Metamorphic evolution and Ar-Ar geochronology of Córrego Paiol gold mine host amphibolites, Tocantins State: implications to mineralization timing.

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Introduction

Typical orogenic gold deposits in Archaean-Paleoproterozoic greenstones were formed nearly contemporaneous with or post-date metamorphism of their host terranes by 70-100Ma (Wong et al. 1991; Hanes et al. 1992). The link between gold mineralization and metamorphism remains a long-standing subject of debate (Kerrich &Fryer 1979). The basic idea is that during progressive metamorphism of the volcano-sedimentary pile, fluid released, mainly in the greenschist-amphibolite facies transition, would have the suitable composition to carry gold bearing complexes (Phillips & Powell 1993). Moreover, the so-called gold-only provinces or the highly mineralized parts of orogens would have a dominant high-T/low-P metamorphic regime (Goldfarb et al. 1991, Phillips & Powell 1993). Aiming to elucidate the timing relationship between gold mineralization in the Córrego Paiol gold deposit (CPD) and regional metamorphism, Ar-Ar dating was accomplished in one sample of hydrothermal muscovite associated with mineralization in the CPD and one sample of metamorphic amphibole from amphibolite of Córrego Paiol Formation, which hosts the deposit. Ar-Ar spectra are interpreted in the light of the thermal evolution of host amphibolites, as obtained from geothermobarometric calculation (Cruz 2001).

Regional Metamorphic Setting

The CPD is hosted by amphibolites of the Córrego Paiol Formation, which is part of the Almas-Conceição Terrane (ACT, formerly refereed as Tocantins Terrane), basement to the northern part of the Brasília Fold Belt (BFB) External Zone (Fig.1). Basement rocks of the External Zone retained a memory of a long thermal history with K-Ar ages ranging from 2487 to 553Ma (Hasui et al. 1980; Sparremberg & Tassinari 1999), revealing the influence of the Brasiliano Orogeny. Thermochronology of the BFB Internal Zone shows an early granulitic event at 790Ma and a more typical Brasiliano metamorphic peak at 590-640Ma (Pimentel et al. 1999).

In the ACT, amphibolites of the Córrego Paiol Formation display an older foliation (S_n), probably coeval to the intrusion of granite-gneiss complexes related to D_n that locally preserve the M1 metamorphic assemblages Fe-hornblende+andesine and hornblende+ilmenite (Cruz &

Kuyumjian 1998, Cruz 2001), which indicate amphibolite facies conditions (>550°C, Liou et al. 1974). Amphibolites cropping out amongst granite-gneiss complexes locally preserve relicts of the assemblage hornblende+clinopyroxene, probably related to M1. M2 assemblages show early albite-epidote facies conditions (Fe-hornblende+albite+epidote±quartz±chlorite) followed by greenschist facies conditions (Fe-actinolite+albite+epidote+quartz+chlorite). The transition between albite-epidote facies occurs at 525±25°C and pressures around 5-7 kbars (Apted & Liou 1983). M2 assemblages are related to mainly N20°E D_{n+1} right-lateral shear zones that host most gold showings in ACT. N0-10°E and N10-20°W righ-lateral shear zones are subordinated (Cruz & Kuyumjian 1999)

Geothermobarometry and P-T-t path

Calculations were performed using the geothermobarometer of Triboulet (1992), which is suitable for the assemblage (Na-Ca)amphibole+albite+epidote+chlorite+quartz. Albite-epidote facies M2 assemblages describe a retrograde trajectory that starts at about 7 kbars and temperatures of 550-600°C and follows a nearly isothermal decompression reaching 3-4 kbars. The P-T-t path bends to describe a nearly isobaric (2-4kbars) trajectory cooling down to 300°C, as calculated from M2 greenschist facies assemblages. Hydrothermal assemblages at CPD are coeval to M2 greenschist assemblages, but result from increasing XCO_2 toward the center of the hydrothermal halo. Hydrothermal chlorite at CPD indicate temperatures of 320-440°C (Cathelineau 1988) for gold mineralization. Pressures around 2kbars were calculated using Berman's (1991) thermodynamic data set. These calculations indicate that gold mineralization took place in the final stages of a clockwise P-T-t path, typical of a collisional setting.

Ar-Ar Geochronology

Samples were irradiated in the USGS Triga reactor, Denver, USA, following the technique described by Snee et al. (1988). The spectrum of amphibole sample (EL-194) at lower temperature shows an initial step with an age of 665.0±1.1Ma (11.2% of ^{39}Ar released at 800°C), followed by a plateau with an age of 702.4±0.9Ma (68.2% of ^{39}Ar released at 950°C)(Fig.2a). The age spectrum then steps to an age of 2019.1±6.4Ma. $^{39}Ar/^{36}Ar$ *vs.* $^{40}Ar/^{36}Ar$ plot shows two events recorded by this sample, one related to the Transamazonian Orogeny and the other to the Brasiliano Orogeny. The Ar release spectrum for hydrothermal muscovite from CPD (sample FD31-348) gives a plateau age of 535.4±0.7Ma (Fig 2b). This apparent muscovite age rises over the last 40% of ^{39}Ar released to up to 593.6±0.8Ma.

Timing of Gold Mineralization

Geothermobarometric study of the CPD and host amphibolites has shown that the onset of gold mineralization occurred after isothermal uplift and during the cooling stage of a clockwise collisional P-T-t path (Fig. 3). Ar-Ar geochronology has constrained this evolution to the Brasiliano Orogeny. Furthermore, our data show that metamorphic peak was reached earlier in the northern part of External Zone (665-702Ma) than in the Internal Zone of the BFB (590-640Ma). The late character of gold mineralization (535Ma) in relation to the thermal evolution of BFB is reinforced by the deformational and metamorphic history of host amphibolites. We propose that D_{n+1} shear zones developed late in the cooling stage of the clockwise P-T-t trajectory and acted as channelways to transport fluids generated in deeper crustal levels. These fluids are more akin to metamorphic fluids because there is no record of Brasiliano igneous activity in the External Zone of the BFB. Therefore, mineralizing hydrothermal fluids are more likely to be generated by dehydration of mid to lower crust while the thickened crust was undergoing slower uplift rates and upper crustal rocks would have already been cooled down to greenschist facies conditions.

Conclusions

Our Ar-Ar geochronology data for the ATC and CPD show a thermal history that lasts at least 170Ma. These data imply that thermal evolution of Proterozoic collisional orogens, and associated gold metallogeny, last longer than those of Archaean-Paleoproterozoic granite-greenstone terranes. Therefore, gold metallogeny models based on Archaean-Paleoproterozoic tectonics are unlikely to be directly applicable to Neoproterozoic collisional orogens. Field work, petrography, and geothermobarometric calculations are essential to constrain the interpretation of Ar-Ar data. A Neoproterozoic age to gold mineralization opens perspectives to gold exploration within overlying Meso-Neoproterozoic units, such as Natividade and Bambuí Groups.

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References

Almeida F. F. M., Hasui, Y., Neves, B. B. de B., Fuck R. A. 1981. Brazilian structural provinces: an introduction: *Earth Sciences Reviews*, **17**:291-317.

Apted M. J., Liou J. G. 1983. Phase relations among greenschist, epidote-amphibolite, and amphibolite in a basaltic system. *American Journal of Science*, **283A**:328-354.

Berman R. G. 1991. Thermobarometry using multi-equilibrium calculations: A new technique, with petrological applications. *Canadian Mineralogist*, **29**: 833-855.

Cathelineau M. 1988. Cation site occupancy in chlorites and illites as a function of temperature. *Clay Minerals*, **23**:471-485.

Cruz E. L. C. C. da; Kuyumjian R. M. 1998. Geology and tectonic evolution of the Tocantins grenite-greenstone terrane: Almas-Dianópolis region, Tocantins State, central Brasil. *Revista Brasileira de Geociências*, **28**(2):173-172.

Cruz E. L. C. C. da, Kuyumjian R. R. 1999. Mineralizações auríferas filoneanas do terreno granito-greenstone do Tocantins. *Revista Brasileira de Geociências*, **29**(3):291-298.

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.

Goldfarb R. J., Snee L. W., Pickthorn W. J. 1993. Orogenesis, high-T thermal events, and gold vein formation within metamorphic rocks of the Alaskan Cordillera. *Mineralogical Magazine*, **57**:375-.

Hanes, J. A.; Archibald, D. A.; Hogdson, C. J.; Robert, F. 1992. Dating of Archean auriferous quartz vein deposits in the Abitibi greenstone belt, Canada, $^{40}Ar/^{39}Ar$ evidence for a 70- to 100-m.y.-time gap between plutonism-metamorphism and mineralization. *Economic Geology*, **87**:1849-1861.

Hasui Y., Tassinari C. C. G., Junior O. S., Teixeira, W., Almeida F. F. M. de, Kawashita K. 1980. Datações Rb-Sr e K-Ar no centro-norte do Brasil e seu significado geológico-geotectônico. In: SBG, Congresso Brasileiro de Geologia, 31, Balneário de Camburiú, *Anais*, 5:2.669-2.676.

Kerrich R., Fryer B. J. 1979. Archean precious-metal hydrotermal systems, Dome Mine, Abitibi Greenstone Belt. II. REE and oxygen isotope relations. *Canadian Journal of Earth Science*, **16**:440-458.

Liou J. G., Kuniyoshi S., Ito K. 1974. Experimental studies of the phase relations between greenschist and amphibolite in a basaltic system. *American Journal of Science*, **274**:613-632.

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.

Phillips G. N., Powell R. 1993. Link between gold provinces. *Economic Geology*, **88**:1084-1098.

Pimentel M. M., Fuck A. F., Botelho N. F. 1999. Granites and the geodynamic history of the neoproterozoic Brasília belt, Central Brazil: a review. *Lithos* **46**:463-483.

Snee L. W., Sutter J. F., Kelly W. C. 1988. Thermochronology of economic mineral deposits: dating the stages of mineralization at Panasqueira, Portuga, by high-precision $^{40}Ar/^{39}Ar$ age specturm techniques on muscovite. *Economic Geology*, **83**:335-354.

Sparrenberger I., Tassinari C. C. G. 1999. Subprovíncia do Rio Paranã (GO): um exemplo de aplicação dos métodos de datação U-Pb e Pb-Pb em cassiterita. *Revista Brasileira de Geociências*, **29**(3):405-414.

Triboulet C. 1992. The (Na-Ca) amphibole-albite-chlorite-epidote-quartz geothermobarometer in the system S-A-F-M-C-N-H_2O. 1. An empirical calibration. *Journal of Metamorphic Geology*, **10**:545-556.

Wong L., Davis D. W., Krogh T. E., Robert, F. 1991. U-Pb zircon and rutilo chronology of Archean greenstone formation and gold mineralization in the Val d'Or region, Quebec. *Earth and Planetary Science Letters*, **104**:325-336.

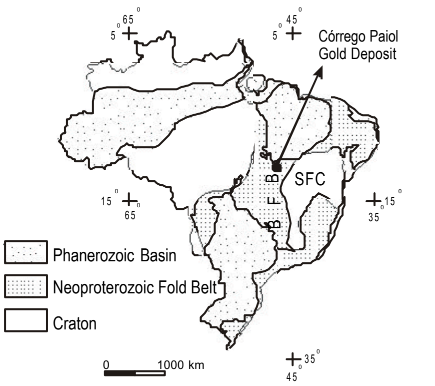

Fig. 1. Brazilian structural provinces (simplified after Almeida *et al*. 1981). Brasília Fold Belt (BFB; São Francisco Craton (SFC)

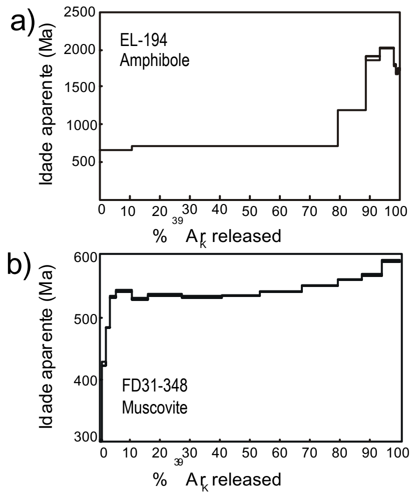

Fig. 2. Ar-Ar age sptectra of studied samples.

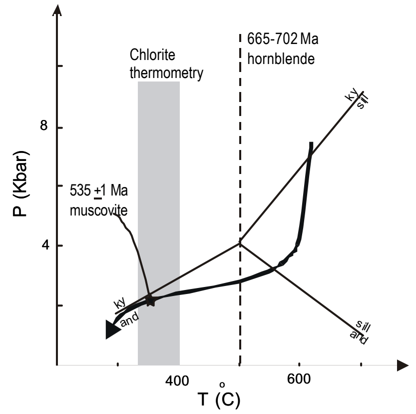

Fig. 3. P-T-t path of Córrego Paiol Formation amphibolites. Star indicate intersection of closure temperature of Ar-Ar system in muscovite with the P-T-t path. Dashed line indicate closure of Ar-Ar system in hornblende. Ky-and-sill triple point is from Holdaway & Mukhopadhyay (1993). Likely temperature interval of gold mineralization is represented by the chlorite thermometry (shaded area).