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Metallogenesis of the Carajás Mineral Province, Southern Amazon Craton, Brazil: Varying styles of Archean through Paleoproterozoic to Neoproterozoic base- and precious-metal mineralisation

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Abstract

The Itacaiúnas Belt of the highly mineralised Carajás Mineral Province comprises ca. 2.75 Ga volcanic rocks overlain by sedimentary sequences of ca. 2.68 Ga age, that represent an intracratonic basin rather than a greenstone belt. Rocks are generally at low strain and low metamorphic grade, but are often highly deformed and at amphibolite facies grade adjacent to the Cinzento Strike Slip System. The Province has been long recognised for its giant enriched iron and manganese deposits, but over the past 20 years has been increasingly acknowledged as one of the most important Cu–Au and Au–PGE provinces globally, with deposits extending along an approximately 150 km long WNW-trending zone about 60 km wide centred on the Carajás Fault. The larger deposits (approx. 200–1000 Mt @ 0.95–1.4% Cu and 0.3–0.85 g/t Au) are classic Fe-oxide Cu–Au deposits that include Salobo, Igarapé Bahia–Alemão, Cristalino and Sossego. They are largely hosted in the lower volcanic sequences and basement gneisses as pipe- or ring-like mineralised, generally breccia bodies that are strongly Fe- and LREE-enriched, commonly with anomalous Co and U, and quartz- and sulfur-deficient. Iron oxides and Fe-rich carbonates and/or silicates are invariably present. Rhenium–Os dating of molybdenite at Salobo and SHRIMP Pb–Pb dating of hydrothermal monazite at Igarapé-Bahia indicate ages of ca. 2.57 Ga for mineralisation, indistinguishable from ages of poorly-exposed Archean alkalic and A-type intrusions in the Itacaiúnas Belt, strongly implicating a deep magmatic connection.

A group of smaller, commonly supergene-enriched Cu–Au deposits (generally <50 Mt @ <2% Cu and <1 g/t Au in hypogene ore), with enrichment in granitophile elements such as W, Sn and Bi, spatially overlap the Archean Fe-oxide Cu–Au deposits. These include the Breves, Águas Claras, Gameleira and Estrela deposits which are largely hosted by the upper sedimentary sequence as greisen-to ring-like or stockwork bodies. They generally lack abundant Fe-oxides, are quartz-bearing and contain more S-rich Cu–Fe sulfides than the Fe-oxide Cu–Au deposits, although Cento e Dezoito (118) appears to be a transitional type of deposit. Precise Pb–Pb in hydrothermal phosphate dating of the Breves and Cento e Dezoito deposits indicate ages of 1872±7 Ma and 1868±7 Ma, respectively, indistinguishable from Pb–Pb ages of zircons from adjacent A-type granites and associated dykes which range from 1874±2 Ma to 1883±2 Ma, with 1878±8 Ma the age of intrusions at Breves. An unpublished Ar/Ar age for hydrothermal biotite at Estrela is indistinguishable, and a Sm–Nd isochron age for Gameleira is also similar, although somewhat younger. The geochronological data, combined with geological constraints and ore-element associations, strongly implicate a magmatic connection for these deposits.

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The highly anomalous, hydrothermal Serra Pelada Au–PGE deposit lies at the north-eastern edge of the Province within the same fault corridor as the Archean and Paleoproterozoic Cu–Au deposits, and like the Cu–Au deposits is LREE enriched. It appears to have formed from highly oxidising ore fluids that were neutralised by dolomites and reduced by carbonaceous shales in the upper sedimentary succession within the hinge of a reclined synform. The imprecise Pb–Pb in hydrothermal phosphate age of 1861±45 Ma, combined with an Ar/Ar age of hydrothermal biotite of 1882±3 Ma, are indistinguishable from a Pb–Pb in zircon age of 1883±2 Ma for the adjacent Cigano A-type granite and indistinguishable from the age of the Paleoproterozoic Cu–Au deposits. Again a magmatic connection is indicated, particularly as there is no other credible heat or fluid source at that time.

Finally, there is minor Au–(Cu) mineralisation associated with the Formiga Granite whose age is probably ca. 600 Ma, although there is little new zircon growth during crystallisation of the granite. This granite is probably related to the adjacent Neoproterozoic (900–600 Ma) Araguaia Fold Belt, formed as part of the Brasiliano Orogeny.

Thus, there are two major and one minor period of Cu–Au mineralisation in the Carajás Mineral Province. The two major events display strong REE enrichment and strongly enhanced LREE. There is a trend from strongly Fe-rich, low-SiO_2 and low-S deposits to quartz-bearing and more S-rich systems with time. There cannot be significant connate or basinal fluid (commonly invoked in the genesis of Fe-oxide Cu–Au deposits) involved as all host rocks were metamorphosed well before mineralisation: some host rocks are at mid- to high-amphibolite facies. The two major periods of mineralisation correspond to two periods of alkalic to A-type magmatism at ca. 2.57 Ga and ca. 1.88 Ga, and a magmatic association is compelling.

The giant to world-class late Archean Fe-oxide Cu–Au deposits show the least obvious association with deep-seated alkaline bodies as shown at Palabora, South Africa, and implied at Olympic Dam, South Australia. The smaller Paleoproterozoic Cu–Au–W–Sn–Bi deposits and Au–PGE deposit show a more obvious relationship to more fractionated A-type granites, and the Neoproterozoic Au–(Cu) deposit to crustally-derived magmas. The available data suggest that magmas and ore fluids were derived from long-lived metasomatised lithosphere and lower crust beneath the eastern margin of the Amazon Craton in a tectonic setting similar to that of other large Precambrian Fe-oxide Cu–Au deposits.

Keywords: Carajás Mineral Province; Fe-oxide Cu–Au deposits; Serra Pelada; Igarapé-Bahia; Alemão; Salobo

1. Introduction

The Carajás Mineral Province is a highly mineralised metallogenic province that lies at the southeastern margin of the Southern Amazon Craton in Brazil (Fig. 1). Two Archean tectonic blocks comprise the Carajás Mineral Province, the older southern Rio Maria granitoid–greenstone terrain (Huhn et al., 1988a,b) and the northern Itacaiúnas Shear Belt (Araújo et al., 1988), which incorporates one of the best-preserved Archean volcano-sedimentary sequences in the world, the Carajás Basin.

The Itacaiúnas Belt, to date, contains by far the largest variety and accumulation of mineral deposits of the Carajás Mineral Province, being traditionally recognised for its giant supergene-enriched iron and manganese deposits (Tolbert et al., 1971; Valarelli et al., 1978; Gibbs and Wirth, 1990). However, more recently, the Itacaiúnas Belt has been recognised as a premier Cu–Au province, hosting a number of large (>200 Mt) Fe-oxide Cu–Au (Mo–Ag–U–REE) deposits (e.g., Cristalino, Igarapé Bahia–Alemão, Salobo, Sossego; Soares et al., 1999; Requia and Fontboté, 2000; Souza and Vieira, 2000; Tazava and de Oliveira, 2000; Tallarico et al., 2000; Ronzê et al., 2000) and a number of smaller (<50 Mt) Cu–Au (W–Sn–Bi) deposits that populate the belt (e.g., Águas Claras, Breves, Estrela, Gameleira; Soares et al., 1994; Silva and Villas, 1998; Tallarico et al., 2004; Volp, 2005). The Serra Pelada deposit, a rare example of a world-class epigenetic, sediment-hosted Au–Pd–Pt deposit (Grainger et al., 2002), also lies within the Itacaiúnas Belt, and, along with the other deposits, is hosted by the Archean volcano-sedimentary rocks of the Carajás Basin. Additionally, Au–(Cu) mineralisation associated with quartz breccias within small granite stocks (e.g., Formiga) has recently become apparent within the Itacaiúnas Belt.

In contrast to the Itacaiúnas Belt, the Rio Maria granitoid–greenstone terrain is characterised by orogenic lode-gold mineralisation only. The major gold deposits (<17 t Au) of this block include Sapucaia, Cumaru, Babaçu, Lagoa Seca, Tucumã and Inajá. These are characteristically base metal-poor gold deposits, in contrast to the Itacaiúnas Belt Cu–Au deposits, and generally occur in structurally-controlled quartz veins within the greenstone belt rocks (Villas and Santos, 2001).

Until recently, much controversy has surrounded the genesis of the Cu–Au deposits of the Itacaiúnas Belt with multiple genetic models being proposed including: (i) an