BRAZILIAN OPHIOLITES WITH EMPHASIS IN THEIR METALLOGENY

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EXTENDED ABSTRACT

In Brazil knowledge on mafic-ultramafic associations has grown in the last decades and have been recognized several ophiolitic bodies and related volcano-sedimentary successions, mainly of Neoproterozic age (the Brasiliano-Pan-African Orogeny, 900-530 Ma), and some older associations. All of Brazilian mafic-ultramafic complexes are precambrian in age except those Mesozoic of alcaline-carbonatitic-kimberlitic association. Many of the mafic-ultramafic associations formely ascribed to ophiolitic sequences are in fact komatiitic volcanic associations belonging to greenstone belt sequences or deformed and metamorphosed layered mafic-ultramafic intracratonic complexes. In this work we reavalueted older geologic-structural, petrological, geotectonic, and metallogenic data and provide some new metallogenic data. Finally, we discuss the metallogenic potential of all Brazilian ophiolites. Neverthless, it should be noted that our present understanding of the metallogenic potential of the Brazilian ophiolites is still poorly developed.

Brazilian geology, in a general view, is composed by the Amazonian, São Francisco, and Rio de La Plata (including the Luís Alves microcraton) Archean to Paleoproterozoic cratons, Mesoproterozoic covers, the Neoproterozic Tocantins (in the central part of Brazil, composed by the Paraguai-Araguaia belt in the northern part and the Brasília belt –composed by its south and central sectors- in the southern part), Mantiqueira (make up by the Araçuaí and Ribeira/Dom Feliciano belts in the eastern side of Brazil), and Borborema (including the São Luís microcraton/plate, in the northeastern part of Brazil) provinces located along the cratonic margins, Phanerozoic volcanic-sedimentary covers (Paraná, Parnaíba and Amazonas intracratonic basis) and more recent units (Figura 1).

The most important and known ophiolitic associations occur in the Araçuaí-West-Congo Orogen/belt, formed between the São Francisco craton and its African counterpart, and in the Brasília Belt between the São Francisco, Amazonian and Rio de La Plata cratons. Some ophiolites occur along the Ribeira/Dom Feliciano belt. Other ophiolites have been described in the northern part of the São Francisco Craton, the Riacho do Pontal, Rio Preto, and Sergipano belts, formerly believed to have only ensialic basement.

Brazilian ophiolites are ultramafic to mafic bodies (sometimes with massive, nodular or disseminated podiform chromitites), aloctones, desmembered, small to very small in size (generally they do not exceed 5 km by 100-1000 m) and have elongated formats. Most of Brazilian ophiolites border the São Francisco Craton and are of Neoproterozoic age that occur in these above mentioned volcano-sedimentary sheared and folded belts. A probable Mesoproterozoic (*ca*. 1.0 Ga) ophiolite has been described in the Paragua and Rio Alegre terrains, in the Sunzas-Aguapeí belt, located at the southwestern border of the Amazonian Craton and there is another one (a retroeclogite-granulite association) of probable Paleoproterozoic (*ca*. 2.1 Ga) age in the Alto Moxotó Terrain (Paraíba State), in the Borborema Province. In the ophiolitic associations, plutonic mafic-ultramafic and volcanic mafic rocks have the same structural heritage of their country rocks.

Crosscutting relationships among Neoproterozoic orogens (and their contained ophiolites), geochronological data, and relative timing relationships among these orogens and sedimentary units show that the oldest are the Brasília (*ca*. 0,9-0,85 Ga) (southern sector of the Tocantins Province), Araçuaí (*ca*. 0,8 Ga, northern part of the Mantiqueira Province), Paraguai-Araguaia (*ca*. 0,76 Ga, central sector of the Tocantins Province), and the Ribeira/Dom Feliciano (*ca*. 0,7-0,6 Ga, southern part of the Mantiqueira Province) belts. The Borborema Province is the youngest belt (*ca*. 0,5 Ga).

Most of the Brazilian ophiolites are in greenschist facies as are their country rocks. A few ones are at amphibolite facies but there even are rarest ones at granulite and retro-eclogite facies (glaucophane schists, eclogites and retroeclogites, located near to Arantina, São Sebastião do Paraíso and Pouso Alegre, in Minas Gerais State, in the southern sector of the Brasília Belt, and retroeclogites and

amphibolites in Canindé, in the Ceará State, and in the Alto Moxotó terrain, in the Paraíba State, in the Borborema Province).

The Paraguai-Araguaia *fold-thrust* belt is localized in the northwestern part of the Tocantins Province with a NS extension of more than 1000 km and average of 150 km verging to west towards to the Amazonian craton. Along this belt, in the southern part of the Pará State is located the biggest ophiolite in Brazil and one of the most preserved sliver of Neoproterozoic (757± 49 Ma., Sm-Nd isochron) oceanic lithosphere, the Quatipuru complex. The Quatipuru ophiolite is represented by a N-S tectonic slice with a extension of 40 km by 1-2 km wide. It is composed by a serpentinite core with rare lenses of dunites enveloping chromitites and silexites in external portions. The serpentinites are derived from mantle peridotites, mainly residual harzburgites with minor dunites. These rocks are crosscut by dykes and sills of pegmatoidal orthopyroxenite and clinopyroxenites, wehrlite, olivine gabbros and diabase.

The Araçuaí belt has more than 500 km of extension and N-S direction. In the São José da Safira and Ribeirão da Folha regions only occur disseminated podiform chromitites and massive sulfide deposits with Ag-anomalies. The Brasília belt in its northern sector has more than 600 km of extension and N-S direction. Inside this belt along a extension of 100-150 Km there only are several bodies of podiform chromitites (*e.g.*, Abadiânia, Morro Feio e Cromínia) with strong Pt and/or Au anomalies related to shear zones, metamorphism and hydrothermalism. No other sort of deposits or mineralizations are known.

The Morro Feio ultramafic body, in the Goiás State, Brasília belt, is a body that forms a N-S elipse, with 3,6 km by 1,5 km. It is formed by magnetite-antigorite-(anthophylite) serpentinites (meta-harzburgites with residual afilliation) and has massive to disseminated podiform chromitites, high Al, with up to 0,5 m x 40 m, concordants with country serpentinite schists foliation. These chromitites and its colluvial and alluvial deposits were mined in the past for Al-chromite, and they have Pt and/or Au anomalies in shear zones inside disseminated to massive chromitites and serpentinites with hydrothermal alteration and neoformation of quartz veins with chalcedony

The Córrego do Rubinho ultramafic body located in the Ribeirão da Folha region is the biggest tectonic sliver in the Araçuaí belt. This body is tabular has an aproximate thickness of 1,5 km and outcrops for 5 km along N30ºE/40ºSE. Notable ductile shear zones indicate transport of the upper part to NW and define the contacts of this tectonic sliver with the Ribeirão da Folha and Capelhinha formations. Detailed geochemical studies of ultramafic rocks from the Araçuaí belt, suggest that those rocks from São José da Safira could represent a section of asthenospheric mantle and those from Córrego do Rubinho would represent a cumulatic ultramafic section of lithospheric mantle. Also the low TiO_2 (< 0,3%) values from both above mentioned areas suggest an oceanic enviroment. Chromite crystals from the Córrego do Rubinho ultramafic body are uniformly rich in Cr_2O_3 (~60%), Al_2O_3 (~9%) poor and have similar tenors of FeO_t (~24%) and MgO (~5,6%), correlating to chromite composition of ophiolitic bodies pseudo-layered.

Litogeochemistry of ultramafic rocks from the Araçuaí and Brasília (northern sector) belts indicates fertile harzburgitic composition ("*HOT- harzburgitic ophiolitic type*"; with mantle residual tectonites and pseudo-layered section). High Al-chromite primary composition of podiform chromitites from Morro Feio and Abadiânia region bodies has been interpreted together with its country rocks (serpentinized residual harzburgites) as formed in a tectonic enviroment similar to those of island arcs with high pH_2O.

Mafic (plutonic to volcanic) rocks of Araçuaí and Brasília belts display a N- to E-MORB geochemistry. In the Brasília belt metabasic rocks evolve from tholeiitic basalts and gabbros up to island arc tholeiites ("IAT"). In the Araçuaí belt, Minas Gerais State, metabasic rocks associate to deep sea pelites, bifs, and massive sulfides of amphibolite fácies. Mafic dykes show a regional distensive event and rift opening that have an age (U-Pb) of 906 ± 2 Ma. Sm-Nd ages from metabasalts and ultramafics constrain the ocean stage and indicate magmatic crystalization at *ca*. 800 Ma.

In the Araçuaí belt the ophiolitic association was transported from Ne to SW by oblique destral thrusts. In the Brasília belt, in its northern sector (Goiás State), the sugested tectonic enviroment is one of island backarc basins with frontal and lateral displacements in a oblique convergence. Thus, tectonic regimes involve suprasubduction (type B), oblique, direct and lateral displacement.

In the Tocantins Province, central part of Brazil, and in the Mantiqueira Province in its Atlantic margin, the Brazilian Orogeny has been atributed to the initial stages of island arc collisions with continents and later to a continental collisions between the Amazonian and São Francisco cratons and among the São Francisco, Congo/Kalahari and Rio de la Plata cratons. The Borborema Province, the youngest neoproterozoic province to be formed developed itself by a collage of crustal segments with different ages and geological history and due to its collision with the northern border of the São Francisco craton.

Due to the characteristics of geological nature, history and processes of Brazilian territory ophiolitic associations in Brazil are subordinated in number, volume and metallogenic potential to those bodies or complexes of greenstone sequences and layered intrusions. These facts can be related to the strong influence and reworking caused by the Neoproterozoic Brazilian/Pan-African Orogeny in the borders of the older Amazonian, São Francisco, and Rio de La Plata cratons and, basically due to the ancient cratonic nature of the Brazilian terrain.

Brazilian ophiolites have an economic potential very poorly known but from the present knowledge the most interesting belts are Brasília (northern sector) and Araçuaí. The Brasília Belt had chromitite mines, has PGE-unusual occurrences, (*e.g.*, Buraco do Ouro mine, with unusual PGE+Au+Ag mineralization hosted by sheared acidic granitic-gneissic rocks with up to 12-15 g/t of Au and an average of 5-7 g/t with no ultramafic rock close to this mine), and some sheared, metamorphosed, hydrothermalized, and laterized ultramafic (serpentinites) rocks, now chalcedonites, with anomalies of Pt (up to *ca*. 1,000 ppb) and/or Au (up to 8,270 ppb) related to fluid discharge zones.

In the podiform chromitites (Morro Feio and Abadiânia region bodies; figures 2 and 3) from the Brasília belt there is a direct relationship between high Au-anomalies and strong shearing, and metamorphic-hydrothermal alteration from Cr-Al-chromite to Fe-chromite with high values of Fe^{+3} associated to high induced porosity regions. It was not possible to identify any single Au grain by eletron microprobe examination despite the very high anomalies (up to 8,270 ppb) suggesting that Au may form invisible grains adsorbed on the surface of Fe-chromite grains and/or included in Fe-oxides/hydroxides. Also in the Brasília belt, the highest Pt values and anomalies are related to nodular chromitites, regions of silification in serpentinites, sites of hydrothermal discharge and development of lateritic soils. In sites and ultramafic rocks where deformation and hydrothermalism are lacking there is no strong Pt anomaly only some weak Au anomalies.

In the Araçuaí Belt of economic interest only occur massive sulphides with Ag-minerals and some small gold occurrences. In the Ribeirão da Folha region, Araçuaí belt, the presence of Ag-minerals (AgBiPbTe: mixing of AgBiTe – volynskite? and PbTe – althaite?, besides PbAgTe and BiAgTe; figures 4 and 5), intense polideformation (occurrence of sheet folds), amphibolite facies metamorphism and Au-anomalies suggest a possible zonation of noble metals in massive sulfide deposits. It should be noted that Ag concentrates in distal positions of exhalative massive sulfides during the formation of these volcanogenic massive sulfide deposits. Thus, is possible to occur Pt, Pd and Au(Ag) deposits formed from hydrothermal discharges in deeper zones of the oceanic crust of the ophiolite and that may have been remobilized to tectono-metamorphic-hydrothermal sites.

In our opinion for Au, Pt, Pd (Ag) mineral exploration and economic deposits of the Brazilian ophiolites the interesting areas are those hydrothermalized and silicified ultramafics and podiform chromitites in the Brasília belt and sulphide horizons and diopside-rich bodies associated to bif's (oxide-magnetite; sulfide and silicate facies) in the Araçuaí belt. Also, a very important metallogenic control on any noble metal deposit in Brazil is the laterization process under development in the present days. Locally due to the "HOT" nature of ultramafic rocks in the Araçuaí and Brasília belts we suggest as possible targets, in less deformed-metamorphosed hydrothermalized sites, sections of ophiolites with original pseudoestratigraphy to search for Pt and/or Pd-rich sulfide horizons.

Figure 1- Geological-tectonic map of Brazil with the its main units and aproximate location of the ophiolitic associations in the neoproterozoic and older mobile belts (adapted from CPRM 2004 in: Suita *et al.* 2004).

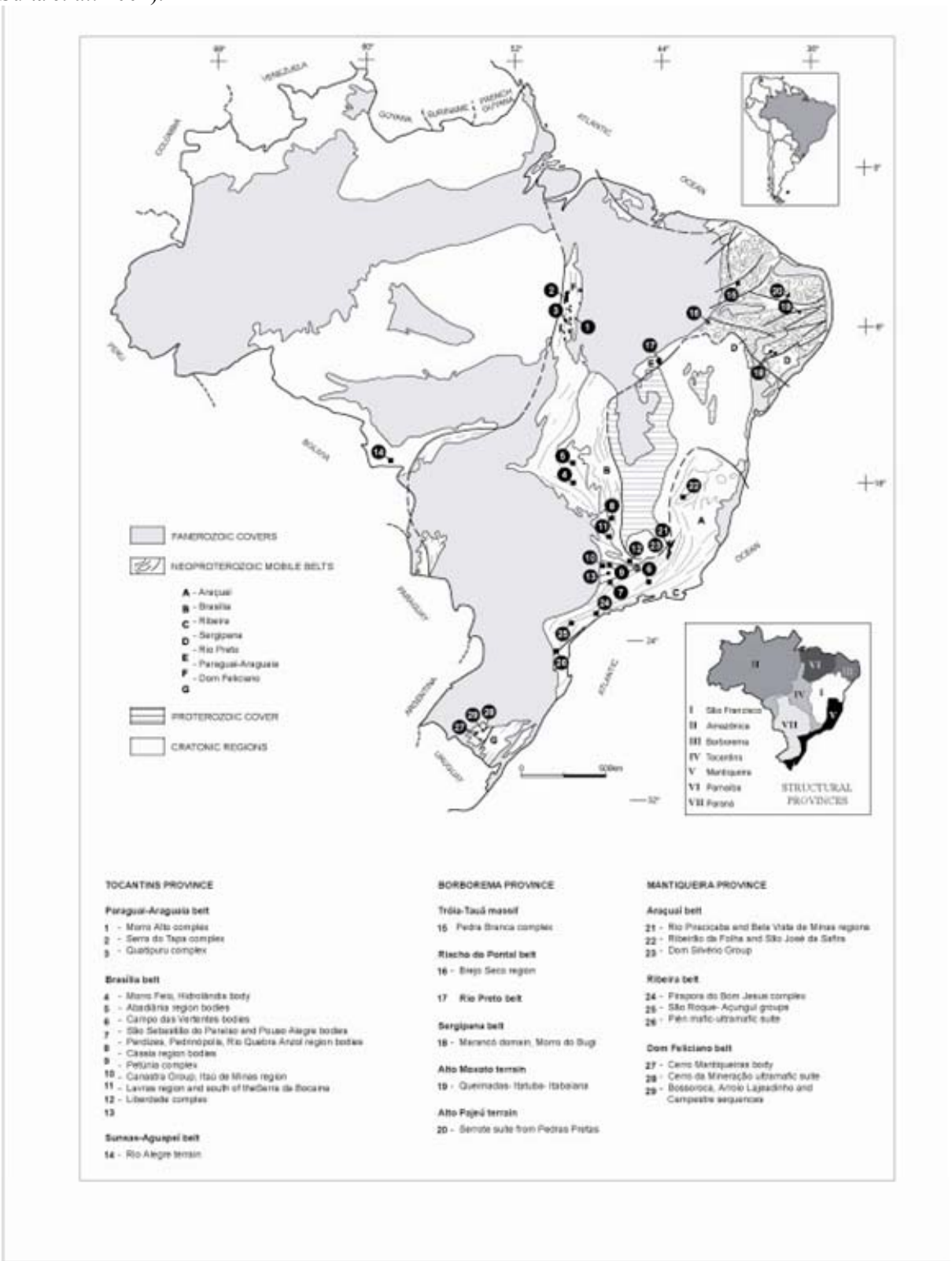

Figure 2- Photography of orbicular podiform chromitite from Morro Feio ultramafic body (Brasília belt, Goiás State).

Figure 3- Photography of massive podiform chromitite from Morro Feio ultramafic body, Brasília belt, (Goiás State).

Figure 4- Photography of an Ag-Pb-Te-mineral from massive sulfide deposits in the Ribeirão da Folha region, Araçuaí belt (Minas Gerais State).

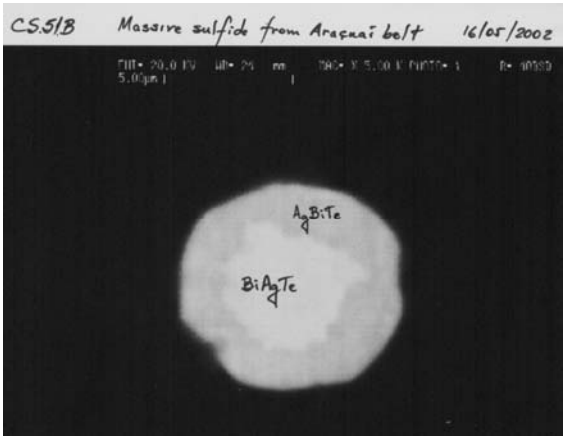

Figure 5- Photography of an Ag-Pb-Te-mineral from massive sulfide deposits in the Ribeirão da Folha region, Araçuaí belt (Minas Gerais State).