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MESOPROTEROZOIC PALEO-HYDROTHERMAL SYSTEM IN THE MORRO DA PEDRA PRETA FORMATION, SERRA DO ITABERABA GROUP, SÃO PAULO STATE, BRAZIL

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ABSTRACT The Serra do Itaberaba Group is a Mesoproterozoic volcano-sedimentary sequence metamorphosed to the Barrovian-type medium-grade facies. Its basal volcano-sedimentary unit corresponds to the Morro da Pedra Preta Formation and is formed by metabasalt with geochemical characteristics compatible with those from mid-ocean ridges (N-MORB). In the upper part of this unit very deformed andesitic/rhyodacitic intrusions are found and, surrounding these bodies, there is a zoned sequence of basic rocks with complete gradation from hornblende amphibolite to garnet-cordierite-cummingtonite/anthophyllite amphibolite, interpreted as having been produced by metamorphism of variably hydrothermalized basic and intermediate protoliths. The different alteration zones were subdivided in rock groups of distinct mineralogical and petrological characteristics. Altered basic rocks are represented by the following groups: weakly altered rocks (hornblende amphibolite with cummingtonite and cordierite), transitional rocks (amphibolites where two or three different amphiboles may coexist), moderately altered rocks (garnet-cordierite-cummingtonite amphibolite) and strongly altered rocks (garnet-cordierite-cummingtonite/anthophyllite amphibolite). Moderate (plagioclase-chlorite-anthophyllite/cummingtonite-quartz rocks) and strong alterations (anthophyllite/cummingtonite-cordierite-quartz ± chlorite rocks) were distinguished in intermediate rocks. Layers of carbonatized metabasite occur under andesitic/rhyodacitic intrusions and bodies of garnet-hornblende amphibolite, cummingtonite-garnet-chlorite schist and corundum-margarite schist are also present. Potassic alteration overprints some lithotypes and silicification overprints most of them. Mass balance calculations in a continuous profile of volcaniclastic-derived basic rocks, ranging from weakly to strongly altered rocks, showed that most samples are variably enriched in Si, Mn, and P and variably depleted in Na, Ca, Al, Fe^{3+}, Mg and K. Trace element analyses showed that the weakly altered rocks are variably enriched in La, Nd, Lu, Eu, Tb, Lu, Ce, Y and Zr. These zones were interpreted as having been produced by ocean floor hydrothermal processes coeval with the emplacement of small andesitic to rhyolitic intrusions.

Keywords: Serra do Itaberaba Group; paleo-hydrothermal system; cummingtonite/anthophyllite rocks.

INTRODUCTION

Medium-grade metamorphism and tectonic transpositions commonly preclude the identification of paleo-hydrothermal systems, as well as the zoned sequences associated with them. Usually the correlation between metamorphic products and hydrothermalized rocks is very difficult and sometimes impossible. However in the Serra do Itaberaba Group (SIG) relatively well-preserved paleo-systems were identified in the field, making petrographic and chemical studies possible. SIG is represented by a Mesoproterozoic metamorphosed volcano-sedimentary sequence (Juliani *et al.* in this volume) partially covered by the Neoproterozoic São Roque Group (Hackspacher *et al.* 1999). Both groups are part of the Ribeira Belt (Hasui *et al.* 1975) or *Região de Dobramentos Sudeste* (Almeida *et al.* 1976). The whole rock pile was intruded by several Neoproterozoic to Fanerozoic granitic plutons and was affected by several NE-SW trending shear zones. SIG's type area is located few kilometers northeast of São Paulo City (Fig. 1) and was subdivided by Juliani (1993) and Juliani & Beljavskis (1995) in the Morro da Pedra Preta (MPPF), Nhanguçu (NF), and Pirucaia (PF) formations. The basal MPPF is a metamorphosed volcano-sedimentary sequence starting with a volcanic and volcaniclastic unit bearing N-MORB geochemical characteristics. This unit is covered by metapelites, commonly containing graphite and sulfides, that are associated with smaller bodies of metamorphosed basalt, tuffs, Algoma-type BIF, tourmalinite, calc-silicate rocks and andesitic to rhyodacitic intrusions. The hydrothermally altered rocks are predominantly distributed in the upper part of the volcanic unit, at the interface with metapelites. NF overlies MPPF and is essentially represented by iron-manganesiferous schist with small lenses of carbonate rocks and calc-pelite, covered by andalusite-rich schist, both deposited under a back-arc basin regime. PF is composed of quartzite and rhythmic quartz schist, deposited by turbidity currents in a coastal environment. The sequences are strongly deformed and metamorphosed to the Barrovian-type medium-grade facies, predominantly in the sillimanite zone.

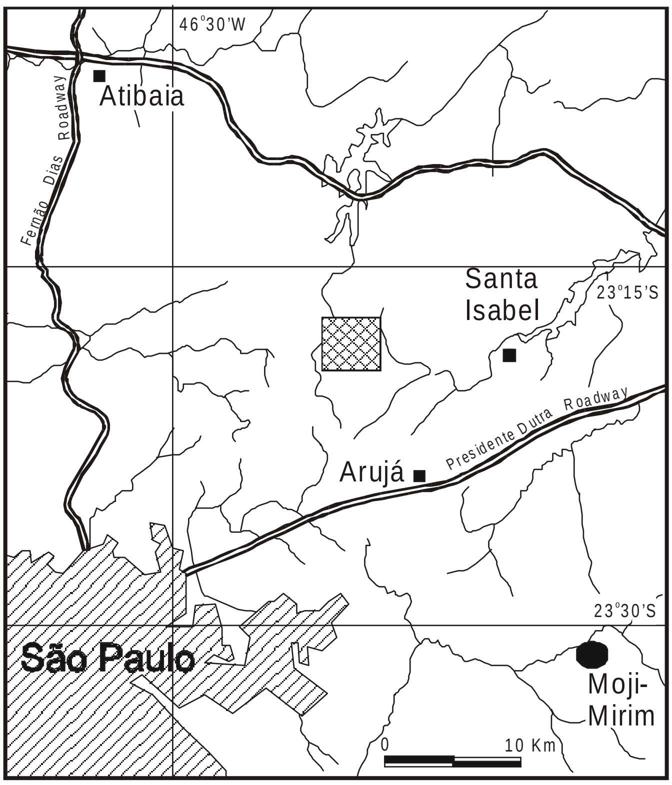

Figure 1 – In the square is the localization of the area where a Mesoproterozoic paleo-hydrothermal system is present.

GEOLOGY OF THE PALEO-HYDROTERMAL SYSTEM

Rocks derived from the hydrothermal alteration prior to metamorphism are predominantly distributed around and beneath lenses of altered metaintermediate rocks, emplaced at the interface between metabasalt and basic metatuff and schists during the subduction of an oceanic plate (Juliani 1993). The upper part of these lenses shows passageways to breccia and sulfide-rich volcanic agglomerate that laterally grade to tuffs. These bodies are covered by calc-silicate rocks and by silicified zones or rocks with metachert intercalations and are sub-concordant with the wall rocks due to intense transposition associated with closed to isoclinal folds. Despite the intense deformation, it can be inferred from the shape of these metaintermediate bodies that they must have been small inverted-cone type intrusions (Pérez-Aguilar 1996). Above these rocks, schists with intercalations of basic and intermediate metatuffs and iron formations are found commonly mineralized with gold.

Schists and calc-silicate rocks were in general not affected by hydrothermal alteration, fact that indicates that the alteration event was predominantly previous to the deposition of pelitic rocks and marbles.

The hydrothermal alteration zones vary from small bodies around 150 m to more than 1.2 km long, with widths varying from 100 to 150

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meters. Structures and textures observed in a regional scale and in outcrops indicate systems formed by pervasive and selectively pervasive alteration styles. From the more external parts towards the center of the alteration system different groups of altered metabasic rocks occur, herein classified as weakly altered, from the transitional zone, moderately altered, and strongly altered (Fig. 2). The alteration of the igneous intrusive and volcaniclastic intermediate rocks was subdivided into moderately and strongly altered rocks. Relict textures shown by plagioclase porphyroblasts suggest the presence of small metarhyolite intrusions but the alteration process makes their recognition difficult. Potassified rocks are generally present in the outer parts of the system. Layers of carbonatized basic rocks and metaspilites occur, respectively, under and above the intermediate intrusions. Potassic alteration overprints some altered rocks and silicification overprints most of them. Later, these rocks were metamorphosed to the Barrovian-type medium-grade facies, resulting in lithotypes that resemble those described by Riverin & Hodgson (1980), Elliott-Meadows & Appleyard (1991), Pan & Fleet (1995) among others.

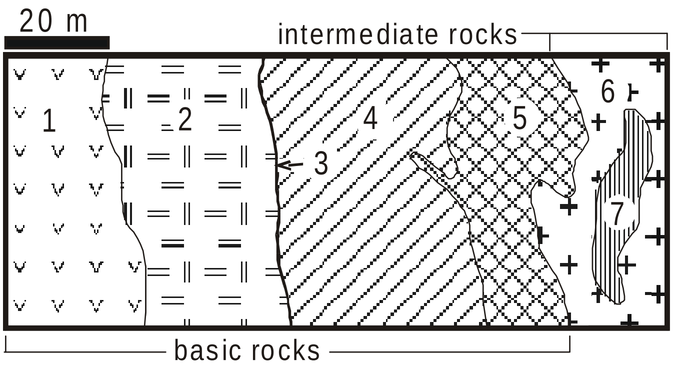

Figure 2 – Schematic relationship between altered rocks around lenses of hydrothermalized intermediate intrusions. (1) basic protolith; (2) weakly altered basic rocks; (3) basic rocks from the transitional zone (4) moderately altered basic rocks; (5) strongly altered basic rocks; (6) moderately altered intermediate intrusions, and (7) strongly altered intermediate intrusions.

PETROGRAPHY OF THE ALTERED BASIC ROCKS

Samples for petrographic studies were collected from bodies showing different alteration zones. As alteration patterns are present regionally and locally, it was possible to sample continuous alteration profiles, a few decimeters-thick, of altered basic and intermediate rocks. Macroscopic structures and microscopic textures clearly helped to recognize gradual and progressive alteration of protoliths until strongly altered rocks were produced, like dissolution features, reaction and infiltration zones and small relicts of less altered rocks within more altered ones.

The unaltered basic igneous and volcaniclastic rocks are amphibolites composed of hornblende and plagioclase, with minor amounts of quartz, sulfides, clinozoisite, epidote, oxides, carbonate, chlorite, zircon and apatite. Blastosubophitic textures are common and plagioclase may show irregular rims, segregation or recrystallization to smaller grains.

In thin section, medium- to fine-grained metavolcaniclastic rocks exhibit characteristic textures, such as rounded to elliptic hornblende aggregates (up to 2 cm) and also smaller hornblende radial arrays. In these rocks the matrix may constitute up to 40% of the volume of the rock.

Weakly altered basic rocks This group of rocks is characterized by hornblende amphibolites with cordierite and cummingtonite. Macroscopically, their colors and textures resemble those of non-altered metabasic igneous or volcaniclastic rocks. These rocks are composed of hornblende + plagioclase ± quartz and small quantities of cordierite and cummingtonite. Textures are similar to those present in non-altered basic rocks. Cummingtonite is present as irregular spots or thin intergrown prisms within hornblende and cordierite as a matrix component. Generally these rocks are richer in quartz and poorer in plagioclase when compared to non-altered rocks. In volcaniclastic rocks andesine/labradorite and bytownite/anorthite may coexist and small quantities of garnet and rutile can sometimes be found.

Basic rocks from the transitional zone This zone is represented by amphibolites where two or three amphiboles may coexist. The rocks are essentially constituted by cummingtonite + hornblende + actinolite ± quartz ± cordierite. In altered volcaniclastic rocks andesine/labradorite and bytownite/anorthite may also coexist. In volcaniclastic derived rocks textures and structures are similar to those present in the basic protoliths. In those of igneous origin cordierite is almost always absent, garnet is sometimes present and generally igneous textures are no more preserved. Besides rutile, accessory minerals are those present in the protolith.

Usually these rocks occur as very narrow zones (3-10 cm) between hornblende amphibolites and amphibolite in which all hornblende has been replaced by a magnesian amphibole. In amphibole aggregates, radial arrays or prismatic sections gradual changes to different amphiboles may be observed. Contacts between two types of amphibolites are irregular and gradual. Irregular, isolated portions of hornblende amphibolite are frequent.

Petrographically, the following types of rocks can be found: cummingtonite-hornblende-actinolite amphibolite, cordierite-cummingtonite-hornblende amphibolite, hornblende-actinolite amphibolite, cordierite-cummingtonite-hornblende amphibolite, hornblende-cordierite-cummingtonite amphibolite, cordierite-actinolite-cummingtonite amphibolite, cummingtonite-hornblende schist, hornblende-cummingtonite schist and garnet-hornblende-cummingtonite schist.

Moderately altered basic rocks Fresh samples exhibit a white-gray color and easily can be taken as calc-silicate rocks. In all of them hornblende has been totally replaced by cummingtonite. Textures are similar to those present in the previous group and contacts between both lithotypes are also irregular and gradual. Two different petrographic zones were distinguished:

ZONE 1 Rocks of volcaniclastic origin largely predominate and are composed of cummingtonite + quartz + cordierite ± bytownite/anorthite coexisting with andesine/labradorite. Staurolite is frequently found as tiny unstable crystals (± 0.3 mm), partially or totally surrounded by cordierite and/or plagioclase. Commonly these rocks show pre-metamorphism silicified portions represented by thin veins or by elliptic, spherical or deformed agglomerates formed essentially by quartz. Rocks of igneous origin are essentially formed by cummingtonite + plagioclase ± quartz. Rutile and biotite may also be present as accessories in igneous and altered volcaniclastic rocks and when present, biotite forms thin lenses or patches. Cordierite-cummingtonite amphibolites and cummingtonite amphibolites represent respectively altered volcaniclastic and igneous rocks.

ZONE 2 These rocks resemble the altered volcaniclastic ones from *zone 1*, the only difference being the presence of euhedral and subhedral garnet crystals (up to 1 cm), being exclusively products of the alteration of the volcaniclastic protolith.

Strongly altered basic rocks This zone is represented by coarse-grained garnet-cordierite-cummingtonite/anthophyllite amphibolites. These rocks exhibit characteristic amphibole radial arrays (± 2.5 cm) and poikiloblastic garnet (± 2 cm) and cordierite (up to 4 cm), with rare or without matrix (Figure 3). Rock-forming minerals are magnesian amphibole + cordierite + garnet + quartz. Rarely garnet is absent and in relation to this mineral, cordierite is almost always more abundant. Plagioclase, phlogopite, rare staurolite (also as tiny unstable crystals) are accessories, and carbonates are absent. Anthophyllite, cummingtonite and rare gedrite represent magnesian amphiboles. Fine lamellae of cummingtonite intergrown with anthophyllite are common. Some samples are very rich in opaque minerals, essentially euhedral magnetite crystals (± 1 mm). Silicified portions, as described in the previous group of rocks, can sometimes be responsible for the entire matrix composition.

PETROGRAPHY OF THE INTERMEDIATE ROCKS The intermediate rocks are represented by altered metandesites, metadacites and metarhyodacites.

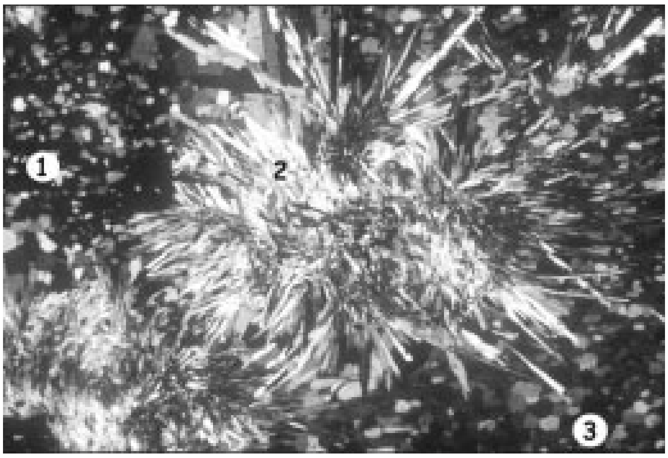

Figure 3 – Strongly altered basic rock represented by coarse-grained garnet-cordierite-cummingtonite/anthophyllite amphibolite, where (1) garnet poikiloblast; (2) cummingtonite and anthophyllite, and (3) cordierite poikiloblast. (figure's larger side ~8mm).

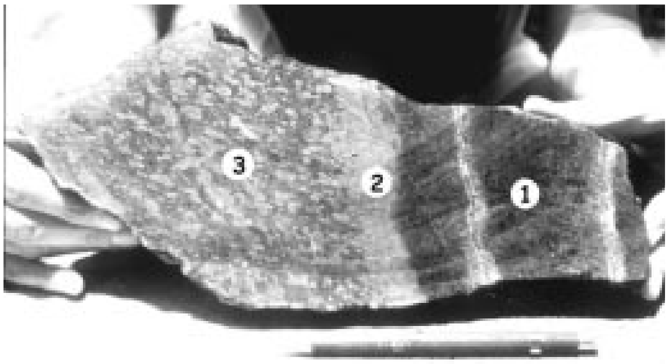

Figure 4 – Detail of lithotypes produced by hydrothermal alteration in basic volcaniclastic rock, where: (1) weakly altered basic rock (hornblende amphibolite with cummigtonite and cordierite) with presence of thin veins essentially composed by epidote + diopside + actinolite; (2) moderately altered basic rock (cordierite-cummingtonite amphibolite), and (3) potassic alteration overprinting moderately altered basic rocks (biotite-cummingtonite amphibolite).

Moderately altered intermediate rocks They are coarse-grained rocks, characteristically formed by radial arrays of magnesian amphiboles (± 2 cm) dispersed in an abundant fine-grained matrix, rich in magnesian chlorite and quartz. They are constituted by cummingtonite + anthophyllite + chlorite + quartz ± plagioclase. Staurolite, allanite, clinozoisite/epidote, apatite and zircon can be found as accessories. Small anhedral and corroded crystals of plagioclase (~ 0.5 cm) are remains of primary porphyritic textures. Allanite, when present, appears as tiny crystals wholly or partially surrounded by clinozoisite/epidote.

Strongly altered intermediate rocks These rocks differ from the moderately altered intermediate rocks by the presence of well-developed cordierite poikiloblasts. Irregular portions of a matrix composed essentially by quartz ± magnesian chlorite are sometimes present. The rocks are essentially composed of magnesian amphibole + cordierite + quartz ± chlorite. Also rutile and biotite can be present as accessories and rarely plagioclase appears in concentrations up to 10% of the rock volume.

Texturally and petrographically these rocks resemble the strongly altered basic rocks, fact also observed by Dobbe (1994) and Pan Fleet (1995) among others. The lack of garnet, the generally lower concentration of magnesian amphibole, the higher concentration of cordierite, and the presence of small quantities of plagioclase can be pointed out as major differences in relation to the strongly altered rocks produced after the alteration of basic protoliths.

POTASSIFIED ROCKS In these rocks biotite concentrations vary from 10 to 20% in volume. Hornblende-biotite schist and biotite-hornblende schist represent potassified basic tuffs. Potassic alteration of the basic igneous protolith was responsible for the presence of hornblende-biotite amphibolite and biotite-hornblende amphibolite. Potassic alteration overprinting moderately altered basic rocks is recognized in biotite-cummingtonite amphibolite. In the latter, irregular patches or islands of cordierite-cummingtonite amphibolite (up to 1.5 cm) are present in a fine to very fine matrix essentially constituted by quartz + biotite + plagioclase + cummingtonite + cordierite (Fig. 4). Some potassified rocks have high concentrations of muscovite, chlorite and quartz, suggesting volcaniclastic acid to intermediate protoliths or, alternatively, mixture with pelites.

CARBONATIZED BASIC ROCKS These rocks are essentially composed of diopside + actinolite + clinozoisite/epidote + quartz + carbonates ± plagioclase. Frequently diopside is unstable, being partially or totally replaced by epidote/clinozoisite or actinolite. In some samples relicts of hornblende amphibolite are observed as thin and discontinuous (up to 5 cm long) lenses of irregular width, or as patches of diffuse contours and different sizes (up to 2 cm). Locally a strong potassic alteration event is overprinted.

OTHER ALTERED LITHOTYPES Garnet-hornblende amphibolite, cummingtonite-garnet-chlorite schist, corundum-margarite schist were also recognized as lithotypes produced by alteration but, because elucidative outcrops are lacking, they could not be related to the above mentioned groups.

Garnet-hornblende amphibolite vary from coarse- to medium-grained, more rarely to very fine-grained. In some of them blastosubophitic textures can be observed. They are constituted by hornblende + garnet + oligoclase/andesine and andesine/labradorite + quartz ± pyrite ± cummingtonite. As accessories opaque minerals, zircon, apatite, carbonates, biotite and chlorite can be present. Pre-metamorphism silicification zones are frequent.

Cummingtonite-garnet-chlorite schist is formed by magnesian chlorite + garnet + cummingtonite and small quantities of plagioclase. Subhedral garnet (up to 3 cm) and narrow cummingtonite porphyroblasts (up to 4 cm) are present in a very fine chloritic matrix where some small plagioclase crystals are also present (1.2 x 0.8 mm).

In some places small lenses of corundum-margarite schist are found containing corundum + margarite + muscovite + rutile + opaque ± plagioclase ± chlorite ± tourmaline, sometimes with kyanite, epidote, zircon and quartz.

MASS BALANCE CALCULATIONS A continuous alteration profile varying from weakly to strongly altered lithotypes was recognized is some outcrops of basic volcaniclastic rocks. The average contents resulting from the whole rock and some trace element analyses of five samples of unaltered metabasic rocks were used as the basic protolith composition. Preliminary mass balance calculations, considering volume variations (Gresens 1967; Grant 1986; Potdevin & Marquer 1987), showed that almost all lithotypes are highly enriched in Si (up to 50% in weight), Mn and P and strongly depleted in Na, Ca, Ti, K, Al (up to 55%) and Fe^{3+} (up to 21%). Magnesium was depleted from most of the altered lithotypes. Regarding analyzed trace elements, the weakly altered rocks are variably enriched in La, Nd, Sm, Eu, Tb, Lu and Y. Cerium is slightly enriched in all samples showing an irregular pattern along the alteration profile. Associated with the intensification of the alteration process, Zr concentrations are progressively higher.

CONCLUSIONS AND DISCUSSION It was possible to recognize a relatively well-preserved Mesoproterozoic ocean floor paleo-hydrothermal system in the volcano-sedimentary MPPF, despite the medium-grade metamorphism and tectonic transpositions that affected the whole rock pile. Hydrothermally altered rocks are predominantly distributed at the interface of metabasalts and basic metatuffs with schists, around and beneath small andesitic/rhyodacitic bodies emplaced during the subduction of an oceanic plate (Juliani 1993), previous to the deposition of the NF and PF metasediments.

Surrounding the intrusions a zoned sequence of metabasic rocks with cummingtonite/antophyllite and cordierite developed, forming alteration cones. Alteration is more intense in the central part of these cones, having produced strongly altered intermediate and basic rocks that are texturally and petrographically very similar. Towards the borders moderately altered intermediate and basic rocks, basic rocks from the transitional zone, and weakly altered basic rocks occur. Potassic alteration is generally present in the outermost zones but also overprints some inner lithotypes. Layers of carbonatized metabasites and metaspilites occur, respectively under and above intermediate intrusions. An intense and late event of silicification overprints most of the altered lithotypes.

With relation to mass balance calculations, a concentration of Mg would be expected, fixed by hydrothermal chlorite. The relative Mg depletion observed might, in part, be due to the strong silica enrichment along the alteration profile, fact that may reduce relative Mg concentrations, as well as of other elements. Si and Mn enrichment is related to late hydrothermal events. In a regional scale, depletion of K, Ca and Na in the altered rocks can be associated with the presence of potassified and carbonatized basic rocks, as well as spilites. Fe depletion may be partly responsible for the genesis of small bodies of Algoma-type BIFs in the upper part of MPPF. High Al depletion is abnormal and its leaching may be partly responsible for the generation of corundum-margarite schist.

The alteration process was also responsible for gold mineralizations and deposition of banded iron formations and sulfide-rich schists.

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