TIN, GOLD AND GRANITOIDS IN BRAZIL

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Summary
Granitoid rocks played an important role in the genesis of tin and gold deposits in Brazil. The Amazonian craton concentrates the largest deposits of both elements. Smaller tin and gold deposits are also found in central and in southern Brazil. Tin is mostly related to Proterozoic, A-type granites of the rapakivi series. W, Nb, F, REE, Th, In and Zr can be associated with Sn, which is contained in cassiterite. The biggest gold deposits are of Archean or Paleoproterozoic age and the Carajas and Tapajos provinces are the more productive.

Introduction

World class tin deposits occur in the Amazonian craton, making Brazil one of the most important tin producers in the last twenty years. Large gold provinces have also been identified in the country and, in many cases, gold deposits are temporally and spatially related with granitoid rocks. Brazilian granitoids cover all the Precambrian times from the Archean to the beginning of the Phanerozoic (final stages of the Brasiliano event).

Tin-Mineralized Granites

The largest tin deposits are found in the Amazonian craton and in the Goias province. Most of the typical tin-mineralized granites yielded U-Pb or Pb-Pb zircon ages between 1.88 and 1.00 Ga (Pimentel *et al*. 1991; Dall'Agnol *et al*. 1999; Bettencourt *et al*. 1999) and are anorogenic, A-type granites of the rapakivi series. However, in the Goias province, tin deposits hosted by 2.2 to 2.0 Ga old, syn- to post-kinematic, peraluminous granites have been recently described. In southeastern Brazil, the 0.59 Ga old, post-collisional granites of the Itu province (Wernick *et al*. 1997) are also sometimes tin-mineralized (Correias Granite). They have affinities with rapakivi, A-type granites and are related to the Brasiliano event.

Almost all tin-mineralized granites correspond to the more evolved phases of a metaluminous to slightly peraluminous series, formed only by felsic rocks (Botelho 1992; Bettencourt *et al*. 1995; Dall'Agnol *et al*. 1999). The dominant rocks are subsolvus syenogranites, however hypersolvus alkali-feldspar granites also occur. The peralkaline subsolvus albite granite of the Pitinga province is a remarkable exception (Horbe *et al*. 1991; Costi *et al*. 1995; Lenharo 1998).

Dall'Agnol *et al*. (1993) compared some tin-mineralized granites of the Amazonian craton with the Mesozoic tin-granites of the Peninsular Thailand Province (Ishihara *et al*. 1980). The latter are representative of the southeastern Asian tin-granites. These two granite groups differ in several aspects: 1) Paleo- to Mesoproterozoic vs. Mesozoic ages; 2) anorogenic, distensional vs. compressional, collisional tectonic setting; 3) A-type, rapakivi series vs. S-type, ilmenite series; 4) low vs. high contents of chlorine in altered granites. Tin-granites of Brazil are distinct in tectonic, petrogenetic and metallogenetic aspects from the southeastern Asian tin-granites. They have in common, however, the fact that both are essentially crustal granites, even if their magmas derived from extremely contrasting sources, dominantly metasedimentary for the Asian granites and metaigneous for the Brazilian granites (Botelho 1992; Dall'Agnol *et al*. 1999). Little information about the Brazilian tin deposits is available in the literature. A consequence is that the relevance of Precambrian tin deposits in a World scale has been underestimated (cf. Routhier 1980; Lehmann 1990).

Several styles of primary tin mineralization have been identified: 1) contained in/or related to albite granites; 2) associated with exo- and endogreisen; 3) present in quartz-veins; 4) associated with subvolcanic pipes; 5) contained in episyenites; 6) in pegmatites or pegmatite-like rocks. The 1, 2 and 3 types are the most frequent and the largest deposits are associated with the 1, 2 and 4 types. In the Pitinga province, the 1, 2, 3 styles are dominant (Horbe *et al*. 1991), nevertheless the only occurrence of tin-bearing episyenites described so far in the Amazonian craton was found in it (Costi *et al*. 1997). Most of the tin-mineralized albite granites are topaz-bearing and peraluminous rocks. The Pitinga albite granite is, however, a peralkaline, cassiterite-, cryolite-, riebeckite bearing, subsolvus granite (Costi *et al*. 1995). In the Bom Futuro district, in the Rondonia region (Bettencourt *et al*. 1995), voluminous tin-mineralization is concentrated in quartz veins and veinlets, associated with two subvolcanic pipes formed by topaz rhyolites and hosted in brecciated gneissic and amphibolitic rocks, and with a peraluminous albite granite with associated greisen. In the Pitinga province, besides cassiterite, massive and disseminated cryolite, together with Zr, Th, Li, Nb, REE and Rb-rich minerals, are abundant associated with the peralkaline albite granite. In other areas, wolframite, topaz, tantalite-columbite, sulphides, and, rarely, beryl, could be associated with cassiterite. In the Goias Province, significant occurrences of indium associated with sulfides have been described in topaz-quartz greisen with low modal contents of mica (Botelho 1992). Secondary deposits, practically exhausted at present, have been important in the Amazonian region (Bettencourt and Dall'Agnol 1987), where palaeovalleys and present valleys containing enriched alluvial placers of cassiterite were exploited during more than twenty years. Colluvial and eluvial placers were also locally significant.

Gold Deposits and Related Granitoids

The largest gold provinces are found in the Amazonian craton, where there are increasing evidence of gold deposits associated to Archean granitoids in the Carajás province. Important primary and secondary deposits are associated with Paleoproterozoic granitoids and volcanic rocks of the Tapajós, Juruena-Teles Pires and Amapá provinces. Many small gold deposits are associated to granitic rocks of different ages in Goias and Tocantins states, mainly related to endogranitic shear zones. There are also small gold deposits associated with Brasiliano age granitoids in southern Brazil. Generally, the gold-mineralized granitoids are described as calc-alkaline or shoshonitic, but in many cases geochemical characterization is poor and the genetic relationship with granite magmatism is also controversial.

Carajas Province – Several important copper-gold deposits have been identified in this Archean province (3.0 to 2.50 Ga). Some authors believe that the largest deposits, occurring in the Serra dos Carajas region, in the northern part of the province, are associated with singenetic, massive sulfides related to 2.76 Ga old, volcanic sequences and banded-iron formations. Other authors have emphasized the dominant role of granitic magmatism in the origin of these deposits (Huhn 1996 and references therein). Two important granitic magmatic events

have been identified in that area: batholiths of deformed alkaline granites were formed at ca. 2.55 Ga (Old Salobo Granite, Lindenmayer *et al*. 1994; Estrela Granitic Complex, Barros *et al*. 1997) and subalkaline anorogenic granites, intruded at ca. 1.88 Ga (Dall'Agnol *et al*. 1999). Recently, ca. 2.74 old, subalkaline granites have also been described. Certainly these alkaline and subalkaline granites affected the Archean sequences formed previously and also the possible associated mineralizations, leaving their geochemical and hydrothermal imprint in the present ore assemblages. The controversy is about the importance of the role played by these granites in the genesis of the mineralizations.

Huhn (1996) suggested that the Serra dos Carajas deposits are of the Cu-Au-U (-ETR) type and analogous to the Proterozoic Australian gold-copper deposits, including the classical Olympic Dam district. More research, including detailed isotopic studies, now being developed, is necessary to get an answer for these questions. However, independent of the future findings, it is clear that the understanding of the relationship between granitic rocks and mineralization is fundamental to clarify the province geologic and metallogenic evolution.

In the southern part of the province, gold mineralization is mostly associated with Archean, mafic-ultramafic greenstone belts. However, in the Cumaru district, Santos and Leonardos (1995) described gold mineralization associated with a granodiorite pluton of volcanic arc affiliation and suggested that both, shear zones and a porphyry-like system were involved in the genesis of the mesothermal gold deposit.

Tapajós Province – Recent geochronological data demonstrated that the Tapajos province is composed essentially by plutonic and volcanic rocks formed at the end of the Paleoproterozoic, between 2.1 and 1.88 Ga (Vasquez *et al*. submitted; Lamarão *et al*. 1999). Gold mineralization in the Tapajós Province has been related to two metallogenic epochs, the first one is older than 1.96 Ga and the second was formed at ca. 1.88 Ga. The older mineralization is hosted by basement gneisses, metasupracrustals and late-orogenic granitoids (1.98 Ga, Creporizão Suite), generated in an orogenic domain, probably related to a subduction zone (Vasquez *et al*. submitted). It is constituted essentially by lode-gold deposits associated to regional-scale brittle to brittle-ductile shear zones. The younger phase occurs as lodes, breccias, stockworks and disseminations. They are probably related to a post-orogenic calk-alkaline (Parauari Suite; ca. 1.89 Ga) to alkaline (Maloquinha Suite; ca. 1,88 Ga) granitic magmatism (Coutinho *et al*., 1997; Klein, in press; Vasquez *et al*., submitted) and resemble the intrusion-related model of Sillitoe (1991). 2.0 to 1.88 Ga old (Lamarão *et al*. 1999), felsic to intermediate volcanic sequences are associated with the granitoids and sometimes are also gold mineralized. The role of the late-orogenic (Creporizão Suite) and of the post-orogenic, alkaline (Maloquinha Suite) granitic magmatism in the genesis of gold mineralization is still under investigation.

Juruena-Teles Pires Province (JTP) - This province is situated in the northern Mato Grosso State (Botelho and Moura 1998) and its basement granitoid-gneissic complex is poorly studied. The JTP is an extension to the South of the Tapajós province and a similar geological evolution is admitted for both provinces (Coutinho *et al*. 1997). In the JTP, gold deposits are hosted in Paleoproterozoic, oxidized, calc-alkaline and alkaline granites. Until now, only small alluvial or primary deposits had been exploited.

The I-type, calc-alkaline granites related to gold mineralization in the JTP contain hornblende, biotite, titanite, magnetite, Fe^{3+}-rich ilmenite, pyrite and pink-colored K-feldspar and are similar to the oxidized I-type granites described in the Paleozoic fold belts of eastern Australia (Blevin and Chappell 1995). The calc-alkaline granites display high (2.6) MgO/TiO_2 ratios, as well as moderate zirconium (100 -249 ppm) and low Nb (15 ppm) and Y (9 ppm) contents. REE patterns are strongly fractionated (La/Yb = 30) with significant Eu anomalies (Eu/Eu*=0.35). These granites have geochemical signatures either of volcanic arc granites or of post-collisional granites. The age of the best known of these I-type massifs, the Matupá Massif is 1872 Ma (Paes de Barros 1994; Moura *et al*. 1997).

In the JTP, gold occurs mainly in high-grade small deposits hosted in quartz veins and often related to shear zones, or disseminated in widespread hydrothermal zones. In the Matupá Granite, gold seems to be related to a porphyry system (Botelho and Moura 1998). The mineralization is concentrated in the most intensely hydrothermalized zones. Gold is either disseminated or filling fractures in pyrite. Potassic, chloritic, sericitic and albitic alteration processes have been identified.

Pyrite and chalcopyrite $\delta^{34}S$ values for the most important gold deposits of the JTP lie between -1.0 and + 3.5, indicating a deep source of sulfur and suggesting that the origin of this gold deposits is related to magmatic fluids

Amapá Province - The Salamangone (Au) deposit (Nogueira, 1999) is one of the several (Au) deposits and prospects which occur in the Lourenço Gold District - Amapá. It is associated to the Lourenço Metamorphic Suite mainly composed of Paleoproterozoic metamorphosed supracrustal rocks and calc-alkaline (TTG) complexes. The deposit lies within a tonalitic to granodioritic pluton dated at 2.155 ± 13 Ma (U-Pb zircon age) and related to a magmatic arc. It is structurally controlled by a ductile-brittle shear zone and encompasses an epigenetic quartz-vein system enriched in Au, As, and with associated Ag, Pb, Cu and Bi. Primary mineralization consists of ribbon-quartz veins, showing gold-bearing quartz infilling microfractures, associated with arsenopyrite, pyrrhotite, loellingite and chalcopyrite, and Au associated to arsenopyrite, besides late quartz-veinlets with carbonate and chlorite.

Gold deposits related to the Brasiliano Event in southern Brazil – A number of small orogenic Au and Au-bearing base-metal deposits and prospects, as recently reported by Remus (1999), occur within the São Gabriel Block, western sector of the Precambrian Shield of Rio Grande do Sul, SW Brazil. The Camaquã, Bloco Butiá, Cerro Rico and Bossoroca deposits are the more important. According to Remus (1999), they were generated during the Brasiliano Cycle and are related to three events at ca. 700, 594 and 562 Ma. A summary of the ideas of the mentioned author about these deposits is presented below.

The Cu (Au-Ag) Camaquã deposit is interpreted to be of magmatic-hydrothermal origin, probably linked to a Cu-Au porphyry. It was generated at ca. 594 Ma during the final period of the Dom Feliciano Orogeny. The deposit is hosted by the volcano-sedimentary sequence of Bom Jardim Group and the mineralization, tentatively related to the Lavras Granite, Hilario volcanic rocks and Caçapava Granite, is dated at ca. 594 Ma. It is controlled by fractures and consists of massive veins, stockworks and disseminated ore.

The Bossoroca, gold deposit is a fault-controlled ore deposit, related to the Neoproterozoic Bossoroca Juvenile Volcanic Arc

(757 Ma). It is hosted by calc-alkaline pyroclastic andesites, dacites and minor basalts and epiclastic rocks. The mineralization encompasses veins and stockworks of quartz-gold ores with minor sulphide and telluride. The mineralizing fluids are related either to solutions derived from post-tectonic granites (550Ma) or to a regional metamorphism.

The Butiá (Au) and Cerro Rico (Cu, Au) deposits of the Lavras do Sul region are genetically associated to a post-collisional magmatism of the Don Feliciano Orogenesis (600-550Ma). The Butiá deposit is hosted by the Lavras Granite (594Ma) and consists of a vein system composed of pyrite, white micas, invisible gold with minor chalcopyrite, galena and carbonate. The Cerro Rico (Au) prospect is enclosed by volcanic rocks of the Hilario Formation (594Ma) and consists of a set of quartz-veins composed of pyrite, chalcopyrite, invisible gold and minor hematite and galena.

Conclusions

Granitoid rocks played an important role in the genesis of tin and gold deposits in Brazil. The Amazonian craton concentrates the largest deposits of both elements. Smaller tin and gold deposits are also found in central and in southern Brazil. Tin is mostly related to Proterozoic, A-type granites of the rapakivi series. W, Nb, F, REE, Th, In and Zr can be associated with Sn, which is contained in cassiterite. The tin deposits in Brazil contrast with those of southeastern Asian provinces in several aspects. The relevance of Precambrian tin deposits has been underestimated. The biggest gold deposits are of Archean or Paleoproterozoic age and the Carajas and Tapajos provinces are the more productive. In the Tapajos and Juruena-Teles Pires provinces gold mineralization is related dominantly to calc-alkaline magmatism.

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