-southwest and dips steeply to the northwest, being emplaced along the contact between the two stratigraphic domains of the Igarapé Bahia Group. In the ore zone, the hydrothermal paragenesis is marked by ferric minerals (magnetite-hematite), sulphides (chalcopyrite, pyrite), chlorite, carbonate (siderite, calcite, ankerite) and biotite, with minor quartz, tourmaline, fluorite, apatite, uraninite, gold and silver. Sericite and albite are rare. The mineralisation is represented by hydrothermal breccias and "hydrothermalites" classified into two types: (1) the BMS type, composed of massive bands of magnetite and chalcopyrite and by polymictic breccias with a matrix comprising magnetite, chalcopyrite, siderite, chlorite, biotite and amphiboles; (2) the BCLS type breccia which comprises brecciated hydrothermalised volcanic rocks with chalcopyrite, bornite, pyrite, chlorite, siderite, ankerite, tourmaline and molybdenite in the matrix, as well as dissemination in the rock. The geochemical association of Fe-Cu-Au-U-REE in iron rich, heterolithic, hydrothermal breccias at the Alemão Cu-Au Deposit, as well as its possible association with an extensional tectonic setting, suggests a correlation with Olympic Dam type mineralisation. The total estimated ore resource, based on a krigging method, is 170 Mt @ 1.5% Cu and 0.8 g/t Au.

Introduction

The Alemão Cu-Au (U-REE) Deposit is located in the Carajás Mineral Province of Pará State, northern Brazil (Fig. 1). This metallogenic province embraces several major reserves of iron, copper, gold, manganese, nickel and bauxite hosted by an Archaean metavolcanosedimentary sequence with significant potential for further mineral discoveries. It has consequently attracted the attention of a range of mining companies and research groups.

The Alemão Deposit is covered by 250 m of Archaean sandstones. The topography surrounding the project area is characterised by plateaux with an elevation of around 650 m and valleys at 250 m, containing an expressive vegetation cover - the Amazon Tropical Forest.

The discovery of the Alemão ore body by DOCEGEO in 1996 resulted from exploration programs utilising both geophysical and geological surveys (Barreira, 1999). It was intersected during a 12 hole exploration drilling program to check magnetic anomalies involving some 6 000 m of surface drilling.

This paper describes the geology and mineralisation of the Alemão Cu-Au (U-REE) deposit, including an overview of its regional tectonic setting as well as discussing its relationship to the iron-oxide copper-gold family of deposits.

Regional Setting

The Carajás Mineral Province represents an Archaean nucleus that occurs in the southern portion of the Amazon Craton (Tassinari and Macambira, 1999) and which is divided into two different tectonic blocks, the southern and northern (Costa *et al.*, 1995) as described below.

The southern block is the older and is known as the Rio Maria granitoid-greenstone terrain (Hunh *et al.,* 1988). It is represented by the greenstone belts of the Andorinhas Supergroup and the associated Rio Maria, Mogno and Parazônia Archaean intrusives granitoids (Fig. 2).

The northern tectonic block (Fig. 2), which is referred to as the Itacaiúnas Shear Belt (Araújo *et al.,* 1988) comprises the Carajás Basin (Itacaiúnas Supergroup), whose basement rocks consist of gneiss and migmatite of the 2.8 Ga Xingu Complex (Machado *et al.,* 1991) and the east-west trending 3.0 Ga orthogranulites of the Pium Complexes (Rodrigues *et al.,* 1992). Docegeo (1988) suggested that the Xingu Complex may be the result of a tectono-metamorphic reworking of the Rio Maria granite-greenstone terrain. According to Teixeira (1994) it represents a crustal block that collided with the Itacaiúnas and Rio Maria tectonic blocks.

The basement rocks are overlain by the volcano-sedimentary sequence of the Itacaiúnas Supergroup which

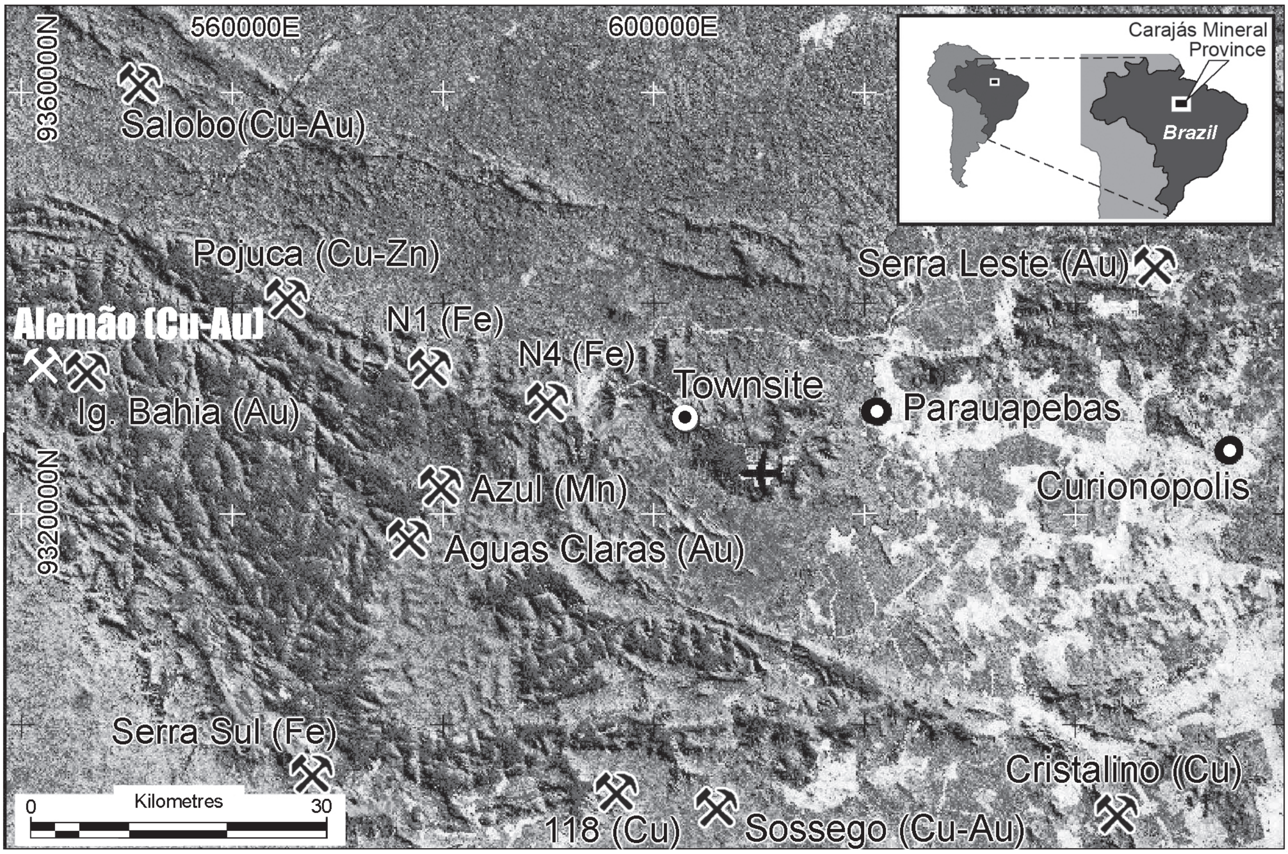


Figure 1: Location map, Carajás Mineral Province, showing the main mines and ore deposits (crossed picks) and towns.

was metamorphosed to greenschist stage grading to amphibolite facies. They (Docegeo 1988) were deposited during Late Archaean time - 2.75 Ga (Machado *et al.*, 1991) and later overlain by an extensive platform consisting of an Archaean clastic succession of sandstones and siltstones known as the Rio Fresco Group (Docegeo 1988) or Águas Claras Formation (Araújo *et al.*, 1988).

The Carajás Basin rocks were intruded by several Archaean to Proterozoic plutons which included granites and diorites, such as the 2.74 Ga Plaquê Suite (Huhn *et al.*, 1999), the 2.75 Ga Estrela Complex alkaline granites (Barros and Barbey, 2000) and the 2.5 Ga Old Salobo Granite (Machado *et al.*, 1991). During Palaeoproterozoic times, many anorogenic alkaline to sub-alkaline granite intrusions were emplaced such as the Central Carajás Granite and the Cigano Granite.

This province was also affected by successive basic magmatic events, represented by sills, dykes and gabbroic bodies (Santa Inês Gabbro) of distinct ages (from Archaean to Neoproterozoic).

The tectonic evolution of the region is associated with several episodes of strike-slip reactivations, changing kinematics from dextral to sinistral transtensional to transpressional deformation. The Carajás Basin was possibly formed under dextral transtension which was later reactivated by sinistral transpression. A later episode of regional extension, or transtension, may be responsible for the presence of several extensional features observed in the region (Pinheiro, 1997).

The Araguaia Belt forms the eastern boundary of the Carajás Mineral Province and comprises rocks of the Tocantins Group which were deformed by oblique ductile thrusts and NNE-SSE shear zones (Hasui and Costa, 1990).

Several types of mineral deposits can be recognised in the Carajás Mineral Province (iron, copper, gold, manganese, nickel, bauxite), most of which are located in the northern portion of this province and are stratigraphically and tectonically associated with the Archaean meta-volcanosedimentary sequence of the Itacaiúnas Supergroup (Fig. 2).

Local Geology of Igarapé Bahia

The volcano-sedimentary sequence of the Itacaiúnas Supergroup (Docegeo 1988) comprises bimodal volcanic, intermediate to acid pyroclastic, clastic and chemical sediments, including banded iron formation and carbonates of different metamorphic grades which have been stratigraphically divided by Docegeo (1988) into the Salobo, Pojuca, Grão Pará, Igarapé Bahia and Buritirama Groups.

The Alemão Deposit, which does not outcrop, is hosted by the rocks of the Igarapé Bahia Group (2.577 Ga - Rb/Sr method - Ferreira Filho, 1985), a low grade Archaean, meta-volcanosedimentary sequence that outcrops as a small structural window within the surrounding Águas Claras Formation/Rio Fresco Group (Fig. 2).

The host rocks of the Igarapé Bahia deposit are characterised by a lower (or footwall) unit referred to as the volcanic

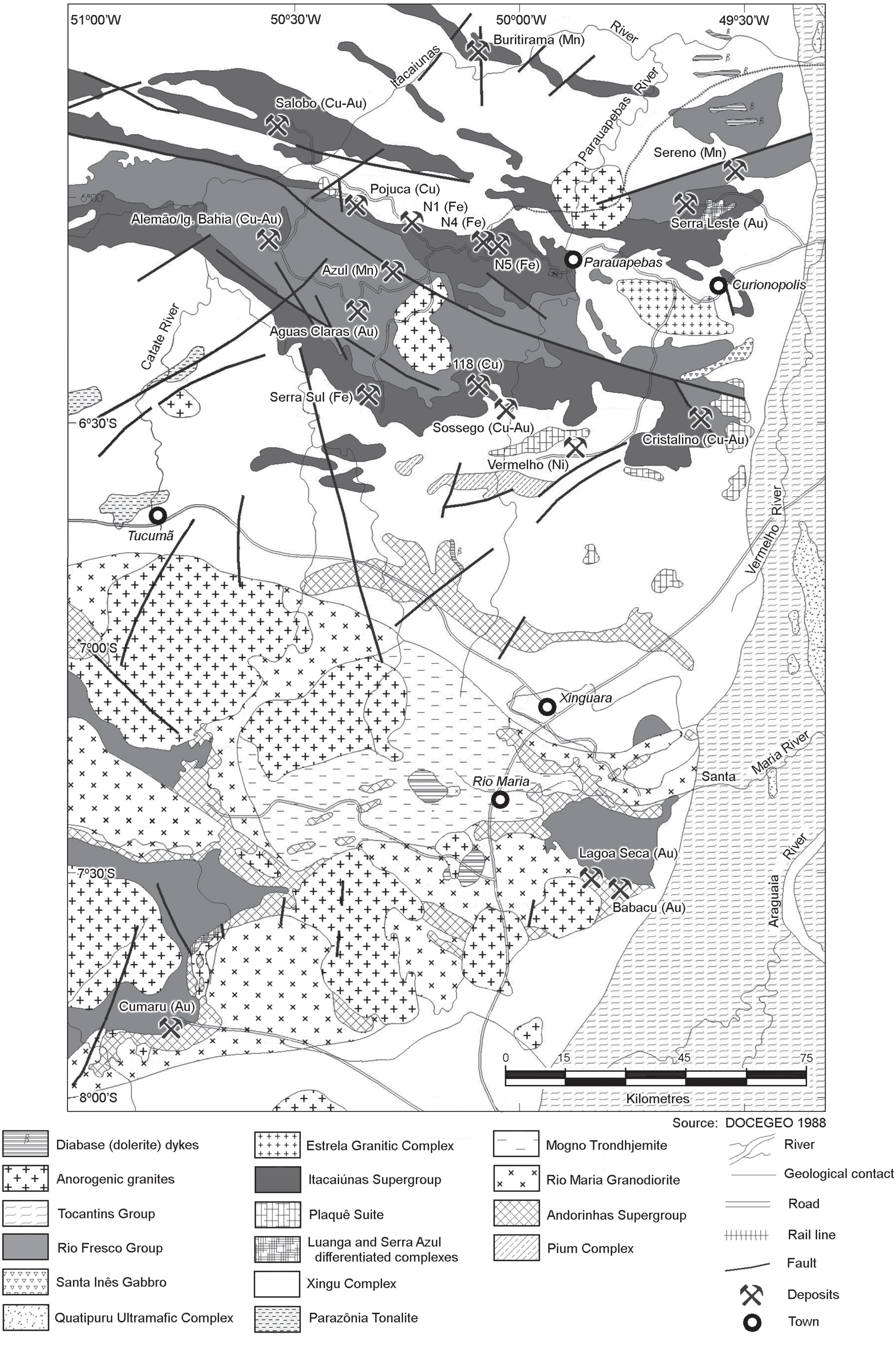


Figure 2: Carajás Mineral Province - simplified geological map.

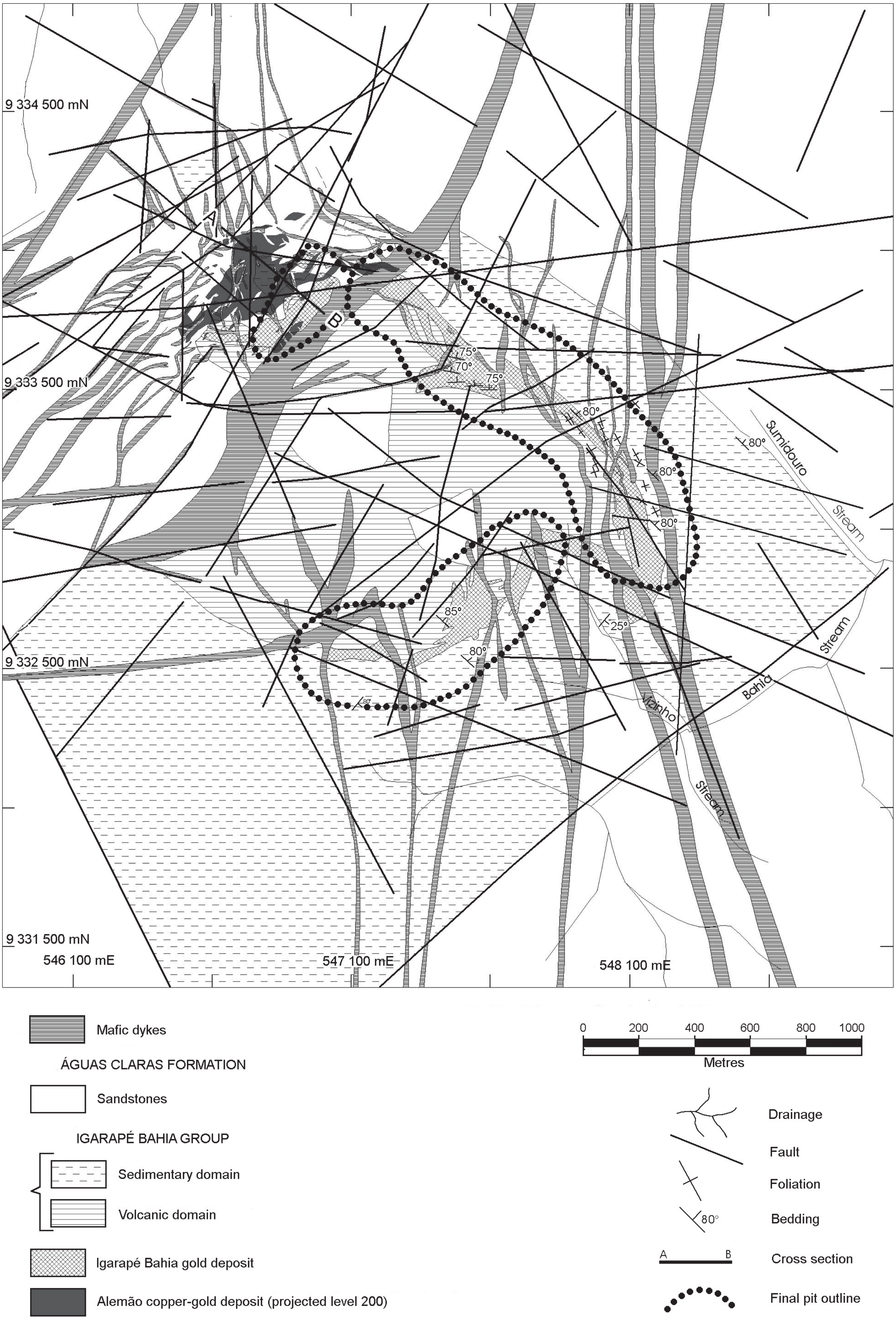


Figure 3: Alemão deposit and Igarape Bahia Mine, geological map.

domain which consists of metavolcanic basic rocks intercalated with minor banded iron formations and pyroclastics and the upper (or hanging wall) unit referred to as the sedimentary domain that is composed predominantly of metasedimentary clastic rocks (meta-rhythmites, meta-siltstones, meta-greywackes) interbedded with intermediate to acid meta-pyroclastics and meta-basalts as well as cherts, and banded and oolitic iron formations (Fig. 3). These rocks host gold and copper mineralisation with impressive supergene enrichment, within a thick oxidised profile that may reach to approximately 150 m in depth. All of these rocks, and the Águas Claras Formation, are cut by gabbroic to dioritic dykes of unknown age (Fig. 3).

The Igarapé Bahia gold mine embraces three orebodies - the Acampamento, Furo Trinta and Acampamento Norte - which are located at the contact between the two units of the volcano-sedimentary host sequence and are usually concordant to bedding. The geometry of these orebodies produce a semicircular trace (Fig. 3) that dips at around 75° to the north east (Acampamento), to the south east (Furo Trinta) and to the north west (Acampamento Norte), forming a domal structure in three dimensions. The projection of the Alemão Deposit to the surface exhibits a north east trend parallel to the Acampamento Norte ore body.

Alemão Deposit Features

Local Geological Setting

The Alemão copper-gold (U-REE) deposit constitutes a classic example of non-outcropping mineralisation, being discovered through an exploration drilling program designed to test a circular magnetic anomaly located adjacent to the Igarapé Bahia gold mine (Fig. 4) and 250 m below the sandstones.

The Alemão ore body is 500 m in length, 50 to 200 m wide and strikes at 45° (Fig. 3). It dips near vertically, at ~80° to the north west, is located along the contact zone between the volcanic and sedimentary domains and is strike concordant with bedding. Its top is situated approximately 250 m below the surface, covered by a discordant layer of sandstones belonging to the Águas Claras Formation (Fig. 5).

The host rocks at Alemão are similar to those of Igarapé Bahia, also being divided into two lithological and stratigraphic domains (Soares *et al.*, 1999): usually, a lower meta-volcanic unit composed dominantly of andesites and basalts with minor volcaniclastics of acid to intermediate composition and banded iron formation; and, an upper metasedimentary unit, characterised by clastic-chemical sediments and some volcaniclastic rocks.

The mineralisation is represented by two classes of hydrothermal breccias: BMS which is composed of massive bands of magnetite and chalcopyrite and by polymitic breccias with fragments of volcanics, tuffs and banded iron formation enclosed within a matrix of magnetite, chalcopyrite, siderite, chlorite, biotite and amphiboles; and, BCLS which is composed of brecciated 'hydrothermalised' volcanic rocks with chalcopyrite, bornite, pyrite, chlorite, siderite, ankerite, tourmaline and molybdenite both within the matrix and disseminated through the rock.

The Alemão Deposit is cut by three fault systems, trending in northeast-southwest, east-west and northwest-southeast directions, all exhibiting predominantly vertical displacements which range from 10 to more than 200 m. The lithological types affected by those faults display an associated brittle to ductile tectonic fabric.

The total estimated ore resource based on krigging is 170 Mt @ 1.5% Cu and 0.8 g/t Au.

Host Rocks and Mineralisation

The host rocks of the mineralisation comprise interbedded volcanic and sedimentary rocks, which, away from the zone of intense hydrothermal alteration may be readily recognised and subdivided in drill core as meta-volcanic, banded iron formation and chert, meta-volcaniclastic, meta-rhythmite, meta-sandstone. Intense alteration has produced lithologies whose original compositions and texture have been totally or almost totally replaced or obliterated. In some cases, it can not be determined whether particular breccia fragments represent primary lithological types or are entirely the product of intense hydrothermal alteration.

The economic mineralisation is characterised by two types of ore: sulphidised magnetite breccia (BMS) and sulphidised chloritic breccia (BCLS).

The individual pre-alteration lithologies are as follows:

Meta-volcanics **-** comprise fine metamorphosed and hydrothermalised andesite to dacite and basalts (green-schist), composed of quartz, chlorite, plagioclase and biotite with the minerals tourmaline and zircon as accessories. It has a weak to moderate foliation and sometimes exhibits relicts of primary features such as amygdules filled with

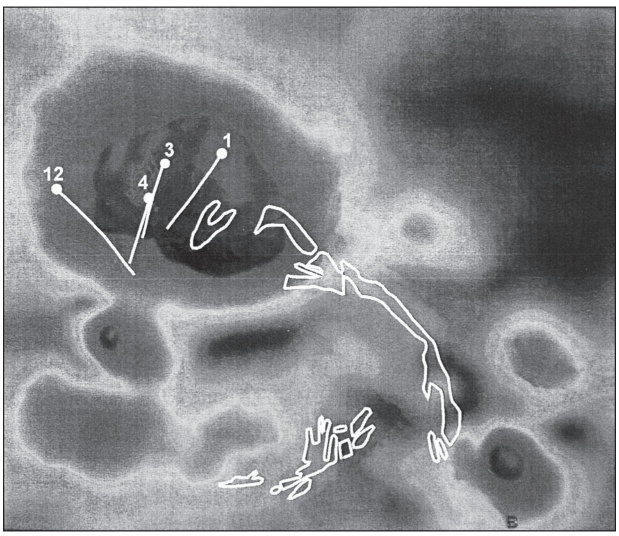


Figure 4: Magnetic anomaly reflecting the Alemão deposit, overlain by the traces of mineralised exploration drillholes and the outlines of the Igarapé Bahia Acampamento and Fruro 30 orebodies.

quartz (Fig. 6), chlorite, biotite and rare albite as well as porphyritic texture. The meta-volcanics are massive although they are commonly brecciated near the zone of intense alteration with clasts set in a chloritic matrix.

Banded iron formation and chert **-** are laminated and composed of oxide facies - magnetite and quartz (Fig. 6) and when associated with the alteration zone are brecciated with laminated fragments of magnetite, amphibole and minor quartz (silicate facies or the product of hydrothermal activity), chalcopyrite, chlorite, carbonate and fluorite. In general, the iron formation is primarily related to meta-rhythmites and subordinately to meta-volcanic/volcaniclastic rocks. The thicknesses of the thin layers range from a few centimetres to less than five metres.

Meta-volcaniclastic rocks **–** are composed of fragments of quartz-chloritic rock and quartz grains, enclosed in a fine matrix of similar composition. Angular fragments range from a few millimetres to 15 centimetres in diameter and are oriented. The matrix is fine-grained and sometimes foliated and includes quartz, chlorite and minor zircon, biotite and sericite. Some fragments exhibit relict texture of the original volcanic rocks. These rocks are massive or exhibit gradational bedding and are classified as laminated tuff, crystal tuff and lapilli tuff (Fig. 6). The origin and classification of these rocks is a matter of debate in the field, with opinions ranging from volcaniclastic or essentially sedimentary rocks.

Meta-rhythmites **-** are laminated epiclastic rocks which are common to the north west of Alemão and are characterised by interbedded, fine and coarser grained siltstones, composed of sericite, chlorite, quartz and feldspar. The rhythmites exhibit stratabound replacement textures with the development of thin chalcopyrite beds only a few millimetres thick, centimetric nodules parallel to primary bedding and as disseminations, usually connected by veins that intercept the lamination (Fig. 6). Tourmaline, zircon and rutile are accessories minerals.

Meta-sandstone **-** is composed essentially of fine to coarse recrystallised quartz grains and chert fragments enclosed in a matrix of chlorite, sericite and biotite. It occurs locally and is intercalated with volcaniclastic rocks and rhythmites, with a few thin beds of meta-conglomerate and meta-greywacke.

BMS or Magnetite-Sulphide-Breccia ore **–** has the richest copper grade and represents around 30 to 40% of the total economic ore. It is composed of massive bands of magnetite and chalcopyrite, sometimes massive sulphide and by polymictic breccias with elongated fragments of volcanics, tuffs and banded iron formation enclosed within a matrix dominated by magnetite, chalcopyrite, siderite, chlorite, biotite and amphiboles with subordinate fluorite, quartz, ankerite, uraninite, REE-carbonates, tourmaline, molybdenite, Fe-pyrosmalite, gold, silver, apatite and monazite. The matrix commonly exhibits a foliation due to the phyllosilicates and chalcopyrite orientations (Fig. 6).

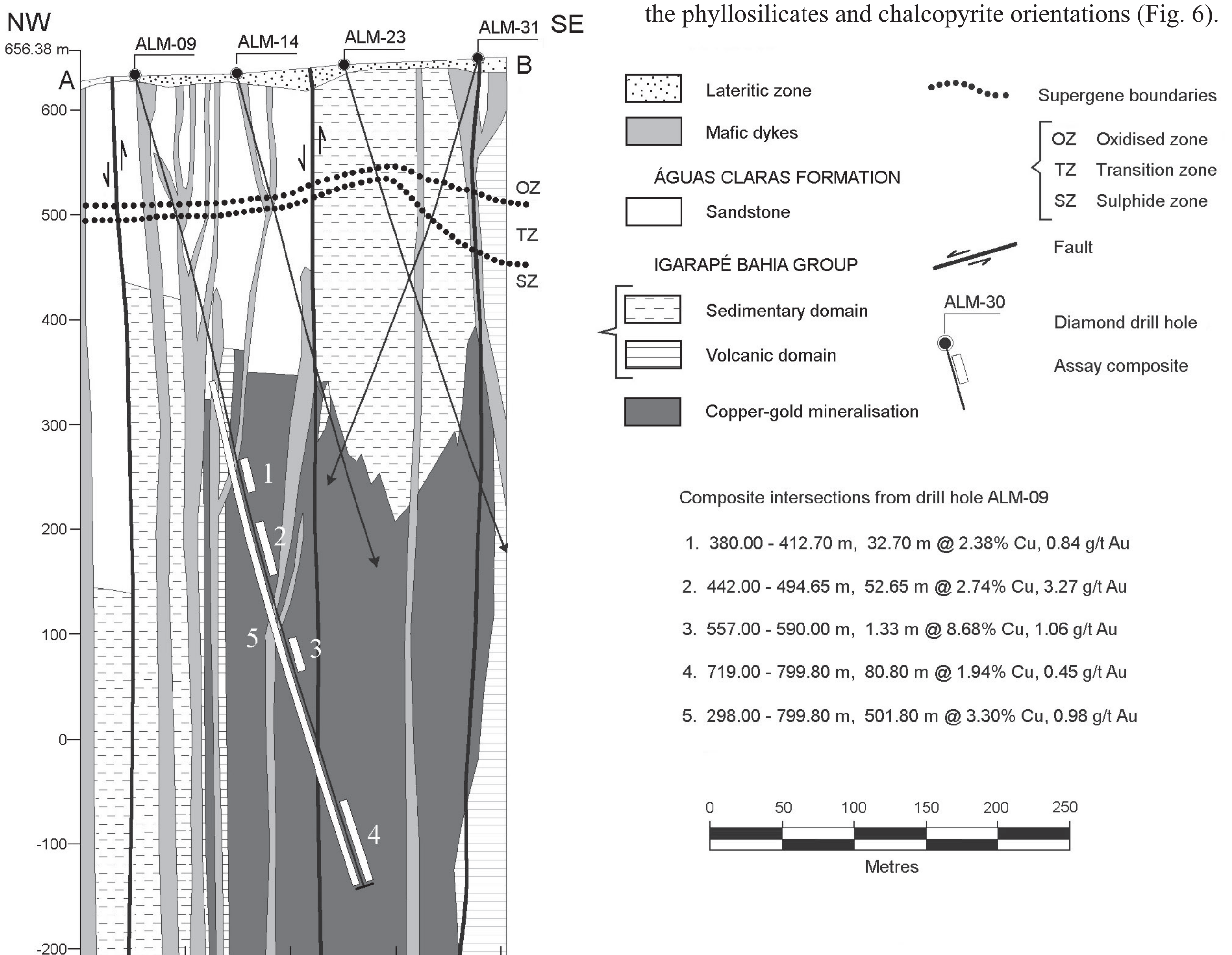


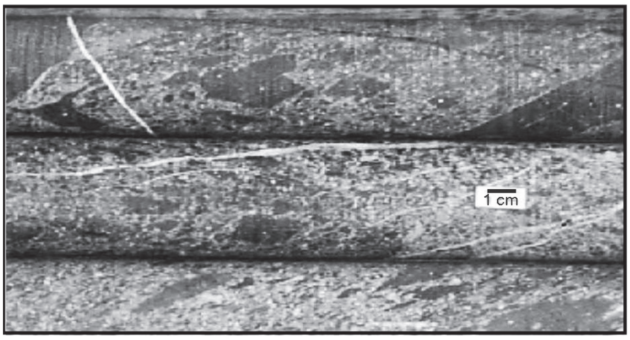
Figure 5: Alemão deposit - cross section A-B - LT 100 NE.

This ore type is commonly crosscut by an irregular array of veins and veinlets of carbonate, fluorite, quartz and minor chlorite, with variable orientations and thickness, most of which have remobilised and re-concentrated gold and Cu-sulphides (Fig. 6f). The BMS ore type averages 1.97% Cu and 1.09 g/t Au.

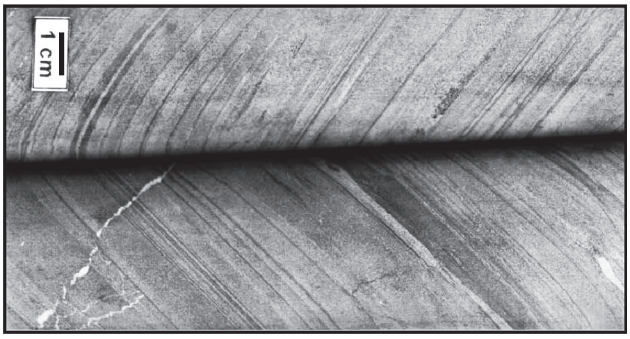
BCLS or Chlorite-Sulphide-Breccia ore – is broadly distributed, representing approximately 60 to 70% of the total economic ore. It is composed of brecciated, "hydrothermalised", volcanic rocks with chalcopyrite, bornite, pyrite, chlorite, siderite, ankerite, tourmaline and molybdenite, and minor monazite, apatite, fluorite, hessite, uraninite, gold and silver in the matrix as well as disseminated in the rock. Sub-angular to angular chloritic volcanic rock fragments are oriented parallel to the foliation. Late carbonate, quartz and chlorite veins also occur in this type of ore, remobilising

Amygdaloidal meta-andesite with quartz, from drill hole ALM-FD09.

Laminated iron formation (oxide facies), from drill hole ALM-FD-09.

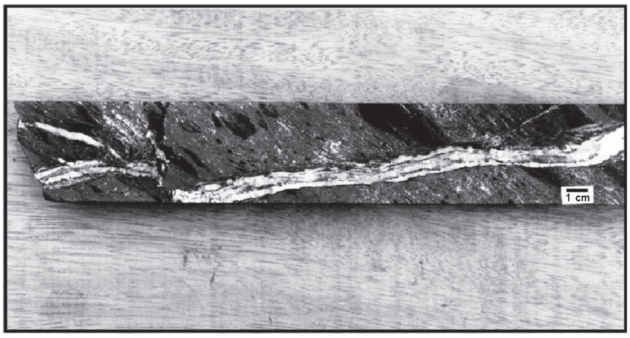


Meta-lapilli tuff with fragments of quartz-rich meta-andesite, from drill hole ALM-FD34.

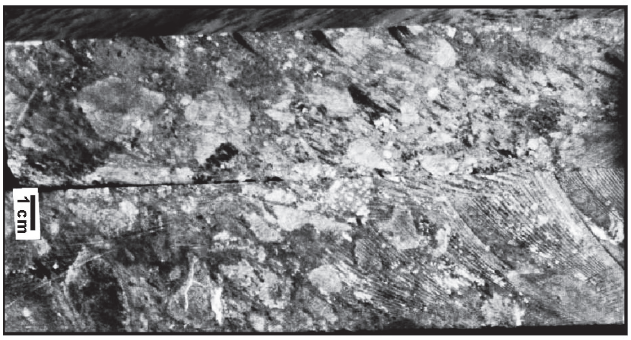


Meta-rythmite with chalcopyrite, from drill hole BAHMAG-FD02.

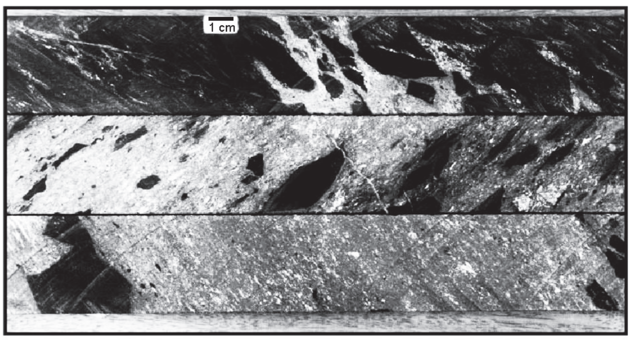
Sulphide-bearing magnetite breccia fragments in an amphibole-chalcopyrite-rich matrix, from drill hole ALM-FD09.



Calcite and chlorite vein cutting sulphide-bearing magnetite breccia, from drill hole ALM-FD09.



Meta-volcanic fragments in a chlorite-bornite-chalcopyrite matrix (sulphide-chlorite breccia), from drill hole BAHMAG-FD01.



Sulphide-bearing magnetite breccia fragments in an amphibole-chalcopyrite-rich matrix, from drill hole ALM-FD09.

Figure 6: Country and mineralised rocks (ore-types) of the Alemão deposit.

Cu-sulphide and gold. The BCLS ore type averages 1.33% Cu and 0.75 g/t Au.

Águas Claras meta-sandstones – are composed dominantly of quartz-arenites with minor sericite and chlorite. They exhibit low grade metamorphism, recrystallisation (silicification) and late carbonate, quartz and chlorite veins sometimes with associated chalcopyrite. The Águas Claras Formation dips at 25 to 40^{o} north east and unconformably overlies the vertical dipping rocks of the Igarapé Bahia Group.

Intrusive rocks – a swarm of gabbroic and dioritic composition dykes of different ages disrupt the ore body, the meta-volcanosedimentary rocks, and the Águas Claras sandstones. The dykes have been affected by hydrothermal alteration of varied intensity and are usually crosscut by quartz and carbonate veins with minor chalcopyrite. They are magnetic and were clearly intruded at a late stage of the mineralising event.

Hydrothermal Alteration

The hydrothermal alteration of each of the lithologies has been studied through detailed petrological investigations, petrography, XRD, SEM and EMPA (Fig. 7), geochemistry and also by geophysical determinations on drill hole core specifically magnetic susceptibility (MS), and gamma-spectrometry in the U, K and Th channels (Fig. 8).

The U, K, Th and MS data have allowed the identification of mineralised and unmineralised zones. The mineralised zones are reflected by higher values, with the exception of MS in the chlorite-sulphide-breccia. This analysis also allows the characterisation of the different types of ore and enclosing rocks.

Detailed petrological studies of drill core from the ore zone and host rocks of the Alemão Deposit have led to the recognition of the six most significant types of alteration: (1) iron-rich metasomatism; (2) chloritisation; (3) biotite alteration; (4) sulphidation; (5) carbonate and (6) silica. These types will be described below. Other less important types are related to sericitisation and albitisation although both are rare. Important hydrothermal minerals are gold, silver, fluorite, apatite, amphiboles, tourmaline, uraninite, REE carbonates, cassiterite and Fe pyrosmalite.

Iron-rich metasomatism is marked by strong magnetite development. This mineral occurs either as a massive replacement or as part of the hydrothermal matrix in metavolcanics, in volcaniclastic fragments or in banded iron formation. Magnetite is developed earlier than the sulphidation as can be inferred by chalcopyrite enclosing, replacing and infilling fractures within the magnetite. The strong iron enrichment by metasomatism is also characterised by the presence of iron-rich chlorite and amphibole (grunerite and cummingtonite), siderite, greenalite, iron pyrosmalite.

Chloritisation is widespread in both mineralised and unmineralised rocks being one of the most expressive hydrothermal alteration products in the Alemão deposit. It can be found in the earlier and later events of the hydrothermal history of the deposit. Mineral chemistry data (Fe/Mg ratio) shows that the chlorites of the mineralised zone are rich in iron while those of the wall rocks are rich in magnesium.

Sulphidation is responsible for developing massive sulphide, dominated by chalcopyrite with subordinate bornite and lesser molybdenite, pyrite and pyrrhotite. Galena, digenite and covellite are also observed. Chalcopyrite is the most frequent sulphide, permeating the magnetite, sometimes

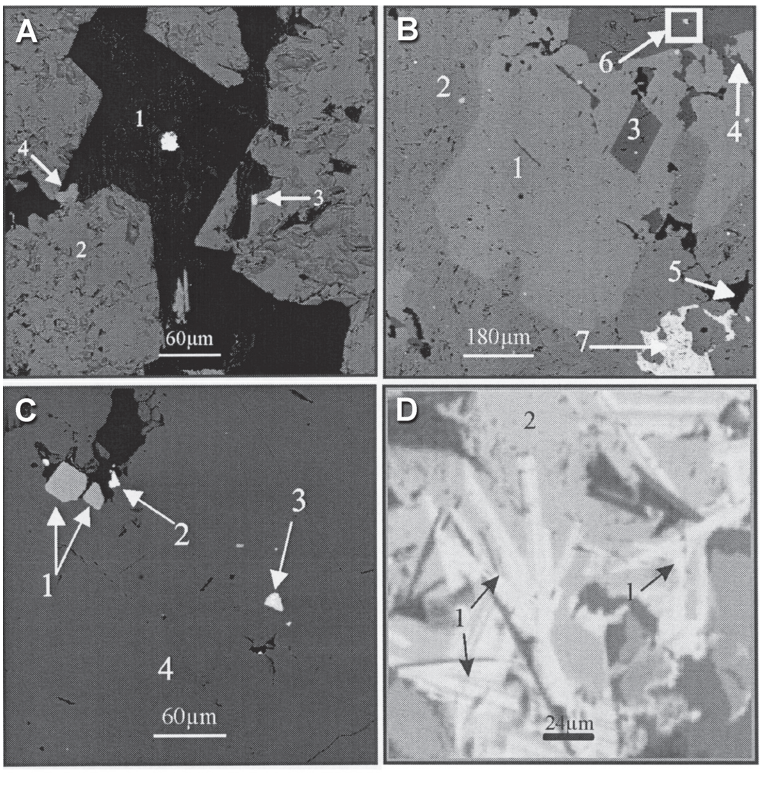


Figure 7: BSE images of sulphidised chloritic breccia and sulphidised magnetite breccia of the Alemão deposit.

A. BSE image showing a uraninite crystal inclusion in greenalite (1), surrounded by magnetite (2), and inclusions of monazite (3) in chalcopyrite (4); from drill hole ALM-FD09.

B. BSE image showing a ferropyrosmalite crystal (1) surrounded by siderite (2), with ankerite inclusions (3), cut by discontinuous calcite micro-veinlets (4), quartz (5), monazite (6) and chalcopyrite (7); from drill hole ALM-FD09.

C. BSE image showing cassiterite (1), Pb-telluride (2), Ag-telluride (3), euhedral crystals as inclusions in chalcopyrite. The Ag-telluride crystals show Ag-Nb telluride inclusions (4); from drill hole ALM-FD09.

D. BSE image showing fibrous bastnaesite (1) crystal intergrowth with chalcopyrite; from drillhole BHMAG-FD01.

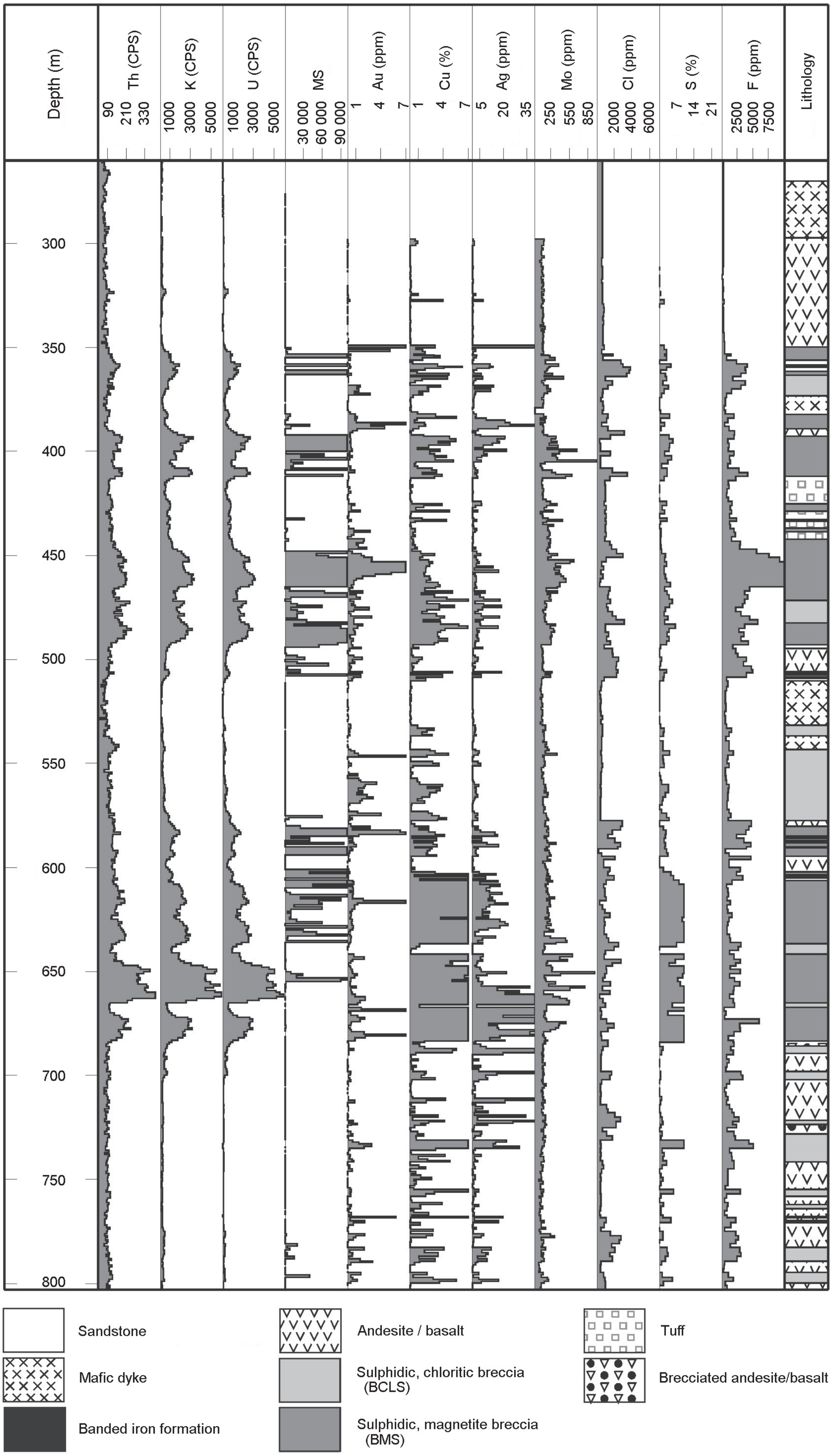


Figure 8: Simplified lithological log with geophysical and geochemical data for diamond drill hole ALM-FD09.

as small, oriented lamellae or as irregular masses. The chalcopyrite rims metavolcanic and banded iron formation fragments and occurs disseminated in the hydrothermal matrix. Molybdenite, gold, silver, pyrite, magnetite, uraninite, sperrylite ($PtAs_2$), discrasite (Ag_3Sb), antimonite are detected as micro-inclusions in the chalcopyrite. SEM also showed cassiterite, Pb, Ni, Ag and Au, Ag tellurides (hessite), galena, Ni, Fe and Cu S-tellurides, indicating later crystallisation of the chalcopyrite. Bornite often occurs in association with chalcopyrite, mainly in the chlorite-sulphide-breccia and to a lesser extent in the magnetite-sulphide-breccia. Pyrite is rare. Sulphidation exhibits transgressive phases indicating multiple stages of sulphide precipitation. The textural relationships between the individual sulphides allows the establishment of a simplified paragenetic sequence of the different types associated with the mineralisation as follows: molybdenite, cobaltite, pyrite and arsenopyrite; then chalcopyrite; and finally, bornite.

Carbonatisation of the mineralised zone was studied through the chemistry of the hydrothermal matrix components which has established the following paragenesis: (I) siderite (main), (II) ankerite and Fe-dolomite and (III) calcite. Late carbonatisation phases are represented by veins and veinlets of calcite cutting all rock types, with associated quartz, chlorite and tourmaline associated, and locally with free native gold.

Silicification is represented by veins and veinlets of quartz cutting all rock types and by fine crystals of quartz in the hydrothermal matrix, or replacing feldspar in the volcanic rocks. Quartz is commonly associated with carbonate, chlorite and sulphide. Free native gold also occurs locally.

As mentioned previously, other minerals are also closely related to the hydrothermal processes. Fluorite occurs as purple crystals associated with later calcite veins that cross-cut the ore types. It is also present as fine grains included in the hydrothermal matrix, permeating amphiboles, magnetite, siderite and biotite zones. It also rims sulphide crystals. Millimetric crystals of black tourmaline occur within the hydrothermal matrix of both ore types as bunches in the metavolcanic rocks or in late quartz-carbonate veins. Apatite has fluorine included in its crystal structure, and occurs as fine disseminated crystals in biotite, chlorite or in magnetite bands. Monazite and uraninite occur as inclusions within chlorite, biotite and amphibole in hydrothermal breccias.

Geochemistry

The whole rock analysis of major, trace and REE elements showed a relative enrichment in Mo, Cu, Au, Ag, Fe, P, H_2O, S, CO_2, Ca, F, P, Mo, Pb, U, Ba, Zn, Ni, Co, Mn, W, Sn, V and the lighter REE elements especially La and Ce (Fig. 9).

Monazite is the main REE fractional phase in the hydrothermal assemblage, followed by the bastnaesite and parisite (REE carbonates).

Statistical analysis based on analytical results from the drill hole ALM-FD009 was carried out to verify the geochemical relationships between the elements that comprise the mineralised zone. The data show that for the BMS ore type, there are good correlation coefficients for U-Mo and Cu-Ag but practically there is no correlation between Cu-Au. For the BCLS ore type there are excellent correlation coefficients for Cu-U, Cu-Ag and U-Mo, although for Cu-Au, the correlation coefficient is relatively better than for the BMS ore type but is still weak. Fluorine does not show good correlation to U or Mo for either type of ore.

Discussions and Conclusions

Recent work in the Carajás District suggests that the copper-gold occurrences there, constitute a distinct class of ore deposit characterised by an Fe-Cu-Au-REE signature (Hunh and Nascimento, 1996 and 1997; Barreira *et al.*, 1999; Soares *et al.*, 1999; Tazava 1999).

The main geological characteristics of Alemão Deposit can be summarised as follows:

1 Host rocks comprise a meta-volcanosedimentary sequence including volcanics, BIFs, pyroclastics, rhythmites and other lithologies.

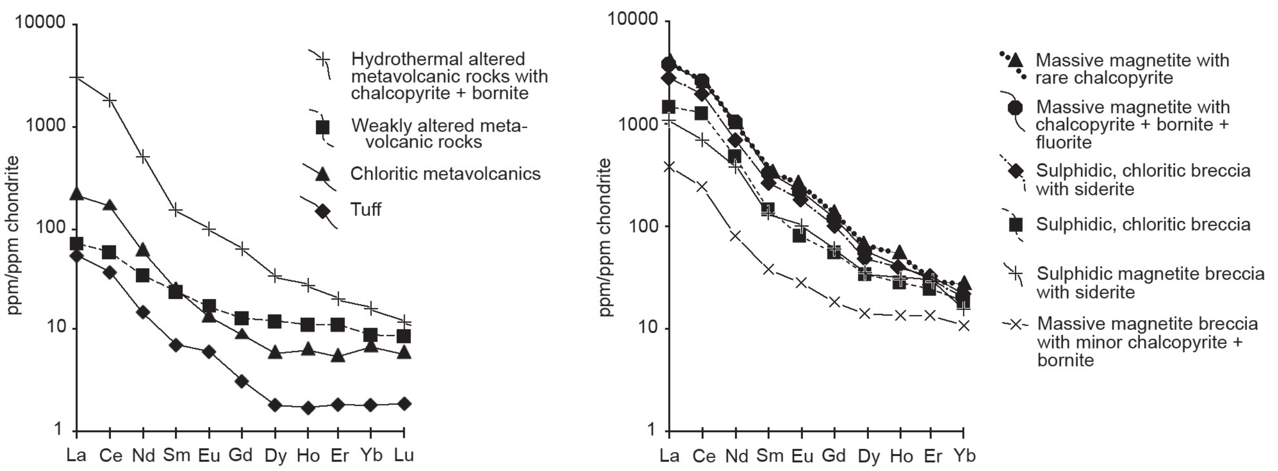


Figure 9: Chondrite normalised REE pattern for mineralised breccias, metavolcanics and tuffs of the Alemão deposit (Rare-Earth elements abundances in chondritic meteorite data from Evensen *et al.*, 1978).

2 The ore body is composed mainly of sulphide minerals particularly chalcopyrite and bornite with minor pyrite, and is conformably emplaced at the interface between volcanic rocks and the overlying sedimentary domain.

3 The style of mineralisation is characterised by breccia-types which dominate and by lesser massive zones.

4 The geometry of the ore body is tabular lensing out at depth where the continuity of the mineralisation could not be confirmed below the –500 m level.

5 The structural setting of the orebody is controlled by a north east trend and steep dip, and a brittle deformation regime that has strongly influenced fluid flow.

6 Hydrothermal alteration is dominated by sulphidation (chalcopyrite greater than bornite); iron-rich metasomatism (magnetite); potassic alteration (biotite and minor sericite); chloritisation and carbonatisation with subordinate tourmaline and silicification.

7 The geochemical signature is characterised by enrichment in Fe, Cu, Au, F, U, Mo, Ag, Ce, La, S, P, Ba, Sn, V, Zn, Ni and CO_2.

The hydrothermal process responsible for the mineralisation has resulted in the high REE concentration observed. The REE enrichment can be explained by the presence of hydrothermal fluids rich in CO_2, F and Cl, allowing the remobilisation of these elements. Oreskes and Einaudi (1990), have proposed the same hypothesis to explain the extreme REE fractionation in the Olympic Dam Cu-U-Au-Ag deposit.

The copper deposits of the Carajás district are geochemically related to magmatic hydrothermal systems, characterised by a Fe-Cu-Au-U-REE signature and by the low content of Ti (Hitzman *et al.,* 1992). The development of these deposits may be related to one of the main late extensional tectonic events previously recognised as being a part of the Carajás regional evolution (e.g., Pinheiro, 1997). This model appears close to that proposed for the Olympic Dam deposit in Australia with its classic Fe-Cu-Au-U-REE geochemical association in iron rich heterolithic hydrothermal breccias, as mentioned previously.

References

Araújo, O.J.B., Maia, R.G.N., Jorge-João, X.S. and Costa, J.B.S., 1988 - A megaestruturação arqueana da folha Serra dos Carajás; *in* Congresso Latino-Americano Geologia, 7, Belém, *Sociedade Brasileira de Geologia/DNPM*, Anais, pp. 324-333.

Barreira, C.F., Soares, A.D.V. and Ronzê, P.C., 1999 - Descoberta do depósito Cu-Au Alemão - Província Mineral de Carajás (PA); *in* Simpósio de Geologia da Amazônia, 6, Manaus, *Sociedade Brasileira de Geologia-Núcleo Norte*, Resumos Expandidos, pp. 136-139.

Barros, C. E. M. and Barbey, P., 2000 - Significance of garnet-bearing metamorphic rocks in the Archean Supracrustal Series of the Carajás Mining Province, Nothern Brazil; *in* International Geological Congress 31, Rio de Janeiro, *Revista Brasileira de Geociências*, v. 30 (3), pp. 367-370.

Barros, C.E. de M., Dall'Agnol, R., Barbey, P. and Boullier, A-M., 1997 - Geochemistry of the Estrela Granite Complex, Carajás region, Brazil: an example of an Archaean A-type granitoid; *Journal of South American Earth Sciences*, v. 10, pp. 321-330.

Costa, J.B.S., Araújo, O.J.B., Santos, A., Jorge João, X.S., Macambira,M.J.B. and Lafon, J.M., 1995 - A Província Mineral de Carajás: Aspectos Tectono-Estruturais, Estratigráficos e Geocronológicos; *Boletim Museu Paraense Emílio Goeldi*, v. 7, pp. 199-235.

Docegeo, 1988 - Revisão litoestratigráfica da Província Mineral de Carajás; *in* Congresso Brasileiro de Geologia, 35, Belém, *Sociedade Brasileira de Geologia*, Anexo aos Anais, pp. 11-56.

Evensen, N.M., Hamilton, P.J. and O´Nions, R.K., 1978 - Rare-Earth abundances in chondritic meteorites; *Geochimica et Cosmochimica Acta*, v. 42, pp. 1199-1212.

Ferreira, Filho, C.F., 1985 - Geologia e mineralizações sulfetadas do Prospecto Bahia, Província Mineral de Carajás, PA; Unpublished Dissertação de Mestrado, *Instituto de Geociências, Universidade de Brasília, Brasília*, 112p.

Gandhi, S.S. and Bell, R.T., 1996 - Kiruna/Olympic Dam-type iron, copper, uranium, gold, silver; *in* Geology of Canadian Mineral Deposit Types, Eckstrand, O.R., Sinclair, W.D., Thorpe, R.I. (eds.), *Geological Survey of Canada*, v. 8, pp. 513-522.

Hasui, Y. and Costa, J.B.S., 1990 - O Cinturão Araguaia: um novo enfoque estrutural-estratigráfico; Congresso Brasileiro de Geologia 36, Natal, *Sociedade Brasileira de Geologia*, Anais, v. 6, pp. 2535-2549.

Hitzman, M.W., Oreskes, N. and Einaudi, M.T., 1992 - Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits; *Precambrian Research*, v. 58, pp. 241-287.

Huhn, S.R.B., 1996 - São os depósitos cupríferos de carajás do tipo Cu-Au-U-(ETR)?; *in* Simpósio de Geologia da Amazônia 5, Belém, *Sociedade Brasileira de Geologia-Núcleo Norte*, Boletim, pp. 140-143.

Huhn, S.R.B. and Nascimento, J.A.S., 1997 - São os depósitos cupríferos de Carajás do tipo Cu-Au-U-ETR?; *in* Costa, M.L., Angélica, R.S. (eds.), Contribuições a Geologia da Amazônia, Belém, *FINEP/Sociedade Brasileira de Geologia-Núcleo Norte*, pp. 143-160.

Hunh, S.R.B., Santos, A.B.S., Amaral, A.F., Ledsham, E.J., Gouveia, J.L., Martins, L.P.B; Montavão, R.M.G. and Costa, V.C., 1988 - O terreno granito greenstone da região de Rio Maria - Sul do Pará; *in* Congresso Brasileiro de Geologia, 35, Belém, *Sociedade Brasileira de Geologia*, Anais, v.3, pp.1438-1452.

Huhn, S.R.B., Souza, C.I.de J., Albuquerque, M.C. de, Leal, E.D. and Brustolin, V., 1999 - Descoberta do depósito Cu(Au) Cristalino: gelogia e mineralização associada - Região da Serra do Rabo - Carajás - PA; *in* Simpósio de Geologia da Amazônia, 6, Manaus, *Sociedade Brasileira de Geologia-Núcleo Norte*, Boletim, pp. 140-143.

Machado, N., Lindenmayer, Z.G., Krogh, T.E. and Lindenmayer, D.H., 1991 - U-Pb geochronology of Archean magmatism and basement reactivation in the Carajás area, Amazon Shield, Brazil; *Precambrian Research*, v. 49, pp. 329-354.

Oreskes, N. and Einaudi, M.T., 1990 - Origin of rare earth element-enriched hematite breccias at the Olympic Dam Cu-U-Au-Ag deposit, Roxby Downs, South Australia; *Economic Geology*, v. 85, pp. 1-28.

Pinheiro, R.V.L., 1997 - Reactivation History of the Carajás and Cinzento Strike-Slip Systems, Amazon, Brazil; Unpublished PhD thesis, *University of Durham, England*, 408p.

Rodrigues, E.S., Lafon, J.M. and Scheller, T., 1992 - Geocronologia Pb-Pb da Província Mineral de Carajás: Primeiros resultados; *in* Congresso Brasileiro de Geologia 37, São Paulo, *Sociedade Brasileira de Geologia,* Resumos Expandidos, v. 2, pp. 183-184.

Soares, A.D.V., Ronzê, P.C., Santos, M.G.S. dos, Leal, E.D. and Barreira, C.F., 1999 - Geologia e mineralizações do depósito de Cu-Au Alemão - Província Mineral de Carajás (PA); *in* Simpósio de Geologia da Amazônia, 6, Manaus, *Sociedade Brasileira de Geologia-Núcleo Norte*, Resumos Boletim, pp. 144-147.

Tassinari, C.C.G. and Macambira, M.J.B., 1999 - Geochronological provinces of the Amazonian Craton; *Episodes*, v. 22, pp.174-182.

Tazava, E., 1999 - Mineralização de Au-Cu-(±ETR-U) associada às brechas hidrotermais do depósito de Igarapé Bahia, Província Mineral de Carajás, PA; Unpublished Dissertação de Mestrado, *Departamento de Geologia, Universidade Federal de Ouro Preto, Ouro Preto*, 81p.

Teixeira, J.B.G., - 1994 - Geochemistry, Petrology, and Tectonic Setting of the Archean basaltic and Dioritic rocks from the N4 Iron deposit, Serra dos Carajás, Pará, Brazil; Unpublished PhD thesis, Department of Geosciences, *Pennsylvania State University, Boston*, 176p.