U-PB AND RE-OS GEOCHRONOLOGICAL CONSTRAINTS ON THE TIMING OF IRON OXIDE-CU-AU SYSTEMS IN THE SOUTHERN COPPER BELT, CARAJÁS PROVINCE

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INTRODUCTION

Most of the known IOCG deposits from the Carajás Province are situated in the Carajás Domain along or close to two distinct E-W and WNW-ESE- trending regional shear zones (>130 km-long), located at the northern and southern contacts between the ca. 2.76 Ga metavolcano-sedimentary rock units of the Itacaiúnas Supergroup (Carajás basin) and the Mesoarchean basement rocks. The Southern Copper Belt, which is the aim of this study, includes the Sossego, Cristalino and Alvo 118 deposits, and several other minor deposits, such as the Bacaba, Castanha, Bacuri, Visconde, and Jatobá IOCG deposits. Additionally, diverse barren massive magnetite bodies have also been recognized.

Succinctly, these deposits were affected by sodic (albite–scapolite–iron oxide), sodic-calcic (actinolite-rich bodies) alteration, iron oxide formation, potassic and chlorite alteration, late sericite, epidote and carbonate formation (Monteiro et al., 2008a,b; Moreto et al. 2011a; Pestilho 2011; Melo et al. Submitted).

The types and distribution of hydrothermal alteration zones, fluid inclusion and stable isotope data (Monteiro et al. 2008a; Pestilho 2011; Torresi et al. 2012) suggest that the IOCG deposits from the Southern Copper Belt were formed at a range of depths, and that the hydrothermal fluids had variable sources. However, a deeper comprehension and comparison between these deposits is limited by the scarcity of reliable geochronological data that allows to define the ages of the alteration and IOCG mineralizing event(s).

U-Pb SHRIMP II in hydrothermal xenotime from the Alvo 118 deposit (Tallarico 2003) suggests ore genesis at 1.88 Ga. Chalcopyrite from the Visconde and Cristalino deposits yielded Neoarchean Pb-Pb ages of 2.74 Ga and 2.70 Ga, respectively, which were interpreted as the timing of mineralization at these deposits (Soares et al. 2001; Silva et al. 2012). At the Sossego deposit, chalcopyrite concentrates from the Sequeirinho and Sossego orebodies provided the 2.53 Ga and 1.59 Ga Pb-Pb ages, respectively, which were attributed to isotopic resetting due to subsequent thermal/ deformational events (Neves 2006).

This study presents new geochronological data, such as Re-Os in molybdenite and U-Pb LA-MC-ICPMS in hydrothermal monazite of the Sossego, Bacaba and Bacuri deposits aiming to determine the age interval(s) of IOCG formation. These results not only provide new insights into the timing of IOCG formation, but also give a clearer comprehension of the IOCG metallogenesis at the Southern Copper Belt.

U-Pb AND Re-Os GEOCHRONOLOGY

Re-Os molybdenite and U–Pb LA–MC-ICPMS monazite data for the Sossego (Sequeirinho, Pista, Sossego and Curral orebodies), Bacaba and Bacuri deposits were acquired at the Radiogenic Isotope Facility of the University of Alberta, Edmonton, Canada. Three samples of molybdenite were selected for the Re-Os systematic, including two mineralized samples from the Pista orebody (Sossego deposit) and one from the Bacuri deposit. Samples SOS 364/76.84 and SOS 364/160.9, from drill cores of the Pista orebody, were hosted by the 2.96 Ga Pista metavolcanic rock and yielded Re-Os model ages of 2,685 ± 11 Ma and 2,710 ± 11 Ma. Molybdenite crystals from oe sample BRID 01/45 from the Bacuri deposit produced a Re-Os model age of 2,758 ± 11 Ma.

Hydrothermal monazite crystals were extracted from ore breccia of the Sequeirinho (SOS 259/270), Sossego (Min-Cp-SOS and SOS315/ 255.1) and Curral orebodies (SOS106/84) of the Sossego deposit, and from the Bacuri (BRID/115.42) and Bacaba (BACD25/229.25 and BACD15/237.4) deposits. A brief description of the samples and the U-Pb results, which yielded ages between ca. 2.72 to 1.89 Ga, are summarized in Table 1.

Table 1. Synthesis of the results of U-Pb dating of monazite

Rock	***Age (Ma)***	***MSWD***
Sossego deposit		
Sequeirinho orebody		
Ore breccia (SOS 259/270)	2,712.3±4.7	1.6
Sossego orebody		
Ore breccia (Min-Cp-SOS)	1,878.9±4.1	1.3
Ore breccia (SOS 315/255.1)	1,904±5.2	1.2
Curral orebody		
Ore breccia (SOS 106/84)	1,889.8±8.5	2.7
Bacuri deposit		
Chlorite and scapolite altered rock (BRID 07/115.42)	2,703.0±5.8	3.9
Bacaba deposit		
Ore hosted by the Bacaba Tonalite (BACD 25/229.25)	2,681±11	3
	2,054.1±8.8	10.2
Albite altered and silicified Serra Dourada Granite (BACD 15/237.4)	2,716.4±8.4	2.4

DISCUSSION AND CONCLUSIONS

The geochronological data presented in this study combined with also reliable data from the Alvo 118 deposits (U-Pb in hydrothermal xenotime; Tallarico 2003) and Pb-Pb systematics (chalcopyrite) from the Cristalino and Visconde deposits (Soares et al. 2001; Silva et al. 2012) suggest that multiple Neoarchean and the Paleoproterozoic hydrothermal systems were responsible for alteration and/or IOCG ore formation at the Southern Copper Belt.

Multiple hydrothermal events took place at: i) 2.76 Ga, recorded in molybdenite from the Bacuri deposit, which predate the main stage of ore formation; ii) 2.71-2.70 Ga, registered in hydrothermal monazite from the Bacuri and Bacaba deposits, and Sequeirinho orebody, and molybdenite from the Pista orebody; iii) 2.68 Ga, obtained in hydrothermal monazite and molybdenite from the Bacaba deposit and Pista orebody, respectively; iv) 2.05 Ga, recorded in hydrothermal monazite from the Bacaba deposit; v) 1.90 Ga, evidenced by hydrothermal monazite grains crystallized at the Sossego orebody; vi) 1.88-1.87 Ga, suggested by hydrothermal monazite from the Sossego and Curral orebodies, and hydrothermal xenotime from Alvo 118 deposit.

The 2.71-2.68 Ga and 1.90-1.87 Ga intervals are interpreted as the main episodes of IOCG ore formation at the Southern Copper Belt. In this sense, recurrence hydrothermal systems, even at a single deposit scale, is strongly suggested. The Pb-Pb ages from the Visconde (2,747 ± 140 Ma, MSWD=12; Silva et al. 2012) and Cristalino (2,700 ± 29 Ma, MSWD=656; Soares et al. 2001) deposits are very imprecise due to their large errors, and for this reason were not associated with any interval of a hydrothermal event as shown above. However, the data possibly indicate that the event(s) responsible for ore genesis likely took place in the Neoarchean.

The older 2.76 Ga hydrothermal event is contemporary with the deposition of the metavolcanic (-sedimentary) sequence of the Itacaiúnas Supergroup. Hydrothermal fluids from the basin may have circulated through crustal weaknesses, causing hydrothermal alteration in the Bacuri deposit area.

The major 2.71-2.68 Ga IOCG mineralizing interval, responsible for deep-emplaced IOCG systems (e.g., Sequeirinho-Pista-Baiano orebodies; Figure 1A), is apparently not directly related to magmatic events. For these systems are proposed that regional circulation of hot (> 500°C) and saline hydrothermal fluids, causing metal leaching from the country rocks and subsequent ore deposition, is related to the ca. 2.7 Ga tectonic inversion of the Carajás Basin, in response to a regional phase of sinistral transpression controlled by a NNE-directed oblique shortening. This tectonic event caused the reactivation of the Carajás and Cinzento strike-slip fault systems, and likely the ductile shear zone where the IOCG deposits are located.

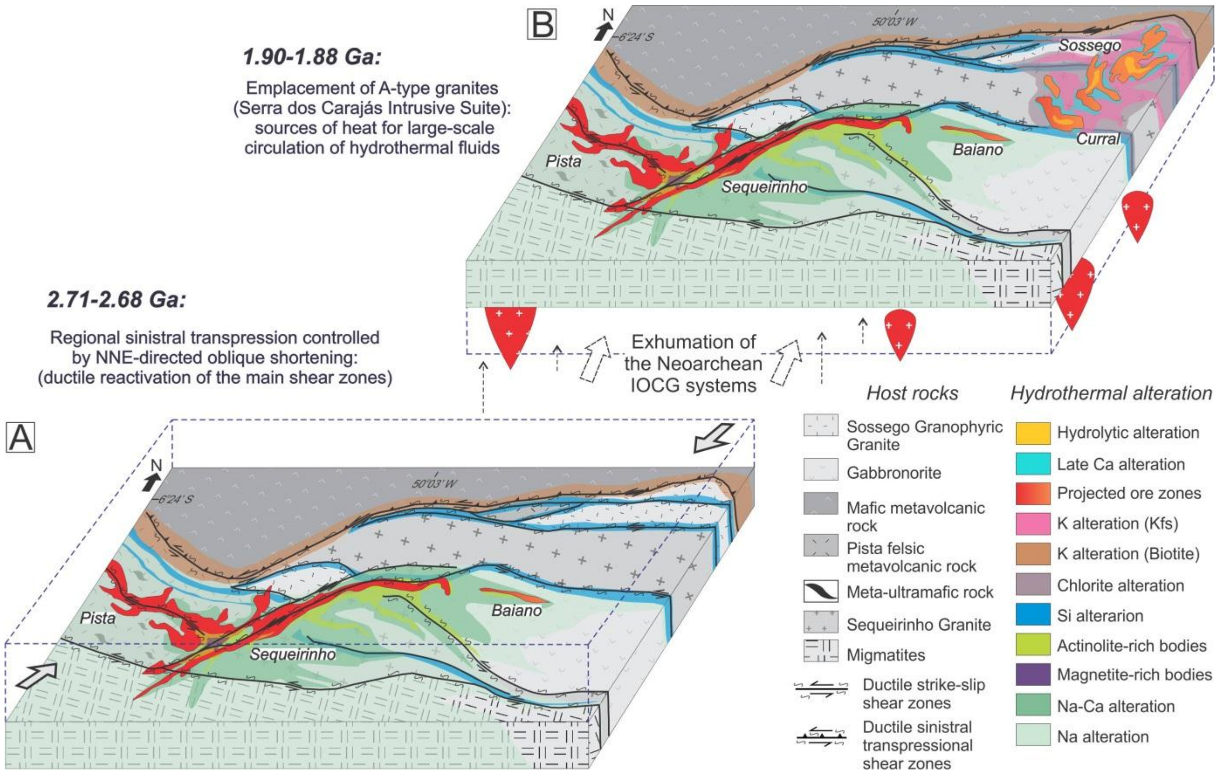

Figure 1. Schematic diagram showing the metallogenetic evolution of the Sossego deposit in time. A) Formation of the Sequeirinho-Pista-Baiano orebodies at 2.71-2.68 Ga in the interception of WNW-ESE and NE-SW ductile shear zones; B) Formation of the vertical pipe-like Sossego-Curral orebodies at 1.90-1.88 Ga after exhumation of the Neoarchean IOCG systems.

The late Rhyacian (2.05 Ga) hydrothermal event, could have also been trigged by heat sources related to another reactivation of the regional shear zones nucleated during the Archean, in response to a weak tectonic inversion of the Carajás Basin between 2.0 to 1.8 Ga, under dextral transtension.

Finally, for the Orosirian event (1.9-1.87 Ga), responsible for shallow-emplaced IOCG deposits emplaced after exhumation of the Neoarchean systems (e.g., Sossego-Curral orebodies; Figure 1B), it is likely that the widespread 1.88 Ga anorogenic magmatism in the Carajás Province provided heat sufficiently high to cause the circulation of hydrothermal fluids in regional scale, along the crustal discontinuities. These hot (> 400°C) and saline fluids may have caused reworking of the Neoarchean IOCG deposits, leading to elements remobilization and additional hydrothermal alteration and ore deposition.

The extensive zones of chlorine-bearing marialitic scapolite alteration in the rocks from the Southern Copper Belt may have played an important role in the episodicity of hydrothermal and ore systems. This type of sodic alteration is not only widely recognized in several deposits (e.g., Bacaba, Castanha, Bacuri, Sequeirinho; Monteiro et al. 2008a, Moreto et al 2011a; Pestilho 2011) but also widespread through the country and host rocks. Regional migration of hydrothermal fluids through areas with widespread marialite alteration possibly released chlorine and sodium to the hydrothermal fluid, increasing its total salinity and, therefore, the capacity of metal (Cu) transport.

Acknowledgements We are very grateful to the VALE Company, notably to Márcio Godoy, Benevides Aires and Cleive Ribeiro for their invaluable assistance. This research was funded by CNPq (555065 /2006-5, 472549 /2009-0 and 303359 /2008-0), INCT GEOCIAM (CNPq/ MCT/ FAPESPA 573733/ 2008-2), and Fapespa/VALE Grant. Carolina P. N. Moreto also thanks FAPESP (2009/ 18371-0) for the PhD scholarship.

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