

ND ISOTOPE SYSTEMATICS RELATED TO PROTEROZOIC EVOLUTION OF THE CENTRAL RIBEIRA BELT IN THE STATE OF SÃO PAULO, SE BRAZIL

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ABSTRACT New Sm/Nd data from different lithologic units of the Ribeira Belt (RB), southeastern Brazil, provide important information about the crustal architecture and geologic evolution of the region. Nd data of basement gneisses of the RB indicate that they represent Paleoproterozoic crustal growth, whereas those of the supracrustal sequences suggest provenance from both Paleoproterozoic and younger sources. On the basis of their Nd signatures, felsic brasiliano plutons derived largely from Paleoproterozoic basement, but systematic variations in their T_{DM} model ages as a function of their chemistry may reflect differences in fractionation, vertical lithospheric heterogeneity, or possibly some contributions from the asthenospheric mantle.

Keywords: Nd signature, Ribeira Belt and Isotopic Evolution

INTRODUCTION The aim of this paper is to characterize the crustal architecture of the Ribeira Belt (RB), in the State of São Paulo, southeastern Brazil, through Sm/Nd data of basement gneisses, granitoid suites and volcano-sedimentary sequences. These results, in turn, can be used to better understand the tectonic evolution and paleogeographic setting of the RB prior to the Brasiliano orogenesis.

The Sm/Nd isotopic system has been widely used to investigate the crustal growth histories of different continental areas, e.g., Nelson & DePaolo (1982), and can also be used to estimate of the nature and age of sediment sources, and thus useful for paleogeographic reconstructions (Barovich *et al.* 1989, Pimentel *et al.* 1999). Nd depleted mantle model ages (T_{DM}) (also called "crust formation ages") are normally assessed using the deplete-mantle model of DePaolo (1981), calculating the isotopic evolution of a crustal sample from present its measured value, back through time when it had the isotopic composition of the depleted mantle reservoir. The slope of the evolution line is proportional to the measured Sm/Nd ratio of the sample. However, T_{DM} values do not necessarily represent the real age of a geological event and the interpretation of model ages of crustal rocks can be complex. As new crust forms, it acquires a Nd signature of the material involved in its genesis (Farmer & DePaolo 1983, Arndt & Goldstein 1987). Hence, if crust does not develop in isolation, i.e., an island arc setting, it can acquire an enriched or "reworked" Nd signature due to input from older crustal sources. In such a situation, the T_{DM} age represents a hybrid crustal formation age (average crustal residence age), and the true age of the crust must be determined by other means, such as by U/Pb zircon methods. Although the Sm/Nd pair is relatively insensitive to fractionation in the continental crust during subsequent melting and metamorphic events, subtle fractionation can occur, creating changes in T_{DM} ages. Also, as different magma types can be derived from various levels of the lithosphere, systematic variation in T_{DM} ages may reflect vertical lithosphere heterogeneity, but also may be a result of contributions from asthenospheric mantle. In any case, variations in the model ages and other geochemical signatures must have geological significance (Sun *et al.* 1995, Zhao & McCulloch 1995).

Several Sm/Nd analyses have been done in the RB indicating a complex evolution history (Tassinari & Sato 1996, Sato 1999, Ratgati 1999). Cordani & Sato (1999) used this methodology to understand the crustal evolution of the South American Platform.

GEOLOGIC SETTING The present configuration of tectonic blocks in the RB is due to lateral escape tectonics that occurred during the Brasiliano/Pan-African collision between the São Francisco and Congo cratons (Campos Neto & Figueiredo 1995, Hackspacher *et al.* 1997). Regional data support the existence of a Paleo- and Mesoproterozoic blocks and terranes that were fused together during the Neoproterozoic.

The geological framework of the studied area consists of three lithotectonic domains (Figure 1): the São Roque, Jundiá and Embu. The São Roque domain, characterized by low-grade (greenschist facies) metasedimentary and metavolcanic rocks, is bounded by the higher-grade (amphibolite facies) Jundiá and Embu volcano-

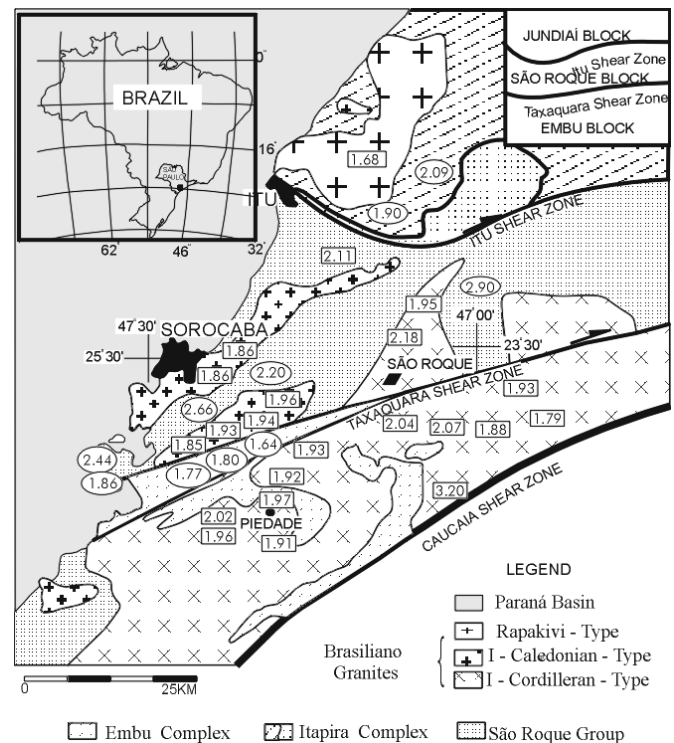


Figure 1 - Distribution of T_{DM} Nd model ages obtained for rocks of the Ribeira Belt in the São Paulo State. In the upper corner, we show the three different tectonic domains recognized in the study area.

sedimentary sequences. The contacts between these domains are NE-SE trending transcurrent shear zones. Paleogeographic reconstruction of the Neoproterozoic history of the RB (Hackspacher *et al.* 2000), suggest the development of a syn-collisional process involved the Embu and Itapira complexes, related to NW thrusting. The São Roque Group is considered as representing a continental back-arc environment that was generated during active collision. Lateral tectonic escape, combined with a vertical tectonic component, was responsible for juxtaposing deep and shallow levels of the crust presently exposed in the RB.

The Brasiliano magmatism is well represented in the three domains. These granitoids display a complex intrusive history that includes a distinctive young magmatic phase of circular small bodies intruding into older phases. These young plutons serve as a regional time marker. The evolutionary history of the plutonism, dated through U/Pb geochronology, record episodes of early magmatism (possibly subduction-related), continental collision, transpression, uplift and collapse (Töfner 1996).

In the central RB the granitoid bodies can be subdivided into in

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three major groups (Wernick *et al.* 1993): 1) - I-type Cordilleran calc-alkaline granites cut by circular, dominantly, alkali-calcic bodies (São Roque, Ibiúna and Piedade granites), related to the syn-collisional phase of the Brasiliano Orogeny (ca. 629-625 Ma); 2) - I-type Caledonian alkali-calcic granites cut by circular rapakivi bodies (Sorocaba and São Francisco granites), and 3) - Circular Rapakivi granite plutons, forming isolated or coalescent intrusions (Itu granite) representing the post-collisional phase, dated at 580 Ma (Töfner 1996).

SAMPLES AND ANALYTICAL PROCEDURES The samples were collected from all three of the domains described above. Several whole-rock samples of the São Roque, Sorocaba, São Francisco and Piedade granitoids, as well as host rocks of Embu and Itapira complexes, were analyzed by Sm/Nd methods. Results are given in Table 1. In the past, the 600 Ma used as a reference age to calculate the initial Nd isotopic composition ($\epsilon_{Nd}(t)$) is due to the fact that this is the average age of the main magmatic event in the RB, and may be used to monitor the effect of late fractionation in these rocks.

The data represents the first results obtained in the Isotope Geology Laboratory of the DPM/IGCE/UNESP. The isotopic analyses were accomplished in the IG/USP and in the IG/UnB, and the analytical procedures used are described in Sato *et al.* (1995) and Pimentel *et al.* (1996).

RESULTS The results of representative samples for each geologic domain of the Ribeira Belt are show in Table 1. All samples analyzed in this work are not in this table. The T_{DM} model age distribution defines groups of values as presented below (Figure 2).

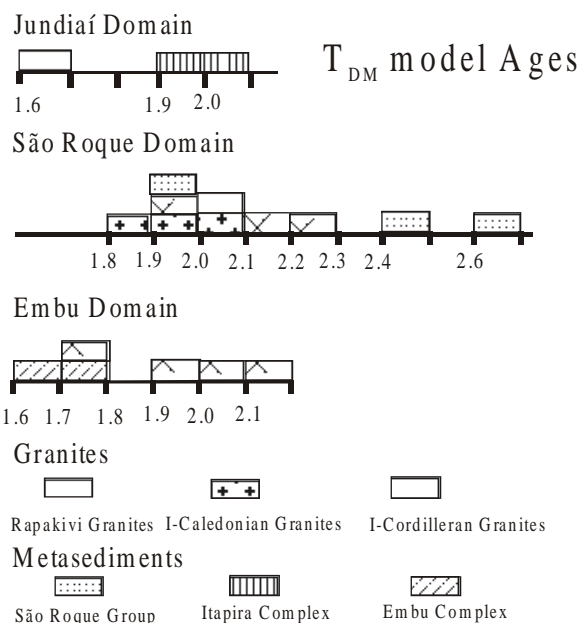


Figure 2 - Histogram of TDM Nd values from metasedimentary rocks and granitoids of different domains identified in the Ribeira Belt. Each box corresponds to one Sm-Nd analysis to granitoid rocks and ellipse to the supracrustal rock.

Table 1 - Representative Sm-Nd results of metasediments of São Roque, Embu and Itapira complexes and intrusive granitoid rocks that occur in the different domains of the Ribeira Belt.

Sample	Rock Type	Sm (ppm)	Nd (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	$\epsilon_{Nd}(0)$	T_{DM} (Ma)	$\epsilon_{Nd}(t=0.6 \text{ Ga})$
SÃO ROQUE DOMAIN								
Supracrustal rocks (São Roque Group)								
H519	Metarhytmite	7.96	52.63	0.091423	0.511552	-21	1.86	-13
H511A	Metapelite	6.54	35.85	0.110300	0.511500	-22.2	2.28	-15
H511B	Metapelite	2.54	12.6	0.12200	0.511567	-20.8	2.44	-15
H511C	Metapelite	3.24	15.0	0.13030	0.511480	-22.6	2.86	-17
M9801E	Metabasite	6.64	33.65	0.11930	0.511469	-22	2.66	-17
Granitoids								
São Francisco Granite								
H524	Diorite	15.15	92.7	0.09900	0.511567	-20.8	1.94	-13
H510	Rapakivi granite	14.4	92.1	0.09400	0.511495	-22	1.96	-14
H509	Rapakivi granite	10.81	73.3	0.08900	0.511524	-21	1.85	-13
H508	Coarse granite	9.92	51.27	0.11700	0.511637	-19	2.20	-13
H507	Granite	34.67	208.1	0.1000	0.511633	-19	1.89	-12
H518	Diorite	11.83	64.05	0.111700	0.511696	-18	2.02	-11
H514	Leucogranite	36.10	239.7	0.091047	0.511507	-22	1.91	-13
São Roque Granite								
H353	Granodiorite	6.45	41.64	0.09369	0.511525	-21.7	1.93	-15
H357	Monzogranodiorite	3.55	20.06	0.1069	0.511514	-21.9	2.18	-15
JUNDIAÍ DOMAIN								
Supracrustal Rocks (Itapira Complex)								
H348	Sillimanite gneiss	1.90	7.31	0.12407	0.511864	-16.2	2.09	-09
H349	Garnet gneiss	2.27	12.29	0.11190	0.511789	-17.1	1.90	-10
Granitoids (Itu Granite)								
M347	Rapakivi Granite	8.00	52.98	0.09135	0.511691	-18.5	1.68	-10
EMBU DOMAIN								
Supracrustal rocks (Embu Complex)								
H513A	Paragneiss	7.04	51.27	0.0830	0.511544	-21.3	1.75	-12
H513b	Paragneiss	5.87	34.56	0.1026	0.511756	-17.2	1.75	-10
H528	Migmatite	10.79	65.46	0.099	0.511687	-18	1.80	-11
H529	Migmatite	2.66	18.3	0.088	0.511682	-18	1.64	-10
Granitoids (Piedade Granite)								
VOX36	Piedade Granite	8.32	55.31	0.091014	0.511469	-23	1.96	-14
VOX25	Granodiorite	4.78	37.09	0.077859	0.511329	-26	1.93	-16

Paragneisses/supracrustal rocks *THE SÃO ROQUE DOMAIN (SRD)* Data for low-grade metasedimentary and metavolcanic rocks of the São Roque Group indicate provenance from Paleoproterozoic sources with a hint of younger source material input. Metarhytmities have T_{DM} ages of 2.44 Ga while the phyllites yield T_{DM} ages of 1.86 Ga with ϵ_{Nd} (600) values of ca. -15. Neoproterozoic metamafic rocks (metadiorites and amphibolites) intercalated in these metasediments possess T_{DM} ages of 2.66 and 2.20 Ga. These values suggest that the igneous rocks were derived from Paleoproterozoic, and possibly Archean lithosphere.

THE JUNDIAÍ DOMAIN (JD): The garnet-bearing migmatites and sillimanite and garnet-bearing granitic gneisses of the Itapira Complex, the main unit of this domain, yield T_{DM} ages between 1.93 and 2.09 Ga with ϵ_{Nd} (600) values of ca. -10.

THE EMBU DOMAIN (ED): Paragneisses and migmatitic paragneisses of the Embu Complex, the main geological unit of the domain, yield T_{DM} values between 1.64 and 1.80 Ga and ϵ_{Nd} (600) values around -12. The younger T_{DM} ages of this domain suggest the sedimentary protolith of these gneisses derived from younger (Neoproterozoic?), as well as Paleoproterozoic sediments.

Granitoids The Embu Domain is intruded by the syn-collisional Piedade and Ibiuna granites. The first is composed mainly of megaporphyroid biotite monzogranites, with T_{DM} values varying between 1.97 and 1.96 Ga. Dioritic enclaves and late leucogranites yield T_{DM} ages of 2.02 Ga and 1.91 Ga, respectively. The Ibiuna massif presents spatial variation in the T_{DM} ages, with values decreasing from the center to the border of the batholith. The central porphyroid monzogranites shows values between 2.14 and 1.93, and the subordinate quartz diorite and granodiorite, presents values between 1.82 and 1.79 Ga.

The late collisional São Roque, Sorocaba and São Francisco granites are intrusive along strike-slip shear zones, in the SRD. The São Roque granite is a high-K calc-alkaline pluton whose predominant facies is made of mega-porphyritic monzogranites with T_{DM} of 2.18 Ga, while late equigranular facies show values of T_{DM} of 1.95 Ga. The Sorocaba granite (Godoy 1989) is represented by coarse-grained monzo and sienogranites, with T_{DM} values varying between 2.11 Ga for the porphyroid facies and 1.86 Ga for the equigranular facies. The São Francisco granite (Godoy 1989) consists of a dominantly porphyritic monzogranite with a T_{DM} age of 1.93 Ga. The subordinate equigranular syenogranites, coarse-grained syenogranites and equigranular monzodiorites show T_{DM} values of 2.20 Ga, 1.94 Ga and 1.89 Ga, respectively. Even-grained and porphyritic rapakivi facies of circular plutons that cut the batholith show T_{DM} age varying from 1.85 to 1.96 Ga and ϵ_{Nd} (600) values ranging between -15 and -11.

The Itu granite is intrusive into the JD during the post-collisional phase, and yields T_{DM} values of 1.68 Ga and ϵ_{Nd} (600) values of -10.

DISCUSSION The Sm-Nd data of granitoids and paragneisses of the RB (São Roque Group, Embu and Itapira complexes) show that this method is useful for chronological determination of events related to different periods of continental crust formation and to constrain the genesis and space and time relationships of the pre-Brasiliano history of the RB. The data presented above suggest that:

- i) The basement rocks to the supracrustal sequences and granitoids are dominated by Paleoproterozoic units, as evidenced by the majority of T_{DM} ages between 1.9 and 2.4 Ga. Although the minor difference in the Nd signatures of the Embu, Jundiaí and São Roque domains, the variation does not indicate an amalgamation of separate exotic terranes. Rather, it appears that these tectonic domains are part of the same crustal or lithospheric block that was

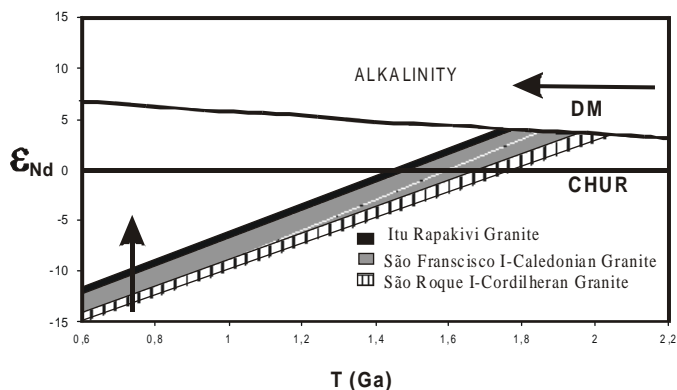


Figure 3 – Nd isotopic composition diagram to granitoids of the São Roque, São Francisco and Itu Granites. The arrow indicates the variation of T_{DM} and ϵ_{Nd} values with increasing of alkalinity from I-Cordilleran, I-Caledonian to Rapakivi types.

dismembered during the transcurrent phase of the Brasiliano orogeny (Hackspacher *et al.* 1997). A single T_{DM} age of 2.66 Ga suggests the presence of an Archean crust in the region, but additional U-Pb zircon studies of the basement are needed to confirm this. Figure 2 shows the rock types versus T_{DM} model ages.

- ii) Nd T_{DM} model ages between 1.6 and 1.8 Ga of metasediments and paragneisses of the Embu Complex suggest a mixture of Paleoproterozoic and younger detritus in the constitution of these rocks. The presence of some ca. 720 to 750 Ma inherited zircons in volcanic rocks of the São Roque Group indicates that some Neoproterozoic crust may be locally present (Hackspacher *et al.* 2000). Studies of detrital zircons from the Embu and Itapira complex paragneisses should help constrain the ages of the source regions.
- iii) Calc-alkaline and alkaline plutonism was synchronous in all three of the lithotectonic domains mentioned above (Wernick *et al.* 1993). A striking feature of several of these plutons, specifically the São Roque, Sorocaba and São Francisco granites, is that they display large variations in terms of T_{DM} values varying between 2.2 – 2.1; 2.0-1.95 Ga and 1.89-1.86 Ga, respectively (Figure 3). This suggests that these intrusions grew by accretion through a series of magmatic pulses into the batholiths. The observed heterogeneity is interpreted to reflect changes in the magma sources over time. These changes may reflect differential crustal contamination, as proposed by Dantas *et al.* (1999). These variations, however, also may reflect a heterogeneous lithosphere or increasing contributions from the asthenosphere (as suggested below). The youngest T_{DM} model age of the Itu granite (1.68 Ga) may reflect a derivation from both Paleoproterozoic and younger lithosphere/crust. Alternatively, the decrease of ϵ_{Nd} and T_{DM} values with increase of alkalinity, also may be the result of melts derived from Paleoproterozoic lithosphere and Neoproterozoic asthenosphere. While the evolved nature of this kind of magmatism may seem at odds with the latter interpretation, the presence of evolved felsic rocks derived from asthenospheric mantle is well documented in the western United States, e.g. Perry and DePaolo (1988) and Perry *et al.* (1993).

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