CONTACT METAMORPHISM IN METAPELITES FROM THE NOVA LIMA GROUP, RIO DAS VELHAS SUPERGROUP, QUADRILÁTERO FERRÍFERO: A MONAZITE Th-U-Pb_T DATING BY THE ELECTRON-PROBE MICROANALYSER

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INTRODUCTION

Th-U-Pb_T dating of monazite by high spatial resolution techniques as the electron-probe microanalyser (EPMA) is a valuable tool for understanding the geochronological patterns of metamorphic events within the continental crust (*e.g*., Vlach and Del Lama, 2002) and, in connection with textural and chemical data for equilibrated metamorpic minerals, can also provide useful constraints on P-T-t paths.

We present chemical and dating results of monazite from an amphibolite-grade aureole metamorphism over the regional metapelites of the Nova Lima Group, Rio das Velhas Supergroup, Quadrilátero Ferrífero (MG), due to a strong thermal imprint caused by Paleoproterozoic regional granite intrusions.

GEOLOGICAL SETTING AND SAMPLING

The last deformation and metamorphism events in the Quadrilátero Ferrífero rocks were controlled by the Brasiliano front of the Araçuaí Orogen. Fold-and-thrust belt deformation presents a decreasing polarity towards W and is associated with white mica, kyanite, and pyrophyllite linear growth.

The granite-gneissic rocks of the Quadrilátero Ferrrífero Archaean basement (Figure 1) are roughly coeval with the Rio das Velhas Super Group metavulcanosedimentary sequence, with ages in the 2.6-2.8 Ga range (Teixeira et al., 2000; Machado et al., 1992). The sedimentation of the basal units of the Minas Supergroup appears to have occurred in the Siderian Paleoproterozoic (*ca*. 2.4 Ga, Babinski et al., 1995). The metasediments of the Sabará Group, discordantly overlying these sequences, and the uppermost Itacolomi Group, present detritic zircon dated at 2.1 and 2.0 Ga, respectively (Machado et al., 1996).

Local contact aureole metamorphism dated at about 2.06 Ga (internal Sm/Nd isochron) occurs in the Sabará Group rocks (CHUR model Sm/Nd ages about 2.2 Ga) near the Belo Horizonte granite-gneissic dome (Brueckner et al., 2000). Similar contact aureoles are widely distributed in the Nova Lima Group.

The structural relationships between the Nova Lima Group and the Moeda Formation of the Minas Supergourp are well exposed at the northern downhill side of the Serra de Ouro Preto (Dorr, 1976). Along the Vitoria-Minas railroad, near the Funil Station, white mica crystallization defines a fine schistosity concordant with the compositional banding in the first layer of the Moeda quartzites. These quartzites clearly overlay the chlorite-muscovite-biotite schists of the Nova Lima Group. It is worth noting that the later rocks contain fibrous white mica after sillimanite. Several muscovite leucogranites are concordand with the main Nova Lima schistosity.

These schists show a high metamorphic gradient towards the Bação granite-gneiss complex and, after about *ca*. 200 m., the mineral paragenesis reaches up to amphibolite facies, with peak P-T conditions of about 650° C and 8 kbar (TEEWQU, Berman, 1991). The typical rocks are quartz-poor schist displaying fresh cm-sized garnet and prismatic sillimanite in a groundmass containing cordierite (?), andalusite, red biotite and andesine. Rutile, graphite, ilmenite, monazite, and relict of prograde staurolite preserved both in plagioclase and sillimanite, are the accessory minerals. This mineral assemblage is syn-kinematic; kyanite appears as post-kynematic porphyroblasts. Monazite forms xeno- and idioblastic crystals, appearing as inclusions in the main minerals and as isolated crystals in the matrix.

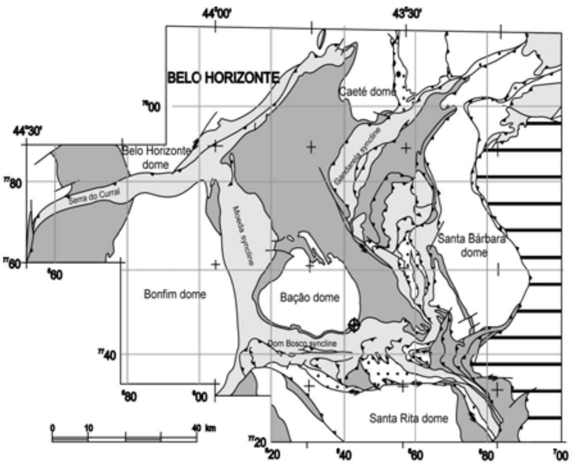

Figure 1: GEOLOGIC MAP OF SE- SÃO FRANCISCO CRATON, MG, BRAZIL.
Modified from Dorr (1969)..

NEOPROTEROZOIC BELT
- MANTIQUEIRA GNEISSES: Paleoproterozoic reworked ortogneisses and migmatites

ARCHAEAN / PALEOPROTEOZOIC
- ITACOLOMI GROUP: coarse and cross-stratified sandstones and polymitic conglomerate
- MINAS SUPERGROUP:I Moeda and Batatal Fms (sandstones and metapelites), Cauê and Gandarela Fms (BIF and carbonates) and Piracicaba and Sabará Grs (metapelites, sandstones, metavolcaniclastic rocks, conglomerates).
- RIO DAS VELHAS SUPERGROUP: Archaean (2.7 Ga) basalt, komatiite and ryolitic lavas intercaleted with sedimentary units
- SOUTHEASTERN SÃO FRANCISCO CRATON GNEISSES : gneiss/migmatite complex, calc-alkaline granitoid plutons and Espinhaço-related syenite and alkaline-like granite-gneisses
- Sample

ANALITYCAL AND DATING METHODS

Monazite EPMA analyses were made in conventional carbon-coated polished thin-sections at the microprobe lab at the Instituto de Geociências, Universidade de São Paulo, with a 5-WDS spectrometer JEOL JXA-8600 machine, following general procedures and instrumental settings described by Vlach and Gualda (2000). The WDS analyses were made after BSE imaging of grains selected under the microscope by textural criteria.

Almost complete monazite analyses were obtained for 35 spots along single traverses and over high-contrast BSE areas in 5 crystals, representing garnet and plagioclase inclusions and isolated grains. Spectral lines for the age determining elements were Mα for Th and Pb and Mβ for U; detection limits were close to 130, 90, and 110 ppm, respectively. Th and Y (on Pb) and Th (on U0 interferences were corrected on-line. Synthetic $ThSiO_4$, UO_2, and $PbCrO_4$ were used as elemental standards. Two homogeneous monazite crystals from high-grade metapelites, with 625 Ma (conventional monazite U/Pb) and 790 Ma (zircon SHRIMP age), respectivley, were used as age-reference standards. Total deviations for these elements were taken as counting deviations, adding 2% to account for other errors. Matrix effects were corrected with a PROZA program.

Chemical (Th^*-Pb_T) isochrons were computed with the IsoPlot software (Ludwig, 1998). Our results are reported on the basis of a 95 % confidence level.

CHEMICAL AND DATING RESULTS

Representative WDS analytical monazite results, molecular proportions of the main components, Th, U, and Pb contents and spot ages are presented in Table 1. BSE imaging of monazite grains reveals contrasted zoning patterns (Figure 2): the inclusions in garnet and feldspar show typical dissolution-recrystallization features, while the isolated crystals present a more normal zoning, Th and U contents step-increasing towards crystal rims.

The studied monazite is a Ce-rich variety with variable amounts of the huttonite, xenotime, and brabantite molecules, depending on textural setting. So, the grains included in garnet and the cores of grains included in feldspars are typically richer in monazite and xenotime and poorer in huttonite and brabantite than the isolated crystals or the rims of grains included in feldspars.

These chemical variations are well correlated with the calculated spot ages and the analytical spots with higher xenotime contents give also older ages (Figure 3). The higher xenotime contents correspond mainly to grains included in garnet and the cores of the grains included in feldspar. The apparent ages suggest to some extent a bimodal data distribution (Figure 4). A chemical cationic isochron (Th* - the measured Th added to the equivalent in Th from the measured U content - vs Pb_T), considering all analytical data yelds a mean age of about 2.06 (± 0.02) Ga, with a good MSWD value.

If we consider, however, a bimodal age distribution, well supported by our chemical data, the isochron computations give an age of about 2.08 (± 0.02 Ga, grains included in garnet and cores of grains included in feldspar) and another one of about 2.04 (± 0.02 Ga, rims of inclusions in feldspar and isolated crystals). The statistical fit parameters (probability of fit and MSWD) will be significantly better (Table 2).

Table 1. Representative WDS data and apparent spot ages of monazite from the studied prophyroblastic schist (c = core, r = rim, b.d. = below detection limit).

	Inclusion in Grt		Isolated crystal	
Grain	2, c	2, r	1, c	5, r
SiO_2	0.08	0.13	0.34	0.52
ThO_2	2.55	4.74	6.79	10.59
UO_2	1.49	0.70	0.73	0.44
La_2O_3	13.91	14.63	12.80	10.28
Ce_2O_3	27.84	28.64	28.29	25.70
Pr_2O_3	3.03	3.20	3.16	3.31
Nd_2O_3	11.11	11.95	12.55	13.36
Sm_2O_3	2.06	1.99	1.95	2.40
Gd_2O_3	1.79	1.40	0.90	0.85
Dy_2O_3	0.81	0.11	bd	0.10
Yb_2O_3	0.05	bd	bd	bd
Y_2O_3	2.44	0.11	0.03	0.04
FeO	0.22	0.18	0.11	0.05
CaO	0.97	1.21	1.41	2.07
PbO	0.77	0.68	0.86	1.10
P_2O_5	30.86	30.50	30.05	29.55
Total	99.99	100.16	99.97	100.35
Molecular proportions				
Huttonite	0.03	0.05	1.4	2.1
Monazite	83.0	87.0	85.0	78.9
Xenotime	8.5	2.2	1.2	1.3
Brabantite	8.2	10.2	12.4	17.8
Age determining elements and deviations (ppm)				
Th	22370	41690	59630	93070
2σ	508	893	1255	1930
U	13173	6151	6435	3891
2σ	298	172	176	143
Pb	7157	6344	8021	10178
2σ	187	175	206	247
Spot age (Ma) and deviations				
Age	2108	2086	2046	2024
2σ	53	59	56	57

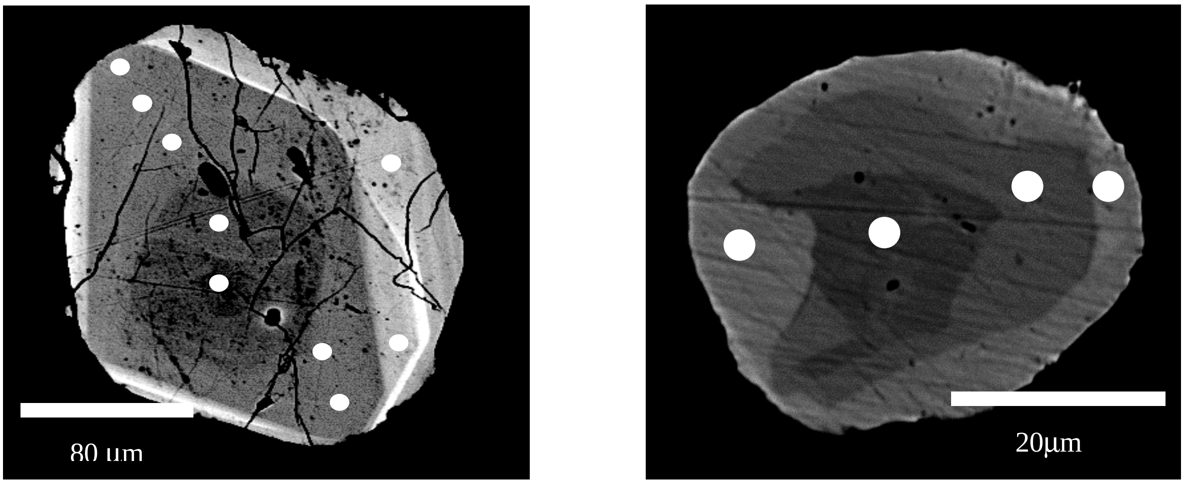

Figure 2. BSE images showing typical compositional zoning patterns of two monazite grains. Left: idioblastic isolated crystal with regular pattern (Th and U step-increase towards crystal rims). Right: rounded inclusion in garnet, showing a complex irregular pattern, suggesting dissolution-recrystallization mechanisms; darker areas are more xenotime-rich than the clearer ones. White circles are WDS spot locations (not to scale).

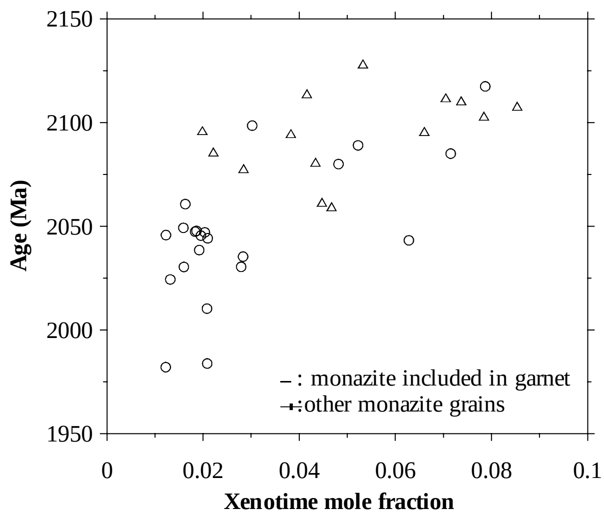

Figure 3. Apparent individual spot aged plotted against the xenotime mole fracion in monazite from the Nova Lima schists. See text for discussion.

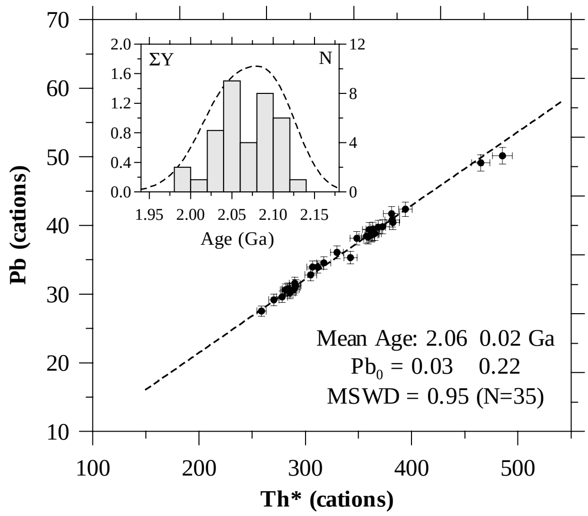

Figure 4. Cationic isochron diagram for all monazite data; computations after Ludwig (1998), fitting through the origin. Inset: apparent spot age distribution. ΣY is the sum of density of probability functions of each spot.

Table 2. Isochron results for monazite from the Nova Lima Schist. Computations after Ludwig (1998), drawing the fit trough origin. Errors are quoted to the 95 % confidence level.

Sampled spots	All data	High xenotime contents (inclusions in garnet and some cores from inclusions in felspars)	Low xenotime contents (isolated grains and rims from inclusions in feldspar)
Age (Ga)	2.06 ± 0.02	2.08 ± 0.02	2.04 ± 0.02
MSWD	0.95	0.40	0.57
Prob. fit	0.55	0.99	0.90
N	35	19	16

DISCUSSION

The mean monazite chemical age of the aureole metamorphism over the Nova Lima Group herein reported is identical to the internal Sm/Nd isochron age obtained by Brueckner et al. (2000) for aureole metamorphism in the Sabará Group. On the other hand, our data bring some additional geochronological constraints to this event.

The chemical EPMA dating results support a bimodal age distribution for the metamorphic event, a point strongly reinforced by both micro-structural and chemical contrasted features of monazite grains occurring included in garnet, in plagioclase, and as idioblastic isolated crystals. A better statistical fit for the bimodal case gives additional support to this interpretation. If both textural monazite generations were formed during an almost continuous contact metamorphic event, we should conclude that such thermal imprint lasted during a time interval up to 40-60 Ma. This metamorphic event is distributed overall the Quadrilátero Ferrífero.

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