Pb-Pb, C and O isotopic evidence for deep and shallow crustal rocks contributing to the Córrego Paiol Gold Deposit (Tocantins State) hydrothermal system

Emílio Lenine Carvalho C. da Cruz[1], Raul Minas Kuyumjian[2], Neal McNaughton[3], Steffen Hagemann[3],

CPRM[1], UnB[2], and UWA[3]: e-mail: ecruz@cprm.gov.br

Introduction

The Neoproterozoic Brasília Fold Belt (BFB) has evolved along the western margin of the São Francisco Craton (SFC) (Fig. 1). The basement rocks exposed in the External Zone of the BFB represent an extension of the cratonic basement (Almeida 1981; Cruz & Kuyumjian 1993) and include the Almas-Conceição Terrane (ACT, formerly refereed as Tocantins Terrane) (Fig. 2). Gold deposits are known in basement rocks, Meso-Neoproterozoic metasedimentary cover and in the Neoproterozoic juvenile arc systems located to the west of the BFB. In most cases these deposits are structurally controled (Araújo Filho & Kuyumjian 1996). Isotopic dating is not available for the great majority of gold deposits. However, the few ages and structural correlations suggest gold mineralizing events associated with the Brasiliano Orogeny. Also related to the Brasiliano Orogeny are lead and zinc deposits hosted by the metasedimentary units that cover most of BFB basement units and large cratonic areas (Iyers et al. 1992). In this work, we interpret Pb-Pb data of mineral deposits of this large region in order to determine the isotopic composition of the main lead reservoirs at the orogenic scale. Also, we discuss lead isotopic data from the Córrego Paiol gold deposit (CPD) ore pyrite and of whole-rock samples of host-amphibolite and surrounding granite-gneiss complexes of the ACT in order to constrain the local source rocks of lead and, by analogy, of gold (Cruz 2001). Additionally, C and O stable isotopes data from ore associated carbonates from the CPD are used to constrain a metallogenetic model for the deposit. It is inferred that the lower crust and overlying Meso-Neoproterozoic units (Natividade, Bambuí and Paranoá groups) contributed fluids, solutes, and perhaps gold, to the mineralizing system.

Major regional lead reservoirs

Reinterpretation of previously published data has led to the identification of the following reservoirs:

i) A lower crustal reservoir that has supplied lead with high $^{238}U/^{204}Pb$ (μ) and Th/U ratios, is found in the Bambuí Group Type II lead of Babinski (1993), the most radiogenic galenas from Morro do Ouro, Morro Agudo and Vazante ores, and the least radiogenic galena from Monte do Carmo gold showings. This lead has most likely a Paleoproterozoic age.

ii) An upper crustal reservoir that corresponds to J-type lead of Bambuí Group galenas, Type III lead of Babinski (1993) and the least radiogenic galenas from the Morro do Ouro, Morro Agudo and Vazante ores. This lead has a great dispersion of $^{206}Pb/^{204}Pb$ and evolution with lower Th/U ratios, that represents an Archaean source.

iii) Type I lead of Babinski (1993) is found in calcareous rocks of the Bambuí Group, and has a source with high U/Pb ratios and a post depositional evolution and may indicate formation during later deformational events.

iv) Neoproterozoic mantle represented by galena of Zacarias Au-Ag-Ba deposit (μ of 9.56-9.61) sited in the Western Goiás Magmatic Arc (Poll 1994).

In this new approach, most of the above mentioned deposits are best explained by a mixture of lower and upper crustal lead, with the exception of Zacarias that has mantle lead. These mixtures yielded the observed linear arrays of lead isotope data for the deposits. Lead isotope data for this large region are best explained in lead evolution by a cratonic or continental environment of Doe & Zartman's (1979) pumblotectonic model , instead of the orogen curves of Stacey & Kramers (1975).

Local Reservoirs

Zircon and titanite U-Pb SHRIMP ages (Cruz et al. 2000) and whole-rock lead analyses of granite-gneiss complexes and granitoid plutons of ACT were used to model initial μ values using the Stacey & Kramer (1975) growth curve. Obtained source μ values were 10.27 for 2,2Ga low-K calc-alkaline metaluminous granitoids (Suite 1), 10.69 for 2.2Ga low-K calc-alkaline peraluminous granitoids (Suite 2), and 10.77 for 2.45Ga low-K calc-alkaline peraluminous granitoids (Ribeirão das Areias Complex, RAC). Amphibolites of Córrego Paiol Formation are intruded by 2,45Ga granitoid, and if this age is considered the minimum age of the amphibolites, the obtained μ (for 2,45Ga), fitted to amphibolite whole-rock lead analysis, would be too low to account for the pyrite ore lead for the CPD.

Pyrite Lead Isotopic Data

All pyrite samples plot above the Stacey & Kramer (1975) curve in an uranogenic lead diagram with μ varying form 10.31 to 11.16. $^{206}Pb/^{204}Pb$ ratios range from 15.830 to 17.414 and $^{207}Pb/^{204}Pb$ from 15.531 to 17.414. Model ages of 1959-1120Ma are much older than the age of mineralization of 535.4±0.7Ma, as given by Ar-Ar dating in hydrothermal muscovite. In the thorogenic lead diagram, pyrite samples plot slightly above Stacey & Kramer's (1975) curve, which indicates a lower crustal reservoir (lower Th/U ratios). $^{208}Pb/^{204}Pb$ ratios range from 35.888 to 37.218.

Source of Lead in Pyrite

Constructions of paleoisochrons of granite-gneiss complexes to 535Ma indicate Suite 2 as the best candidate for the local source of lead in CPD pyrite. Suite 2 has isotopic ratios as low as those of pyrite and μ in the same range. RAC granitoids have a suitable μ, but its isotopic ratios are much higher than those of ore pyrite. However, the least radiogenic lead in pyrite has a lower crustal signature (higher Th/U) suggesting that mineralizing fluids percolated through lower crustal rocks. Modelled μ (10.69-10.77) for the source region of Suite 2 and RAC indicate that the lower crust of ACT has $^{238}U/^{204}Pb$ ratios high enough to yield such a signature. The generation of granulitic belts during the Transamazonian Orogeny (~2.1Ga) in adjacent basement terranes (SFC and Porto Nacional Complex) may have depleted the lower crust of ATC in uranium. Therefore, the delayed isotopic evolution of CPD lead may be produced by granulite facies metamorphism of ACT lower crust. Further, granulitic enclaves are described amongst granite-gneiss complexes (Costa 1984). Moreover, the most radiogenic lead of CPD pyrite may represent a mixture of upper crustal lead with local sources such as Suite 2 granitoids.

Carbonate C and O Isotopes

Ore ankerite was analysed for C and O stable isotopes. $\delta^{13}C$ (PDB) values (-2.2 to –0,7‰) is typical of marine carbonate and/or calcareous rocks. Moreover, these values are in agreement with those found in calcareous rocks of Meso-Neoproterozoic cover (Bambuí and Paranoá Groups) that range from –2.6 to +16.1‰ (Babinski 1993, Santos et al. 2000), with the lowest values coming from the basal units of these groups. $\delta^{18}O$ (PDB) values (-17.6 to –16,6‰) are more negative than those of Meso-Neoproterozoic cover (-13.9 to –0.2‰) and suggest that fluids derived from, or interacted with, a deep source. Therefore, stable isotopes are in agreement with lead results indicating deep and upper (Bambuí, Paranoá and Natividade? groups) crustal reservoirs.

Conclusions

Isotopic data of CPD ore indicates that auriferous fluids interacted with rock units of both lower and upper crustal origin. Lead isotopic ratios suggest that a Pb reservoir with high initial $^{238}U/^{204}Pb$ ratios (μ) that was depleted in U by granulitization during the Transamazonian Orogeny is present in the lower crust of ACT and SFC. $\delta^{13}C$ values points to the participation of components from Meso-Neoproterozoic rocks in the auriferous hydrothermal systems and places a genetic link between the basement-hosted CPD and deposits hosted by Meso-Neoproterozoic cover, such as the Santa Rita Prospect (Olivo et al 1991).

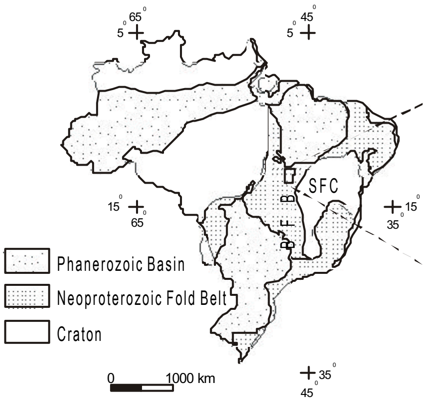

Fig. 1. Brazilian structural provinces (simplified after Almeida *et al.* 1981). Brasília Fold Belt (BFB); São Francisco Craton (SFC)

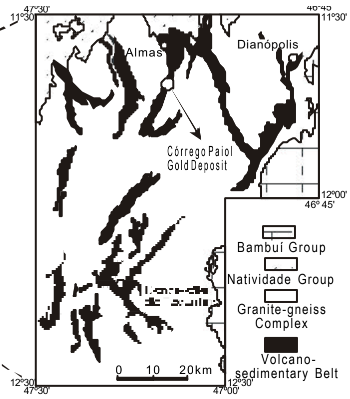

Fig. 2. Geological map of Almas-Conceição Terrane (simplified after Padilha 1984)

Acknowledgements. We thank CVRD for providing access to the Córrego Paiol mine drill cores and Dr. S. S. Iyer (University of Calgary)for stable isotopes analysis. The first author specially thanks CNPq for its financial support (grants 143168/96-7 and SWE 201150/97-2).

References

Almeida F. F. M.1981. O Cratón do Paramirim e suas relações com o do São Francisco. In: SBG, Simpósio sobre o Craton do São Francisco e suas Faixas Marginais, Salvador, *Anais*, 1-9.

Araújo Filho J. O., Kuyumjian R. M. 1996. Regional distribution and structural control of the gold occurrences/deposits in the Goiás Massif and Brasília Belt. *Revista Brasileira de Geociências*, **26**(2):109-112.

Babinski M. 1993. *Idades isocrônicas Pb-Pb e geoquimica isotópica de Pb das rochas carbonáticas do Grupo Bambuí, na porção sul da Bacia do São Francisco*. Instituto de Pesquisas Energéticas e Nucleares, Autarquia Associada à Universidade de São Paulo, São Paulo, Tese de Doutoramento, 129p.

Costa J. B. S. 1984. *Aspectos litoestruturais e evolução crustal da região centro-norte de Goiás.* Centro de Geociências, Universidade Federal do Pará, Belém, Tese de Doutoramento, 210p.

Cruz E. L. C. C. da, Kuyumjian R. M. 1993, O embasamento da porção norte da Faixa Brasília na região de Almas-Dianópolis (TO) e seu contexto geodinâmico durante o Brasiliano. In: SBG, Simpósio sobre o Craton do São Francisco Salvador, 2, Salvador, *Anais*, 302-304.

Cruz E. L. C. C. da, Kuyumjian R. M., McNaughton N., Hagemann S. 2000. Paleoproterozoic U-Pb SHRIMP ages of low- and high-Al low-K calc-alkaline granitoids in the Brasilia Fold Belt basement. In: International Geological Congress, Rio de Janeiro, 31st, *Abstract Volume CD-ROM*.

Cruz E. L. C. C. da. 2001. *A gênese e o contexto tectônico da mina Córrego Paiol: um depóito de ouro hospedado em anfibolito do embasamento da Faixa de Dobramentos Brasília*. Instituto de Geociências, Universidade de Brasília, Brasília, Tese de Douroramento, 183p.

Doe B. R., Zartman R. E. 1979. Plumbotectonics: The Phanerozoic. In: H. L. Barnes (ed.) *Geochemistry of Hydrothermal Ore Deposits*, Wiley Interscience, 22-70p.

Iyer S. S., Hoefs J., Krouse H. R. 1992. Sulfur and lead isotopo geochemistry of galenas from the Bambuí Group, Minas Gerais, Brazil—implications for ore genesis. *Economic Geology*, *87*:437-443.

Padilha, J. L. 1984. Prospecção de ouro na região nordeste de Goiás - Projeto Pindorama - DOCEGEO. In: SBG, I Encontro Regional do Ouro de Goiás, Goiânia, *Anais*, 78-92.

Poll N. P. 1994. *The geology of the Zacarias gold-silver-barite deposit, Goiás State, Brazil*. Department of Geology and Geological Engineering of the Colorado School of Mines, Golden, Master of Science Thesis, 124p.

Olivo G. R., Marini O. J., Giuliani G. N. 1991. Hydrothermal gold occurrences hosted by middle to upper Proterozoic carbonate sequence: The exemple of Santa Rita prospect, Goiás, Brazil. In: E. A. Ladeira, (ed.), *Brazil Gold'91*, Balkema, Rotterdam, 339-341.

Santos R. V., Alvarenga C. J. S., Dardenne M. A., Sial, A. N., Ferreira V. P. 2000. Carbon and oxygen profiles across Meso-Neoproterozoic limestones from central Brazil: Bambuí and Paranoá groups. *Precambrian Research*, **104**:107-122.

Stacey J. S., Kramers J. D. 1975. Approximation of terrestrial Lead isotope evolution by a two-stage model. *Earth and Planetary Science Letters*, **26**:207-221.