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Nd isotopes from the Ribeira Belt in the Rio Paraíba do Sul region, SE Brazil: significance for its Neoproterozoic evolution

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Abstract: A systematic Nd isotope study carried out along the border between São Paulo and Rio de Janeiro states, in SE Brazil, enabled the recognition of different tectonostratigraphic domains originated during the diachronous collisional events that formed the Brasília and the Ribeira fold belts during the Brasiliano orogeny. Each domain has a characteristic Nd isotopic signature. A dominant Paleoproterozoic source, with TDM model ages varying between 1.6 to 1.9 Ga and 2.0 to 2.2 Ga, characterizes the supracrustal sequences of the Embu and Andrelândia Domains, respectively, whereas a mixture of Neoproterozoic and older sources is recorded in rocks of the Costeiro Domain, with TDM model ages varying between 1.2 and 1.4 Ga. A new occurrence of basement rocks was identified along the tectonic contact between the Andrelândia and Embu Domains showing TDM model ages between 2.7 and 3.2 Ga, suggestive of an Archean source. Neoproterozoic granites across the Ribeira Belt also show multiple sources, covering values between 1.4 and 2.4, but no systematic distribution across the domain boundaries could be found. The isotopic data add to the discussion about the presence of suture zones between terranes in the Ribeira Belt and helps to understand the Neoproterozoic evolution of this segment in the South America platform.

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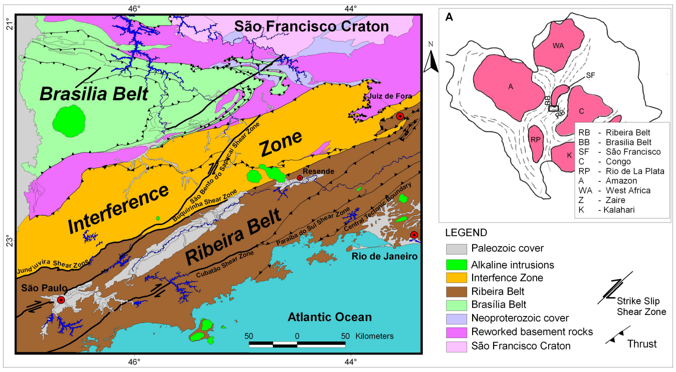
Introduction

The geologic framework of the central portion of the Mantiqueira Province is characterized by the diachronous evolution of the Brasília and Ribeira Belts from the Early Neoproterozoic to the beginning of the Paleozoic (750-480 Ma; Unrug, 1997). These belts were formed in association with the collisional events between the São Francisco, Congo and Paraná-Rio de La Plata Cratons (Brito Neves et al., 1999; Trouw et al., 2000; Cordani et al., 2000), which resulted in the formation of a series of superposed structures between the two belts (Interference Zone, Figure 1) that hinder the understanding of their evolutionary history (see also Hackspacher et al, this volume).

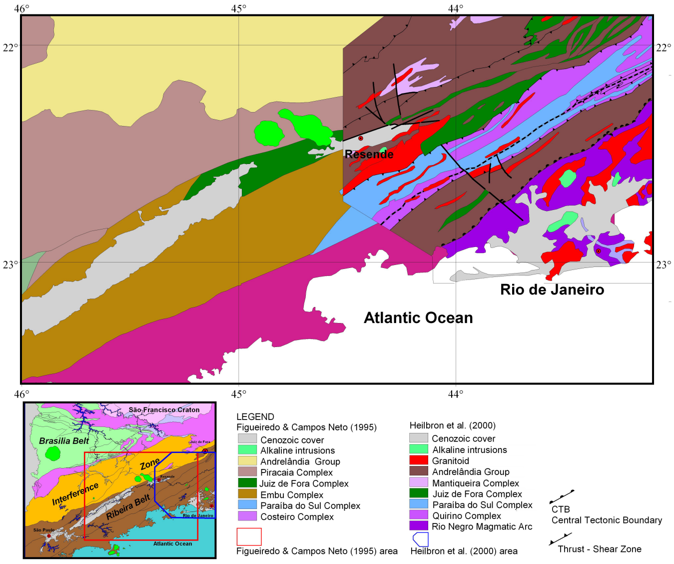
Figure 1. Tectonic framework of the central segment of the Mantiqueira Province



Tectonic framework of the central segment of the Mantiqueira Province in southwest Brazil (modified and compiled from Heilbron, 1995, Morais et al, 1999; Bizzi et al., 2001). Simplified geotectonic outline of western Gondwana. A complex structural interference zone is formed due to the superposition between the Brasilia and Ribeira orogenesis.

There are major complications in the stratigraphic correlations within the different units of the Ribeira and Brasilia Belts, which become apparent in comparisons between the classical geological papers on the region (Hasui and Oliveira, 1984; Machado Filho, et al., 1983; Machado and Endo, 1993; Heilbron et al., 1995 and 2000; Machado and Demange, 1992; Ebert and Hasui, 1998; Morais et al., 1999; Trouw et al., 2000; Campos Neto, 2000; Ribeiro et al., 2003). There is no consensus as to nomenclature, rock components or names of different stratigraphic units (Table 1). The major controversy refers to a unit of meta-sedimentary rocks, including gneissic and migmatitic rocks with calc-silicate, marble and metabasic rock intercalations. This unit is interpreted to be part of the Paraíba do Sul Complex (Hasui and Oliveira, 1984) or the Embu Complex (Morais et al., 1999; Campos Neto, 2000) or even the Andrelândia Group (Heilbron, et al., 2000 and 2003, Trouw et al., 2000 and 2003) and the Juiz de Fora Complex (Campos Neto and Figueiredo, 1995). A good example of this divergence is shown in Figure 2 .

Figure 2. Comparative geological maps of the studied area



Comparative geological maps of the studied area showing the contrasting interpretations between A: Campos Neto (2000) and B: Heibron et al. (2000).

More recently, Sm-Nd isotopes are being used as tracers of tectonic environments to help understanding the complex evolutionary history of the Neoproterozoic fold belts, enabling the identification of different juxtaposed terranes involving similar structural and lithologic characteristics, and showing distinct isotopic signatures (Dantas et al. 2000; Pimentel et al. 2001; Van Schmus et al. 2003). This paper presents new isotopic results related to the rocks exposed along the border between São Paulo and Rio de Janeiro states, in SE Brazil, where the tectonic-stratigraphic correlation is uncertain. The aim is to assess the tectonic framework of this central part of the Ribeira Belt, based on a systematic Sm-Nd isotopic study combined with remote sensing and digital terrain model data, in order to constrain the nature and location of the crustal boundaries between different Precambrian terranes.

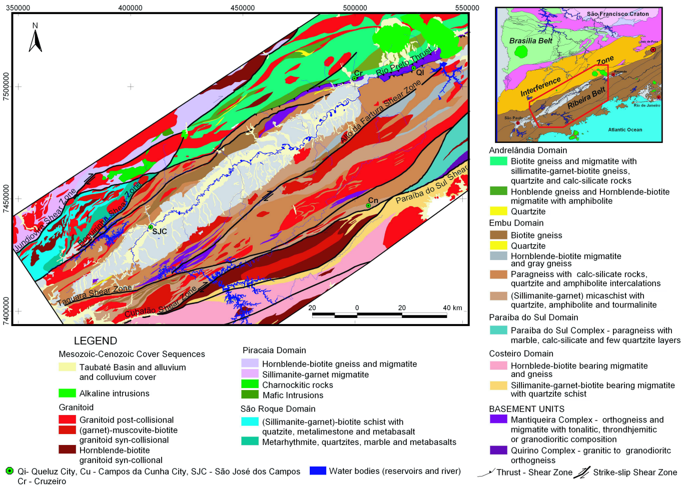
Geological Setting

The Ribeira Belt (Hasui et al., 1975) extends over approximately 1,400 km along the southeastern Brazilian coast, where its central segment - to the south of the São Francisco Craton - is formed by different juxtaposed crustal slices trending NE-SW, metamorphosed at medium to high-grade conditions (Heilbron, 1995; Trouw et al., 2003). Tectonothermal and magmatic activities occurred between 700 - 450 Ma (Trouw et al., 2000). The metamorphic peak took place around 595-565 Ma (Machado et al., 1996), contemporaneously with a thrusting tectonic event with NE-vergence, and was associated with syn-collisional granite magmatism. A system of dextral strike slip shear zones crosscuts older fabrics of the Ribeira Belt and controls late-collisional (540-520 Ma) to post-tectonic (520 and 480 Ma) granite intrusions (Heilbron, 1995; Trouw et al., 2000).

The tectonostratigraphic framework discussed here is based on the integration of published maps, radar images and the digital terrain model (DTM) of the Shuttle Radar Topography Mission (SRTM) project, description of 276 outcrops, and whole-rock Sm-Nd isotopic data. The main geologic maps used in the integration were: the tectonic framework map from the central Ribeira Belt in Rio de Janeiro state (Heilbron et al., 2000), Santos and Guaratinguetá sheets (Morais et al., 1999), at 1:250.000 scale; geologic maps from Fernandes (1991), Pereira (2001) and Almeida (2002) at the 1:100.000 scale; and the semi-detailed work of Cordani (1976) and Riccomini (1989). The nomenclature used does not follow a specific author but uses the tectonostratigraphic denomination most suitable to the local geologic context, and the more accepted terms found in literature.

In order to simplify the understanding of regional geology, the results are described according to three major units: basement rocks (Mantiqueira Complex); meta volcano-sedimentary and sedimentary sequences defining the São Roque, Andrelândia, Embu and Costeiro Domains; and Brasiliano granite plutons (Figure 3).

Figure 3. Geological map of the Paraíba do Sul Valley



Geological map of the Paraíba do Sul Valley in the States of São Paulo and Rio de Janeiro.

Basement Rocks

The rocks of the basement (Mantiqueira Complex) form an elongated slice trending NE-SW, tectonically interlayered with rocks from the Embu Domain, or along the contact between the Andrelândia and the Embu Domain (Figure 3). Basement rocks are commonly migmatitic, porphyritic hornblende-biotite gneiss, with composition varying from tonalite to granodiorite (Figure 4), with a variety of migmatite structures - stromatic, agmatic, schöllen, schlieren - with prevalence of stromatic structure showing layers and lenses of hornblendite (Figure 5). Leucosomes are layered, centimetric to decimetric, and may present hornblende porphyroblasts. Its composition varies from granite to monzogranite, while the mesosome is of tonalite composition. Locally homogeneous metagranitoids are associated with the migmatites (e.g. south of the town of São Luiz do Paraitinga, Figure 3).

Figure 4. Porphyritic hornblende-biotite gneiss of the Mantiqueira Complex

Porphyritic hornblende-biotite gneiss of the Mantiqueira Complex, showing a sub-horizontal foliation. (UTM23S - 420113/7423675)

Figure 5. Migmatitic gneiss of the Mantiqueira Complex

Migmatitic gneiss of the Mantiqueira Complex showing layers and lenses of hornblendites. (UTM23S - 508924/7504977)

Supracrustal Rocks

Andrelândia Domain. The main components of this unit are migmatitic and mylonitic (sillimanite - garnet)-biotite banded gneiss (Figure 6), and hornblende tonalitic to granodioritic gneiss (Figure 7). There are centimetric to metric intercalations of quartzite, quartz-schist, thin layers of marble and sperssatite quartzite, amphibolite and common calc-silicate rocks associated with the garnet-biotite gneiss. This domain occurs to the north of the Rio Preto shear zone (Figure 3), and is considered to be part of the Andrelândia Group of Trouw et al. (1980, 2000), although some authors believe that they belong to the Piracaia Complex - Socorro Terrain (Morais et al., 1999; Campos Neto, 2000; Pereira et al., 2001).

Figure 6. Sillimanite-biotite gneiss

Sillimanite-biotite gneiss of the Andrelândia Group showing regular banding. (UTM23S-521141/7509504)

Figure 7. Banded hornblende migmatitic gneiss

Banded hornblende migmatitic gneiss of the Andrelândia Domain. (UTM23S-421327/7501520)

Embu Domain. The Embu domain crops out between the NE-SW trending Rio Preto and Cubatão shear zones, and is covered by the Tertiary Taubaté and Resende Basins (Figure 3). This unit is composed of a variety of rock types, including hornblende-biotite gneiss, biotite gneiss, garnet-biotite gneiss, sillimanite-garnet gneiss (kinzigite), quartz-biotite-feldspar migmatite, quartz-feldspar schist, quartzite, calc-silicate rock, amphibolite and orthogneiss (Hasui et al., 1975; Fernandes, 1991; Morais et al., 1999 and Pereira et al., 2001). Orthopyroxene-bearing granulites were described by Cordani (1976) and Almeida (2002) as part of this unit.

Three different sequences were identified in this domain. A paragneiss sequence is characterized by biotite gneiss, garnet-biotite gneiss, sillimanite-garnet gneiss, quartz-muscovite-sillimanite schist, with rare layers of quartzite and amphibolite and occasional layers of sillimanite schist (Figure 8). A biotite gneiss sequence is fine to medium-grained and gray and has migmatites of tonalitic to granodioritic composition. Banded migmatites are the dominant lithology and have white to pink, coarse-grained leucosome composed of quartz, biotite and K-feldspar, and melanosome composed of (hornblende)-biotite banded gneiss. Pegmatite dikes are also common (Figure 9). A schist sequence is composed of fine-grained muscovite-biotite schist, with subordinate quartz-biotite schist, sillimanite-biotite and quartz-feldspar schist (Figure 10), and is commonly deeply weathered, making their mapping difficult. Tourmalinite layers can be used as a regional layer guides in this unit, and laminated rhythmites alternated with biotite gneiss, quartzite, and amphibolite occur locally. The presence of low-grade schists (including biotite, muscovite and feldspar) was registered by Ebert (1968).

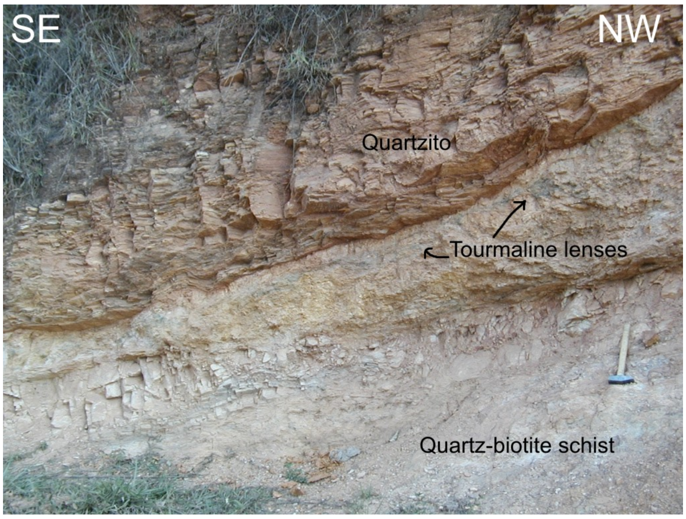
Figure 8. Sillimanite-garnet-biotite schist

Sillimanite-garnet-biotite schist of the Embu Domain showing a small centimeter lens rich in sillimanite. (UTM23S-481508/7471975)

Figure 9. Migmatitic biotite gneiss of the Embu Domain

Migmatitic biotite gneiss of the Embu Domain with pegmatite intrusions related to a sub-vertical shear zone. (UTM23S-533705/7496420)

Figure 10. Quartz-biotite schist



Quartz-biotite schist interlayered with quartzite showing tourmaline rich lenses. Embu Domain. (UTM23S-492424/7463760)

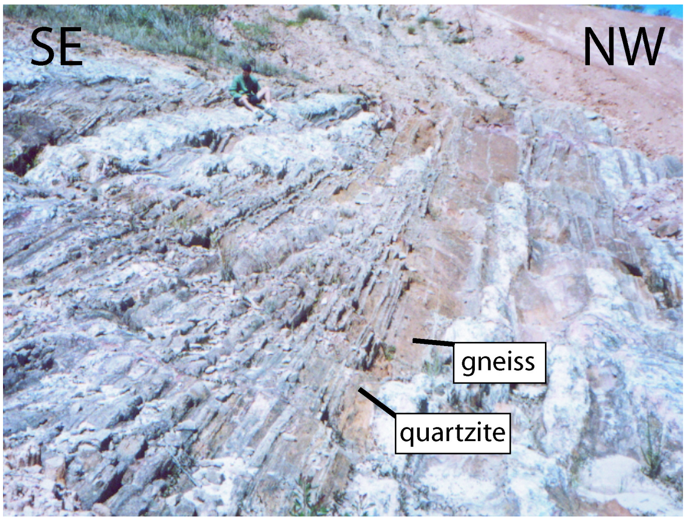
Paraíba do Sul Domain. Metasedimentary rocks and orthogneisses of the Paraíba do Sul Domain occur in the southeast portion of the studied area (Figure 3). This domain corresponds to the Paraíba do Sul klippe defined by Heilbron (1995) and is represented by the Quirino Complex (Valladares, 1996; Machado et al., 1996) and Paraíba do Sul Complex (Machado Filho et al., 1983). The Quirino Complex includes homogeneous granite to granodiorite orthogneiss, with enclaves of basic and calc-silicate rocks. The Paraíba do Sul Complex include a sequence of pelitic schists and biotite gneiss with marble, calc-silicate and a few quartzite layers (Almeida et al., 1993).

Costeiro Domain. This domain appears close to the coast of São Paulo and Rio de Janeiro States, separated from the Embu and Paraíba do Sul Domains by the Cubatão and Paraiba do Sul shear zones (Figure 3). Two different rock sets prevail in this domain: a) biotite granite gneiss and migmatite (Figure 11), and b) paragneiss intercalated with schists and quartzites (Figure 12). Lenticular hornblende-biotite tonalite gneiss bodies and xenoliths of amphibolite are commonly migmatized.

Figure 11. Migmatite of the Costeiro Domain

Migmatite of the Costeiro Domain. (UTM23S-441574/7398005)

Figure 12. Gneiss interlayered with quartzite



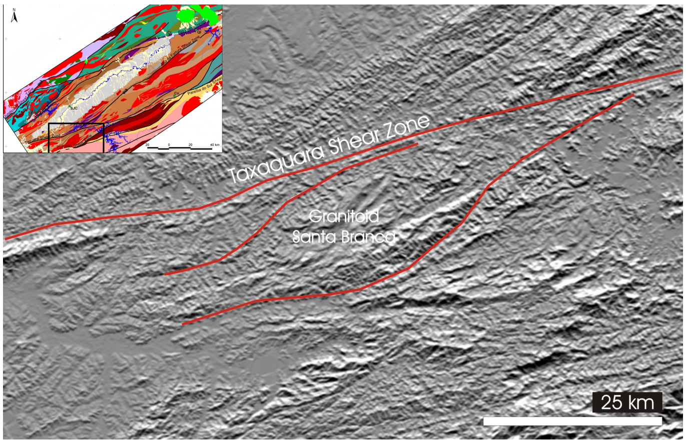
Gneiss interlayered with quartzite of the Costeiro Domain. (UTM23S-484345/7400678)

São Roque Domain. There are several meta volcano-sedimentary sequences, characterized by low-grade (greenschist facies) metamorphism, cropping out between the Jundiuvira and Buquirinha shear zones grouped into the São Roque Domain (Figure 3 ; Janasi, 1999; Juliani et al., 2000, Hackspacher et al., 2000; Campos Neto, 2000). This unit is composed of a prevailing psammite and pelite associations (phyllites, quartzite, (sillimanite-garnet)-biotite schist, garnet schist) with carbonate layers and basic to intermediate metavolcanic rocks.

Granitoids

There are several granitoid bodies intruding the domains described above and originated during the Brasiliano orogeny (Heilbron, 1995; Wernick, 2000). As a rule, plutons in the Ribeira Belt are elongated with a NE-SW trend, associated with strike slip shear zones (Figure 3), and present a well-developed tectonic fabric. These bodies are easily recognized in satellite and radar images. On the SRTM digital terrain model (DTM), plutons can be distinguished from the host rocks by high topography (Figure 13). Four magmatic episodes were identified in the Ribeira Belt in the Rio de Janeiro segment (Heilbron, 1995; Trouw et al. 2000): 1) pre-collisional magmatism (630-600 Ma); 2) early to syn-collisional (595-565 Ma) generated during the peak of metamorphism at around 580 Ma, and associated with the main deformational event; 3) syn-collisional magmatism (565-540 Ma), associated with the main transcurrent shear zones; and 4) late-collisional magmatism, granitoid plutons and dikes not foliated (520-480 Ma).

Figure 13. Santa Branca Granitoid associated with the Taxaquara shear zone



The granitoid shows sigmoidal form. The area of flat topography to the north is underlain by basin sediments. The NE-SW regional fabric of the area can be seen in this image. SRTM image with a directional filter. Insert on the upper left-hand side indicates the location of the image on the regional geological map of Fig. 3.

S-type intrusions are predominantly gray to white, porphyritic, two-mica granitic to granodioritic composition, represented by the Quebra Cangalha Granites in the Embu Domain (Morais et al., 1999; Trouw et al., 2003). I-type intrusions are characterized by (hornblende)-biotite granites, monzogranite, granodiorite and tonalite, represented by the Natividade pluton in the Costeiro Domain and the Lagoinha-Turvo pluton in the Embu Domain.

Structural Framework

Proposed tectonic models for the Ribeira Belt are incompatible with each other, suggesting a southwestern or northwestern subduction, involving collision between the São Francisco-Congo and the Rio de La Plata Cratons. An oblique collision resulted in the diachronous formation of the Brasília and Ribeira Orogenic Belts, whose transpressional tectonics and strain partitioning were identified as significant shortening mechanisms during the Brasiliano Orogeny (Ebert and Hasui, 1998).

Three main deformational events were identified in this segment of the Ribeira Belt (Trouw et al., 2000 and 2003; Heilbron, 1995; Heilbron et al., 2003; Hackspacher et al., 2003). The first (Dn) is characterized by a thrusting system whose main tectonic transport shows top to the NNW. The second (Dn+1) relates to an E-W compressive convergence of colliding plates, responsible for the formation of the anastomosing system of strike slip shear zone trending NE-SW that divides the region into different crustal blocks or domains, such as those defined above (Figure 3). The third event is related to the final stage of Brasiliano Orogeny, characterized by uplift and exhumation of the strike slip shear zones.

The first event took place 660-640 Ma and is associated with the pre-collisional granitic magmatism resulting from subduction of a Neoproterozoic oceanic crust (Hackspacher et al., 2003). The second is linked to the syn- to late-collisional magmatism phase in the Ribeira Belt around 625-590 Ma (Wernick, 2000). The third event characterized by a strong vertical exhumation during post-collisional escape tectonics of the Brasiliano Orogeny occurs in the Ribeira Belt between ca. 590-540 Ma, and is associated with the emplacement of sub-alkaline granites (Hackspacher and Godoy, 1999).

Dn structures developed a Sn regional foliation trending NE-SW with variable dip direction, predominantly SE, and have been described as D1 and D2 structures by others (Heilbron, 1995, Trouw et al., 2000). In the Embu Domain, this foliation is anastomosed in macro- and meso-scales and is indicative of a NW movement with the development of low-angle mylonitic shear zones (Figure 14). The Rio Preto thrust separates the Embu and Andrelândia Domains.

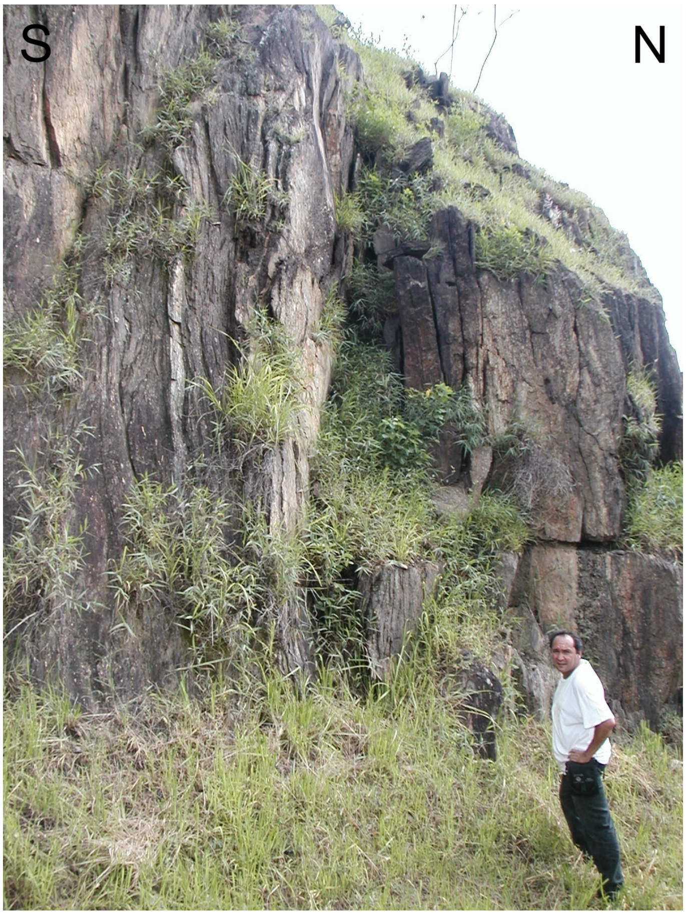
Kinematic indicators such as S-C fabric, stretching lineation, and asymmetric mica fish suggest tectonic transport towards NNW.

Figure 14. Ultramylonitic biotite gneiss of the Embu Domain

Ultramylonitic biotite gneiss of the Embu Domain in the Rio Preto thrust with stretching lineation plunging 15 towards 130 (UTM23S-474424/7494730).

Dn+1 structures occur throughout the region and were described as D3 events in several papers (i.e. Trouw et al. 1986; Ribeiro et al. 1990; Heilbron 1993; Heilbron et al., 2003). They are represented by sub-vertical shear zones trending NE-SW (Figure 15) and dextral movement, forming an anastomosed system (i.e. Jundiuvira, Taxaquara, Cubatão, Buquirinha, Alto da Fartura shear zones, and Paraíba do Sul fault; Figure 13). These shear zones are easily identified by their morphology in satellite images and digital terrain model and can be traced for several kilometers (Figure 13). Some strike slip shear zones are 5 km wide and characterized by a strong sub-horizontal or oblique stretching lineation plunging between 30° - 40° to WSW.

Figure 15. Sub-vertical mylonitic foliation development



Sub-vertical mylonitic foliation development in the Quebra Cangalha granite defining the Alto da Fartura shear zone. The shear zone was active during emplacement of the Quebra Cangalha granite. (UTM23S -503775/7481955).

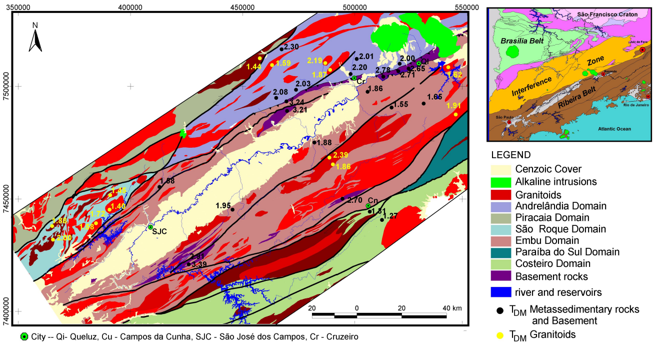
Analytical procedures

Isotopic analyses performed at the Geochronology Laboratory of the University of Brasília followed the procedures described in Gioia and Pimentel (2000) and used a Finnigan MAT 262 mass spectrometer in static mode. Uncertainties regarding the Sm/Nd and 143Nd/144Nd ratios are considered to be better than ± 0.1% (1s) and 0.00001 (1s), respectively, based on the repeated analysis of international rock standards BCR-1 and BHVO-1. 143Nd/144Nd ratios were normalized to a 146Nd/144Nd ratio of 0.7219. Nd procedure blanks were less than 100pg. eNd (t) values were calculated for t = 600 Ma, taken as the average age of the peak of metamorphism during the Brasiliano Orogeny in this region (Heilbron, 1995; Trouw et al., 2000). TDM results follow the depleted-mantle model of DePaolo (1981).

Results

Isotopic analyses of samples from the study region are presented in Tables 2 and 3. All major rock units in the region were reviewed, including basement rocks, supracrustal sequences, and granitoids from the different tectonostratigraphic domains identified (Figure 3). Table 2 contains 23 analyses made by the authors, and Table 3 presents a compilation of all regional data published. TDM model age map distribution are presented in Figure 16 ,histograms of TDM model ages from metasedimentary rocks and granitoids in Figure 17 , and the relationships between the eNd(t) values and time in Figure 18 .

Figure 16. Geological map of region indicating the location of the TDM model ages

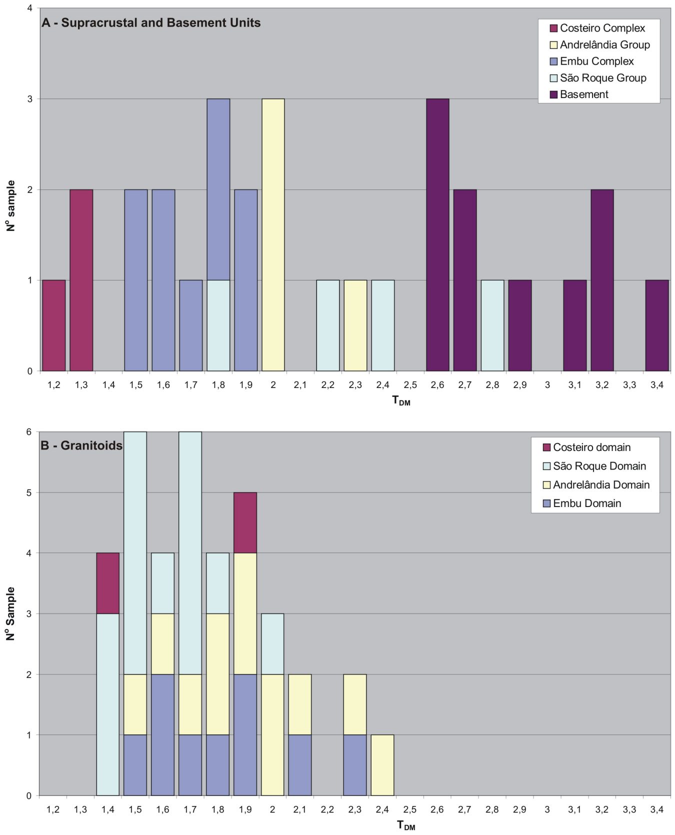


Geological map of region indicating the location of the TDM model ages.

Basement Rocks

A new occurrence of basement rocks (Mantiqueira Complex in Table 2) was identified along the tectonic contact between the Andrelândia and Embu Domains, in the vicinities of the towns of Cruzeiro and Queluz (Figure 16), showing TDM model ages between 2.7 and 3.2 Ga (Figure 17), suggestive of an Archean source. Although absolute U-Pb zircon ages are not available, Nd isotopic signatures and characteristics of these rocks are similar to those identified by Sato (1999), a few kilometers to the southeast, indicating the existence of Archean crust remnants (Figure 3).

Figure 17. Histogram of the TDM model age



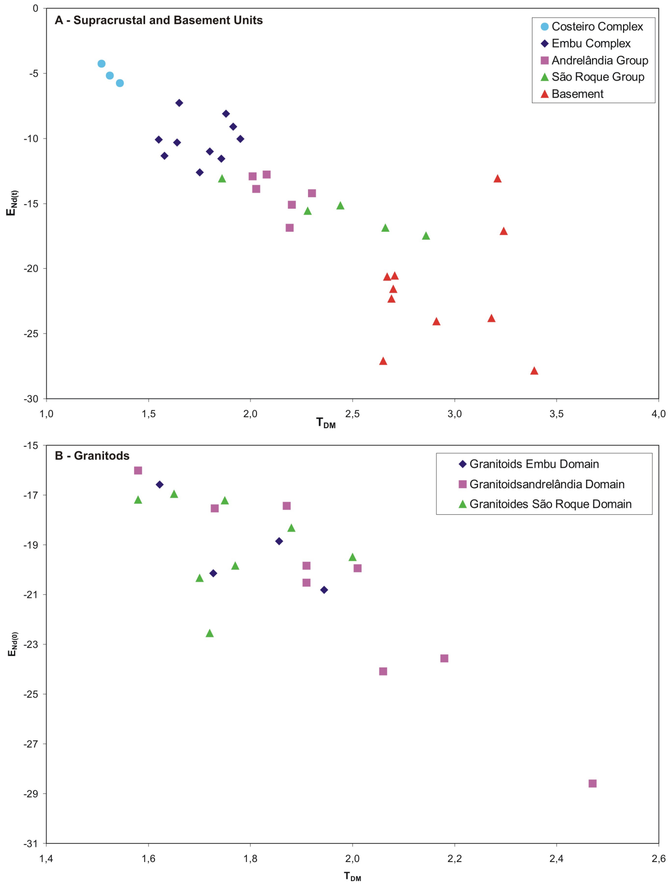
A: for supracrustal metasedimentary rocks and basement units. The Costeiro Domain has younger TDM model ages and the basement rocks yield Archean TDM model ages. The Embu Domain yields slightly younger values than the Andrelândia and São Roque Domains but with some overlap.

B: Granitoids range in value between 1.4 and 2.4 but no systematic distribution across the domain boundaries could be found. Data from tables 2 and 3.

Supracrustal Rocks

Embu Domain. Samples from this domain have TDM model ages ranging from 1.55 to 1.95 Ga (Figure 17 A), suggesting a bimodal distribution of their sources. A prevailing Paleoproterozoic source is evident in the central portion of the area, close to the southern border of the Taubaté Basin, with average TDM model ages of 1.88 Ga. Younger TDM model ages (1.55 to 1.65 Ga) are found to the south of Queluz and north of São José dos Campos (Figure 16). These results suggest a Mesoproterozoic source or, most probably, a mixture between Paleo and Neoproterozoic sources. The latter hypothesis is highlighted in the diagram plotting TDM model ages versus Nd (600) (Figure 18 A) in which the analytical data points are aligned between old and young end members (basement rocks and Costeiro Domain).

Figure 18. Nd(600) versus TDM diagram



A: Samples of the Andrelândia, São Roque, Costeiro and Embu Domains and basement rocks.

B: Granitoids from all domains. Data from tables 2 and 3.

Andrelândia Domain. In the northern portion of the studied area, rocks from this unit have predominantly Paleoproterozoic model ages (TDM), with values higher (~2.0-2.3 Ga) than those of the rocks from the Embu Domain. They also display more negative Nd(600) values (Figure 18 A).

Costeiro Domain. Gneiss and migmatites of this domain yielded TDM model ages between 1.27 and 1.42 Ga, defining a very homogeneous distribution of their source, with values lower than those from the Embu and Andrelândia Domains (Figure 17). This unit displays Nd(600) values between -4 and -6, less negative, therefore, than those of the Embu Domain (around -10, Figure 18 A).

São Roque Domain. Data for metasedimentary and metavolcanic rocks from this domain partly overlap with those of the Andrelândia Domain and indicate provenance from Paleoproterozoic sources with a probable contribution from a younger source material. Metarhythmites have TDM model ages of 2.44 Ga whereas the phyllites yield TDM model age of 1.86 Ga, with Nd(600) of ca. -15 values (Table 3). Neoproterozoic metamafic rocks (metadiorites and amphibolites) intercalated with these metasediments display TDM model ages of 2.66 Ga. These values suggest that the igneous rocks were derived from Paleoproterozoic, and possibly Archean lithosphere.

Granitoids

Six different granitoid bodies of the Embu and Andrelândia Domains were analysed. TDM model ages vary between 1.8 and 2.2 Ga, and negative Nd(t) values between -20.5 to -13, suggest derivation from crustal Paleoproterozoic sources (Figure 18). However, a group of granites (Funil and Rio Branco, Table 2) shows TDM model ages between 1.7 and 1.6 Ga and Nd(t) with values close to -8, indicative of a possible involvement of younger and more juvenile source in their genesis.

Discussion

Integration of new Sm-Nd isotopic data (Table 2) with previously published regional Sm-Nd data (Table 3) allows the re-interpretation of the architecture and tectonic framework of this part of the Ribeira Belt during the Neoproterozoic (ca 600 Ma).

The data presented above suggest that:

i. The basement rocks to the supracrustal sequences are dominated by Archaean to Paleoproterozoic units. The bimodal distribution of TDM model ages of migmatites and orthogneiss (2.65 to 2.7 and 3.39 Ga; Figure 17 A) from the basement rocks indicate that source rocks in this region are isotopically comparable to basement rocks elsewhere in the Ribeira Belt (Fischel et al., 1998; Ragatky et al. 2000; Fetter et al. 2000, Figure 19). The consistency in the isotopic characteristics of basement rocks over these regions (> 200 km lateral extent) may indicate that they share a common Archean crustal basement, except for Costeiro Domain, where no old basement rocks have been identified.

ii. The Sm-Nd data of supracrustal rocks demonstrates that each domain has a distinct Nd isotopic signature. Despite the likely existence of an Archean basement, most of the supracrustal sedimentary rocks in these domains have much younger TDM model ages (1.4 - 2.2 Ga) reflecting significant addition of juvenile components at or after 2.2 Ga (Figure 18 A). Along an E-W transect across the Ribeira Belt, TDM model ages and Nd(600) values decrease to the Costeiro Domain in the east, as represented in Figure 20 .

iii. Another potentially important result is that the supracrustal rocks of the Embu Domain may define a bimodal distribution of TDM model ages. Biotite gneiss with TDM model ages of around 1.5 to 1.6 Ga and small negative Nd(600) values (-7 to -11) suggest the important participation of a Neoproterozoic juvenile source, whereas other rock types (sillimanite-gneiss) yielded predominant Paleoproterozoic model ages (1.86 to 1.96 Ga);

iv. The gneisses and migmatites of the Costeiro Domain yielded TDM model ages between 1.27 and 1.42 Ga, with Nd(600) values around -4 and -5. The isotopic signature of these rocks is very homogeneous compared with those of the other domains in the Ribeira Belt. Also in the Costeiro Domain, the source rocks are more radiogenic than other domains, suggesting the participation of a significant (but certainly not dominant) Neoproterozoic juvenile source (Figure 18 , 19).

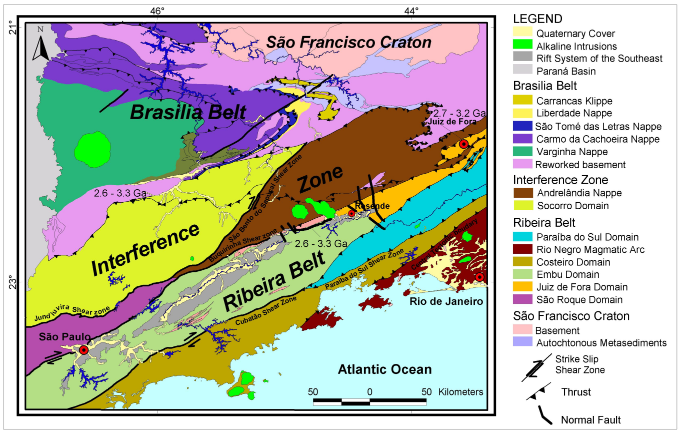
v. In contrast to the Costeiro Domain, the granitoids of the Andrelândia, Embu and São Roque Domains display similar and large variations of TDM model age values between 2.2 - 1.6 Ga, with dominant values around 1.7 Ga. The observed heterogeneity may reflect derivation from both Paleoproterozoic and younger lithosphere/crust.

vi. Integrated isotopic signature of basement, supracrustal sequences and granitoids in the Ribeira Belt in this area suggest that the Andrelândia, Embu and São Roque Domains constitute a single lithospheric block. A similar situation is described by Dantas et al. (2000) in the southern portion of the Ribeira Belt. However, this interpretation is in disagreement with the proposal that the different domains represent distinct tectono-stratigraphic terranes separated by suture zones (Campos Neto, 2000; Almeida, 2002).

vii. The isotopic signature contrast between the Costeiro and Embu Domains reinforce the interpretation that the Cubatão shear zone represents a suture zone, based on the gravimetry data by Almeida (2002). Also, the Costeiro Domain have similar TDM model ages to those observed in rocks of the Rio Negro Magmatic Arc, about 150 km to the east of the area studied (Tupinambá et al., 2000). We suggest, therefore, that the arc extends to the Paraíba do Sul Valley region, as proposed by Trouw et al. (2000) and Campos Neto (2000).

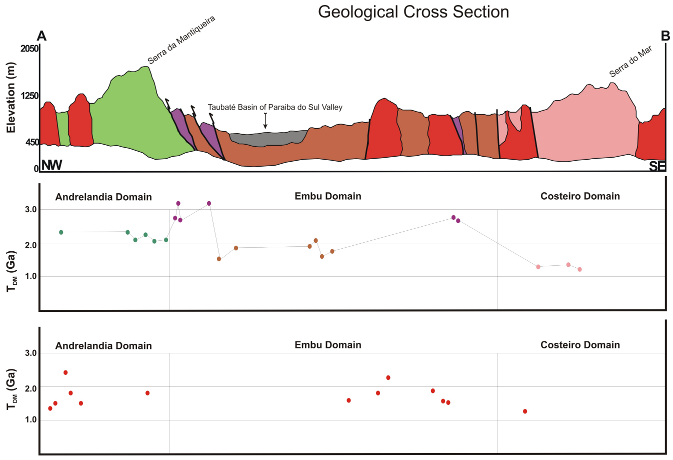
viii. The Ribeira Belt resulted from the collision between the São Francisco-Congo and Rio de La Plata Cratons during the assembly of west Gondwana during the Brasiliano orogeny. Fragments of these cratons may be present as slices in the crystalline basement of the Ribeira Belt, as indicated by the isotopic results on basement rocks (Figure 20). Zircon inheritance work could help define the absolute ages of these buried slices. The lack of TDM model ages between 2.6 and 2.3 Ga in the metasedimentary sequences indicate minor participation of Archean rocks as sediment sources to form the Neoproterozoic sequences.

Figure 19. Tectonic subdivisions of the Mantiqueira Province



Tectonic subdivisions of the Mantiqueira Province, compiled and modified after Heilbron, 1995, Morais et al, 1999; Bizzi et al., 2001.

Figure 20. Schematic geologic cross-sections



A: Schematic geologic cross-section of the Ribeira Belt.

B and C: TDM model age profiles for basement and supracrustal rocks and granitoids.

The profile shows that the basement rocks (purple) yield Archean TDM model ages, and that the supracrustal rocks in the Embu Domain are consistently younger than those in the Andrelândia Domain, and Costeiro Domain is younger than the other domains.

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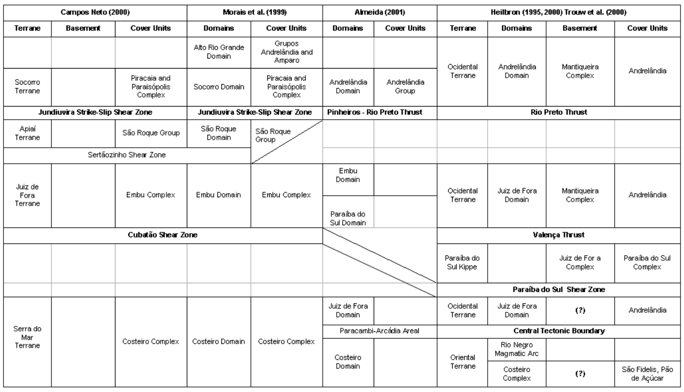
A. Tables

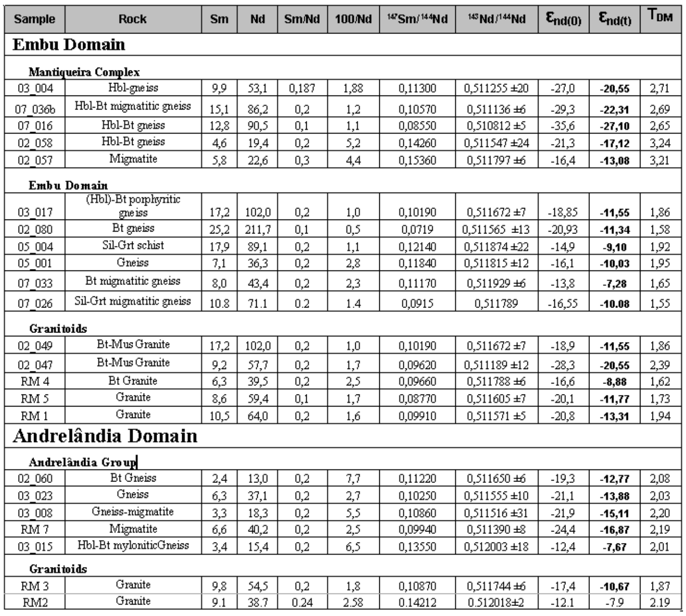
Figure T1. Tectonic domains of the Ribeira Belt



Campos Neto (2000)			Morais et al. (1999)		Almeida (2001)		Heilbron (1995, 2000) Trouw et al. (2000)			
Terrane	**Basement**	**Cover Units**	**Domains**	**Cover Units**	**Domains**	**Cover Units**	**Terrane**	**Domains**	**Basement**	**Cover Units**
			Alto Rio Grande Domain	Grupos Andrelândia and Amparo			Ocidental Terrane	Andrelândia Domain	Mantiqueira Complex	Andrelândia
Socorro Terrane		Piracaia and Paraisópolis Complex	Socorro Domain	Piracaia and Paraisópolis Complex	Andrelândia Domain	Andrelândia Group				
Jundiuvira Strike-Slip Shear Zone			**Jundiuvira Strike-Slip Shear Zone**		**Pinheiros - Rio Preto Thrust**		**Rio Preto Thrust**			
Apiaí Terrane		São Roque Group	São Roque Domain	São Roque Group						
Sertãozinho Shear Zone										
Juiz de Fora Terrane		Embu Complex	Embu Domain	Embu Complex	Embu Domain		Ocidental Terrane	Juiz de Fora Domain	Mantiqueira Complex	Andrelândia
					Paraíba do Sul Domain					
Cubatão Shear Zone							**Valença Thrust**			
							Paraíba do Sul Kippe		Juiz de For a Complex	Paraíba do Sul Complex
							Paraíba do Sul Shear Zone			
Serra do Mar Terrane		Costeiro Complex	Costeiro Domain	Costeiro Complex	Juiz de Fora Domain		Ocidental Terrane	Juiz de Fora Domain	**(?)**	Andrelândia
					Paracambi-Arcádia Areal		**Central Tectonic Boundary**			
					Costeiro Domain		Oriental Terrane	Rio Negro Magmatic Arc		
								Costeiro Complex	**(?)**	São Fidelis, Pão de Açúcar

Tectonic domains of the Ribeira Belt in the States of São Paulo and Rio de Janeiro States according to a number of authors, from NW (São Francisco Craton) to SE (Atlantic Coast). The horizontal lines correspond to tectonic boundaries, but it does not necessarily indicate geographic correlation.

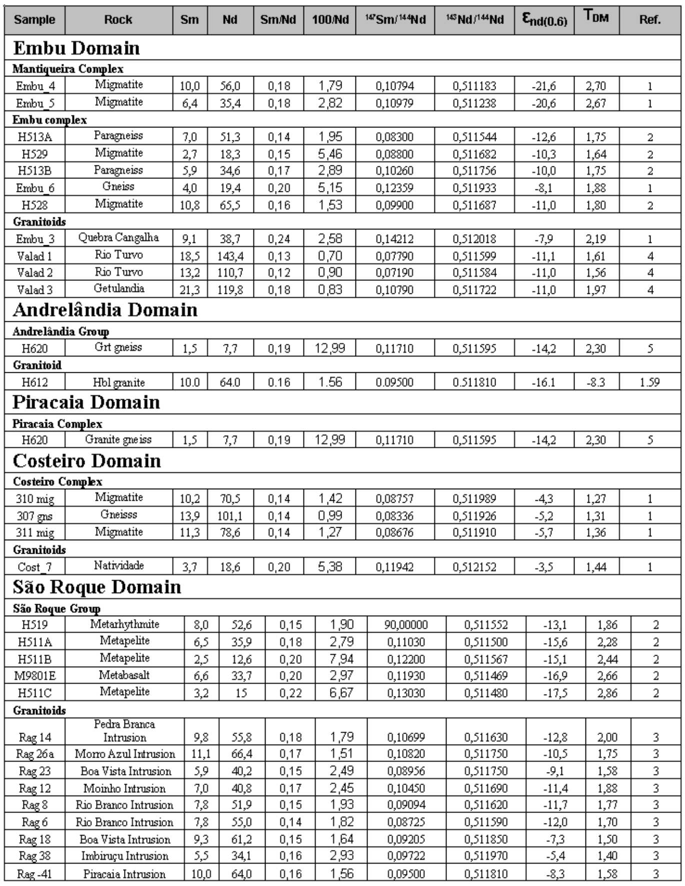
Figure T2. Representative Sm-Nd isotope results



Sample	Rock	Sm	Nd	Sm/Nd	100/Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\varepsilon_{nd(0)}$	$\varepsilon_{nd(t)}$	T_{DM}
Embu Domain										
Mantiqueira Complex										
03_004	Hbl-gneiss	9,9	53,1	0,187	1,88	0,11300	0,511255 ±20	-27,0	**-20,55**	2,71
07_036b	Hbl-Bt migmatitic gneiss	15,1	86,2	0,2	1,2	0,10570	0,511136 ±6	-29,3	**-22,31**	2,69
07_016	Hbl-Bt gneiss	12,8	90,5	0,1	1,1	0,08550	0,510812 ±5	-35,6	**-27,10**	2,65
02_058	Hbl-Bt gneiss	4,6	19,4	0,2	5,2	0,14260	0,511547 ±24	-21,3	**-17,12**	3,24
02_057	Migmatite	5,8	22,6	0,3	4,4	0,15360	0,511797 ±6	-16,4	**-13,08**	3,21
Embu Domain										
03_017	(Hbl)-Bt porphyritic gneiss	17,2	102,0	0,2	1,0	0,10190	0,511672 ±7	-18,85	**-11,55**	1,86
02_080	Bt gneiss	25,2	211,7	0,1	0,5	0,0719	0,511565 ±13	-20,93	**-11,34**	1,58
05_004	Sil-Grt schist	17,9	89,1	0,2	1,1	0,12140	0,511874 ±22	-14,9	**-9,10**	1,92
05_001	Gneiss	7,1	36,3	0,2	2,8	0,11840	0,511815 ±12	-16,1	**-10,03**	1,95
07_033	Bt migmatitic gneiss	8,0	43,4	0,2	2,3	0,11170	0,511929 ±6	-13,8	**-7,28**	1,65
07_026	Sil-Grt migmatitic gneiss	10.8	71.1	0.2	1.4	0,0915	0,511789	-16,55	**-10.08**	1,55
Granitoids										
02_049	Bt-Mus Granite	17,2	102,0	0,2	1,0	0,10190	0,511672 ±7	-18,9	**-11,55**	1,86
02_047	Bt-Mus Granite	9,2	57,7	0,2	1,7	0,09620	0,511189 ±12	-28,3	**-20,55**	2,39
RM 4	Bt Granite	6,3	39,5	0,2	2,5	0,09660	0,511788 ±6	-16,6	**-8,88**	1,62
RM 5	Granite	8,6	59,4	0,1	1,7	0,08770	0,511605 ±7	-20,1	**-11,77**	1,73
RM 1	Granite	10,5	64,0	0,2	1,6	0,09910	0,511571 ±5	-20,8	**-13,31**	1,94
Andrelândia Domain										
Andrelândia Group										
02_060	Bt Gneiss	2,4	13,0	0,2	7,7	0,11220	0,511650 ±6	-19,3	**-12,77**	2,08
03_023	Gneiss	6,3	37,1	0,2	2,7	0,10250	0,511555 ±10	-21,1	**-13,88**	2,03
03_008	Gneiss-migmatite	3,3	18,3	0,2	5,5	0,10860	0,511516 ±31	-21,9	**-15,11**	2,20
RM 7	Migmatite	6,6	40,2	0,2	2,5	0,09940	0,511390 ±8	-24,4	**-16,87**	2,19
03_015	Hbl-Bt myloniticGneiss	3,4	15,4	0,2	6,5	0,13550	0,512003 ±18	-12,4	**-7,67**	2,01
Granitoids										
RM 3	Granite	9,8	54,5	0,2	1,8	0,10870	0,511744 ±6	-17,4	**-10,67**	1,87
RM2	Granite	9.1	38.7	0.24	2.58	0.14212	0.512018±2	-12.1	-7.9	2.19

Representative Sm-Nd isotope results for metasedimentary, basement and granitoid of Embu and Andrelândia Domains.

Figure T3. Compilation of representative Sm-Nd isotope results



Sample	Rock	Sm	Nd	Sm/Nd	100/Nd	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	$\varepsilon_{nd(0.6)}$	T_{DM}	Ref.
Embu Domain										
Mantiqueira Complex										
Embu_4	Migmatite	10,0	56,0	0,18	1,79	0,10794	0,511183	-21,6	2,70	1
Embu_5	Migmatite	6,4	35,4	0,18	2,82	0,10979	0,511238	-20,6	2,67	1
Embu complex										
H513A	Paragneiss	7,0	51,3	0,14	1,95	0,08300	0,511544	-12,6	1,75	2
H529	Migmatite	2,7	18,3	0,15	5,46	0,08800	0,511682	-10,3	1,64	2
H513B	Paragneiss	5,9	34,6	0,17	2,89	0,10260	0,511756	-10,0	1,75	2
Embu_6	Gneiss	4,0	19,4	0,20	5,15	0,12359	0,511933	-8,1	1,88	1
H528	Migmatite	10,8	65,5	0,16	1,53	0,09900	0,511687	-11,0	1,80	2
Granitoids										
Embu_3	Quebra Cangalha	9,1	38,7	0,24	2,58	0,14212	0,512018	-7,9	2,19	1
Valad 1	Rio Turvo	18,5	143,4	0,13	0,70	0,07790	0,511599	-11,1	1,61	4
Valad 2	Rio Turvo	13,2	110,7	0,12	0,90	0,07190	0,511584	-11,0	1,56	4
Valad 3	Getulandia	21,3	119,8	0,18	0,83	0,10790	0,511722	-11,0	1,97	4
Andrelândia Domain										
Andrelândia Group										
H620	Grt gneiss	1,5	7,7	0,19	12,99	0,11710	0,511595	-14,2	2,30	5
Granitoid										
H612	Hbl granite	10.0	64.0	0.16	1.56	0.09500	0.511810	-16.1	-8.3	1.59
Piracaia Domain										
Piracaia Complex										
H620	Granite gneiss	1,5	7,7	0,19	12,99	0,11710	0,511595	-14,2	2,30	5
Costeiro Domain										
Costeiro Complex										
310 mig	Migmatite	10,2	70,5	0,14	1,42	0,08757	0,511989	-4,3	1,27	1
307 gns	Gneisss	13,9	101,1	0,14	0,99	0,08336	0,511926	-5,2	1,31	1
311 mig	Migmatite	11,3	78,6	0,14	1,27	0,08676	0,511910	-5,7	1,36	1
Granitoids										
Cost_7	Natividade	3,7	18,6	0,20	5,38	0,11942	0,512152	-3,5	1,44	1
São Roque Domain										
São Roque Group										
H519	Metarhythmite	8,0	52,6	0,15	1,90	90,00000	0,511552	-13,1	1,86	2
H511A	Metapelite	6,5	35,9	0,18	2,79	0,11030	0,511500	-15,6	2,28	2
H511B	Metapelite	2,5	12,6	0,20	7,94	0,12200	0,511567	-15,1	2,44	2
M9801E	Metabasalt	6,6	33,7	0,20	2,97	0,11930	0,511469	-16,9	2,66	2
H511C	Metapelite	3,2	15	0,22	6,67	0,13030	0,511480	-17,5	2,86	2
Granitoids										
Rag 14	Pedra Branca Intrusion	9,8	55,8	0,18	1,79	0,10699	0,511630	-12,8	2,00	3
Rag 26a	Morro Azul Intrusion	11,1	66,4	0,17	1,51	0,10820	0,511750	-10,5	1,75	3
Rag 23	Boa Vista Intrusion	5,9	40,2	0,15	2,49	0,08956	0,511750	-9,1	1,58	3
Rag 12	Moinho Intrusion	7,0	40,8	0,17	2,45	0,10450	0,511690	-11,4	1,88	3
Rag 8	Rio Branco Intrusion	7,8	51,9	0,15	1,93	0,09094	0,511620	-11,7	1,77	3
Rag 6	Rio Branco Intrusion	7,8	55,0	0,14	1,82	0,08725	0,511590	-12,0	1,70	3
Rag 18	Boa Vista Intrusion	9,3	61,2	0,15	1,64	0,09205	0,511850	-7,3	1,50	3
Rag 38	Imbiruçu Intrusion	5,5	34,1	0,16	2,93	0,09722	0,511970	-5,4	1,40	3
Rag -41	Piracaia Intrusion	10,0	64,0	0,16	1,56	0,09500	0,511810	-8,3	1,58	3

Compilation of representative Sm-Nd isotope results for metasedimentary, basement and granitoids from Embu, Andrelândia, Costeiro and São Roque Domains of the Ribeira Belt.

References in last column: (1) Sato (1998); (2) Dantas et al. (2000); (3) Ragatky 1998; (4) Valladares (1996); (5) Fetter et al. (2003); (6) Ebert and Hasui (1998).