ISOTOPIC SIGNATURE OF LATE-MAGMATIC ARC TO POST-COLLISONAL MAGMATISM IN THE VILA NOVA BELT, SOUTHERN BRAZIL

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Keywords: Sr, Nd, Pb isotopes, late-magmatic arc magmatism, post-collisional magmatism, mantle sources, crustal contamination

INTRODUCTION

The Vila Nova Belt, western part of the Sul-rio-grandense Shield, has been studied by several authors and interpreted as a juvenile accretion area. Zircon U/Pb data obtained by Babinski *et al.* (1996) indicate 704±13 Ma for dioritic gneisses which are taken as representative of early magmatism in this area. Sm/Nd isotopic data are discussed by Babinski *et al.* (1996), Chemale Jr. (2000), and Saalmann *et al.* (2005a). Whole-rock Rb/Sr data were obtained in successive magmatic pulses by Silva Filho and Soliani Jr. (1987) ranging from 703±41 Ma (R_0 = 0.7038) for early-formed dioritic gneisses to 673±65 Ma (R_0 = 0.7040) and 643±28 (R_0=0.7040) for tonalitic and granitic intrusions, respectively. The work of Garavaglia *et al.* (2002) has demonstrated the post-collisional character of late magmatism in this area, represented by the Lagoa da Meia Lua Intrusive Suite (UFRGS, 1997), probably correlated to the last magmatic event dated by Silva Filho and Soliani Jr. (1987). The dioritic-tonalitc magmatism of the Vila Nova Belt is currently under investigation by Garavaglia (2006) who established the timing of magmatic pulses relative to regional tectonics, as well as the structural and petrogenetic characterization of each pulse regarding processes of syntectonic mixing, mingling and flow segregation.

The first regional deformation phase (D_1) is related to thrusting under middle- to upper-amphibolite facies conditions, and the resulting structures are present in paragneisses that form megaxenoliths in the studied rocks. Syntectonic magmatism related to such early phase is very scarce in the study area, and is not presently investigated. During the late stages of the thrusting regime (D_2), large upright folds are formed, with fold axes parallel to regional stretching. The progressive evolution of D_2 leads to the formation of large-scale, NE-trending, dextral transcurrent shear zones, D_3, as the Palma-Vila Nova Shear Zone (PVNSZ), which has acted as important site for dioritic and tonalitic magma emplacement.

The studied magmatism is thus grouped in early and late phase, each of them containing three different pulses, as recognized by intrusive relations. The early phase (EP) comprises a first pulse of dioritic-tonalitic magmas emplaced during the waning stages of thrust tectonics (D_2), intrusion geometry being mostly controlled by the subhorizontal metamorphic banding affected by regional folds. The next two magmatic pulses are controlled by the discontinuities of the PVNSZ, whose peak activity is registered in the second magmatic pulse of this early phase. The rocks formed in the early magmatic phase are strongly deformed and correspond to orthogneisses and highly-deformed diorites and tonalites. The late phase of magmatism (LP) is marked by relatively low, although variable, stress conditions. It comprises a first pulse of dioritic and tonalitic magmas emplaced in extensional jogs of the PVNSZ with minor solid-state deformation features, followed by extensive magmatism where magmatic flow structures are well-preserved, as in the Capivaras Diorite studied by Garavaglia *et al.* (2002). The last magmatic pulse results in foliated, undeformed tonalitic rocks that follow the PVNSZ trend.

Geochemical studies by Garavaglia (2006) show that magmas from both phases are relatively rich in total alkalies, and additional K-enrichment is evident from EP to LP magmas. The EP dioritic magmas are calcalkaline, while the LP ones are alkali-calcic to slightly alkaline. The least differentiated LP magmas have medium to high-K tholeiitic affinity. Relative to the LP, EP rocks have higher LILE and lower LREE contents which, together with their slightly peraluminous character, suggest higher degrees of crustal contamination.

ISOTOPIC PROCEDURES

Whole-rock samples for Rb-Sr, Sm-Nd and Pb-Pb isotopic analyses were powdered in agate mortar in order to get fraction <200 mesh. Samples were then weighted and spiked with a $^{149}Sm/^{150}Nd$ and $^{87}Rb/^{84}Sr$ tracer and digested in concentrated HF-HNO_3 and HCl in 7ml teflon vials in a hot plate for seven days. After complete digestion, the samples were dried down and redissolved in 2.5 N HCl. Rb, Sr and REE were separated by using standard cation exchange columns with a DOWEX AG 50X8 resin (200-400 mesh) using 2.5 N HCl for Rb and Sr and 6 N HCl for the REE. Nd and Sm were separated from the other REE by using exchange columns with HDEHP LN resin (50-100μm) and 0.18 N HCl for Nd and 0.5 N HCl for Sm. Pb was separated using exchange columns with DOWEX AG-1 X 8 resin (200-400 *mesh*) eluted with 0.6 N HBr and collected with 6 N HCl. Isotope analyses were carried out at the Laboratório de Geologia Isotópica (Universidade Federal do Rio Grande do Sul) using thermal ionisation mass spectrometry with a VG Sector 54 multicollector mass spectrometer operating at static mode. Rb, Sr, Sm, and Pb were run on Re single filaments while Nd isotopes were run on Ta-Re-Ta triple filaments. Rb was deposited with HNO_3, while H_3PO_4 was used for Sr, Sm, Nd and Pb; the latter was also deposited with silica gel. Sr isotopes were compared to the Sr standard (NBS 987) with values $^{87}Sr/^{86}Sr$ of 0.71026 ± 0.000011 (1σ; n = 100) and the fractionation was corrected to $^{86}Sr/^{88}Sr$ = 0.1194. La Jolla Nd standard measures obtained was 0.511848 ± 0.000021 (1σ; n = 100) and isotopic ratios were normalised to $^{146}Nd/^{144}Nd$ = 0.7219. Pb was corrected for the fractional effect in 0.1% amu^{-1} based in 38 analyses of NBS-981 standard. The total procedure blanks for Rb and Sm were < 500 pg, for Sr < 60 pg, for Nd <150 pg and for Pb < 100 pg. Typical analytical errors for $^{87}Rb/^{86}Sr$, $^{147}Sm/^{144}Nd$ and $^{206}Pb/^{204}Pb$ ratio are equal or better than 0.1 %. Nd model ages were calculated according to De Paolo (1981). The decay constants used were those recommended by Steiger and Jäger (1977) and Wasserburg *et al.* (1981).

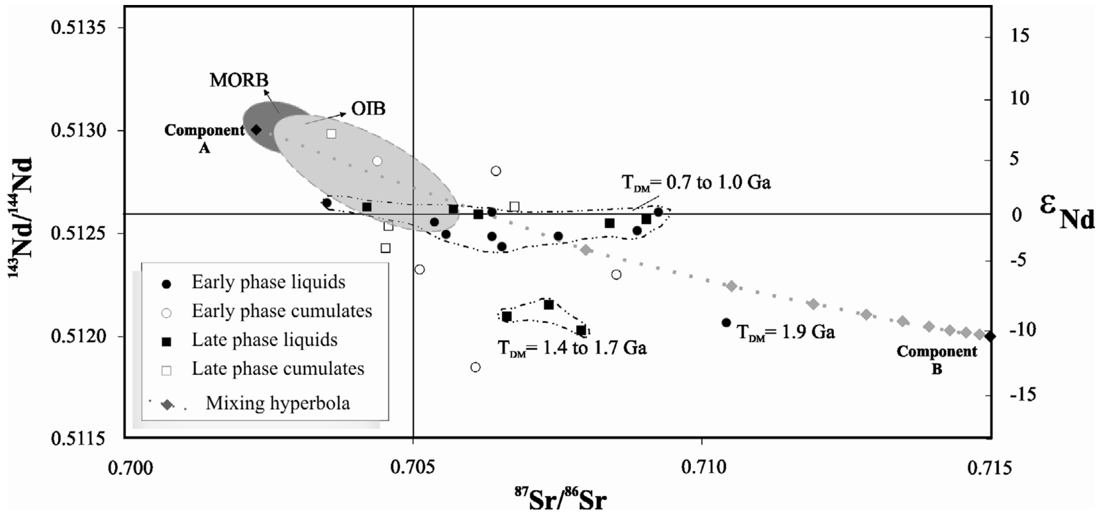

Figure 1. Isotope composition of Nd and Sr (t =present-day) for samples of the early and late phases of magmatism in the Vila Nova Belt. MORB and OIB composition fields from Zindler and Hart (1986). Mixing hyperbola calculated from the following endmember compositions at 10% mixing intervals: mantle component A - {$^{87}Sr/^{86}Sr$ = 0.7023, $^{143}Nd/^{144}Nd$ = 0.5130, Sr = 136 ppm, Nd = 8 ppm} and crustal component B -{$^{87}Sr/^{86}Sr$ = 0.7150, $^{143}Nd/^{144}Nd$ = 0.5120, Sr = 1000 ppm, Nd = 200 ppm}.

RESULTS AND DISCUSSION

Dioritic and tonalitic rocks from the Vila Nova region were analysed in two sets representative of early (15 samples) and late magmatism (13 samples). Nine of these samples are cumulates, as determined by Garavaglia (2006), and the remaining ones are taken as representing liquids. Sr and Nd isotope ratios were corrected for decay to 700 Ma, which is the crystallization age of dioritic gneisses determined by Babinski *et al.* (1996).

Cumulatic rock samples from both phases show highly variable Nd and Sr isotope compositions (Fig. 1), and their interpretation is not straightforward. LP mafic cumulates plot in the upper left quadrant, felsic cumulates in the upper right and plagioclase-amphibole cumulates at intermediate positions. Thus, their isotope composition seems to reflect the different capabilities of cumulative minerals to concentrate radioactive elements, rather than the magmatic system as a whole. The dataset for EP cumulates is even more scattered, and may reflect cumulate assembly as well as mixing and contamination processes. The significance of isotope data in cumulatic rocks is currently under investigation, and they will not be further discussed.

Samples corresponding to magmatic liquids from the early phase (EP) show significant variations for $^{87}Sr/^{86}Sr_{(t=700Ma)}$ and $\varepsilon Nd_{(t=700Ma)}$ values, ranging from 0.7018 to 0.7057, and –5.9 to +6.1, respectively. For the late phase (LP), $^{87}Sr/^{86}Sr_{(t=700Ma)}$ values vary from 0.7001 to 0.7050 and εNd from -4.0 to +5.8. The crustal residence time for the early-phase rocks ranges from 0.7 to 1.0 Ga, except for one sample that shows very high T_{DM} (1.9) and radiogenic Sr (0.7104). Two T_{DM} age groups are present in LP rocks, one ranging from 0.7 to 0.9 Ga and another one from 1.4 to 1.7 Ga. The $^{206}Pb/^{204}Pb$ ratios for EP rocks range from 17.68 to 18.76, $^{207}Pb/^{204}Pb$ ratios range from 15.44 to 15.52, and $^{208}Pb/^{204}Pb$ ratios range from 37.27 to 38.70. The Pb isotope composition for LP rocks is similar to the EP ones in $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values, respectively 15.04 to 15.50 and 36.01 to 40.38, but their $^{206}Pb/^{204}Pb$ ratios are lower, from 15.72 to 18.75.

On a $^{87}Sr/^{86}Sr$ *vs.* εNd diagram (Fig. 1), samples representative of liquids from the early and late phases of magmatism plot mostly in the lower right quadrant, except for two samples which plot in the upper left. They define a main trend where EP and LP rocks show wide Sr variations within a narrow interval of Nd values. All samples from this trend have T_{DM} Nd model ages around 0.9 Ga. A subordinate trend is formed by samples having higher radiogenic Nd and similar Sr contents, with T_{DM} model ages around 1.5 Ga. Despite the structural and geochemical distinction shown by early and late phases, pointing to a progressive evolution in the magmatism, such difference is not detected in their isotopic signatures. This is suggestive of magmas stemming from a common source and partly modified by crustal contamination.

The spreading of samples for constant Nd values with increasing radiogenic Sr contents, together with high T_{DM} values, suggests crustal contamination of a mantle-derived magma, possibly through processes of hybridization and AFC (De Paolo, 1981). Samples plotting near the OIB compositional field possibly derive from the mantle previously enriched by subduction-related metasomatism. Samples with higher $^{87}Sr/^{86}Sr$ ratios would represent contamination of such magmas in the crust. Mixtures of mantle-derived magmas and a higher crustal source are interpreted as potential materials for the origin of EP and LP rocks. Trace-element geochemistry indicates stronger crustal contamination of magmas generating the EP rocks. High LILE and LREE contents in both magmatisms indicate mantle sources previously modified during subduction.

Possible mantle endmembers would have compositions similar to OIB and/or MORB (Zindler and Hart, 1986). In order to test for possible crustal contamination, several mixture models were applied using different contaminants, such as acid and mafic gneisses from the Santa Maria Chico Granulitic Complex (Mantovani *et al.,* 1987, Hartmann, 1988), metasedimentary rocks from the Vacacaí Group (Saalmann *et al.*, 1995a,b), gneisses from the Cambaí Complex (Silva Filho and Soliani Jr., 1987), and gneisses from the Encantadas Complex (Soliani Jr., 1986). The results were negative for all cases, since the potential contaminants have low Nd and Sr concentrations as compared to the studied rocks, where Sr concentrations up to 1200 ppm and Nd up to 40 ppm are found. On the other hand, OIB compositions (EM I and II) have higher Sr and Nd contents than the ones found in the studied rocks. Possible alternatives include the contaminant being different from the modelled ones and having high radiogenic Sr concentrations, or contamination having involved more than one source.

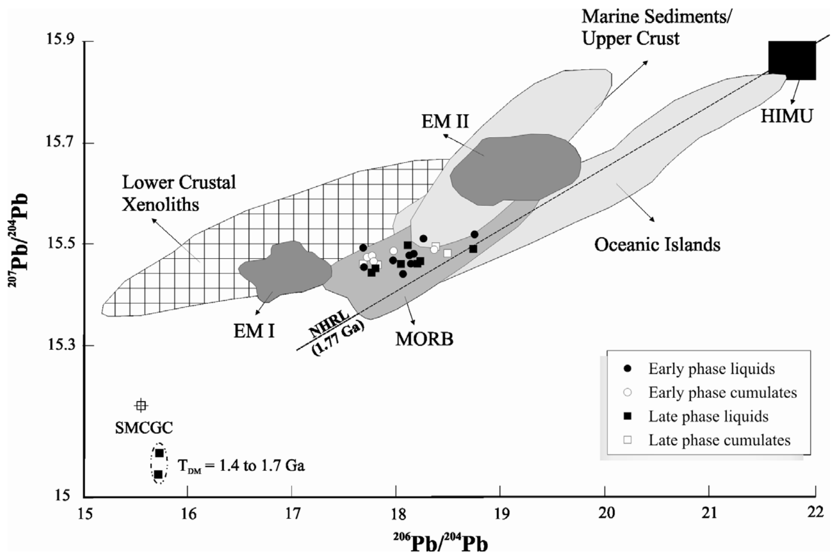

Figure 2. Pb isotope ratios for rocks of the early and late phases of magmatism in the Vila Nova Belt and for felsic gneisses from the Santa Maria Chico Granulitic Complex (SMCGC - data from Mantovani *et al.*, 1987). Composition fields for upper and lower crust, MORB and OIB from White (2005); EM I, EM II and HIMU fields from Zindler and Hart (1986). Northern Hemisphere Reference Line indicated (NHRL).

The contamination of mantle-derived magmas to produce T_{DM} values similar to the crystallization age of the studied rocks may be explained through a theoretical model, with little (*ca.* 10 to 20%) participation of crustal melts having $^{87}Sr/^{86}Sr$ = 0.7150, $^{143}Nd/^{144}Nd$ = 0.5120, Sr = 1000 ppm, and Nd = 200 ppm de Nd (mixing hyperbola and endmember compositions in Fig. 1). In order to account for high Sr contents in the contaminant, melting and contamination are admitted to have occurred under high pressures, at the base of the crust.

The group of samples representing liquids from the late phase of magmatism (LP), with T_{DM} values of 1.4 to 1.7 Ga, has similar Sr contents and higher amounts of radiogenic Nd relative to the EP rocks. In the $^{208}Pb/^{204}Pb$ *vs.* $^{206}Pb/^{204}Pb$ isotope diagram (Fig. 2), high T_{DM} LP samples plot apart from the rest. Their Pb isotope compositions approximately match the Santa Maria Chico Granulitic Complex felsic gneisses, if high-pressure partial melting is admitted for this contaminant. For the other samples, the Pb isotope data are compatible with magmatism generated from sources having compositions close to OIB or MORB.

CONCLUSIONS

The early and late phases of magmatism in the Vila Nova region have a common mantle source, possibly similar to OIB-type magmas, *i.e.*, mantle source modified by metasomatism related to previous subduction. Such source is also indicated by the geochemical signature of liquids from both phases, with high LREE/Nb or Ta ratios. The increase in Nb, Ta, LREE and HFSE contents from early- to late-phase magmatic rocks indicates a transition from magmatic arc to post-collisional geotectonic environment. In part of the studied magmatism, crustal contamination is ascribed to very low degrees of partial melting under high pressure, reflected in their high contents of radiogenic Sr. Pb isotope compositions indicate participation of a second type of contaminant, produced by partial melting of felsic gneisses from the Santa Maria Chico Granulitic Complex.

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