Sr, Nd, AND Pb ISOTOPE SYSTEMATICS AND K/Ar AGES FROM THE NEOPROTEROZOIC MINA DO MORRO AURIFEROUS DEPOSIT, CAMPO LARGO TOWN, PARANÁ STATE, SOUTHERN BRAZIL

JEFFERSON DE LIMA PICANÇO [1], COLOMBO C.G. TASSINARI [2], MARIA JOSÉ MALUF DE MESQUITA [1], LILIANE PETRONILHO [2] & SOLANGE SOUZA [2]

[1] Departamento de Geologia, Universidade Federal do Paraná; [2] Centro de Pesquisas Geocronológicas, Universidade de São Paulo; e-mail: jeffpicanco@ufpr.br

INTRODUCTION

The Mina do Morro deposit (MMD) is a vein-tipe gold deposit enclosed to the Passa Três Granitic Massif (PGTM), near Campo Largo town, Paraná State, Southern Brazil. The present study discusses the ages obtained using Sm/Nd fluorite isochron, Rb/Sr isochron (whole rock and pyrite leachates), and K/Ar method in white mica. We have also obtained Sr, Nd, and Pb isotope data to determine the source of the ore fluids and the extent of isotopic exchange between fluid and wall rock during the hydrothermal activity of the deposit.

GEOLOGICAL SETTING

The study area is located in the Apiaí Terrane (AT), southern part of the Ribeira belt (RB, Cordani *et al*, 2000). The southern portion of AT comprises rocks from Açungui group, a low to medium-grade meta-volcanosedimentary Neoproterozoic sequence, whose rocks were intruded by several syn- to late tectonic granitic massifs.

In Campo Largo area, Água Clara formation (ACF) and Votuverava formation (VF) constitute the Açungui group, intruded by Passa Três Granitic Massif (PGTM). The PTGM is a stock (c. 5 Km^2 area) with NE-SW trend, and it has tectonic contacts with both ACF and VF. It is a high-K calc-alcaline metaluminous sienogranite, with an REE pattern depleted in HREE, with slight Eu negative anomaly (Picanço 2000). The ACF is constituted by calc-schists, micaschists, garnet-bearing schists, micaceous quartzites, and metabasite lenses. The metamorphism is in upper greenschist fácies. The VF comprises mainly siltstones, fine meta-sandstones and meta-limestones. The metamorphic conditions indicate lower greenschist facies.

The main foliation (S_n) in Açungui rocks is related to an initial D_n thrusting event (Fiori, 1993). The S_n has been affected by a regional transcurrent event D_{n+1}, whose representative structure in the area is the dextral Cerne shear zone. Cerne shear zone controlled the PTGM intrusion during a thrust-partitioning component of the D_{n+1} event. Afterwards, the PTGM was deformed by later transpressional and transtensional, brittle to brittle-ductile events responsible for the quartz vein formation and gold mineralization.

MINE GEOLOGY

The gold ore in the Mina do Morro deposit occurs as quartz-sulphite veins occupying discrete brittle-ductile shear zones internal to PTGM. The main gold-related shear zones show an average direction of N60W, with dips varying 30º to 85º southward.

The veins are irregular and discontinuous, 30 to 50 cm thick, and attain locally 1,5 m thickness, but it may disappear in some places, cut by faults. In that case, a thin argillic zone rich in sulphites is the guide prospector. The vein may be affected by thin S-type phylonite planes (1-3 cm thick). The phyllonites could be gray, green or black and are composed by chlorite-smectite, white mica, clay minerals and sulphites (Picanço & Mesquita, 2001).

The Gangue minerals are mostly composed by quartz, but white mica, chlorite, carbonates, and fluorite are also common. Pyrite occurs in most massive, anhedral to subhedral aggregates. These earlier pyrite is fractured, with fractures filled by chalcopyrite, sphalerite, calcite, galena and gold. There are also euhedral pyrite grains in later shear zones with clay gouge. Gold occur as free or filling cracks with chalcopyrite inside pyrite grains. Gold also occurs as a globular habit with chalcopyrite matrix in pyrite grain boundaries.

The alteration zones in MMD comprise potassic, propylitic, phyllic, argillic and sulphite zones (Picanço & Mesquita, 2001; Mesquita et al, 2002). There are also vein systems composed by K-feldspar, carbonates, fluorite and quartz-sulphite. The earlier zones, potassic and propilitic have low fluid/rock ratio. The latest alteration zones, phyllic, argillic and sulphites, may have high fluid/rock ratios.

ISOTOPE SYSTEMATIC

K/Ar results

Two samples were analyzed by the K/Ar method. The white mica of PT-4 sample came from a tabular pegmatitic body. The age obtained of 602±15 ma, turns out to be a cooling age of the pluton. The white mica of

MM-28 sample, from a late argillic fault gouge, gives an age of 527±10 ma, which could be representative of the closing of the fault system.

Sm-Nd results

The Sm and Nd concentrations in fluorite samples are aligned in 616±36 ma (model 1 isochron Ludwig, 2000), initial ratio (Nd_i) 0,510963±72 and MSWD 1,9 (1σ), figure 1A. The ε_{Nd} value for 600 ma is -17. The alignment of different types of fluorite (white and violet colors) obtained from the same sample is indicative of sample scale isotopic homogenization.

Previous studies in hydrothermal systems (e.g. Michard, 1989) show that Nd is mostly immobile, controlled by pH, Eh, temperature, water/rock ratio and the geochemical/ petrochemical nature of the country rocks. In low water-rock systems, the REE content and also the ε_{Nd} of hydrothermally altered rocks are buffered by the rock system, and it retains the fresh rock REE and ε_{Nd} contents (Michard, op.cit). Bau & Dulski (1995) pointed out that hydrothermal fluorites might retain its source REE characteristics when the distance between fluid mobilization and mineral deposition is close. The 616±36 ma Sm-Nd fluorite isochron age may represent a late magmatic REE fractionation episode that remains in the isotopic "memory" of the system. The main fractionation episode could be in this case related to the cooling of the granite body, and the Sm/Nd ratio was remained unchanged in the earlier rock-dominated ore-forming hydrothermal system. One important assumption is that the fluorine-rich fluid has internal derivation, with small distance between remobilization from granite fluids and deposition in quartz-sulphite veins (Bau & Dulski, 1995).

Rb/Sr results

The hydrothermal altered granite whole-rock isochronic diagram gives an Rb/Sr age of 526±13 ma (model 3 isochron, Ludwig, 2000), with $^{87}Sr/^{86}Sr$ initial ratio (Sr_i) 0,70995 and MSWD 6,2 (2σ). The samples, whose suffer strong phyllic and carbonate alteration, are out of the calculations. The uncertainties in isochron calculations are probably the sum of different kinds of mineral assemblages and alterations. This age represents, at least partially, the age of one of the hydrothermal episodes. The 0,709 value of initial ratio could be related to crustal or mixed sources, and might reflect the isotopic ratios of the initial hydrothermal fluids.

Five sulphite leachates (L1-L5 plus residue) give an isochronic age of 510±32 ma (model 1, Ludwig, 2000), with Sr_i 0.7113 and MSWD 0,41(1σ). The leachates L1 and L4 are out of the calculations, because they have a great analytical error besides the specificity of the selective chemical attack. Most of the concentrates plus the residue are situated near the axis, constraining the initial ratio. On the other hand, only the L5 sample determines the age of isochron. The Sr content in the sulphites is strongly controlled by the presence of Rb, which is attributed to accidentally trapped Rb in sulphite lattice. The assumption made here is that the isochron represents the age of early pyrite crystallization, reflecting the re-homogenization and interaction between wall rock granitic fluids and external fluids.

Sr isotopes

The measured $^{87}Sr/^{86}Sr$ data (Sr_m) of carbonate, fluorite and sulphite concentrates from MMD are represented in table 1. The process of the temporal evolution of Sr_i values are dependent of several factors, such as the Sr isotopic composition of sources and the wall rock, the amount of fluid flux and the thickness of the veins (Petke and Diamond, 1995). The results of Sr_m in carbonates are between 0.7110 and 0.7134. The fluorite Sr_i values are much more closer, between 0,7110 and 0,7116. Most of vein-related massif pyrite samples have Sr_m values between 0.711-0,713, although some samples may attain more radiogenic values.

These Sr_m results are higher than Sr_i of the hydrothermally altered granitoid rocks (0,7099) and approximately similar the Sr_i of sulphite leachates isochron (0,7113). The data could indicate that the $^{87}Sr/^{86}Sr$ ratio of the ore fluid vary between 0,7110 and 0,7130, and probably meant the mixing between Sr from the wall rock granite and other fluids.

Pyrite samples from late argillic fault gouge have radiogenic values, between 0.712-0.714. The chalcopyrite Sr_m values are consistently higher than pyrite separates from the same sample, because the differences between crystalline structures of both sulphites.

Pb isotopes

Two pyrite samples, related to quartz-sulphite veins and one related to the late argillic fault gouges were presented in the "Plumbotectonic" diagrams of Zartman & Doe (1981). In the uranogenic diagram, the pyrite samples from quartz-sulphite veins are radiogenic and plot near the orogen curve, with model ages between 1,2 and 1,6 Ga. These results are similar to the galena samples from Pb ore in the Apiaí terrane (the Panelas-type signature of Tassinari *et. al.* 1990). This data may indicate the presence of mixed Pb sources, including the PTGM and their host metavolcano-sedimentary sequences. The pyrite from the late argillic fault gouge shows more radiogenic values relative to the others, indicating some Pb remobilization in the deposit. In the thoriogenic diagram, the pyrite from quartz-sulphite veins shows the presence of high Th/Pb sources.

DISCUSSION

The MMD is a granitoid-hosted vein-type deposit, in an extensional structure related to a Cerne Shear Zone. The 616±36 ma Sm-Nd isochron and the 602±15 ma K/Ar white mica data may represent a minimum age to PTMG emplacement. These data are in agreement with the main granitoid-formation ages in AT (e.g., Gimenez Fº *et al*. 2000). The minimum age of the MMD ore is around 520 ma, as indicated by K/Ar in white mica, Rb/Sr whole rock, as well as pyrite leachates. These ages are clearly post granitoid emplacement and related to the late strike slip shear zone event (Fiori, 1993).

The Sm/Nd data in fluorites indicates the lack of significant Nd exchange during the hydrothermal process. It could attest an endogenous origin for the fluids with fluorite, and a low fluid/rock ratio. The negative ε_{Nd} value for 600 ma is strongly related to an crustal origin.

The Sr was significantly mobile during hydrothermal process, and reflects the interaction between the granitic wall rocks and external sources. The Sr_i of hydrothermalized granitoid isochron (0,709) reflects a maximum value for granite initial isotopic composition, and also a minimum value from Sr_i of hydrothermal fluid. The mineralizing fluid could initially be buffered by wall rock reactions, probably close to 0,711 (Sr_m of fluorite and Sr_i of pyrite leachates isochron). Sr_m values above 0,711 probably reflect the influence of external fluid source.

The Pb data from massive sulphite indicate the presence of two main Pb sources: one from PTGM itself and from regional host pile, probably the supracrustal Açungui rocks. The model Pb ages also reveal remobilization of mesoproterozoic Pb sources, similar to Panelas-type galenas (Tassinari et al, 1990).

The formation model for the ore deposit involves a shear-zone controlled granitoid emplacement. The ore has been formed after the PTMG emplacement, related to a thrust component of the later strike slip event. There was complex interaction between fluids from the granitoid and from external sources. The shear zones hydrothermal alteration, initially with low fluid/rock ratio and controlled by PTGM isotope content, has been changed progressively to high fluid/rock ratios and has been controlled by outward isotope fluid content.

Acknowledgements

The authors are grateful to staff of Geochronological Research Center (CPGeo-USP), to FAPESP for financial support, to CAPES (grant to JLP) and to Mineração Tabiporã to allow the research in the mine and for the logistic support.

References

Bau, M. & Dulski, P. (1995). Comparative Study of Yttrium and Rare-Earth Element Behaviors in Fluorine-Rich Hydrothermal Fluids. **Contrib. Mineral. Petrol**. 119:213-223

Cordani U., Sato K., Teixeira W., Tassinari C.C. G. & Basei, M. A. S. (2000). **Crustal Evolution of the South American Plataform**. In: Cordani U. G., Milani E. J., Thomaz Filho A., Campos D. A. (eds.), Rio de Janeiro, SBG. *Tectonic Evolution of South America*, 19-40.

Fiori, A.P.(1993) O Sistema de Cavalgamento Açungui. **Geociências**, 12(1):187-208.

Gimenez fº A., Janasi V., Campanha G.A.C., Teixeira W. & Trevizoli Jr L.E. (2000) U-Pb and Rb-Sr isotope geochemistry of the eastern portion of the Três Córregos Batholith, Ribeira Fold Belt, São Paulo. In **Rev. Bras. de Geoc**.30(1):45-50.

Ludwig K.R. (2000) Users Manual for isoplot/Ex – version 2.3 – A Geochronological Tool for Windows Excel®. **Berkeley Geochronological center, Special publication** 1a. Available: http://199.108.3.26/ (research in June 14th/2000).

Mesquita M. J. M., Marczinsky E. S., Vasconcellos E., Picanço J. L., Salamuni E. (2002) Alteração hidrotermal precoce das mineralizações de ouro tipo-veio da Mina do Morro, Campo Largo, Paraná In: 41º Congr. Bras. de Geol., 2002, João Pessoa. **Anais.** João Pessoa: Sociedade Brasileira de Geologia - Núcleo Nordeste**,** 2002. V.único. P.216 – 216

Michard A. (1989) Rare-earth element systematics in hydrothermal fluids. **Geoch. Comoch. Acta**, 53:745-750.

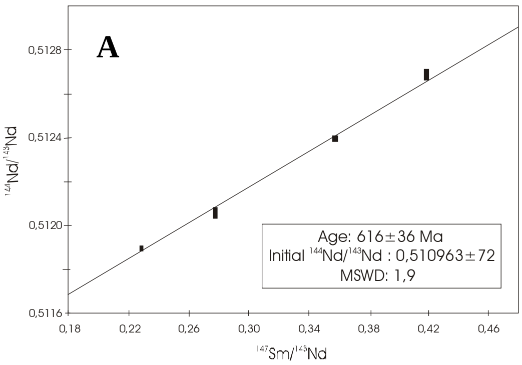
Petke T. & Diamond L. (1997) Oligocene gold quartz veins at Brusson, NW Alps: Sr isotopes trace source of ore-bearing fluid to over a 10-km depth. **Econ. Geol**. 92:389-406.

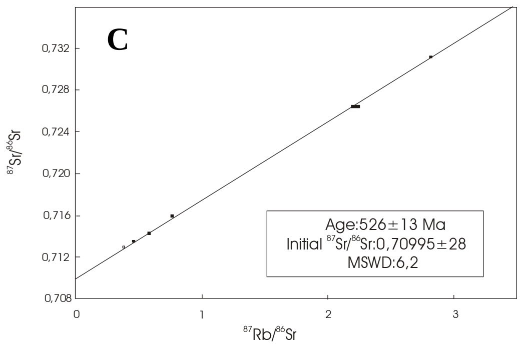
Picanço, J.L. Mesquita, MJM. Ouro no estado do Paraná. **Guia das excursões**. In: 8º Congresso Brasileiro de Geoquímica, Curitiba, 2001. CD-ROM.

Picanço, J.L. (2000) Composição isotópica e processos hidrotermais associados aos veios auríferos do maciço granítico Passa Três, Campo Largo, Pr. Thesis, IG-USP, 160 pp

Tassinari C.C.G, Barbour A.P., Daitx E. & Sato K. (1990) Aplicação dos isótopos de Pb e Sr na determinação da natureza das mineralizações de chumbo do vale do Ribeira – São Paulo e Paraná. In: Congr. Bras. de Geol, 36, Natal, 1991. **Anais**. Natal, SBG-NE 3:1254-1266.

Zartmann, R.E. & Doe, B.R. (1981) Plumbotectonics: The Model. ***Tectonophysics***, *75:135-162.*





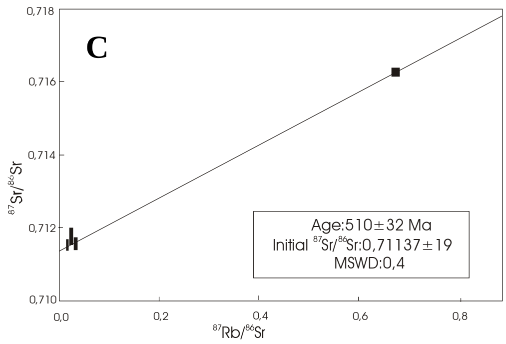


Figure 1 - A) Isochronic Diagram Sm/Nd in fluorites; B) Isochronic Diagram Rb/Sr (whole-rock) in hydrothermalized granitic wall rocks; C) Isochronic Diagram Rb/Sr in pyrite leachates, sample V14.

Table 1 - Sr isotopic analyses of gangue minerals from the Mina do Morro deposit.

N^O LAB	SAMPLE	ROCK	MAT	$^{87}Sr/^{86}Sr$
13735	G4-C	Veinlet in hidrothermally altered granite	carbonate	0,71271±08
13740	MM-24	Veinlet in hidrothermally altered granite	carbonate	0,71103±09
13739	MM-23	Hidrotermal breccia	carbonate	0,71171±06
13736	MP-10	Carbonate vein in hidrothermally altered granite >	carbonate	0,71180±07
13737	MP-11	Carbonate vein in hidrothermally altered granite	carbonate	0,71327±08
13738	V1C	Qz-sulphite vein	carbonate	0,71265±09
13733	MP-2	Qz-sulphite vein	carbonate	0,71342±10
13831	MP-1	Qz-sulphite vein	pyrite	0,712229±11
13832	MP-1	Qz-sulphite vein	chalcopyrite	0,71560±15
13833	MP-2	Qz-sulphite vein	pyrite	0,711160±9
13834	MP-2	Qz-sulphite vein	chalcopyrite	0,71692±19
13835	V-13	Qz-sulphite vein assoc c/ Fluorite	pyrite	0,71159±9
13836	V-14	Qz-sulphite vein	pyrite	0,71190±9
14321	V13-A	Purple fluorite/ Qz-sulphite vein assoc c/ pyrite	Fl	0,711420±6
14323	V13-B	Purple fluorite/ Qz-sulphite vein assoc c/ pyrite	Fl	0,711187±71
14323	MM-20	Purple fluorite/ Qz-sulphite vein assoc c/ pyrite	Fl	0,711321±2
14325	MM-21/V	Purple fluorite/ Qz-sulphite vein assoc c/ pyrite	Fl	0,711431±50
14326	MM-21/B	White fluorite/ Qz-sulphite vein assoc c/ pyrite	Fl	0,711684±28
14322	MM-19	Purple fluorite/Qz-vein	Fl	0,711018±14
13838	MP-7B	Qz-sulphite vein (ccpy dominates Py)	chalcopyrite	0,71204±12
13837	MP-6	hidrothermally altered granite	pyrite	0,71318±8
133839	MM-16	Qz-sulphite vein in hidrothermally altered granite	pyrite	0,7178±12
133840	MM-25	Late fault gouge	pyrite	0,71479±9
133841	MM-27	Late fault gouge	pyrite	0,71234±10