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# SALOBO 3 ALPHA DEPOSIT: GEOLOGY AND MINERALISATION

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**Abstract –** The Salobo 3 Alpha Deposit is located in the southeast of the Amazon Craton, north of the Serra dos Carajás, in the State of Pará, Brazil. The deposit is contained in supracrustal rocks of the Archaean age Igarapé Salobo Group, represented by iron-rich schists, meta-greywackes, amphibolites and quartzites. This sequence overlies the basement gneisses of the Xingú Complex, composed of partially migmatised gneisses. The original stratigraphic relationships are masked by intense ductile-brittle shear zones responsible for the generation of allochthonous rocks. The deposit extends over an area of approximately 4000 m along a northwest-trending strike, is 100 to 600 m wide and has been recognised to depths of 750 m below the surface. The estimated mineral resources are of the order of 789 Mt with 0.96% Cu and 0.52 g/t Au. Copper mineralisation occurs as chalcocite and bornite, with subordinate quantities of chalcopyrite, together with variable proportions of molybdenite, cobaltite, covellite, gold and silver, hosted in schists with variable proportions of magnetite, amphibole, olivine, garnet, biotite, quartz and plagioclase. Brittle-ductile shear zone deformation has resulted in lenticular shaped ore shoots that characteristically show close associations between copper mineralisation and magnetite contents. The host rocks were progressively metamorphosed to pyroxene hornfels facies, at equilibrium temperatures of 750ºC, resulting from sinistral transcurrent transpressional shearing accompanied by oblique thrusting. A first hydrothermal event developed at temperatures of between 650 and 550°C causing partial substitution of chalcopyrite by bornite and chalcocite, accompanied by intense potassic metasomatism. This was followed by sinistral transcurrent, transtensive, shear zone formation, causing green schist facies metasomatism, characterised by intense chloritisation and partial substitution of bornite by chalcocite. Several hypotheses have been proposed for the genesis of the deposit. Based on similarities in the ore mineralogy and the hydrothermal alteration pattern, this deposit could be ascribed to the broad class of iron oxide copper-gold deposits.

## Introduction

In 2000, the Salobo Project comprised a joint venture study with equal interests held by Anglo American Plc. and CVRD.

The deposit is located in the Carajás Mineral Province, situated in the southeast of the state of Pará in Brazil. The geology of this province is dominated by granite-greenstone terrains, sedimentary-volcanic sequences and gneisses, together with clastic and chemical sedimentary covers.

During recent decades, various exploration campaigns were undertaken in the Carajás region, by both mining companies and research institutions (Docegeo, Projeto Radam Brasil, Companhia Meridional de Mineração, UFPA, UnB, USP, Unicamp, Unisinos, etc.), enlarging the geological knowledge with the determination of stratigraphic columns and characterisation of the Carajás Mineral Province.

The information contained in this paper has been derived from internal studies carried out by Salobo Metais S.A., from academic post-graduate studies, and existing publications on the deposit.

## Exploration History

Prospecting at Salobo is a classic example of the steps involved in mineral exploration. Beginning with an aerial geophysical survey over a huge potential mineral province, this was followed by geochemistry, ground geophysics, mapping, tunnelling, diamond drilling campaigns and finally, the evaluation of copper and associated mineral resources.

In 1974 CVRD/DOCEGEO initiated an exploration campaign in the Carajás region to follow up targets generated from an initial aerial geophysical survey. In 1977, during a follow-up program of magnetic anomalies existing in the Igarapé Salobo Basin, geochemical anomalies of up to 2700 ppm Cu were detected in stream sediments collected from tributaries of Salobo Creek. This led to the development of successive semi-detailed studies in the area, involving geological, geochemical and geophysical mapping of the prospective area. In 1978 copper sulphide bearing magnetic schists were identified in the area. These studies were followed by diamond drilling campaigns, totalling approximately 93 000 m and the opening of three investigation adits (1400 m). Geological and geostatistical modelling of the deposit, undertaken in Anglo American´s Santiago office in Chile, estimated the mineral resources at 789 Mt averaging 0.96% Cu and 0.52% Au.

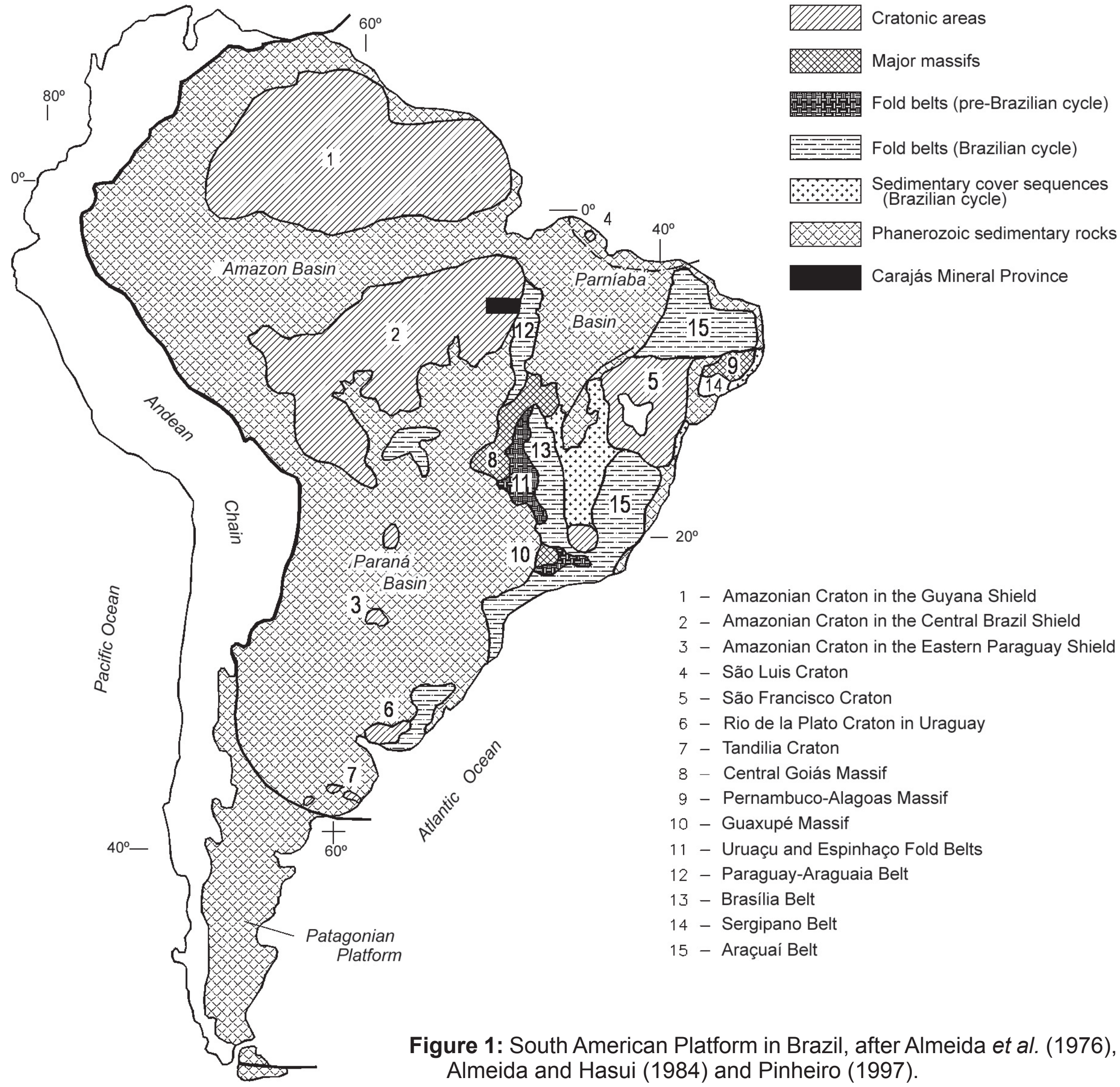


**Figure 1:** South American Platform in Brazil, after Almeida *et al.* (1976), Almeida and Hasui (1984) and Pinheiro (1997).

# Regional Geology

The region of Serra dos Carajás is situated in the southeast portion of the Amazon Craton in the Brazilian Central Shield (Fig. 1). In this region Archean rocks outcrop where basement rocks predominate (Pium Complex, 3.0 Ga - Rodrigues *et al.*, 1992; Xingú Complex - Silva *et al.*, 1974, with 2.86 Ga - Machado et al 1991; Suite Plaquê - Araújo and Maia 1991), forming granite-gneiss terrains. These terrains are covered by volcanics and sedimentary rocks dated at 2.76 to 2.6 Ga belonging to the Itacaiúnas Supergroup (Igarapé Salobo Group, Igarapé Pojuca Group, Grão Pará Group and Igarapé Bahia Group) and the Águas Claras Formations.

These supracrustal rocks are cut by several granitoids dated at 2.53 Ga (Granito Estrela Complex) and 1.9 to 1.8 Ga (Cenral Granite of Carajás), and also by gabbros of various ages (2.6 Ga and possibly younger intrusions) and swarms of Proterozoic and probably Phanerozoic dykes.

According to Pinheiro, 1997, these rocks can be divided in an Archaean *Basement Assemblage* (including the Granite-Gneiss Complex and the Igarapé Salobo Group) and a *Cover Assemblage* (including the Igarapé Pojuca and Grão Pará groups and the Águas Claras Formation).

The *Basement Assemblage* is deformed in a broad braided zone of steeply-dipping, east-west trending, ductile shearing, known as the Itacaiúnas Shear Zone. The Igarapé Salobo Group is located at the western end of the Cinzento Transcurrent System and shows a lenticular form enclosed by the Xingú Complex; these rocks are inferred to have been originally deposited unconformably upon the Xingú Complex, prior to the deformation and upper amphibolite facies metamorphism associated with the development of the Itacaiúnas Shear Zone. Kinematic indicators suggest a regime of sinistral transpression with partitioning of deformation producing linked systems of ductile strike-slip and thrust dominated shear zones (Araújo *et al.*, 1988, Araújo and Maia, 1990; Costa *et al.*, 1994; in Pinheiro, 1997; Fig. 2).

The *Cover Assemblage* is represented by low to very low grade metamorphosed rocks resting unconformably on the Granite-Gneiss Complex. These rocks constitute the Igarapé Pojuca and Grão Pará groups. The un-metamorphosed Águas Claras Formation overlies both. All of these rocks are preserved in fault bends and offset regions along the Carajás and Cinzento Transcurrent systems and are characterised by low temperature metamorphism and predominantly brittle deformation.

The tectonic environment for the deposition of all these groups is most likely one of extensional continental crust accompanied by ocean basin formation, in agreement with Hutchinson (1979), Wirth (1986) and Lindenmayer (1990), in Pinheiro, 1997.

# Local Geology

The Salobo Deposit is located within the Cinzento Transcurrent System, which contains gneisses of the Xingú Complex and supracrustal rocks of the Igarapé Salobo Group (Siqueira, 1990, 1996). The Deposit is situated within a lens of supracrustal rocks belonging to the Igarapé Salobo Group, bounded by gneisses of the Xingú Complex.

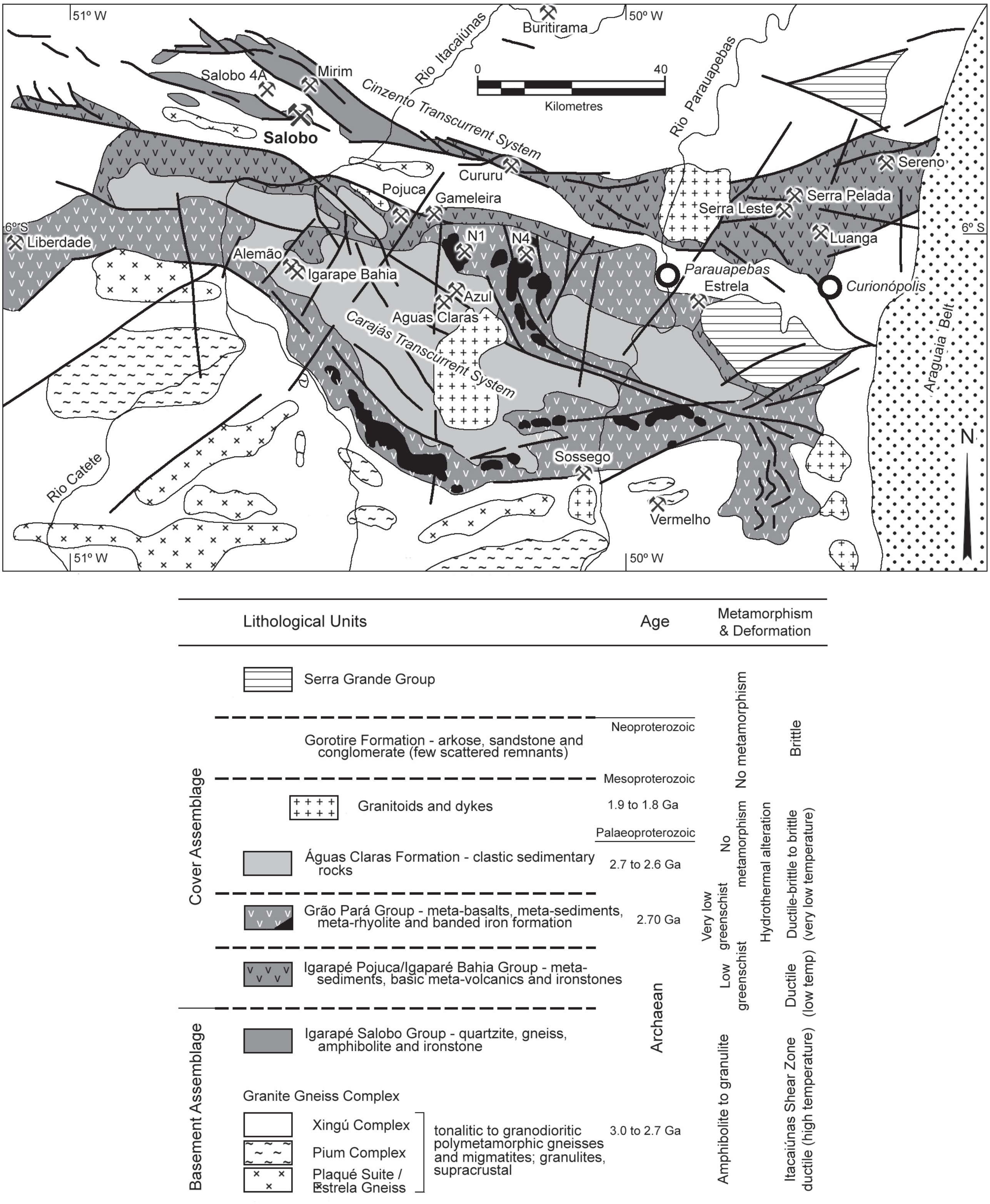


**Figure 2:** Regional geological map of the Carajás Mineral District showing the location of ore deposits and structural setting (upper), and a tectonostratigraphic column for the Itacaiúnas Belt (lower), which also serves as a legend to the map (after Pinheiro, 1997).

The geographic distribution of the rocks is strongly controlled by older ductile thrusts of the Itacaiúnas Shear Zone, which caused generalised imbrication of the lithological units and tectonic layering, defined by lenses of supracrustal rocks alternated with gneisses at several scales. As a result, the determination of the original lithological characteristics and their stratigraphic relationships can be extremely subjective (Siqueira, 1990, 1996; Fig. 3).

## Xingú Complex

The Xingú Complex comprises the basement rocks of the Igarapé Salobo Group. These are characterised by banded gneisses with intercalations of amphibolites and metasedimentary rocks. The main petrographic units of the Xingú Complex are tonalitic and trondhjemitic gneisses (Silva *et al.*, 1974) occurring as irregular bands, sub-vertical and elongated in a 110° direction.

## Igarapé Salobo Group

The Igarapé Salobo Group (DOCEGEO, 1988; Siqueira, 1990; Costa and Siqueira, 1990; Costa *et al.*, 1992) contains metamorphosed volcano-sedimentary rocks encrusted in gneisses of Xingú Complex. Conventional radiometric dating indicates an age of 2761±3 Ma, probably corresponding to amphibolite facies metamorphism (U/Pb, zircon, Machado *et al.*, 1998). Age determinations of 2776±240 Ma in magnetite and 2762±180 Ma in chalcocite were obtained by Mellito *et al.*, 1998, using Pb leaching.

The Igarapé Salobo Group strikes at approximately 110°, with sub vertical dips and widths between 300 to 600 m. So far, the unit has been identified over a strike extension of more than 10 km. It is cut by granitic bodies dated at 2.57 Ga (Machado *et al.*, 1991) and 1.88 Ga (Rb/Sr, Cordani, 1981), and basic dykes dated at 560 Ma (K/Ar, Cordani, 1980).

This group is comprised of lenticular bodies of several petrographic types, including iron-rich units originally formed by chemical precipitation and/or hydrothermal processes, detrital rocks and intercalated amphibolites.

### Amphibolites

These rocks occur as 2 to 5 m thick layers or lenses intercalated at the contact between the Xingú Complex and the iron formations. They comprise medium to fine-grained rocks with hastingsite and plagioclase. The amphibolites have been interpreted as metamorphosed tholeiitic basaltic rocks emplaced in an ocean basin forming environment (Lindenmayer, 1990).

### Iron Formations

On the basis of mineral assemblages and rock compositions Lindenmayer (1990) differentiates two types of iron formations. Type 1 Iron Formation consists of massive or foliated rocks with magnetite (>50%), fayalite ±grunerite, and minor hastingsite, biotite, almandine, greenalite. Accessory minerals include fluorite, graphite, ilmenite, allanite, apatite, copper sulphides, uraninite and molybdenite. Type 2 Iron Formation comprises foliated or schistose rocks, displaying magnetite (10 a 50%), almandine, grunerite (generated from fayalite transformation)

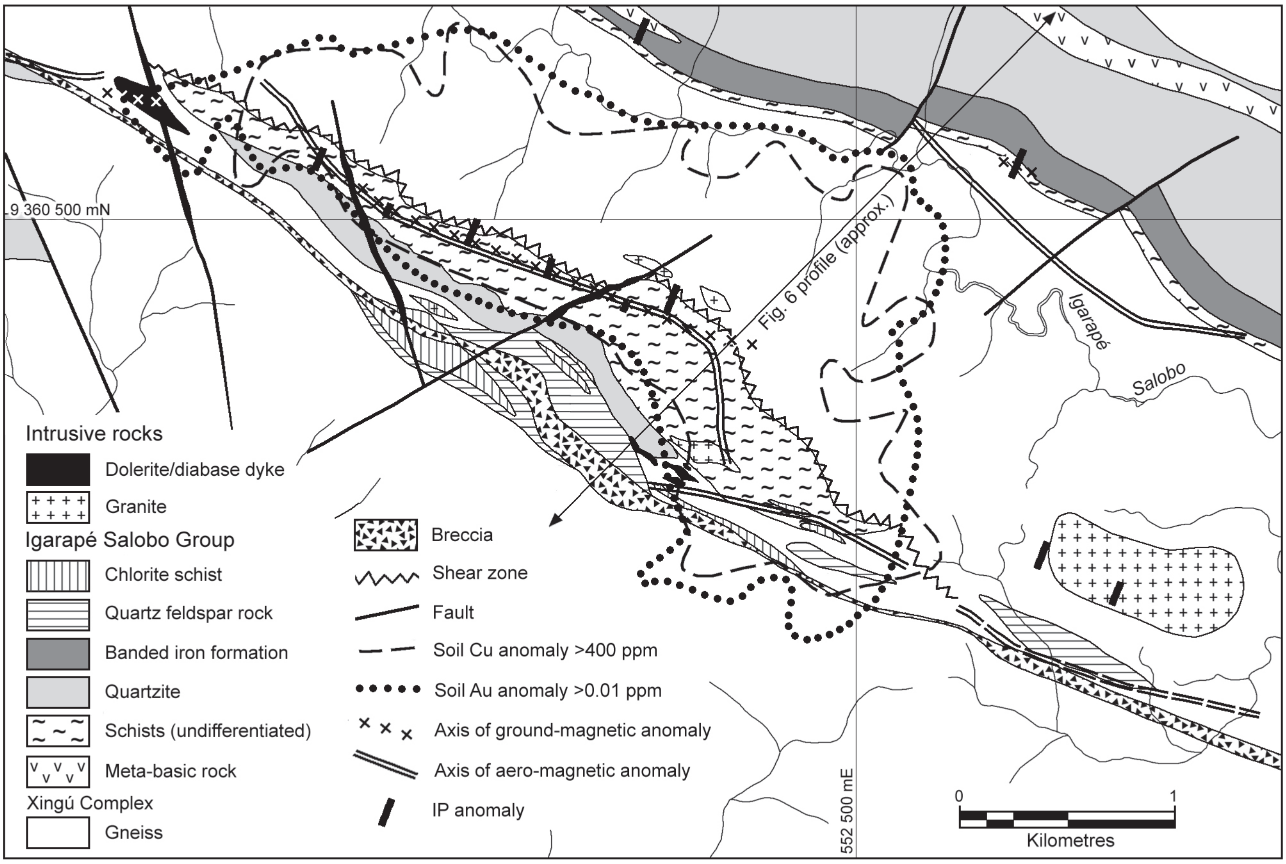


**Figure 3:** Geology map with superimposed geochemical and geophysical expression of the Salobo 3 Alpha deposit.

±fayalite, biotite and minor hastingsite, chlorite, quartz, tourmaline, with accessory fluorite, apatite, allanite, zircon, graphite, copper sulphides, uraninite and molybdenite.

Type 1 rocks are Fe-Si-rich ($FeO_{total}$= 27.2 to 83%; $Al_2O_3$ < 3%). On the other hand, Type 2 are often Al-rich indicating detrital contribution ($FeO_{total}$ = 23 to 79%; $Al_2O_3$ = 3.1 to 14%). Both types occur in lenticular bodies, oriented in the 110° direction, and host the copper sulphide mineralisation. According to Lindenmayer (1990) the highly fractionated REE chondrite-normalised pattern of Type 1 iron formation and strong positive Eu anomaly indicate that these chemical sediments were strongly affected by hydrothermal solutions; the positive correlation between Fe-REE and Fe-Cu could indicate a common hydrothermal origin for Fe, Cu and REE.

The Salobo Project nomenclature for Type 1 iron formations is schist X1, while the Type 2 iron formations are denominated schist X3.

## *Meta-greywackes*

Metagreywackes are the most common rocks of the Igarapé Salobo Group. They form individual layers 10 to 30 m thick intercalated with iron formation. They show strong schistosity, are medium to coarse-grained and are composed principally of biotite, almandine and grunerite, with subordinate muscovite, plagioclase, quartz, chlorite and magnetite. According to Lindenmayer, 1990, the major and trace element, as well as the REE contents of the meta-greywackes suggest that these rocks were derived from a mixed detrital-volcanoclastic source with a possible hydrothermal contribution.

Rocks which show biotite predominating over grunerite are denominated schist X4 . Where grunerite abounds, these rocks are denominated as schist X2.

## *Banded Iron Formations*

Banded Iron Formation occurs locally as narrow segmented lenses with maximum widths reaching 15 m, in proximity to meta-greywackes, grading to the quartzites and gneisses to the southeast; to the northeast widths increase where they can reach more than 100 m. They are fine grained, and contain essentially quartz, hematite and grunerite, alternating in millimetric beds.

## *Quartzites*

Quartzites occur as a layer approximately 200 m thick, normally forming the high portions of the hill. The northern contact with the metagreywakes is sheared. They are medium to fine-grained massive to foliated rocks composed of quartz (average=70%), subordinate muscovite and minor chlorite, sillimanite, biotite, feldspar, magnetite and garnet.

Other rock types that occur close to the Quartzite Unit are: (a) *Quartz-Feldspathic Rocks*, showing a reddish coloration essentially composed of k-feldspar and quartz; (b) *Chlorite Schists*, essentially composed by chlorite and quartz. The Quartz-Feldspathic Rocks are the result of potassic hydrothermal alteration of quartzites and/or gneisses, while the Chlorite Schists represent intense hydrothermal alteration of gneisses; these lithological units normally occur in the vicinity of important brittle shear zones, representing the conduits for the hydrothermal solutions (Fig. 3).

## *Intrusive Rocks*

### *Granitoid Rocks*

Two types of granitoid intrusions were emplaced within the Salobo Deposit area: (a) *Old Salobo Granite*, dated at 2573±2 Ma (Machado *et al.*, 1991), showing mylonitisation and brecciation, medium to coarse-grained, composed of k-feldspar, oligoclase, quartz, augite, hornblende, chlorite and magnetite. Contact metamorphism is not observed in the adjacent host rocks. This intrusion has been classified as syntectonic, peralkaline, sodic and metaluminous; (b) *Young Salobo Granite*, dated at 1880±80 Ma (Rb-Sr, Cordani, 1981), homogeneous, composed of albite, K feldspar and quartz; classified as post-tectonic, potassic and metaluminous (Lindenmayer and Fyfe, 1994).

### *Dolerite/Diabase Dykes*

Two undeformed dolerite (diabase) dykes cut the Salobo Deposit. The first occurs in the central-southeastern part striking at approximately 70°; the second occurs in the northwestern portion of the deposit with a strike of 160°. Both dykes show chilled vitreous margins grading towards the centre into porphyritic and sub-ophitic granular rocks.

**Table 1:** Classification of the Salobo 3A schists

| Lithology | Mineralogy: Main | Mineralogy: Subordinate | Sulphides | Structure | Copper content |
|---|---|---|---|---|---|
| X1 | Mag ≥50% | Gar, Bio, Fay, Gru, Graphite, Fluorite, Qz | bn - cc<br>bn - cp ± cc | Massive in general, occasionally banded | ±2.8% Cu |
| X2 | Gar, Gru | Bio, Qz, Mag ≤10% | ±bn - cc (cp) | Isotropic to partially foliated | ±0.5% Cu |
| X3 | Bio, Gar. Mag (10-50%) | Fay, Qz, Gru, (Plg) | cc - bn<br>bn - cp ±cc | Foliated / banded | ±1.5% Cu |
| X4 | Bio, Gar | Gru, Qz, Fay, Plg, Mag ≤10% | cc - bn ±cp | Foliated / banded | ±0.5% Cu |
| X5 | Qz, Plg, Bio, Af | ±Gar | bn - cc (cp) | Laminated, fine grain size | ±0.3% Cu |

They are composed of plagioclase, augite, magnetite, ilmenite and quartz. One fine textured sample from a dyke margin has been dated at 553±32 Ma; a second medium-grained sample from a dyke centre was dated at 561±16 Ma (K/Ar whole rock, Cordani, 1981).

A third dyke was cut by a drill hole at the western end of the deposit; it is composed of hornblende, plagioclase and quartz. It shows a foliated structure and its strike is estimated to be the same as the second dyke described above (i.e., 160°).

These dykes intruded schear zones with lateral ramp (70°) and frontal ramp (160°) geometries. These structures were formed during a transpressional regime, although later transtensional strain led to dilation and, late dyke emplacement.

### *Classification of the Salobo 3 Alpha Schists*

Based on the variation of the mineralogical constituents of the rocks (quartz, garnet, biotite, fayalite, magnetite and Fe-amphiboles), their textural aspects, as well as chemical assays, Vieira *et al.* (1988) distinguished five principal lithological groups (see Table 1), which host the majority of the sulphide mineralisation.

Schist types X1 and X3 are the two main host rocks of the copper mineralisation. They comprise magnetite-bearing iron formations, with varied proportions of Fe-amphiboles, fayalite, almandine and biotite.

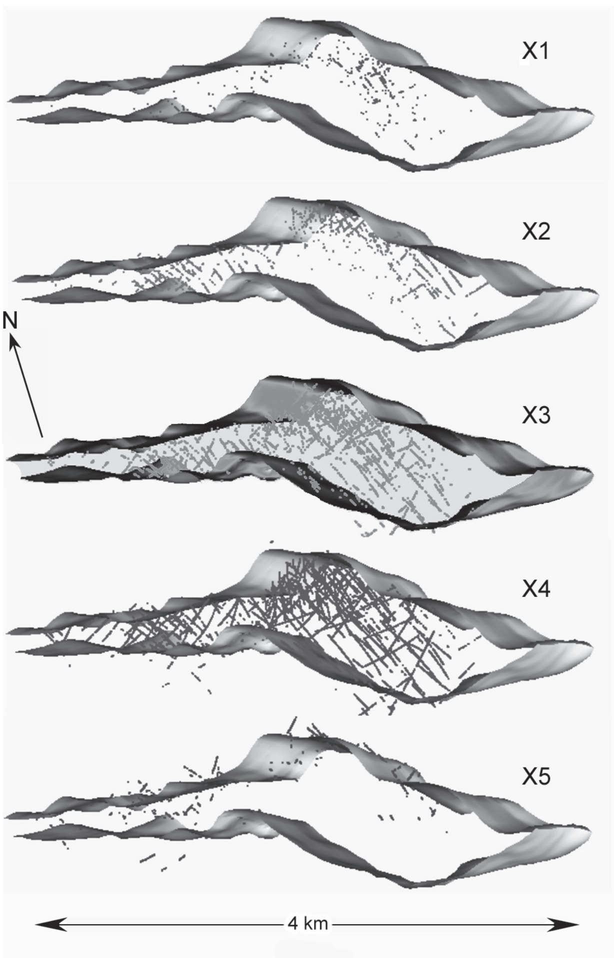


Figure 4: Distribution within drill core of the Salobo 3A schists.

Type X2 and X4 schists contain principally almandine, Fe-amphiboles and biotite with smaller proportions of quartz and magnetite.

Type X5 schists, frequently found at the base of the Igarapé Salobo Group, are characteristically low grade, finely laminated and are composed of quartz, oligoclase, biotite, Fe-amphiboles and subordinate almandine. These rocks were formed by shearing and hydrothermal processes at the contact with Xingú Complex gneisses.

Fig. 4 shows the drill core distribution of these schists in the deposit.

Some important characteristics of this figure are:

- The spatial discontinuity observed, particularly for X1, X2 and X5 is the result of intense tectonic movement, involving imbrication and hydrothermal alteration, resulting in complex small scale lenticular intercalations of the different schist types.
- Despite the physical discontinuity, the occurrence of large scale zone of X1 and X3 can be delineated within the deposit. When viewed at this scale, it is possible to separate units according to the predominance of certain schist types. This was prioritised in the development of the current geological model.
- X5 represents zones that underwent greater ductile strain, as a result of both shearing and hydrothermal activity, particularly within the gneisses.

## Structural Geology, Metamorphism and Hydrothermal Activity

The Salobo Deposit lies at the western termination of the Cinzento Transcurrent System, comprising a kilometre-scale curved structure thought to be fault-bounded (Pinheiro, 1997). The tectonic evolution of the area was complex, including sinistral transpressional ductile shearing with associated thrusts, followed by sinistral, transtensional, brittle shearing.

### *Sinistral Transpressional Ductile Shear Zone*

This event produced a widespread mylonitic sub vertical foliation orientated northwest-southeast, imbrication of the lithological units and the tectonic layering, defined by strips and lenses of supracrustal rocks alternated with gneisses (Siqueira,1996). The age of this event lies somewhere between 2851 ±4 Ma and 2761±3 Ma (U/Pb, zircon, Machado *et al.*, 1991). This event must have been long lived given that it also affected the Old Salobo Granite dated at 2573±2 Ma (Machado *et al.*, 1991).

The transpressional event produced ductile thrusts at the Salobo Deposit scale, generating a sinistral lateral ramp (70°) associated with frontal ramp (20°) geometries causing mass motion from NNE to SSW on the northwest side of the lateral ramp. In crossing this lateral ramp structure from southeast to northwest, the sub-vertical dipping changes to NNE, the thickness of the schist package is reduced and copper mineralisation begins to appear within the quartzites to the SSW (Fig. 5).

## *First Metamorphic Event*

According to Lindenmayer (1990) the early transpressional shearing was accompanied by the first metamorphic event, represented by rocks which are almost anhydrous and occur as scarce lenses irregularly distributed within the mineralised zone. These rocks display a coarse granoblastic texture, consisting of fayalite, almandine, spessartine, magnetite, graphite, hastingsite, chalcopyrite and graphite. This assemblage represents the highest metamorphic grade attained by the Salobo rocks, characterised by high temperature, low pressure thermal metamorphism (750°C; 2 to 3 Kbar), compatible with pyroxene hornfels facies metamophism. It is important to note that chalcopyrite remained stable during this anhydrous metamorphic stage. According to Lindenmayer, 1990, these X1 type schists show a correlation between Fe-REE and Fe-Cu, suggesting a hydrothermal origin for copper and iron prior to the first metamorphic event.

## *First Hydrothermal Event*

Following the high grade metamorphic event, high temperature potassic alteration took place, marked by fluid penetration and hydration of dehydrated minerals. This event is characterised in the iron formation by partial destruction of fayalite, hastingsite and chalcopyrite. The resulting mineral assemblages are grunerite, almandine, magnetite, biotite, bornite and chalcocite. This alteration assemblage developed under intense ductile deformation at temperatures between 650 to 550°C (Lindenmayer, 1990).

Some textural evidences for this alteration are: the growth of grunerite along cleavage planes of fayalite; the substituition of fayalite by grunerite plus magnetite; formation of almandine containing inclusions of grunerite; the substitution of chalcopyrite by bornite and chalcocite (Lindenmayer, 1990).

The fluid would have been acidic, weakly oxidising, rich in $SiO_2$ plus K+, and also highly saline, given that it introduced Si and K and removed Ca, Mg and Na. As a result of the potassic alteration, the lithologies of the supracrustal rocks were enriched in $Fe^{2+}$, K, Ce, Th, U and REE (Lindenmayer, 1990). Fig. 6 shows a soil geochemistry profile over the deposit, illustrating some of these characteristics.

Requia *et al.*, 1998, studied the effects of this first hydrothermal event in amphibolites. Their conclusions are an early episode of Na-metasomatism indicated by the replacement of Ca-plagioclase by Na-plagioclase. This event was followed by extensive K-metasomatism expressed by the partial or total replacement of plagioclase by K-feldspar and/or biotite.

## ***Sinistral Transtensional Brittle Shear Zone***

The second episode of deformation was characterised by the generation of sinistral transtensional brittle shear zones, particularly at the contact of quartzites with gneisses, in the southwest portion of the deposit. This event overprinted the earlier structures with sub-parallel structures, dated by Mellito *et al.*, 1998, from magnetite in brecciated iron rocks (2172±230 Ma Pb-Pb) and from chloritised gneisses (2135±21 Ma, Rb-Sr, whole rock).

## *Second Hydrothermal Event*

A second hydrothermal event was characterised by propylitic alteration associated with the brittle shearing, at temperatures less than 370°C. This stage is mainly characterised by the infiltration of Ca-bearing fluids accompanied by intense chloritisation resulting in greenschist-facies rocks. In the iron formations this alteration produced intense choritisation of almandine, biotite and hastingsite. Another low-T alteration effect was the generation of greenalite plus fluorite and uraninite in fringes enclosing fayalite and grunerite. This was accompanied by partial substitution of bornite by chalcocite.

Veinlet mineralogy consists of quartz, stilpnomelane, fluorite, allanite, chalcopyrite, molybdenite, cobaltite and gold. The fluid introduced during this stage was probably acidic, weakly saline and more oxidising than the high-T fluid (Lindenmayer, 1990).

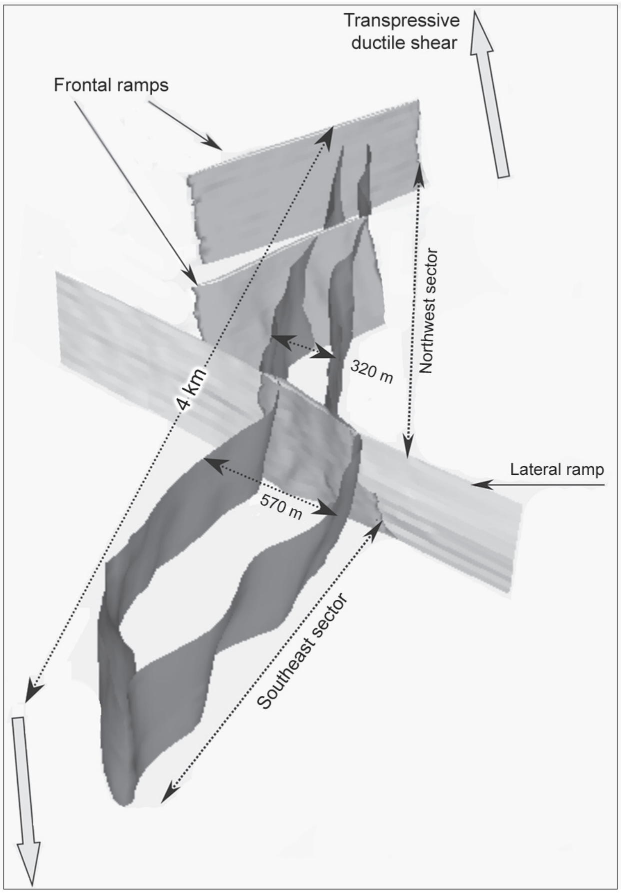


**Figure 5:** Geological structure of the Salobo 3A deposit, looking 290°.

## Geological Modelling and Mineral Resources

The genesis of the Salobo Deposit comprises an extremely complex geological evolution, closely related to structural deformation and hydrothermal alteration, which generated, modified and redistributed mineral species of economic interest.

### Geological Modelling

For the purpose of estimating the mineral resources, a geological model was developed using the following criteria:

(a) Division of the deposit into two sectors, to the northwest and southeast respectively, based on differences in structural and hydrothermal alteration patterns, and concomitant lithological, mineralogical and chemical characteristics.

(b) Broad delineation of orebody shoots based on the predominance of particular schist types (see Figs. 7 and 10).

Fig. 7 shows the six mineralised orebodies that were differentiated in order to develop the mineral resource model. These show the following characteristics:

***Orebody 1*** – shows a predominance of X5 and is restricted to the NNE margin of the deposit. It corresponds to intensely sheared gneiss material and contains generally low copper and gold grades.

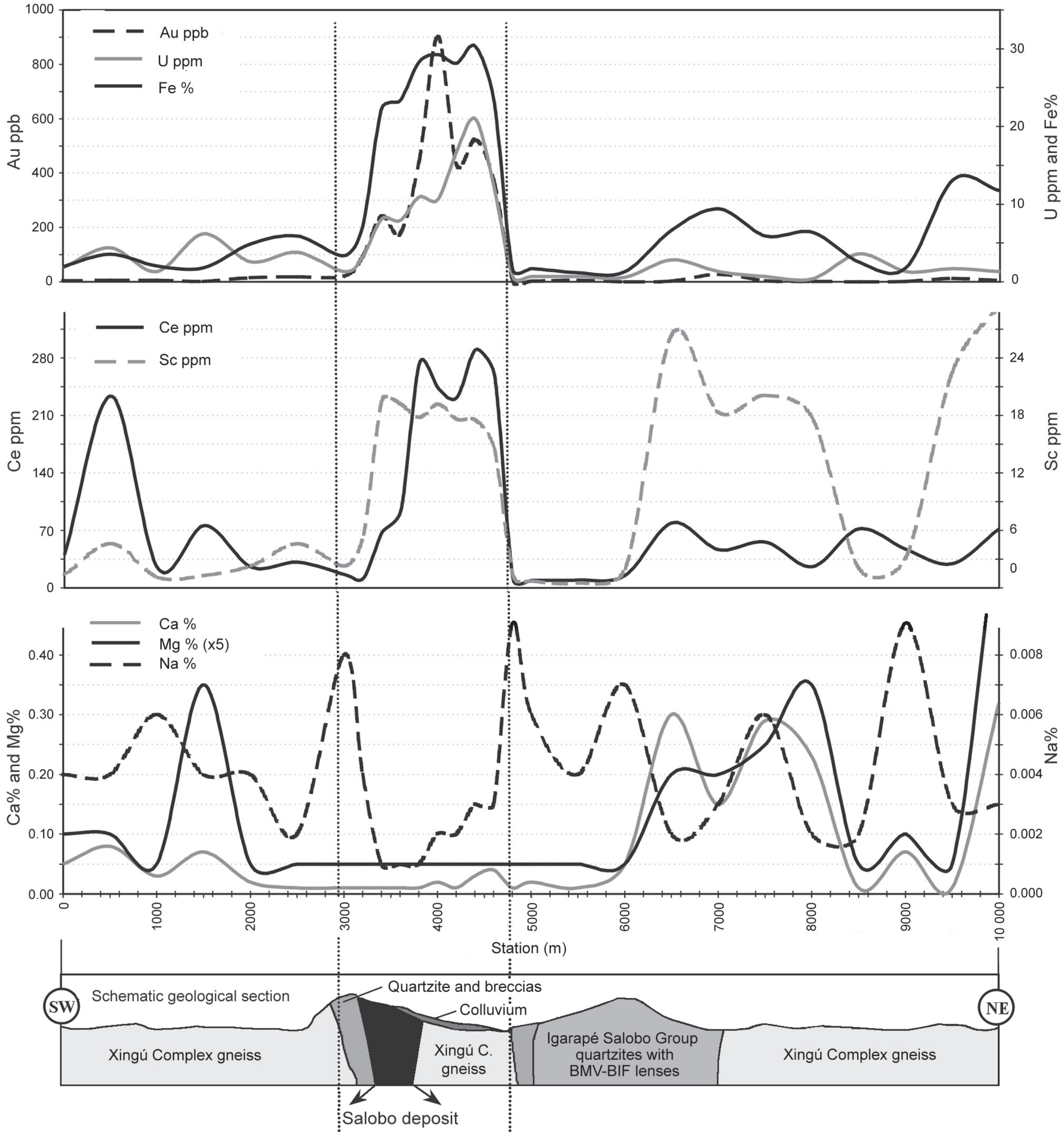


**Figure 6:** Salobo project geochemistry; -6.0 mm soil profile, sampled each 500 m (background) and each 200 m (ore + colluvium); 27 samples; ACME GRP 1F - AR - ICP-MS analysis for 51 elements. See the profile location on Fig. 3.

***Orebody 2*** – shows a predominance of X4 lithologies and generally hosts only background mineralisation.

***Orebody 3*** – comprises the most important mineralised body in that it contains the highest grades in copper and gold. This mineralisation is accompanied by higher proportions of magnetite relative to other bodies. Orebody 3 also contains higher proportions of schist types X1 and X3 and has been subdivided into Orebody 3NW (Northwest sector) and Orebody 3SE (Southeast sector).

***Orebodies 4 and 5*** – correspond to smaller mineralised bodies which contain the highest proportions of X1 and higher grades in gold and copper relative to the background mineralisation. These were the least affected by greenschist facies metasomatism, preserving much of the primary high amphibolite facies mineralogy. As a result, the rock units within these bodies contain greater proportions of chalcopyrite when compared to the other bodies.

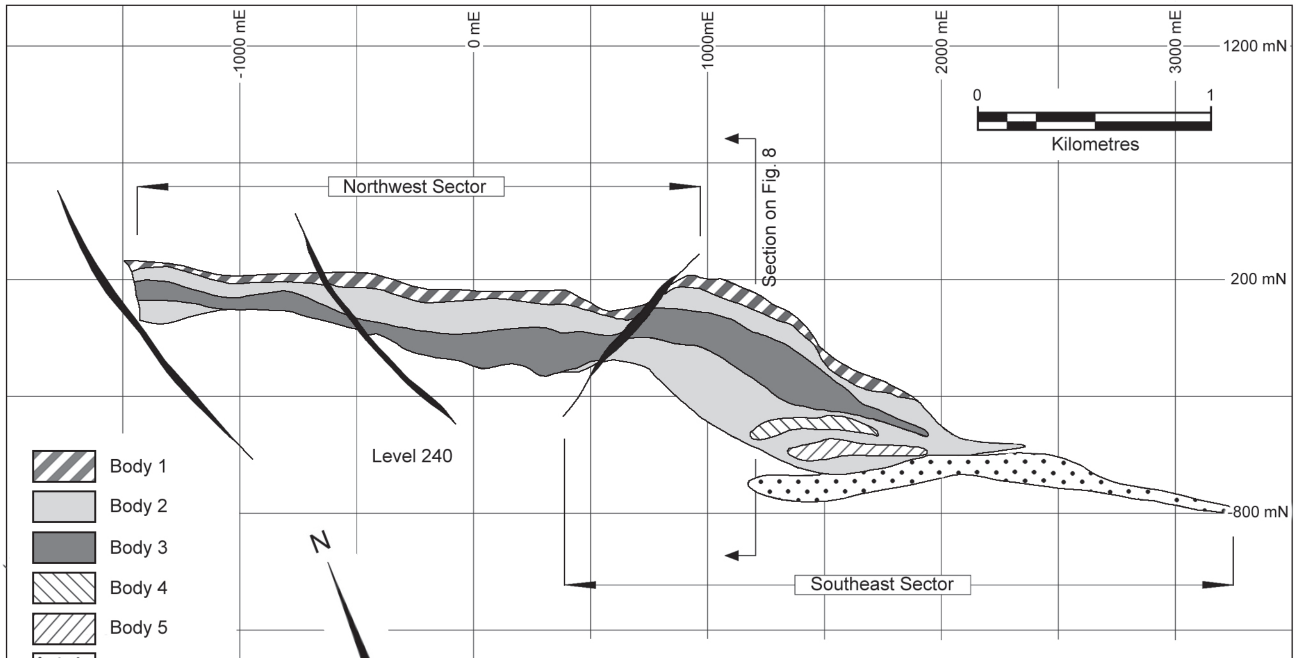


**Figure 7:** Geological orebody model of the Salobo 3 Alpha deposit on level 240 (see Fig. 8).

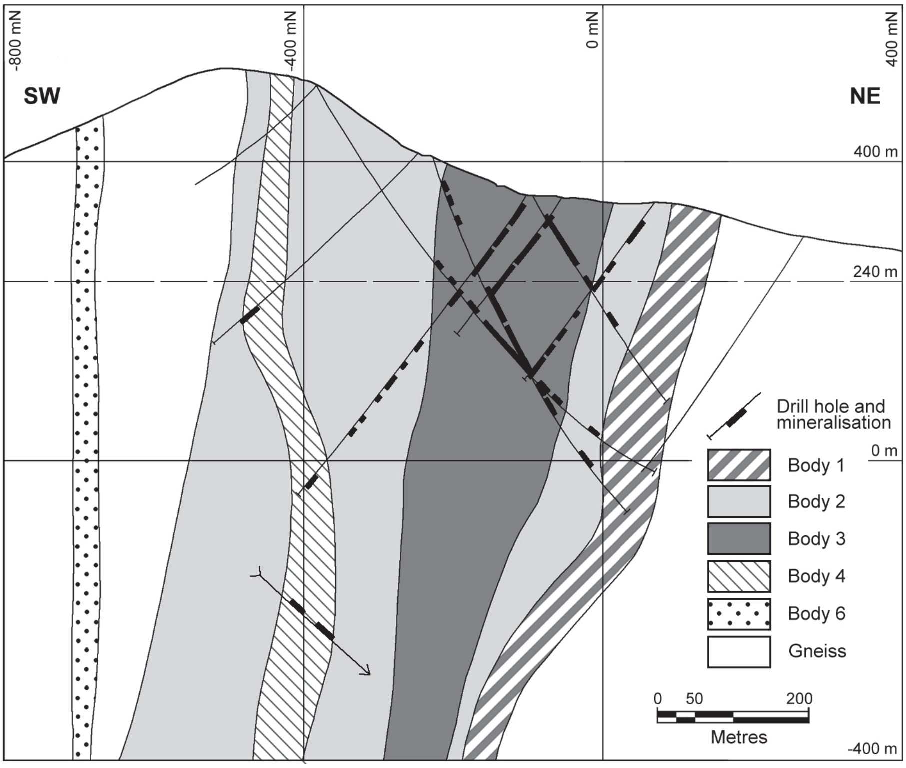


**Figure 8:** Vertical geological cross section through the Salobo 3 Alpha deposit showing the modelled orebodies. See location on Fig. 7.

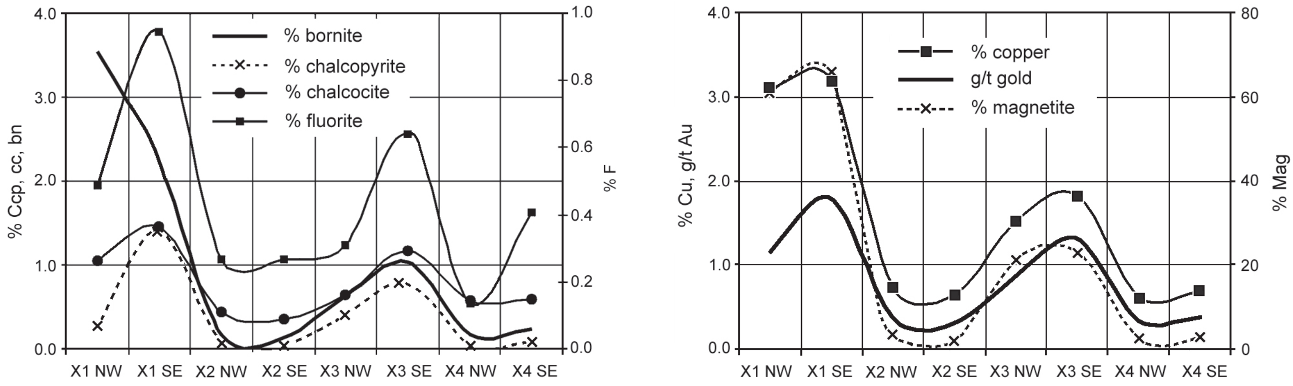


**Figure 9:** Chemical, mineralogical and lithological differences between sectors of the Salobo 3 Alpha orebodies.

***Orebody 6*** – corresponds to a mineralised body occurring mainly within the gneissic rocks, and comprising a southeastern extension of the deposit. This orebody is characteristically epigenetic, resulting from late remobilisation of mineralisation from the Salobo schists to the Xingú gneisses along brittle shear zones.

The cross section shown in Fig. 8 illustrates the sub-vertical nature of the orebodies. Note that Orebody 6, unlike the other bodies, is contained completely within the gneisses.

Figure 9 shows the principal lithological differences between Orebody 3NW and Orebody 3SE. From this figure, note the following:

(a) In comparing the same schist types in both sectors, note that those of the Southeast sector are richer in copper, gold, fluorine and magnetite.

(b) Bornite is the principal copper sulphide occurring within schist X1 lithology, however, the proportion of bornite with respect to other sulphides within this rock type is higher in the Northwest sector than in the Southeast sector.

(c) Chalcocite is the predominant sulphide species in the other schist types in both sectors. Nevertheless, chalcocite contents are higher in the Southeast sector in comparison to the Northwest sector.

From these observations, the following conclusions can be drawn:

(a) The compressional frontal ramp tectonics that led to a reduction in the thickness of the schist package to 250 m in the Northwest sector were preserved to a greater extent during the proceding extensional tectonics and associated hydrothermal alteration. As a consequence, this sector preserves to a greater degree the characteristics associated with the first metamorphic/hydrothermal event, such as the partial transformation of chalcopyrite to bornite and fayalite into grunerite and magnetite.

(b) The fact that the Northwest sector contains greater proportions of X2 relative to X4, indicates that the potassic alteration attributed to the first hydrothermal event remained incipient within this sector.

(c) The greater proportion of biotite in schist X4, the predominance of chalcocite over other mineralising sulphide species and the higher fluorite contents of the Southeast sector, leads to the conclusion that this sector was strongly affected by both the first and second hydrothermal events.

(d) Even though the Southeast sector was more strongly affected by the second phase hydrothemal alteration, this sector does contain small orebodies (4 and 5) with relict characteristics of the first hydrothermal event (greater proportions of chalcopyrite, magnetite and

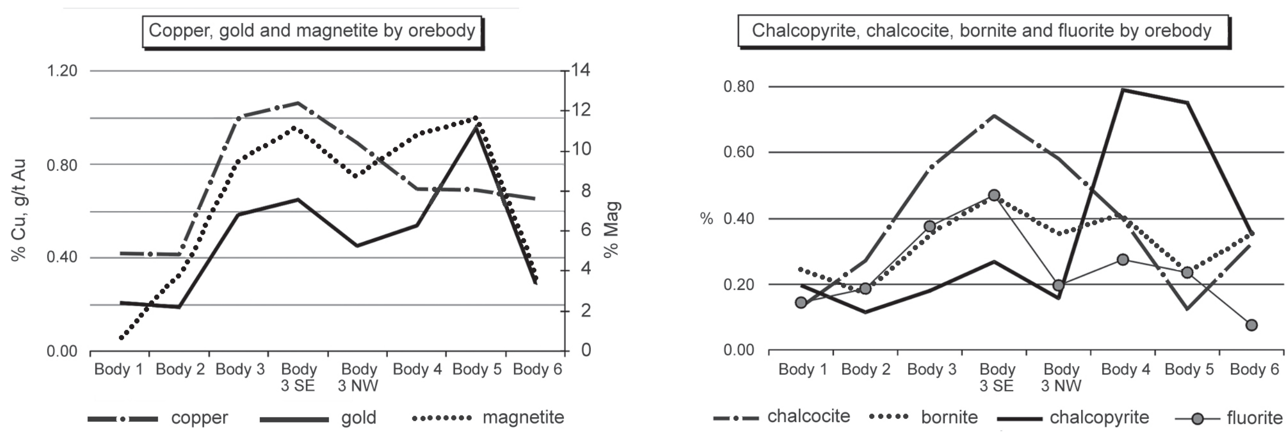


**Figure 10:** Chemical and mineralogical differences between Salobo 3 Alpha orebodies.

**Table 2:** Total measured + indicated + inferred sulphide resources estimated for the Salobo 3 Alpha deposit.

| Cut-off Cu% | Tonnes millions | Indicated % | Copper % | Gold g/t | SG | Magnetite % | Carbon % | Sulphur % | Fluorine % |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1926 | 78 | 0.59 | 0.34 | 3.33 | 6.07 | 0.16 | 0.27 | 0.23 |
| 0.4 | 1297 | 80 | 0.74 | 0.43 | 3.39 | 7.71 | 0.16 | 0.33 | 0.27 |
| 0.6 | 746 | 82 | 0.93 | 0.56 | 3.47 | 9.79 | 0.18 | 0.39 | 0.32 |

X1). These only show incipient characteristics of the second hydrothermal event. The preservation of these bodies clearly demonstrates that the hydrothermal processes are restricted to shear zones and are not penetrative.

Figure 10 shows chemical and mineralogical characteristics of the different orebodies. Differences are mainly due to the extent to which each orebody was affected by the two hydrothermal events, which is also reflected in the different relative proportions of schist types X1 and X2.

### *Mineral Resources*

Geological modelling and geostatistical evaluation was carried out by Salobo Metais S.A. working in conjunction with Anglo American´s resource evaluation group in Santiago Chile. The resource model was reviewed and approved by both Anglo American and CVRD staff. Table 2 summarises the estimated mineral resources of the Salobo 3 Alpha Deposit.

## Conclusions

Considering similarities in the ore mineralogy, geochemistry, tectonic environment and hydrothermal alteration patterns, the Salobo Deposit could be ascribed to the large class of iron oxide (Cu-U-Au-REE) deposits.

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