PETROGRAPHIC CHARACTERIZATION OF THE HYDROTHERMAL ALTERATION ZONES ASSOCIATED WITH GOLD MINERALIZATION IN GRANITIC ROCKS OF THE BATALHA GOLD FIELD, TAPAJÓS (PARÁ) - BRAZIL.

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ABSTRACT The granitic rocks that host gold mineralizations in the Batalha gold field (Pará State, Brazil) present granophyric structures that indicate crystallization at shallow levels and the influence of alkalis- and silica-rich, post-magmatic fluids. Locally, they present weakly developed rapakivi textures and their composition is predominantly of 3a and 3b granites. Their petrographic characteristics allow correlation with the Maloquinha Suite rocks, of ages around 1.84 Ga. Petrographic studies carried out using samples from drill-holes that intersect zones mineralized in gold made the characterization of ample pervasive hydrothermal alteration zones possible, showing continuous variations of the fluid compositions from the post-magmatic stages. The oldest event is characterized by sodic alterations, followed by potassic alteration producing microcline and biotite, which confers a dark red color to the rocks; propylitic alteration is superimposed on both. Final stages may have evolved to locally pervasive sericitic alteration, but this type was better characterized as of fissure style and associated with minor shear zones. Gold mineralizations are predominantly associated with propylitic alterations, but the highest grades are observed in sericitic zones and, more specifically, as free, coarse-grained gold hosted by minor quartz veins, with associated carbonates, sulfides and fluorite.

Keywords: Tapajós, hydrothermal alteration, granite, gold.

INTRODUCTION The Tapajós Mineral Province (Delgado *et al.* 1995, in Vasquez *et al.* 1996) has been responsible for a considerable fraction of the gold production in Brazil. Despite this production having been largely represented by panning, a few primary mineralizations were already known in 1997, when the interest for the region once again grew, resulting in systematic exploration and, as a consequence, the discovery of several primary gold occurrences.

Most of the mineralizations in the province are of lode-type and associated with Proterozoic acid suites (Faraco *et al.* 1996), being controlled by shear zones and major, regional NW-SE-trending lineaments and hosted by coarse-grained, red granite to monzogranite. Only recently has the characterization of hydrothermal alteration types associated with shear zones begun in some gold fields, such as Batalha (Coutinho *et al.* 1996).

Drillhole sampling in the Batalha Gold Field allowed petrographic studies and the characterization of the hydrothermal alteration processes. Part of these alteration types associated with gold mineralization are not linked with shear zones, suggesting that the hydrothermal systems were genetically associated with the emplacement of the Batalha granitic rocks at shallower crustal levels, with fluids generated and/or remobilized by the intrusion. These systems acted upon ample volumes of rock by means of alkaline metasomatism, evolving to propylitic alteration zones with decreasing temperature and K^+ and Na^+ activity. The sericitic alteration is mainly associated with late shear zones (Corrêa Silva 1999).

GEOLOGIC CONTEXT The Batalha gold field is located at the left margin of the Tapajós River, alongside Transamazonian Highway (Fig. 1).

The Tapajós Mineral Province is part of the Guaporé Shield that, together with the Guiana Shield located north of the Amazonas River, composes the Amazon Craton (Almeida *et al.* 1976).

The Tapajós Province basement was locally named Cuiú-Cuiú Metamorphic Suite (Andrade *et al.* 1978, in Santos & Loguércio 1984), being composed of gneisses, migmatites and smaller amphibolite bodies. This Suite was at first considered as part of the Archean Xingu Complex and basement for the whole Guaporé Shield. However, Santos *et al.* (1997) recommends that the Cuiú-Cuiú

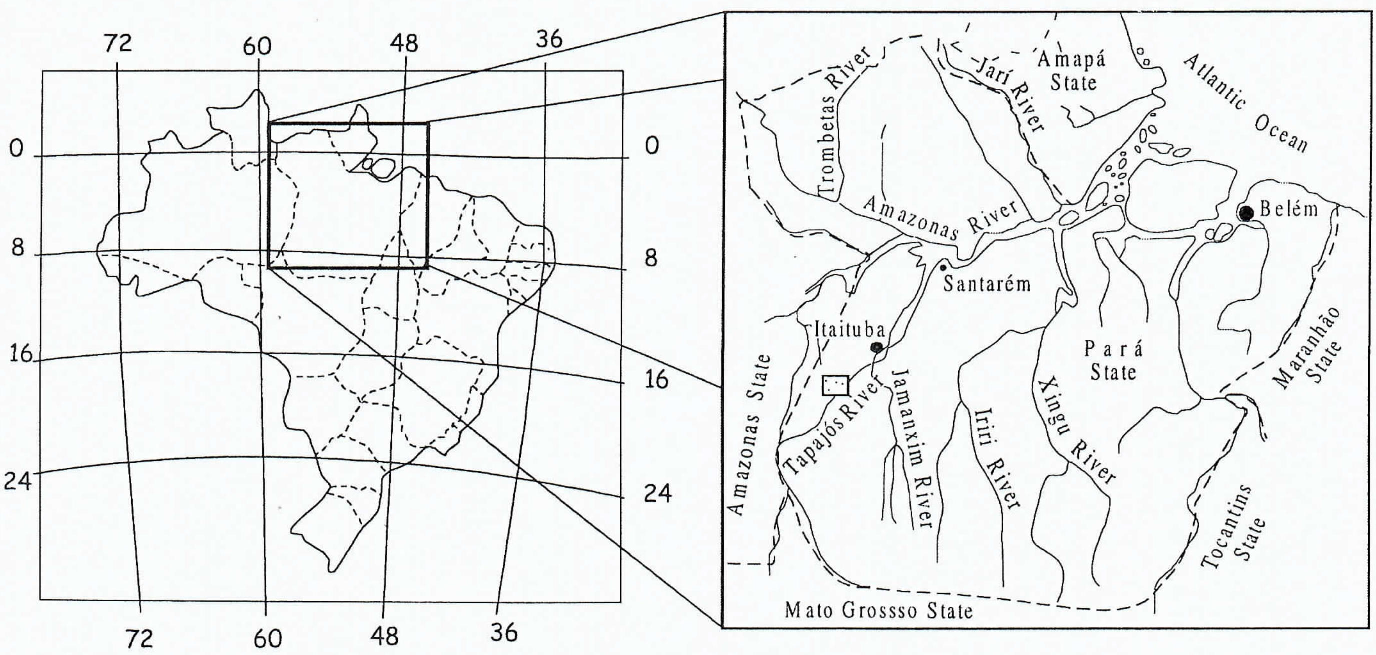

Figure 1 – Location map of the Batalha Gold Field.

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Metamorphic Suite be separated from the Xingu Complex due to its Transamazonian age.

The Batalha granitic rocks belong to the Maloquinha Intrusive Suite (Coutinho *et al.* 1996), which includes subvolcanic granites with orthogenetic characteristics and alaskitic trends. These are equivalent to the Saracura (Roraima), Mapuera (Pará/Amazonas) and Serra dos Carajás (Pará) granites and are associated with the Paleoproterozoic Uatumã acid volcanism that is part of the Iriri Group (Santos *et al.* 1975 and Andrade *et al.* 1978, in Santos & Loguércio 1984).

The Maloquinha Suite granites yield Rb/Sr ages around 1840 ± 26 Ma (Santos *et al.* 1997) and are necessarily a little younger than the Iriri Group volcanics, as their intrusive features indicate. Therefore, they represent the final magmatism of the Uatumã event.

The Maloquinha Suite is composed of alkali-feldspar granite, syenogranite, monzogranite and granophyre that occur mainly as stocks and subordinately as rounded and ellipsoidal batholiths (Brito *et al.* 1997).

Its lithotypes present petrographic and chemical characteristics and REE distribution patterns similar to those corresponding to peraluminous and sub-alkaline A-type granites. Chemical compositions range between the average for the crust and for island arc basalts, corresponding to certain tectonic environments, including post-collisional granites and those related to the final stages of a long period of high heat flow and granitic magmatism in stabilizing orogenic areas (Brito *et al.* 1997).

Coutinho *et al.* (1996) recognized the potassic alteration affecting these rocks but did not associate their red color with this type of alteration, as characterized by Corrêa Silva (1999) and Corrêa Silva *et al.* (1999).

PETROGRAPHY The petrographic characterization was carried out using samples from drill-holes that crosscut mineralized zones and reached up to 182 m in depth. Textures and parageneses of igneous and hydrothermally altered rocks were identified and compared, as well as their relative chronologies.

In its less-altered portions the granite is pink-gray, massive and leucocratic, presenting a medium- to coarse-grained, inequigranular phaneritic texture. Locally, the textures are rapakivi-like and granophyric, similar to those described by Dall'Agnol *et al.* (1994) for the Maloquinha Suite rocks. The rocks color has a gradual change towards the more intense potassic alteration zones that are characterized by a dark red coarse-grained granite. Locally, decimetric aplite and basalt dikes presenting igneous flow structures crosscut the granitic rocks and andesite xenoliths are also present.

The predominant mineral composition is of a 3a and 3b granite (Fig. 2), with less than 5% modal biotite. Biotite- and hornblende-bearing rocks are a little more mafic, but mafic minerals content is less than 10%. Intense silicification and compositional variations are observed in some samples with potassic feldspar or plagioclase enrichment, predominantly due to potassic or sodic hydrothermal alteration. The trends suggest that the unaltered rock is predominantly a monzogranite.

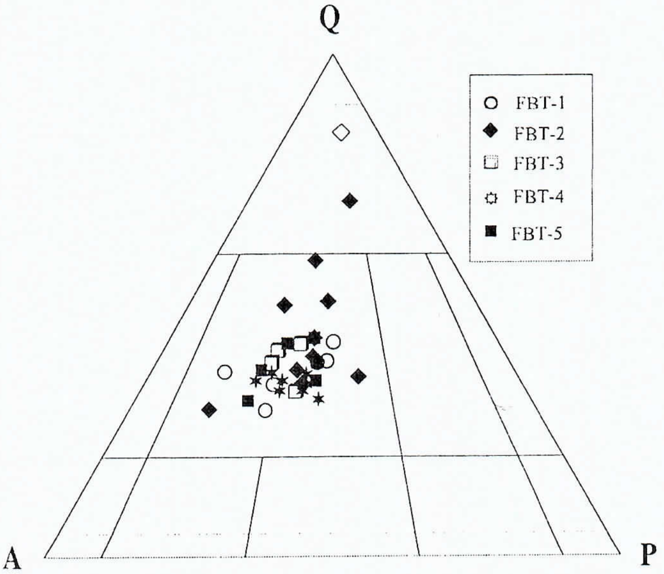

Figure 2 - QAP diagram. Silicification and enrichments in plagioclase and potassic feldspar are produced by hydrothermal alteration. The enrichment trends suggest that the unaltered rock was a monzogranite.

Hydrothermal alteration sometimes makes the precise distinction of the igneous minerals very difficult. However, igneous quartz can be texturally distinguished by its subhedral shapes, corrosion features, whereas hydrothermal quartz shows irregular shapes, fills interstices and is intergrown with microcline and perthitic orthoclase, generating incipient granophyric textures. Hydrothermal quartz can also enclose magmatic quartz. Quartz veinlets are normally present. Both quartz generations present undulatory extinction and two-phase/gas-liquid, locally supercritical and monophase, fluid inclusions, arranged along tracks and clouds.

The igneous orthoclase is perthitic to mesoperthitic, with irregular albite inclusions, and is partly inverted to microcline. The largest volume of microcline in the rock was produced by crystallization from hydrothermal-metassomatic fluids. The grains characterizing this generation are fine, fill interstices and have anhedral to euhedral shapes. They are locally zoned, substituting and enclosing orthoclase and plagioclase crystals.

The igneous plagioclase composition varies between oligoclase (An_{28}) and andesine (An_{35}) and the crystal shapes are generally euhedral, almost always with cores partially or totally saussuritized. Plagioclase can form rims around alkaline feldspar crystals generating a weakly developed rapakivi texture. In places, smaller grains occur as relicts enclosed by hydrothermal microcline.

The hydrothermal plagioclase is always more sodic and the later phases have compositions close to pure albite. Commonly, the crystals present euhedral shapes with normal compositional zoning. It crystallizes around potassic feldspar in many cases, generating rapakivi-like textures.

Two biotite generations were also distinguished. The igneous biotite is red-brown colored and its shapes tend to be euhedral, whereas the hydrothermal biotite is green, fine-grained, and substitutes the igneous biotite so as fills fissures and interstices between grains of other minerals. Locally the crystals form radial patterns.

Hornblende relicts, partially replaced by green biotite and chlorite, can be recognized in some portions of the rock. Allanite and zircon occur as accessory minerals. Euhedral to anhedral pyrite crystals, sometimes associated with chalcopyrite and galena, occur disseminated in a paragenetic assemblage with hydrothermal quartz and sericite. Locally, they constitute small veins.

CHARACTERIZATION OF THE HYDROTHERMAL ALTERATION **Alkaline metasomatism** This alteration includes potassic and sodic varieties (Pirajno 1992) and differently affects the whole set of samples in a pervasive form.

Albitization is the oldest hydrothermal alteration event that followed the granite consolidation, indicating Na^+ enrichment in relation to K^+ in the initial fluids. It mainly caused growing of discontinuous rims of plagioclase around orthoclase or its partial substitution, generating textures morphologically similar to perthite. In this case, subsolidus reactions produced regularly distributed, fine exsolution lamellae, generally following the crystallographic orientation. The albite that comprises the lamellae was taken as crystallization nuclei for the hydrothermal albite growth. The increase of albite content due to orthoclase substitution caused deformation of the host crystalline structures. Locally, orthoclase substitution by albite was almost complete, generating textures very similar to the ones described by Pirajno (1992). These textures are not homogeneously distributed in the rock and are better observed in the less potassified portions.

The rims of the hydrothermal albite differ from those observed in the rapakivi textures by their discontinuities and irregularities, corrosion features, inclusion of several potassic feldspar grains and by the characteristic association with hydrothermal biotite and quartz (Figs. 3, 4).

Potassic alteration follows sodic alteration, due to Na^+ depletion in the fluids caused by albite precipitation. The potassic alteration affects the samples more intensely and is characterized by microclinization of igneous and hydrothermal alkaline feldspars, accompanied by crystallization of green biotite, which also substitutes other mafic minerals.

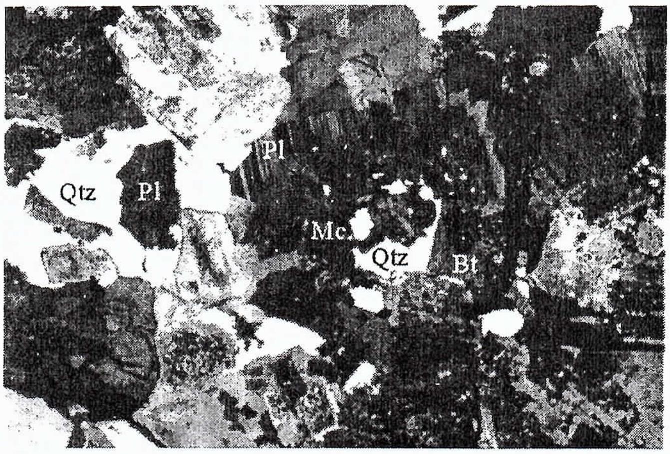

Figure 3 - Perthitic microcline with rims of albite is observed in the center of the figure, with intergrowth of quartz, showing a rapakivi-like texture. Qtz - Quartz, Bt - Biotite, Mc - Microcline, Pl - Plagioclase. Crossed nicols.

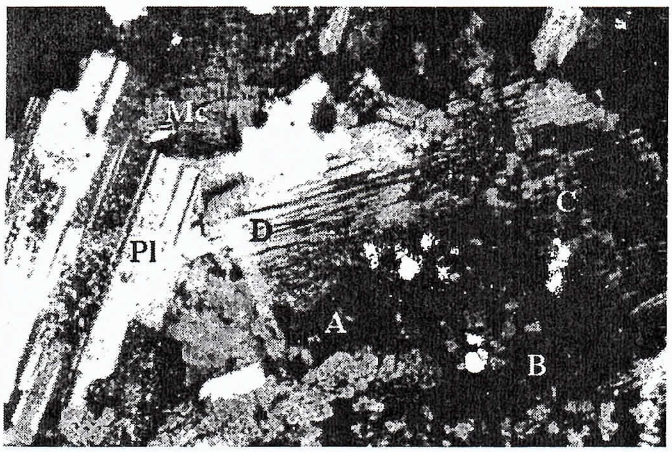

Figure 4 - A) Microclinized perthitic orthoclase. B) Partial substitution of orthoclase in plagioclase domain, creating similar morphological textures of perthites. C) Plagioclase concentration domain, giving rise to a discontinuous rim of albite. D) Rim of albite in orthoclase, like rapakivi texture. Pl - plagioclase, Mc - Microcline. Crossed nicols.

The hydrothermal microcline typically occupies grain interstices, encloses igneous orthoclase, plagioclase and quartz, and usually substitutes discontinuously and irregularly hydrothermal albite rims. During this process, Fe^{2+} liberated from the feldspar crystalline lattice is oxidized and precipitates as hematite micro-inclusions, conferring the red color to the rocks close to gold mineralizations.

Due to temperature decrease during these events there is also partial inversion of orthoclase to microcline.

The microcline chemical composition shows continuous variation between $Ab_3Or_{97}An_0$ to $Ab_{43}Or_{57}An_0$ (Fig. 5). Although precision is limited by the size of the microprobe electron beam, these variations are surely related to partial substitution of potassic feldspar by albite, once they are also observed at the rims of hydrothermal microcline that typically substitutes plagioclase from the rapakivi textures.

Propylitic alteration This type of alteration affects the samples in fissure and pervasive styles, predominating the latter. It results from the impoverishment in alkalis and temperature decrease in the hydrothermal system and increase in H_2O, CO_2, and locally S, contents with minor H^+ metasomatism. Typically, it generates epidote, clinozoisite, chlorite, calcite/dolomite, fluorite, potassic feldspar, albite and pyrite, yielding textures that indicate crystallization after the generation of alkaline metasomatism assemblages. Through this kind of alteration, hornblende was totally or partially replaced by green biotite, chlorite, carbonates and epidote. Biotite generated during this event is optically similar to that crystallized during potassic metasomatism and the criterion used for distinction was its association with carbonates and epidote.

Carbonates associated with epidote also occur filling veins and microfractures. Chlorite is younger and substitutes igneous and hydrothermal biotite.

Anhedral to euhedral fluorite associated with quartz, opaque minerals and carbonates fills veins and locally cements brecciated zones.

Sericitic alteration It is characterized by the association of quartz + sericite ± pyrite ± chalcopyrite ± galena, occurring predominantly in the fissural style. In general, this alteration is genetically linked with brittle shear zones and associated fractures and breccias. The minerals typically fill fractures, but subordinately, can occur pervasively around major fissure zones. Despite the impossibility of a petrographic characterization, it is likely that this type of alteration corresponds in part to the final stages of the hydrothermal system that generated alkaline metasomatism and propylitic alteration.

The interpreted post-magmatic and pre-shearing system fluid evolution, is schematized in Figure 6.

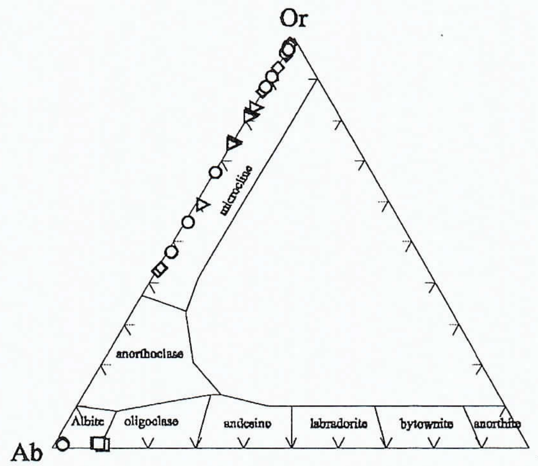

Figure 5 - Ab-Or-An diagram. The variation on the composition of microcline is due to the substitution of potassic feldspar for plagioclase and to the size of the microprobe electron beam, while analyzing perthite. The albite points in the diagram were obtained from analyses of the rims of plagioclase on potassic feldspar.

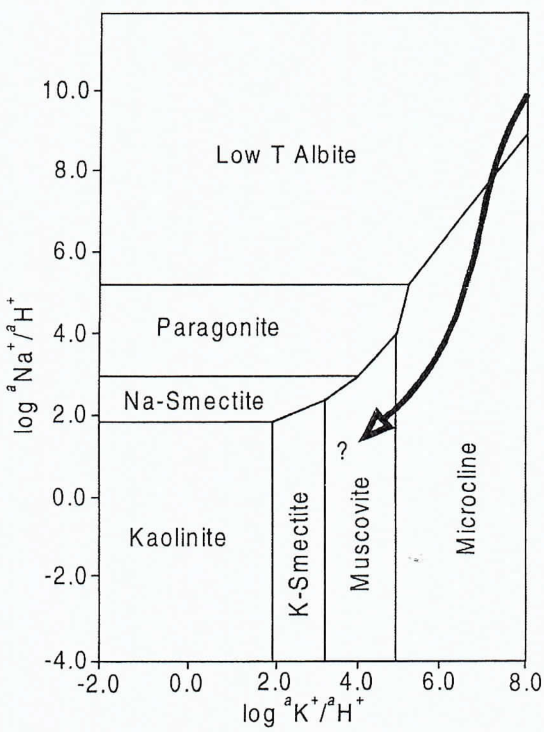

Figure 6 – Proposed post-magmatic schematic hydrothermal fluid evolution in theoretical diagram, recalculated from the activity of the $HCl-H_2O-Al_2O_3 - K_2O-Na_2O-SiO_2$ system, pressure at 1 atm, temperature 250^0C (Log $^aH_4SiO_4$ = Quartz saturation) (after Pollard et al. 1983)

Relationship between hydrothermal alteration and gold mineralization Among the hydrothermally altered rocks, the sericitic alteration zones present the highest gold grades, especially where these zones are crosscut by sulfide-bearing quartz and/or carbonate and fluorite veins. In them, gold occurs free and is coarse-grained. However gold concentrations are low in ample zones showing strong propylitic alteration, suggesting that the mineralization is older than the shear zones. Thus, the shear zones could have played an important role in the concentration and deposition of gold preferentially in veins.

CONCLUSIONS

The Batalha Gold Field is located in granitic rocks with petrographic characteristics similar to those of the Maloquinha Suite. Their composition is predominantly of 3a and 3b granites and present granophyric textures that indicate magma consolidation at shallow depths and influence of late silica- and alkali-rich fluids. Rapakivi textures were locally weakly developed.

The post-magmatic fluid-system evolution caused hydrothermal alterations in ample parts of the massif, with which gold mineralizations are associated.

Hydrothermal alteration overprints late-magmatic textures and minerals, starting with sodic alteration followed by potassic and propylitic alterations, resulting in albitization, microclinization, biotitization, propylitization and silicification of granitic rocks. In the later stages, sericitic alteration, mainly related to brittle faulting regimes, took place causing formation of minor cataclastic zones and breccias.

The dark red color observed in the granitic rocks results from potassic metasomatism that produced intense microcline crystallization, obliterating the lighter colors of fresh or slightly altered rocks.

Gold is disseminated preferentially in propylitic alteration zones, but the highest grades are found in sericitic alteration zones associated with shearing, suggesting that faults and later hydrothermal systems were responsible for gold concentration in minor quartz veins bearing sulfides, carbonates and fluorite. Mining activity is favored thanks to the coarser grain size of the free gold in these veins.

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