ND – SR ISOTOPES AND TRACE ELEMENT CONSTRAINTS ON THE SOURCE OF THE BASALTIC SILLS FROM SOUTHERN PARANÁ MAGMATIC PROVINCE, MORUNGAVA REGION, BRAZIL

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1. INTRODUCTION

The source of the Paraná-Etendeka Magmatic Province (PEMP) has long been subject of debate, mainly regarding the role of the long-lived Tristan da Cunha (TC) hotspot and the amount of SCLM fusion involved. Many studies support a significant contribution of the TC hotspot in the petrogenesis of the PEMP (O'Connor and Duncan, 1990; Peate et al., 1990; Hawkesworth et al., 1992; Gibson et al., 1995, 1999; Milner and Le Roex, 1996; Ewart et al., 1998) while others consider the TC hotspot only as a passive contributor, providing heat for lithospheric mantle melting (Peate, 1997; Comin-Chiaramonti et al., 1997; Marques et al., 1999). More recently, this dispute has been intensified with very polarized opinions. For Ewart et al. (2004), who worked mainly with the Etendeka magma types, the TC hotspot has played a major role, triggering the volcanism and contributing materially, with local asthenospheric mantle upwelling. On the other hand, Ernesto et al. (2002), who worked mainly in the Paraná side of the Province, even discarded completely the participation of the TC hotspot in the PEMP evolution, considering very difficult to reconcile the geochemical behavior of the lavas with a convective mantle source and suggesting that the position of the TC hotspot at the time of the PEMP formation would be very far from the rifting site.

At the Paraná Province, few examples of intrusive primitive rocks are known and no plume-related magma was previously identified. The lavas normally show crustal contamination characteristics and fractionation features that difficult the identification of the original sources. Conversely, at the Etendeka Province, many intrusions occur and some of them in addition to mafic lavas show geochemical features that clearly point to a strong plume participation.

At the Morungava region, southeastern part of the Paraná Province, occur a swarm of mafic to ultramafic sills that were recently (Marques et al., in prep.) identified as geochemically similar to the Tafelkop magma type or LTZ.H series (Milner and Le Roex, 1996; Ewart et al., 1998) from the Etendeka Province, which are believed to be plume-related. These data and further isotopic evidences are discussed here.

2. GEOLOGICAL SETTING

The Paraná Province is located in central South America and represents one of the largest igneous provinces of the world, with 1.2 x 10^6 km^2 in area and a preserved thickness of up to1.7 km in the north (Peate et al., 1990; Peate, 1997). Flood basalts, giant dyke swarms, sills and intrusive complexes constitute this immense volume of magma. Recent dating from the Paraná Province constrains the magmatism to the interval 127-138 Ma (Baksi et al., 1991; Hawkesworth et al., 1992; Renne et al., 1992; Stewart et al., 1996). During this short time, a diversity of magmas has been generated, possibly from complex interactions between different sources.

Tholeiitic basalt or basaltic andesite accounts for 90% of the entire Paraná flood basalts, but significant compositional variation exists. In the southeastern part of the basin, adjacent to the continental margin, a major amount of acid rocks occurs in the volcanic sequence. A virtual absence of rock types within 60-64% SiO_2, produces a natural separation used in the Paraná volcanic classification, generalized as “rhyolites” (>64% SiO_2) and “ basalts” (<60% SiO_2).

Concerning the basaltic magmatism, different petrologic models have been suggested since the 80’s. Initial classification divided the basalts in two types or series: the high-Ti and the low-Ti basalts (Bellieni et al., 1984, 1986; Mantovani et al., 1985; among others). The high-Ti basalts are well exposed in the north part of the province while the low-Ti basalts predominate in the south region. Only minor amounts of high-Ti and low-Ti are found in the southern and northern regions, respectively.

The high-Ti basalts have TiO_2 > 2.0 %, high incompatible elements amount, $^{87}Sr/^{86}Sr$ initial ratio around 0.704-0.706 and negative ε_{Nd} (-2.5 to –4.6), while the low-Ti basalts have TiO_2 < 2.0 %, low incompatible elements amount, higher $^{87}Sr/^{86}Sr$ initial ratio (0.707-0.710) and higher negative ε_{Nd} (-3.5 to –7.9). In addition to that, Peate (1997) distinguished six magma types on the basis of major and trace element abundances. The low-Ti basalts were divided in the Gramado and the Esmeralda types whereas the high-Ti basalts were separated in the Urubici, the Pitanga, the Paranapanema and the Ribeira varieties.

Regarding the intrusive rocks, three important areas have already been studied (Comin-Chiaramonti et al., 1983; Bellieni et al., 1984; Piccirillo et al., 1990; Hawkesworth et al., 1992; Ernesto et al., 1999): the Ponta Grossa arch, a site of a huge basaltic dyke swarm; the Florianópolis dyke swarm; and, the Santos-Rio de Janeiro dyke swarm. Intrusive rocks from the Morungava region and adjacent areas are mostly underground and were revealed during a drilling coal prospecting program. The sills and dykes from this region are mainly intrusive in Permian sedimentary units of the Paraná Basin such as coal levels of the Rio Bonito Formation and carbonatic shales of the Irati Formation. Some of them are the most primitive intrusions identified in the Paraná Province.

3. MORUNGAVA SILLS

The Morungava region, located close to Porto Alegre metropolitan area, is characterized by the occurrence of several mafic to ultramafic sills. The majority of the sills consist of a dark-reddish-grey olivine gabbro with a medium-grained granular ophitic to subophitic texture. The rocks are dominantly aphanitic to fine-grained near to the contacts. Quenched facies are common. The sills may vary from dunitic orthocumulate layers into an olivine free-microphaneritic gabbro, evolving sometimes to an adcumulatic anorthosite.

The studied sills were preliminary subdivided in two types: The Type 1 is a fine to medium-grained olivine-, clinopyroxene- and plagioclase-rich rock with mesocumulate to orthocumulate igneous texture, while the Type 2 is a fine to very fine-grained clinopyroxene and plagioclase-rich rock that shows quench-like texture close to the margins. Detailed work revealed very important petrological differences between them.

3.1. GEOCHEMICAL RESULTS

The selected samples from the Type 1 sill are meso- to orthocumulate rocks with more than 20% of intercumulus plagioclase. Consequently, the compositions are dependent on the type and amount of the cumulus phases and the amount of trapped intercumulus liquid. On the other hand, samples selected from the Type 2 sill are considered to be very similar to its parental melt.

The Type 1 sill is characterized by relatively low SiO_2 (< 45 wt%) and high MgO (20 to 25 wt%), very low TiO_2 (< 1%) and low values of LILE and HFSE. The primitive mantle-normalized diagram shows that trace element abundances for all samples from the Type 1 sill, including those from the upper margin, have similar signatures with negative anomalies for some LILE and HFSE, suggesting that all rocks crystallized from similar parental magmas. All samples from Type 1 sill have similar fractionation for both LREE and HREE. The most rich-REE sample is the most Mg-poor sample. It is a fine-grained sample from the upper margin of the sill that could represent a close approximation to the parental magma composition.

The concentration of the parental magma from all trace elements were calculated from 7 gabbro samples from the Type 1 sill using partitioning coefficients (Marques et al., in prep.). The composition obtained for the parental magma of the Type 1 sill is very similar to that of the samples from the upper margin, supporting the idea that upper margin would possible represent a supercooled border or a volumetrically minor influx of the same type of magma that generated the Type 1 sill.

The Type 2 sill has no variation throughout the stratigraphy. The main geochemical characteristics are the relative high SiO_2 (57 wt%) and low MgO content (2 wt%), which characterizes this sill as a basaltic andesite. The TiO_2 are close to 2 wt%. The Type 2 sill is relatively enriched in all incompatible elements, especially Th and U (LILE). Strong Sr and Nb negative anomalies can be observed in the primitive mantle-normalized trace element diagram. The primitive mantle-normalized REE patterns show enrichment in light REE (LREE) and have a less fractionated pattern for the heavy REE (HREE). The Type 2 sill has Eu anomaly (not observed in the Type 1 sill), suggestive of plagioclase fractionation.

3.1. ND - SR ISOTOPES RESULTS

Sm-Nd and Rb-Sr isotope data were obtained at the Laboratório de Geologia Isotópica of the Instituto de Geociências da Universidade Federal do Rio Grande do Sul. Twelve samples from Type 1 sill and eigth samples from Type 2 sill were analyzed. The results revealed marked differences between them. The crystallization age considered for calculations was 132 Ma.

The Type 1 sill show depleted mantle Nd model ages (T_{DM}) between 190 and 600 Ma, positive $\varepsilon_{Nd(t)}$ that varies from +4.1 to +7.6, high initial Nd^{143}/Nd^{144} ratio that ranges from 0.51265 to 0.51285 and low initial Sr^{87}/Sr^{86} ratio that ranges from 0.704695 to 0.706957. On the other hand, the Type 2 sill show model ages around 1500 Ma, negative $\varepsilon_{Nd(t)}$ that range from –5.9 to –7.0, lower initial Nd^{143}/Nd^{144} ratio ranging from 0.51210 to 0.51218 and higher initial Sr^{87}/Sr^{86} ratio that ranges from 0.713 to 0.715. The Nd evolution diagram for the Morungava region sills shows the outstanding differences between Type 1 and Type 2 sills (Fig. 1).

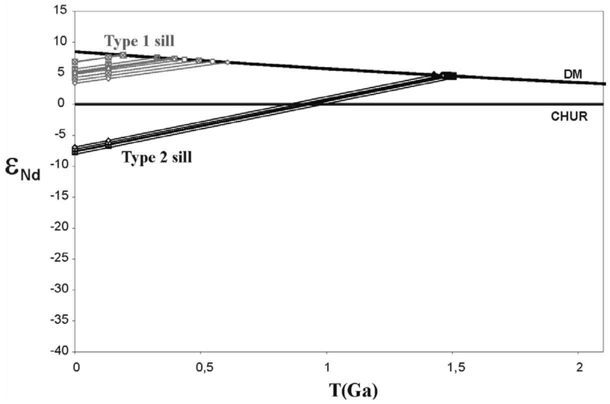

Figure 1. The Nd evolution diagram for the Type 1 sill and Type 2 sill samples from Morungava region.

4. DISCUSSION

The comparison between the characteristics and composition of the Type 1 and 2 sills revealed that the two sills are definitely different. On the primitive mantle-normalized diagram, the Type 1 sill shows smoother pattern, roughly similar to those from convective mantle derived magmas, while the Type 2 sill has typical low-Ti basalts patterns, similar to Gramado magma type. The higher Ti/Zr (> 60) and Ti/Y (>350) ratios and lower Th/Nb (<0.2) ratio from Type 1 sill are distinctive when compared to Type 2 sill that has relatively lower Ti/Zr (~50) and Ti/Y (~250) ratios and relatively higher Th/Nb (>0.5) ratio. The geochemical characteristics of Type 2 sill (higher Th/Nb, lower Ti/Y ratios and negative primitive-mantle normalized anomalies of P and Nb) may be indicative of some degree of crustal contamination or might reflect contributions from a lithospheric source.

The Low-Ti basalts are broadly similar to the Etendeka regional low Ti and Zr basalts (LTZ type or Tafelberg magma type) that also dominate in the south part of the Etendeka province (Erlank et al., 1984; Bellieni et al., 1986; Peate, 1997). Similarities between these two segments are also recognized by geochronological studies (e.g. Renne et al., 1996; Stewart et al., 1996).

The Morungava magma types identified here are very similar to two series of basalts identified in the Goboboseb Mountains region, Etendeka Province: (i) the LTZ.H series (Ewart et al., 1998) or the Tafelkop magma (Milner and le Roex, 1996) and the ferropicrites (Gibson et al., 2000; Thompson et al., 2001); and (ii) the LTZ.L series (Ewart, 1998). The former is interpreted as a plume derived magma type while the second is considered similar to the regional LTZ type or Tafelberg magma type (Ewart et al., 1998). The Type 1 sill magma type is very analogous to the LTZ.H series while the Type 2 sill magma is comparable to the LTZ.L series. Elements like Ti, Zr and Y can discriminate the magmas very well.

The clear correlation between the Morungava sills and the Etendeka series are also disclosed by primitive mantle-normalized diagrams (Fig. 2). Strong negative Nb, Sr, P and Ti anomalies characterize both Type 2 sill and LTZ.L series (Fig. 2a) whereas the Type 1 magma exhibits nearly the same pattern as the LTZ.H series (Fig. 2b). The Type 1 sill samples are less enriched in incompatible elements, but show the same smoother primitive mantle-normalized pattern as the LTZ.H series. Furthermore, when the calculated parental magma envelope is considered, not only the pattern is parallel but also the abundances of incompatible elements are similar to those from the LTZ.H series samples.

The isotope data strong support the above considerations. The Type 1 sill has similar initial Nd^{143}/Nd^{144} and Sr^{87}/Sr^{86} ratios than the LTZ-H series and Tristan plume, close to OIB composition. Some samples fit also close to the MORB-like Horingbaai dikes (Thompson et al. 2001) On the other hand, Type 2 sill, LTZ.L series and further low-Ti magma types have lower initial Nd^{143}/Nd^{144} and higher initial Sr^{87}/Sr^{86} (Fig. 3).

The geochemical composition and isotope features of the Type 1 sill clearly characterize it as the first primitive mafic magma occurrence identified in Brazil that shows materially contribution of a mantle plume to the petrogenesis of the Paraná Province.

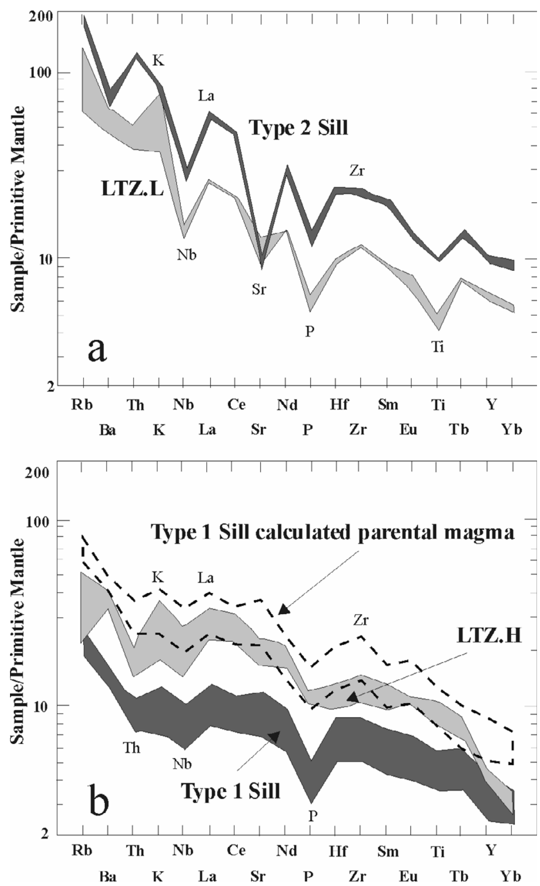

Figure 2. Primitive mantle-normalized trace-element patterns comparing Type 1 and 2 sills to magmas series from Goboboseb Moutains region. a) Type 2 sill and LTZ.L series showing clear similarities; b) Type 1 sill and its calculated parental magma envelope showing clear correlation with the LTZ.H series. Both show smoother patterns comparable to a convective mantle source. Normalization from McDounough and Sun (1995).

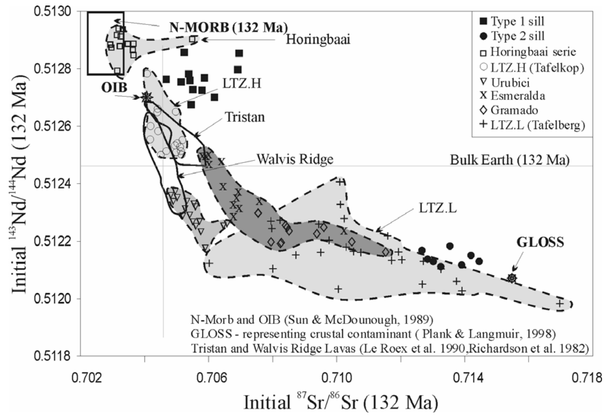

Figure 3. Initial (132 Ma) Nd–Sr isotopic compositions of Morungava sills. Fields from Etendeka mafic rocks and Paraná Basin basalts (see text for references), Walvis Ridge and Tristan da Cunha lavas, N-MORB and OIB, and GLOSS are showed for comparison.

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RESUMO

Este estudo revela dois diferentes tipos de sills máficos (Tipo 1 e Tipo 2) que ocorrem em subsuperfície na regiâo de Morungava, borda sul da Província Magmática Paraná, Brasil. O sill Tipo 1 compreende cumulados ricos em olivina que são geoquimicamente diferentes dos basaltos baixo-Ti e o Tipo 2 consiste de um sill de textura fina, mais evoluído e que se assemelha ao típico magma baixo-Ti.
O sill Tipo 1 é a primeira occorrência de magma máfico primitivo identificado no Brasil que mostra contribuição material de uma pluma mantélica à petrogênese da Província Magmática Paraná. O magma parental do sill Tipo 1 é extremamente similar tanto no conteúdo de elementos traços quanto na composição isotópica a pouco volumosa série LTZ.H da Província Etendeka. O valor positivo de εNd(132), que varia de +4,1 a +7,6, e a baixa razão inicial de Sr87/Sr86, que varia de 0,704695 a 0,706957, comparável à série LTZ.H, sugere fortemente que este magma foi gerado a partir de uma pluma mantélica.