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MASS BALANCE FROM CHLORITIC ALTERATION ZONES ASSOCIATED TO MESOPROTEROZOIC KUROKO-TYPE PALEO-HYDROTHERMAL SYSTEMS FROM THE SERRA DO ITABERABA GROUP, SÃO PAULO, BRAZIL

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Northeast São Paulo city, comprising part of the Ribeira Fold belt (Almeida et al., 1973), is present the Mesoproterozoic metamorphosed volcano-sedimentary Serra do Itaberaba Group (SIG) (Juliani & Beljavskis, 1995; Juliani et al., 2000), which is partially covered by the Neoproterozoic metamorphosed siliciclastic São Roque Group (Juliani et al., 1986; Hackspacher, 1999), being the whole sequence of supracrustal rocks crosscut by several Neoproterozoic to Phanerozoic granitic plutons, and affected by several NE-SW trending shear zones (Almeida et al., 1981). The SIG was affected by two progressive medium- to low-grade regional metamorphic events, which occurred during the Mesoproterozoic and the Neoproterozoic.

The paleo-hydrothermal systems developed first in a mid-ocean ridge environment and afterwards in a following back-arc basin stage associated with the emplacement of relative small andesitic to rhyodacitic intrusions (Fig. 1). Genetically associated to paleo-hydrothermal systems are found the metamorphic products of a large chloritic alteration zone (CZ1) and restrict chloritic (CZ2), argillic, and advanced argillic alteration zones that crosscut CZ1 and correspond to fluid channel ways (Fig. 1). These alteration zones are similar to those present associated to Kuroko-type deposits (Franklin, 1993; Ohmoto, 1996). The premetamorphic event responsible for the geneses of the CZ1 affected in variable degrees basic and intermediate, igneous and volcaniclastic rocks.

Complete gradation in metamorphic products of hydrothermally altered rocks include weakly, transitional, moderately, and strongly altered lithotypes from the outermost zone to the inner part of the CZ1, which are recognized by the presence of variable amounts of Mg-amphibole(s) (cummingtonite-anthophyllite rocks). The metamorphic products of CZ2 rocks are Mg-chlorite rich rocks (metachloritites). Also present are metamorphosed carbonatization, potassification, and silicification alteration zones, Algoma type BIF´s, tourmalinites, iron-manganiferous metapelites, gold-bearing graphite/sulfide metapelites, and Cu and Zn soil anomalies (Juliani, 1993; Juliani et al., 1992; Beljavski et al., 1999; Pérez Aguilar, 2001; Pérez-Aguilar et al., 2005).

Mass balances showed that most metabasites from the hydrothermal alteration zones (HAZ) that exhibit a normal metamorphic mineralogical assemblage (hornblende + plagioclase), and because or this considered as protoliths, were already submitted to significant chemical changes, if compared with metabasites localized out of the HAZ. Potassium was systematically depleted from these metabasites. In relation with the other major elements, systematic depletion or enrichment patterns could not be established, having been most major elements either enriched or depleted, sometimes with significant absolute variations, but samples enriched in Mg and Ca, depleted in Fe, Ti, and P, and without significant Si variations predominated. Most samples were depleted in almost all trace metals, including base metals, S, REE, Y, and Zr, thus being some samples very rich in Ni (up to 147%), Cu (up to 124%), As (up to 189%), Ba (up to 70%), Cr (up to 338%), Pb (up to 390%), and Rb (up to 1051%).

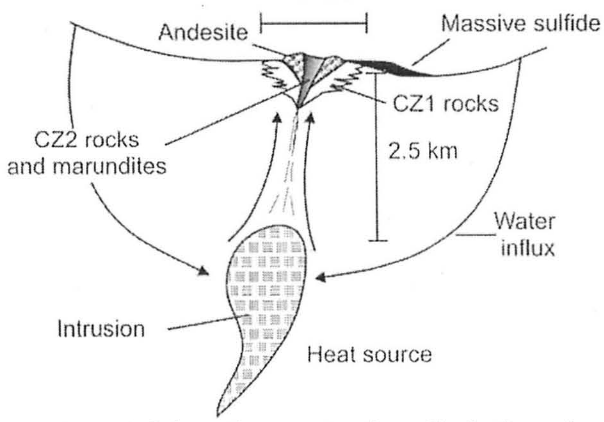

Figure 1. Schematic reconstruction of hydrothermal systems (Pérez-Aguilar et al., 2005).

Analyzing the whole lithotypes of hidrothermalized metabasites from the CZ1, most of them were depleted in Na, K, Ca and Fe, having been Al, Ti, Mn, Si, P and also S enriched in some samples and depleted from others. Strongly altered metabasites were enriched in Mg (up to ~90%) and were depleted in Al, Ti, K, Na, Ca, Fe, and P, being observed locally Si enrichments (up to 31%).

Hydrothermally altered intermediate igneous rocks are those that show more homogeneous mass balance patterns, having been most of them enriched in Mg (up to 116%), Fe (up to 100%), and P (up to 52%), and depleted in K (up to 100%), Na (up to 96%), Ti (up to 66%), and Al (up to 54%). Ca and Mn were enriched (up to 789%

and 260%, respectively) in some samples and depleted from others. Si showed relatively low enrichments (up to 12%). Most trace elements, including Y, Zr, and REE were depleted from these rocks, although Ce was enriched (up to 305%) in all samples. Sr showed a chemical behavior similar to that of Ca. The tendency of Ca, Mn, and Sr is to decrease its concentration as intensity of hydrothermal alteration increases.

Hydrothermalized intermediate metavolcaniclastic rocks from the CZ1 due not show so homogeneous depletion or enrichment patterns if compared with related igneous protoliths. Generalizing, most of these rocks were enriched in Na (up to 398%), Fe (up to 113%), Ti (up to 69%), Al (up to 47%), and P (up to 93%), and were depleted in Ca (up to 92%), Mn (up to 91%), Mg and Fe (up to 38%). Na and Ca were progressively depleted as intensity in hydrothermal alteration increased. In these rocks REE were depleted and most of the other trace elements were enriched, including Zr, having concentrations of Li (up to ~2250%), Sc (up to 333%), Co and Nb (up to 284%), Ta (up to ~300%), Hf (up to ~100%), Th (up to ~50%), and V (up to 96%) progressively enriched in samples as intensity in hydrothermal alteration increased. Some samples were enriched in Bi (up to 60956%), Rb (up to 11980%), Mo (up to 5812%), S (up to 2457%), Sn (up to 627%), B (up to 883%), and Ba (up to 571%).

In rocks affected by CZ2, metasomatic processes were responsible for significant volume variations (up to –~50%). The main mass balance features from these rocks are the extreme Mg enrichments (up to 162%) and Si depletions (up to 46%). Due to silica lixiviation the Al and Ti residual concentrations increase (up to 29% and 41%, respectively). In relation with the other elements, these rocks were also enriched in Mn and depleted in Na, Ca, and also in S. Some CZ2 samples were enriched in K (up to 110%) due to the overprinting of a potassic alteration.

Carbonatized rocks were enriched in Ca, Mg, K Ba, Rb, Li and U, and potassified rocks were highly enriched in K.

The lixiviation of K from hydrothermally altered rocks was responsible for the presence of a diffuse zone of K-enrichment marked by the presence of biotite-bearing basic and intermediate rocks that envelope the CZ1, which defines a lower temperature potassic alteration. Lixiviated Ca from thee rocks was responsible for the presence of large carbonatized rocks present in deeper parts of the system, being locally Ca and Na enrichments due to the overprinting of carbonatization and albitization events. B remobilizations are compatible with the presence of volcanogenic tourmalinites.

Enrichments of rocks in Bi, Rb, Mo, and Sn suggest the presence of fluids associated to acid rocks. Depletions in Y, and Zr, indicate the presence of carbonated complexes in hydrothermal fluids. Sr chemical behavior, similar to that of Ca, denotes that initial fluids destabilized plagioclase, being Sr reintroduced associated to later carbonate rich-fluids. Depletions in Fe and Mn were responsible for the formation of overlying Algoma-type BIF's and iron-manganiferous metapelites. The abnormal enrichment or depletions of samples in S and also in base metals indicates mobility of these elements through hydrothermal fluids, which associated to the identification of several pre-metamorphic hydrothermally altered zones and superimposed hydrothermal events, similar to those of Kuroko-type base metal mineralizations, so as obtained stable isotope patterns (Pérez-Aguilar et al., 2005), the presence of Cu and Zn soil anomalies and associated gold mineralization, suggest the possibility of the existence of base metal deposits associated to paleo-hydrothermal systems, expanding the mineral potential for the occurrence of base metal deposits in the Serra do Itaberaba Group and in the volcano-sedimentary sequences of the Ribeira Fold Belt.

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