

## Anais da Academia Brasileira de Ciências



All the contents of this journal, except where otherwise noted, is licensed under a Creative Commons Attribution License. Fonte:

[https://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S0001-37652001000200010&lng=en&tlng=en](https://www.scielo.br/scielo.php?script=sci_arttext&pid=S0001-37652001000200010&lng=en&tlng=en). Acesso em: 12 jan. 2021.

### REFERÊNCIA

PIMENTEL, MÁRCIO M.; BOTELHO, NILSON F. Sr and Nd isotopic characteristics of 1.77-1.58 Ga rift-related granites and volcanics of the Goiás tin province, central Brazil. **Anais da Academia Brasileira de Ciências**, Rio de Janeiro, v. 73, n. 2, p. 263-276, jun. 2001. DOI: <https://doi.org/10.1590/S0001-37652001000200010>. Disponível em: [http://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S0001-37652001000200010&lng=en&nrm=iso](http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0001-37652001000200010&lng=en&nrm=iso). Acesso em: 12 jan. 2021.

# Sr and Nd isotopic characteristics of 1.77-1.58 Ga rift-related granites and volcanics of the Goiás tin province, Central Brazil

MÁRCIO M. PIMENTEL and NILSON F. BOTELHO

Instituto de Geociências, Universidade de Brasília – 70910-900 Brasília, Brasil

*Manuscript received on April 5, 2000; accepted for publication on February 5, 2001;  
contributed by MÁRCIO M. PIMENTEL\**

## ABSTRACT

Supracrustal rocks of the Araí Group, together with coeval A-type granites represent a ca. 1.77-1.58 Ga old continental rift in Brazil. Two granite families are identified: the older (1.77 Ga) group forms small undeformed plutons, and the younger granites (ca. 1.58 Ga) constitute larger, deformed plutons.

Sr-Nd isotopic data for these rocks indicate that the magmatism is mostly product of re-melting of Paleoproterozoic sialic crust. Initial Sr ratios for both granite families are ca 0.726 and 0.720. Most TDM model ages are between 2.58 and 1.80 Ga.  $\epsilon_{Nd}(T)$  values are between +3.6 and -11.9. Araí volcanics are bimodal, with basalts and dacites/rhyolites interlayered with continental sediments. The felsic volcanics show Nd isotopic characteristics which are very similar to the granites, and are also interpreted as reworking of Paleoproterozoic crust.

Detrital sediments of the Araí Group revealed  $T_{DM}$  model ages between 2.4 and 2.16 Ga, indicating that they are the product of erosion of Paleoproterozoic crust.

The data indicate that the Araí rift system was established on crust that had just become stable after the Paleoproterozoic orogeny.

**Key words:** Sr-Nd isotopes, Paleoproterozoic, tin granites, Transamazonian.

## INTRODUCTION

The Araí Group sediments and volcanics represent a well preserved Paleo- to Mesoproterozoic continental rift association in the central-eastern part of the Tocantins Province, central Brazil (Figure 1). Volcanic rocks are represented by 1.77 Ga old alkali-rich basalts and rhyolites near the base of the sedimentary pile. These volcanics are known only in the eastern part of the basin. Coeval alkali-rich A-type granites are also abundant in the region and repre-

sent the plutonic counterparts of the Araí volcanics. Younger granite intrusions (ca. 1.58 Ga) are known also and form large bodies in the western part of the area. These granitic rocks host several tin deposits and this region is part of the so-called Goiás Tin Province (Marini and Botelho 1986, Botelho and Moura 1998). Recent studies have also revealed important indium occurrences (Botelho and Roger 1990, Moura and Botelho 1994) associated with the tin granites.

In this study we present new Sr and Nd isotopic data for the granitic and volcanic rocks, as well as for detrital sediments of the Araí Group, and discuss

\*Member of Academia Brasileira de Ciências  
Correspondence to: Márcio M. Pimentel  
E-mail: marcio@unb.br

their significance with respect to the petrogenesis of the original magmas and to the tectonic evolution of the Araí rift system.

#### REGIONAL GEOLOGIC SETTING

The study area is located in the eastern part of the Tocantins Province, in central Brazil (Figure 1). This province represents a large Neoproterozoic orogen formed between the Amazon, São Francisco/Congo and Paraná (or Rio de la Plata) continental blocks. The Brasília Belt supracrustals occupy the eastern part of the Tocantins Province and constitute a ca. 1000 km long N-S fold-and-thrust belt formed along the western margin of the São Francisco plate. According to the tectonic framework described by Trompette (1994), the Brasília Belt had a long-lived tectonic history, with sedimentation starting at ca. 1.1 Ga and final ocean closure at ca. 0.6 Ga.

In the study area, the Araí Group and the granite-gneiss basement are overlain unconformably by the Meso-Neoproterozoic sedimentary rocks of the Brasília Belt (the Paranoá and Bambuí groups; Figure 2). The rocks investigated in this study, therefore, represent the basement on which the Meso-Neoproterozoic sediments were deposited. All rock units were subsequently affected by the Brasiliano/Pan-African orogeny at ca. 0.6 Ga. The Neoproterozoic deformation is progressively less intense towards the east, so that in the easternmost parts of the studied area, the rocks hardly display any effect of deformation and metamorphism.

#### THE ARAÍ GROUP AND ITS BASEMENT

The Araí Group is a ca. 1500m thick sedimentary sequence made of continental to shallow marine sediments. Its basal section comprise eolian and fluvial deposits corresponding mostly to alluvial fan conglomerates and sandstones, and to fluvial sandstones. These continental sediments are well developed and exposed mostly in the eastern part of the Araí Basin (Alvarenga et al. 2000). Alkali-rich basalts, dacites, rhyolites and ignimbrites dated

at  $1771 \pm 2\text{Ma}$  (U-Pb zircon age; Pimentel et al. 1991) are associated with them. The upper part of the group is formed by post-rift sediments constituting a transgressive marine sequence (Alvarenga et al. 2000). They correspond to siltstones and mudstones and small carbonate lenses deposited in transitional and shallow marine environments. To the west, the Araí Group is in fault contact with the pelitic-psammitic sediments of the Serra da Mesa Group, which has been interpreted as a lateral equivalent of the marine sediments of the upper part of the Araí Group (Marini et al. 1984, Alvarenga et al. 2000).

The Araí Group rests unconformably on: (i) granite-gneiss complex of unknown age (Archaean/Paleoproterozoic?), and (ii) an older metasedimentary sequence formed by carbonaceous micaschist and paragneiss (Ticunzal Formation) (Figure 2). In the Cavalcante-Teresina de Goiás area, the granite-gneiss complex is made mainly of hornblende-biotite metatonalite with subordinate diorite and granodiorite. Preliminary trace and major element geochemistry indicate that these are typical arc-type calc-alkaline suites (Botelho, unpublished results). They have been intruded by several peraluminous granites such as the Aurumina granite, a small, foliated, two-mica granite which hosts a small gold deposit (Botelho, unpublished results). Recent mapping has identified a large volume of such granites, which are presently known as the Aurumina suite. In the whole region, these S-type granites host greisens and pegmatites with cassiterite and tantalite such as in the small intrusions in the Porto Real and Monte Alegre de Goiás areas. In the latter, muscovite of a pegmatite has a K-Ar age of ca. 2.1 Ga and the cassiterite has U-Pb ages ranging between ca. 2.02 Ga and 2.27 Ga (Sparrenberger and Tassinari 1998). K-Ar amphibole age for metabasic rocks of the São Domingos volcano-sedimentary sequence, to the northeast of the area studied here, is also Paleoproterozoic (ca. 2.04 Ga) (Hasui et al. 1980). These very preliminary geochronological data suggest that the sialic basement of the Araí

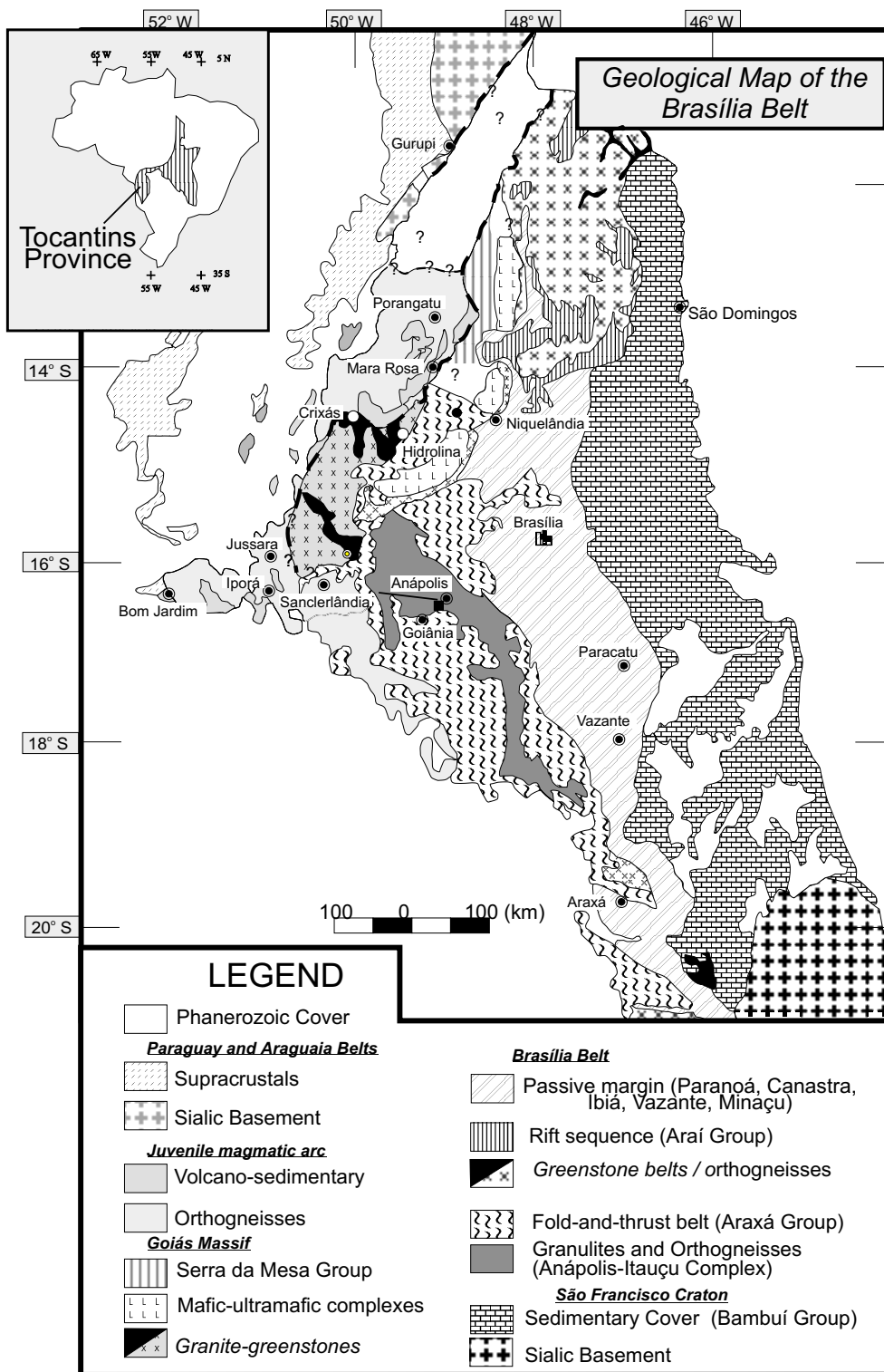


Fig. 1 – Tectonic sketch map of the southeastern part of the Tocantins Province (Brasília Belt).

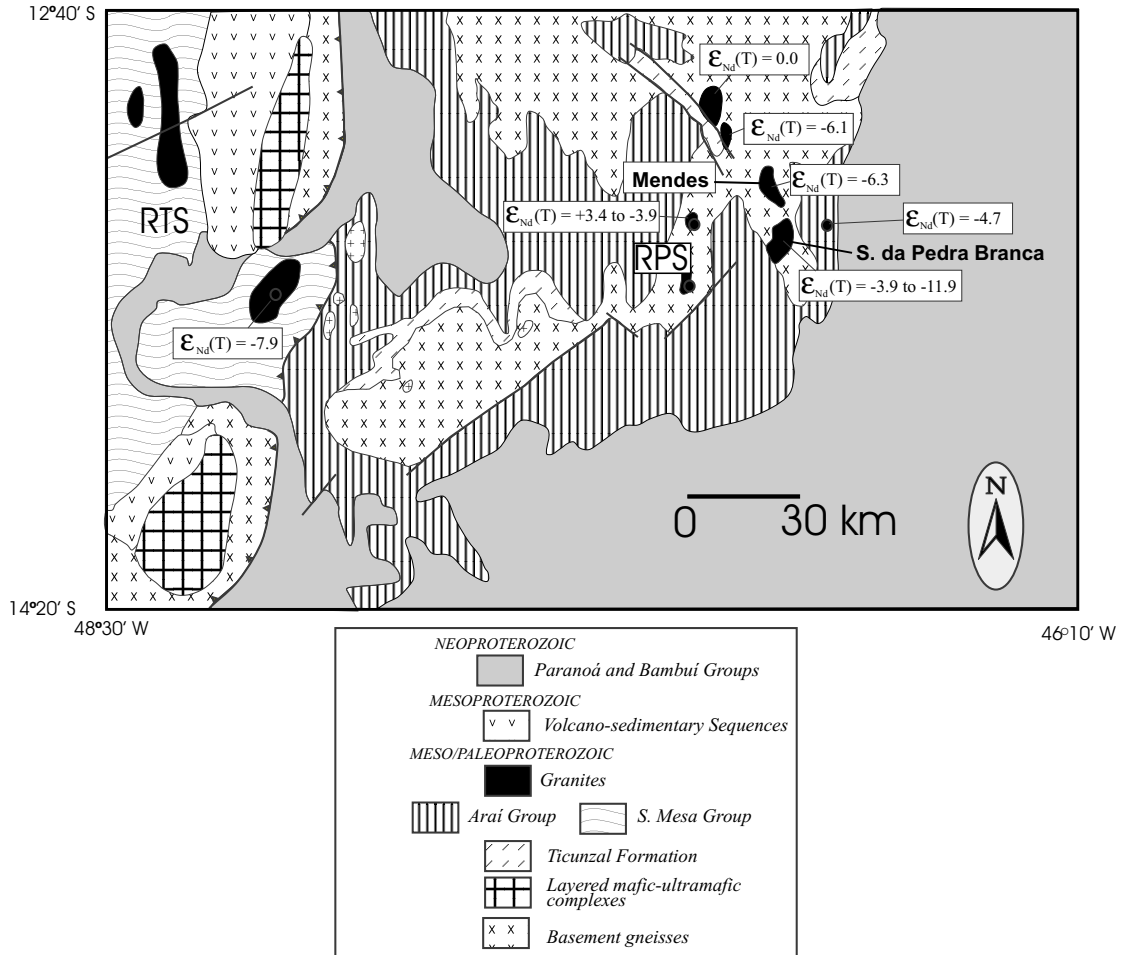


Fig. 2 – Geologic map of the study area.

Group has been strongly affected by the Transamazonian orogeny.

**THE A-TYPE GRANITES**

Several A-type intrusions are known in the area and correspond, in part, to the plutonic equivalents of the Araí volcanics. These intrusions have been grouped into two tin-bearing sub-provinces, which have distinct field, structural, petrographic and geochemical characteristics: (i) the Rio Paranã Sub-Province (RPS) in the east and (ii) the Rio Tocantins Sub-Province (RTS) in the west (Figure 2).

Eight granite plutons constitute the RPS. They

intrude into rocks of the gneissic basement as well as into micaschists of the Ticunzal Formation. No intrusive relationships have ever been described between these granites and the Araí Group supracrustals. These plutons are small, with diameters not exceeding ca. 15 km. Sub-volcanic textures are common. The RTS contains nine plutons (Figure 2), which are generally larger than those of the RPS. They are elongated in the NS direction forming dome-like structures which deform the surrounding metasediments of the Serra da Mesa and Araí groups. These granites are normally deformed, especially along the margins of the intrusions. The field relationships between these plutons and the en-

closing metasediments are obscure and have originated some controversy. Marini and Botelho (1986) stress that there is no field evidence indicating that they are intrusive into the supracrustal units. Other authors, however, have described intrusive relationships (Macambira 1983).

All granites in the RPS and RTS have general petrographic and geochemical features which are similar to those normally attributed to A-type granites. They are alkali-rich and have high F, Sn, Rb, Th, Y, Nb, Ga, and REE contents (Botelho 1992). In the RPS, two distinct families of granite intrusions have been identified and are referred to as the g1 and g2 granites. Those of the g1 family, identified only in the RPS, are older (U-Pb zircon age of 1.77 Ga; Pimentel et al. 1991) and coeval, therefore, with the Araí rhyolites. They are potassic and display clear alkaline affinity, with high Nb, Zr, Th, Y and REE contents. The g2 granites are younger (1.6-1.5 Ga – U-Pb zircon and Pb-Pb ages; Pimentel et al. 1991, Reis Neto 1983, Rossi et al. 1992) and show metaluminous to peraluminous character, with lower K/Na ratios and higher Li, Rb, Sn and Ta contents. g2 granites form the large intrusions in the RTS but occur also as subordinate facies of the granite plutons in the RPS. Tin and indium deposits and occurrences are dominantly associated with the g2 granites.

#### PREVIOUS GEOCHRONOLOGICAL DATA

The most reliable previous geochronological data for these granites are the U-Pb and Pb-Pb data in Pimentel et al. (1991), Reis Neto (1983), and Rossi et al. (1992). The Soledade and Sucuri g1 granites in the RPS have been dated at  $1769 \pm 2$  Ma and  $1767 \pm 10$  Ma, respectively, and the Serra da Mesa g2 granite yielded an unprecise U-Pb age falling in the interval between ca. 1.57 and 1.61 Ga (Pimentel et al. 1991). Zircons from this granite have a Pb-Pb evaporation age of 1.58 Ga (Rossi et al. 1992). Whole-rock samples of the Serra da Mesa and Serra Branca g2 granites produced a Pb-Pb isochron with the age of  $1658 \pm 44$  Ma (Reis Neto 1983). The geochronological data available indicate, therefore,

a time interval of ca. 170 Ma between the emplacement of g1 and g2 granites.

Previous Rb-Sr and K-Ar studies have indicated the clear imprint of the Brasiliano/Pan-African orogeny, resulting in open system behaviour of these isotopic systems (Reis Neto 1983, Reis Neto and Cordani 1984). K-Ar mineral ages are mostly between 0.51 and 0.67 Ga (Hasui and Almeida 1970, Reis Neto 1983) and most Rb-Sr whole-rock isochron ages are between 1.64 and 1.34, distinctively younger than U-Pb zircon ages (for a review, see Pimentel et al. 1991).

#### ANALYTICAL TECHNIQUES

Rb-Sr and Sm-Nd isotopic analyses were carried out at the Geochronology Laboratory of the University of Brasília.

Rb and Sr concentrations were determined by isotope dilution. Sr was separated from whole-rock powders using a conventional cation exchange procedure (Pankhurst and O'Nions 1973). Sr samples were loaded onto double Re filaments and the isotope measurements were carried out on a multi-collector Finnigan MAT-262 mass spectrometer. Mass fractionation corrections were made using  $^{88}\text{Sr}/^{86}\text{Sr}$  ratio value of 8.3752.  $1\sigma$  uncertainties on the measured  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{87}\text{Rb}/^{86}\text{Sr}$  ratios were better than 0.2% and 2%, respectively. Isotope dilution analysis are carried out with the use of a  $^{85}\text{Rb}$ - $^{84}\text{Sr}$  spike and procedure blanks for Sr are typically lower than 100pg. Uncertainties for the isochronic age values were calculated using Isoplot-Ex and are presented at the 95% confidence level. Errors have been augmented by the square root of MSWD/Crit-F.

Sm and Nd extraction from whole-rock powders followed the technique of Richard et al. (1976), in which the separation of the REE as a group using cation-exchange columns precedes reversed-phase chromatography for the separation of Sm and Nd using columns loaded with HDEHP (di-2-ethyl-hexyl phosphoric acid) supported on Teflon powder. We have also used, more recently, the RE-Spec and

Ln-Spec resins for REE and Sm-Nd separation. A mixed  $^{149}\text{Sm}$ - $^{150}\text{Nd}$  spike was used. Sm and Nd samples were loaded onto Re evaporation filaments of a double filament assembly. Uncertainties on Sm/Nd and  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios are considered to be better than  $\pm 0.05\%$  ( $1\sigma$ ) and  $\pm 0.00001$  ( $1\sigma$ ) respectively, based on repeated analyses of international rock standards BCR-1 and BHVO-1.  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios were normalized to a  $^{146}\text{Nd}/^{144}\text{Nd}$  ratio of 0.7219. Nd procedure blanks were smaller than 100pg.

### ISOTOPIC RESULTS

Sr and Nd isotopic data for the granite rocks and Araí volcanics and sediments are listed on Tables I and II.

#### RB-SR DATA FOR THE SERRA DA PEDRA BRANCA AND SERRA DO MENDES GRANITES

The Serra da Pedra Branca granite is a small, circular pluton exposed to the east of the town of Aurumina in the RPS (Figures 2 and 3). It is made mostly of a medium- to coarse-grained porphyritic biotite granite belonging to the g1 family. In the southern border and central part of the pluton, g2 facies are also recognized. These are mainly equigranular to porphyritic biotite granites and less voluminous zinnwaldite and topaz-bearing leucogranite with cassiterite. Quartz diorite and granodiorite have also been mapped along the southern margin of the pluton. Like other dioritic rocks in the area (e.g. in the Serra do Mendes and Mangabeira intrusions) these have been interpreted as part of the older basement into which the granites have intruded. As discussed below, this study indicated that at least some of the diorites are part of the 1.77 Ga magmatic event, agreeing with the fact that these rocks are only slightly deformed.

Whole-rock samples of g1 and g2 granites of the Serra da Pedra Branca pluton have been analysed for their Sr isotopic compositions. Two g1 granite samples from the Serra do Mendes pluton have also been included.

The Rb-Sr data for samples of the g1 granite reflect their very evolved geochemical nature.  $^{87}\text{Rb}/^{86}\text{Sr}$  ratios vary from 3.9 to 79.4. The best fit line through the all seven points (MSWD=21) (Figure 4a) have yielded an age of  $1769 \pm 100\text{Ma}$  which agrees with U-Pb zircon age of ca. 1769 Ma for g1 granites of the Sucuri and Soledade intrusions. The high initial ratio of ca. 0.718 indicates that the original magma is the product of re-melting of older sialic material. Regression calculated with the five samples from the Serra da Pedra Branca intrusion yielded a similar age of  $1757 \pm 132\text{Ma}$  and a very poorly defined initial ratio of ca. 0.72.

Samples of the g2 granite facies of the Serra da Pedra Branca intrusion also demonstrate its very evolved character with  $^{87}\text{Rb}/^{86}\text{Sr}$  ratios varying between 10 and 75. Despite the very large spread of the data points, they align reasonably well (MSWD=7,5) and the regression line indicates the age of  $1555 \pm 88\text{Ma}$  and initial ratio of ca. 0.720 (Figure 4b). The Rb-Sr age of ca. 1,57 Ga of the Serra da Pedra Branca g2 granites agrees well with U-Pb and Pb-Pb ages observed for g2 granites in the RTS and confirm the large time interval between the emplacement of the two granite families.

Initial Sr ratios for both g1 and g2 facies are very poorly defined due to the strongly evolved nature of the original magmas and consequent high values of the  $^{87}\text{Rb}/^{86}\text{Sr}$ . Nevertheless, the high values ( $> 0.710$ ) for these ratios suggest re-melting of older continental crust.

#### ND ISOTOPIC COMPOSITION OF G1 AND G2 GRANITES AND ARAÍ SUPRACRUSTALS

The granite and volcanic samples investigated show relatively high REE contents, with Nd values normally above 100 ppm (Table II).  $^{147}\text{Sm}/^{144}\text{Nd}$  ratios vary between 0.099 and 0.249. Values above 0.14 are observed in five samples and those were not used for  $T_{\text{DM}}$  model age calculations. The high  $^{147}\text{Sm}/^{144}\text{Nd}$  values for some of the samples are due to strong fractionation between Sm and Nd which is common in very alkali-rich granitic and volcanic

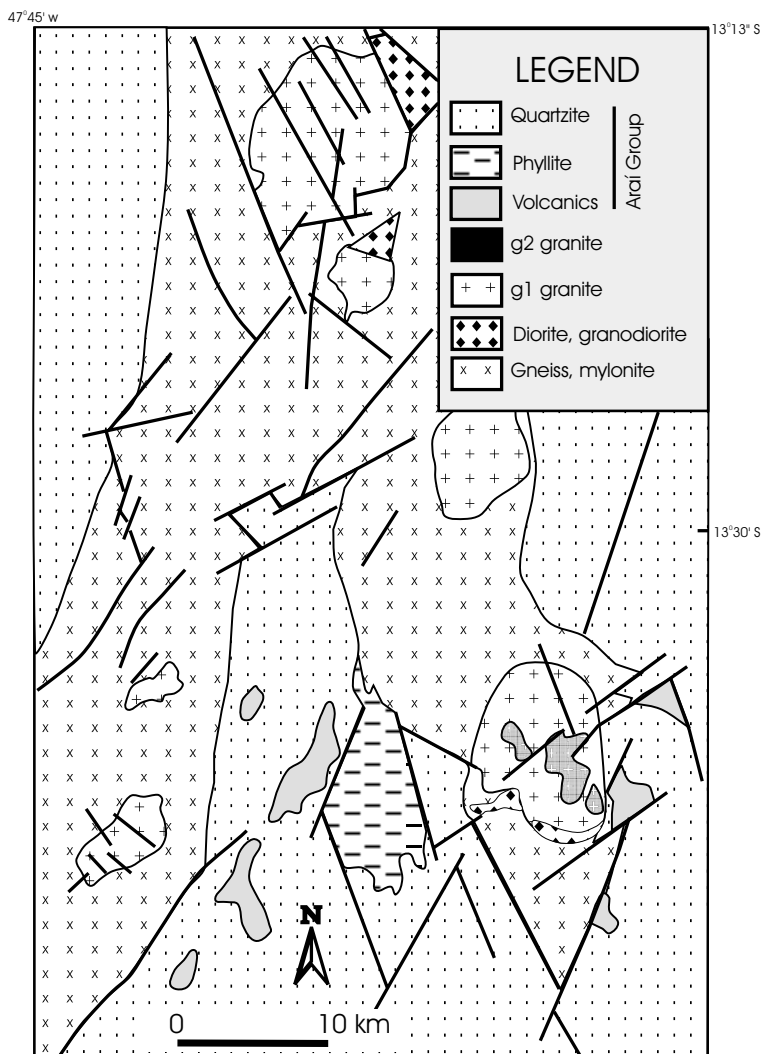


Fig. 3 – Geologic map of the Rio Paranã subprovince. g1 and g2 granites within the Serra da Pedra Branca granite are shown.

rocks. Similar cases have been described in other granite plutons in Brazil such as the alkali granites of Iporá and Israelândia in Goiás (Pimentel and Charnley 1990) and of Japi, Rio Grande do Norte (Hollanda et al. 1999). The fractionation can normally be accounted for by the separation of LREE-rich accessory phases such as monazite or allanite.

$T_{DM}$  model ages of the granites vary between 2.77 and 1.8 (Table II) and  $\epsilon_{Nd}(T)$  values vary within +3.6 and -11.9. Most of the  $T_{DM}$  ages fall in the

interval between 2.5 and 1.8 Ga, suggesting that the original magmas are melts derived mainly from Paleoproterozoic crust, with limited contribution from Archaean material. The dominance of Paleoproterozoic model ages seems to indicate that most of the sialic basement in the region was accreted during the Transamazonian orogeny.

The Nd isotopic characteristics of g1 and g2 granites are illustrated in Figure 5. There are no major differences between them, although some sam-



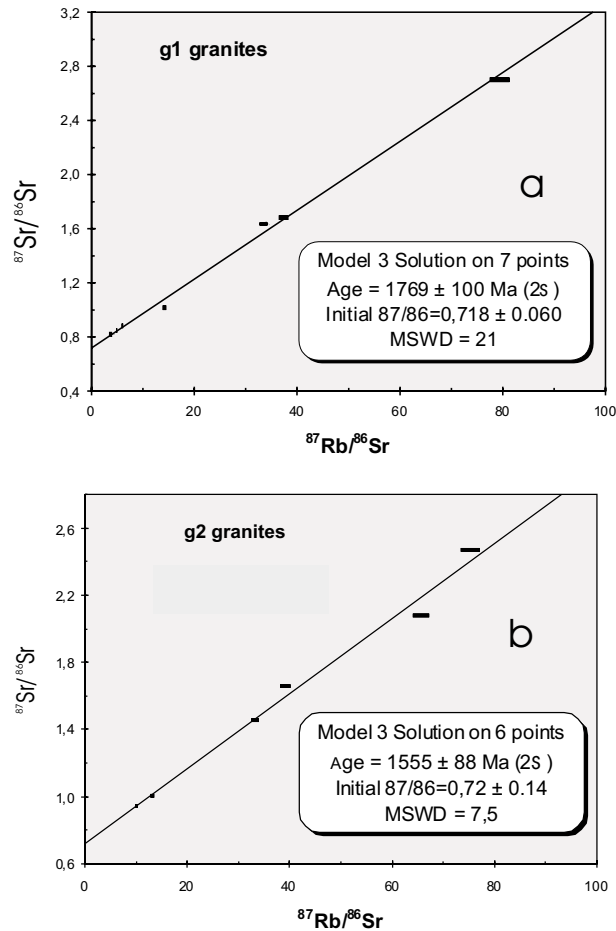


Fig. 4 – Rb-Sr isochrons of g1 (a) and g2 (b) facies of the Serra da Pedra Branca intrusion.

ples of the g1 family are more radiogenic. This indicates the presence of some mantle component in the origin of the g1 granites. In fact, as discussed above, dioritic/granodioritic rocks are associated with some of the plutons in the RPS and could represent the mantle end-member. One sample of these diorites in the southern margin of the Pedra Branca intrusion yielded the most positive  $\varepsilon_{Nd}(T)$  value (+3.6) and the youngest model age (1.80 Ga), only slightly older than the crystallization age of the g1 granites of that pluton. This confirms that these diorites are in fact coeval with the granite magmatism and proba-

bly have a large proportion of the mantle component involved in that magmatic event.

Nd isotopic compositions of basaltic and felsic volcanics of the Araí Group are also displayed in Figure 5. Their compositions are within the same range as for the g1 and g2 granites, with  $\varepsilon_{Nd}(T)$  values from  $-1.5$  to  $-5.9$ , and model ages between 2.59 and 2.2 Ga. Basaltic rocks have high REE concentrations and present the most negative  $\varepsilon_{Nd}(T)$  values, suggesting strong contamination of the original mafic magma with the Paleoproterozoic continental crust.

Four samples of fine-grained sediments of the

**TABLE I**  
**Rb-Sr isotopic data for g1 and g2 granites**

Sample	Rb(ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ ( $\pm 2\text{SE}$ )
g1 granites				
ME-01A <sup>1</sup>	194.0	145.0	3.91	0.81902(02)
ME-12 <sup>1</sup>	223.5	135.1	4.85	0.84547(02)
PB-45 <sup>2</sup>	262.5	129.2	5.99	0.88095(03)
PB-46 <sup>2</sup>	437.8	41.3	33.45	1.63457(03)
PB-51 <sup>2</sup>	371.3	31.5	37.35	1.68136(04)
PB-188A <sup>2</sup>	496.0	21.6	79.39	2.70090(02)
PB-190 <sup>2</sup>	240.1	50.4	14.20	1.01531(03)
g2 granites				
PB-47A <sup>2</sup>	367.2	29.6	39.22	1.65625(01)
PB-75A <sup>2</sup>	335.6	31.3	33.29	1.45634(02)
PB-81A <sup>2</sup>	419.8	18.9	75.36	2.47277(02)
PB-107A <sup>2</sup>	360.1	18.1	65.64	2.07796(04)
PB-166 <sup>2</sup>	332.0	75.2	13.14	1.00672(03)
PB-171C <sup>2</sup>	192.9	57.1	10.01	0.94310(03)

<sup>1</sup>Serra do Mendes granite, <sup>2</sup>Serra da Pedra Branca granite. Precise location of the sampling sites can be obtained directly from the first author.

Araí Group were also analysed.  $T_{\text{DM}}$  values are also Paleoproterozoic, ranging between 2.41 and 2.16 Ga, indicating that they represent the products of erosion of juvenile Paleoproterozoic continental crust, with only very limited contribution from Archaean sources.

#### DISCUSSION AND CONCLUSIONS

The new Sr and Nd isotopic data for rocks of the Araí rift system suggest the following:

1. In spite of the large uncertainties, Rb-Sr isochron ages confirm the large time lag between the emplacement of g1 and g2 granites;
2. Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios, although poorly defined, are high, indicating that the original magmas are melts derived from older sialic crust;
3. Sm-Nd model ages indicate that most of the sialic crust that originated the parental magmas to the tin granites was accreted during the Paleoproterozoic and was probably involved in the ca. 2.0 Ga Transamazonian orogeny;
4. Most detrital sediments of the Araí Group are the product of erosion of the Paleoproterozoic juvenile crust;
5. Nd isotopic data for g1 and g2 granites show a very large spread in  $\epsilon_{\text{Nd}}(T)$  values, especially for the g1 granites. This can be preliminarily interpreted in two ways: (i) the original magmas are the product of different degrees of mixing between 1.7-1.8 Ga mafic magmas and felsic crust-derived melts, or (ii) the sialic source is very heterogeneous in terms of age and iso-

TABLE II

## Nd isotopic composition for the Araí rocks and A-type granites

Sample	Sm (ppm)	Nd (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}$ ( $\pm 2\text{SE}$ )	$^{143}\text{Nd}/^{144}\text{Nd}$	$T_{\text{DM}}$ (Ga)	$\epsilon_{\text{Nd}}(T)$
g1 granites						
MM-1A <sup>1</sup>	13.17	68.75	0.116	0.511386(05)	2.58	-6.1
ME-08 <sup>2</sup>	13.43	66.44	0.122	0.511769(06)	2.10	0
PB-188A <sup>3</sup>	21.35	83.12	0.155	0.511824(03)	-	-6.5
SU-05A <sup>4</sup>	21.03	127.9	0.099	0.511677(04)	1.81	+3.4
ME-01A <sup>2</sup>	19.57	78.79	0.150	0.511388(05)	-	-13.9
SU-06A <sup>4</sup>	28.73	132.3	0.131	0.511675(05)	2.50	-3.9
SS-1 <sup>5</sup>	17.06	88.62	0.116	0.511479(04)	2.43	-4.3
g2 granites						
84-GD-SM2 <sup>6</sup>	27.57	138.0	0.121	0.511356(04)	2.77	-7.9
PB-75A <sup>2</sup>	27.97	148.8	0.114	0.511423(06)	2.47	-3.9
PB-02 <sup>2</sup>	72.40	175.5	0.249	0.512639(04)	-	-11.9
SB-322 <sup>7</sup>	25.51	116.1	0.133	0.511796(04)	2.34	-3.4
PE-283 <sup>8</sup>	19.19	96.26	0.120	0.511761(05)	2.07	-1.4
SM-20 <sup>6</sup>	17.73	89.21	0.120	0.511572(03)	2.38	-5.0
MO-06 <sup>9</sup> (greisen)	26.87	81.86	0.198	0.512307(06)	-	-6.3
Pedra Branca diorite						
PB-152	2.547	12.190	0.126	0.512003(10)	1.80	+3.64
Volcanic rocks						
PB-40 (rhyo)	8.44	31.83	0.160	0.511446(10)	-	-4.7
TF-95-II-72 ( $\beta$ )	5.208	26.31	0.120	0.511444(05)	2.59	-5.9
TF-95-I-108 ( $\beta$ )	3.600	18.95	0.115	0.511419(07)	2.50	-5.5
A-III-14B (dac)	16.70	86.85	0.116	0.511624(05)	2.20	-1.5
TF-95-IV-93 (rhyo)	16.92	89.29	0.115	0.511427(06)	2.49	-5.0
Sediments						
FENG	39.04	208.6	0.113	0.511444	2.41	-4.3
CV-20	3.170	17.38	0.110	0.511497	2.21	-2.6
MORSOL	3.450	18.44	0.113	0.511559	2.24	-2.1
CACH120	4.090	23.31	0.106	0.511508	2.16	-1.5

<sup>1</sup>Mangabeira granite, <sup>2</sup>Serra do Mendes granite, <sup>3</sup>Serra da Pedra Branca granite, <sup>4</sup>Sucuri granite, <sup>5</sup>Soledade granite, <sup>6</sup>Serra da Mesa granite, <sup>7</sup>Serra Branca granite, <sup>8</sup>Serra Dourada granite, <sup>9</sup>Mocambo granite. Ages for  $\epsilon(T)$  calculations are 1.77 Ga for g1 granites and Araí volcanics, and 1.58 Ga for g2 granites. Precise location of the sampling sites can be obtained directly from the first author.

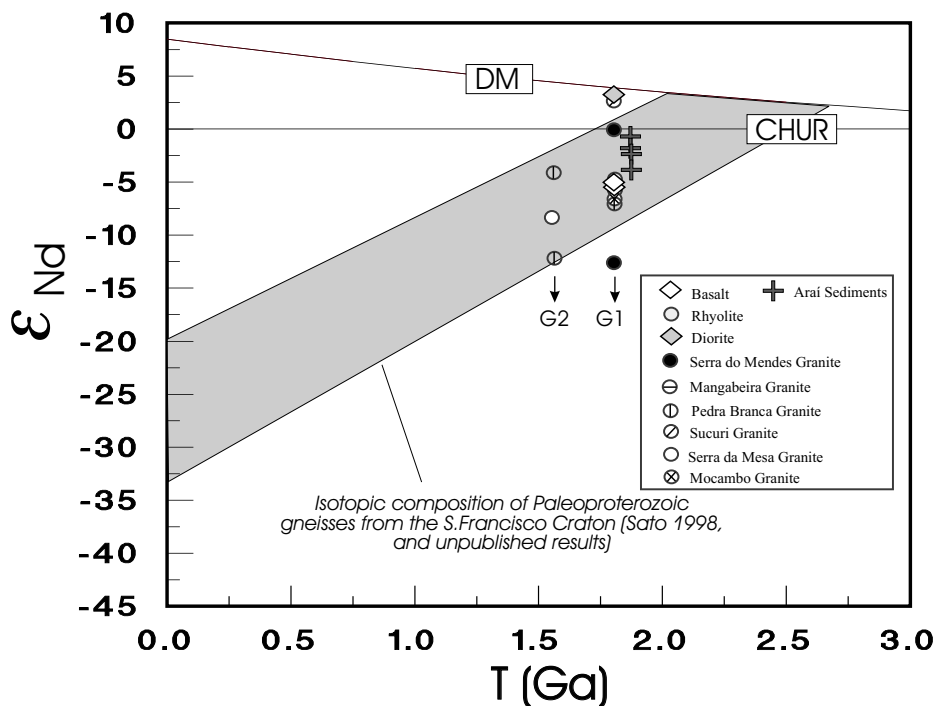


Fig. 5 – Nd isotopic composition of the granites, and Araí supracrustals, compared to the composition of Paleoproterozoic rocks of the São Francisco Craton.

topic characteristics. A combination of the two alternative is also a likely possibility, especially for the g1 granites, due to their spatial association with dioritic rocks. Therefore, the g1 magmatic event is bimodal and the melting of Paleoproterozoic sialic crust was most probably triggered by the heat provided by mafic magmas invading the crust, during the initial stages of development of the continental rift;

6. Nd isotopic composition of the Serra da Pedra Branca diorite indicates the depleted nature of the mantle source, pointing to a lithospheric source.

Similar associations of extension-related granites and volcanics occur in other parts of the world in this same time interval (for a review see Windley 1993). In the northern hemisphere, 1.77 to 1.5 rapakivi granites and associated volcanic rocks are emplaced almost always into Paleoproterozoic oro-

genic belts such as the Svecofennian, Ketilidian and Penokean orogens, or as in the Amazon Craton. One of the most studied of these associations is the one including the classical rapakivi granites intruded into the Svecofennian accretionary orogen of northern Europe (Haapala and Rämö 1990). In that region, the rapakivi granites were emplaced about 70-200 Ma after the last compressive events of the Paleoproterozoic Svecofennian orogeny.

The preliminary data presented here for the Goiás tin granites seem to indicate a similar tectonic situation, although precise ages for the Transamazonian orogeny affecting the basement granite-gneiss complex are not available. However, the Nd model ages indicate that most of the country rocks was accreted and subsequently deformed during the Paleoproterozoic.

The time-lag observed between the final stages of deformation of the Paleoproterozoic orogens and the onset of extension and bimodal magmatism is

explained in terms of the thermal and tectonic state of the lithosphere (Windley 1993). Two variables control the time interval: (i) the initial Moho temperature and (ii) the amount of thickening during the Paleoproterozoic orogeny (Sonder et al. 1987). Wherever thickening is limited (for example in accretionary orogens) and the Moho is heated up to 600°C, it might still take ca. 100 Ma (or more) for extension to start. Therefore, the Paleo-Mesoproterozoic "anorogenic" granites that characterize the Precambrian terrains in several continents might still bear an orogenic connection, although their emplacement took place much later (up to 200 Ma) after the last tectonic events of Paleoproterozoic orogens (Windley 1993).

Therefore we suggest a model to be tested, which considers the 1.77 Ga A-type granites/volcanics of the Araí rift, together with those of the Espinhaço Supergroup, as post-orogenic to a Paleoproterozoic orogen. As a suggestion for further investigation, one might consider a model in which, after the last deformational/crustal thickening events of the Transamazonian orogeny in northern Goiás/southern Tocantins, there was a long time lag before the continental crust became gravitationally unstable and crustal extension took place, leading to upwelling and decompression melting of the mantle. The mafic magmas produced invade the crust, triggering melting of gneisses/granulites/metasediments and producing granite magmatism. One can envisage a situation in which continental blocks amalgamate along Paleoproterozoic orogens originating a large continental mass(es), which soon becomes unstable and rift attempts occur. The Araí sequence is correlated with the basal parts of the Espinhaço Supergroup in Bahia and Minas Gerais, ca. 600 km to the east. This indicates that this continental rift system covered large areas of the continental crust at the end of the Paleoproterozoic, suggesting an important attempt to rift a large continental plate at that time.

To test the model suggested here, the major questions to be addressed in the future are related to

the nature and precise timing of igneous and metamorphic events of the Paleoproterozoic terrains that underlie the northwestern margin of the São Francisco Craton.

#### ACKNOWLEDGEMENTS

The authors thank CNPq for supporting field and laboratory work.

#### RESUMO

As rochas supracrustais do Grupo Araí, e os granitos tipo-A associados, representam um rift continental paleomesoproterozóico. Duas famílias de granitos são identificadas: a mais antiga (ca. 1,77 Ga) forma pequenos plutons circulares enquanto a mais jovem (ca. 1,58 Ga), constitui corpos maiores e deformados.

Dados isotópicos Sr-Nd indicam que o magmatismo félsico é predominantemente o produto de re-fusão de crosta de idade paleoproterozóica. Razões  $^{87}\text{Sr}/^{86}\text{Sr}$  iniciais das duas famílias são ca. 0,726 e 0,720. A maioria das idades modelo  $T_{DM}$  caem no intervalo entre 2,58 e 1,80 Ga e os valores de  $\epsilon_{Nd}(T)$  se distribuem entre +3.6 e -11.9. Rochas vulcânicas do Grupo Araí são bimodais, com basaltos e dacitos/riolitos intercalados em sedimentos continentais. As vulcânicas félsicas mostram características isotópicas de Nd muito semelhantes às dos granitos e também são interpretadas como produtos da re-fusão de crosta paleoproterozóica.

Sedimentos do Grupo Araí indicaram  $T_{DM}$  entre 2,4 e 2,16 Ga, demonstrando que são o produto da erosão de crosta paleoproterozóica.

Os dados apresentados indicam que o rift Araí se instalou em crosta recém estabilizada, após a orogenia Paleoproterozóica.

**Palavras-chave:** Isótopos Sr-Nd, Paleoproterozóico, granitos estaníferos, Transamazônico.

#### REFERENCES

- ALVARENGA CJS, BOTELHO NF, DARDENNE MA, CAMPOS JEG, MARTINS FAL, MENEZES PR AND MOURA MA. 2000. Magmatic and stratigraphic evolution of a Paleo/Mesoproterozoic syn-rift to post-rift basin: example of the Araí Basin, Brazil. In: Intern

- Geol Congress 2000, Rio de Janeiro, Abstracts – CD-ROM.
- BOTELHO NF. 1992. *Les ensembles granitique subalcalins a peralumineux mineralisés en Sn et In de la Sous-province Paranã, Etat de Goiás, Brésil (paragenèses hydrothermales associées: micas lithini-fères, helvite, cassitérite, minéraux d'indium)*. Doctorate Thesis, Univ. Pierre et Marie Curie (Paris VI), 343p, unpublished.
- BOTELHO NF AND MOURA MA. 1998. Granite-ore deposit relationships in Central Brazil. *J South Am Earth Sci* 11(5): 427-438.
- BOTELHO NF AND ROGER G. 1990. Découverte de minéraux d'indium dans la paragenèse sulfurée du gîte stannifère protérozoïque de Mangabeira, Goiás, Brésil. *C.R. Acad Sci Paris* 310(II): 247-253.
- HAAPALA I AND RÄMÖ T. 1990. Petrogenesis of the Proterozoic rapakivi granites of Finland. *Geological Society of America Special Paper* 246: 275-286.
- HASUI Y AND ALMEIDA FFM. 1970. Geocronologia do centro-oeste brasileiro. *Bol da Soc Brasil de Geol* 19(1): 5-26
- HASUI Y, TASSINARI CCG, SIGA JR O, TEIXEIRA W, ALMEIDA FFM AND KAWASHITA K. 1980. Datações Rb-Sr e K-Ar no centro-norte do Brasil e seu significado geológico-geotectônico. *Congr Bras Geologia* 31, 1980, Balneário Camboriú, Anais... SBG, p. 2669-2676.
- HOLLANDA MHBM, JARDIM DE SÁ EF, PIMENTEL MM AND MACEDO MHF. 1999. Sr-Nd isotopic evidence of an Archaean source involved in the Brasiliano syntectonic alkaline magmatism (Seridó Belt, northeastern Brazil). In: *South Am. Symp. on Isotope Geology*, 2., Actas... SEGEMAR, Cordoba, p. 215-218.
- MACAMBIRA MJB. 1983. Ambiente geológico e mineralizações associadas ao granito Serra Dourada (extremidade meridional) – Goiás. MSc Thesis, Univ. Fed. Pará, Belém, 132p., unpublished.
- MARINI OJ AND BOTELHO NF. 1986. A província de granitos estaníferos de Goiás. *Rev Bras Geoc* 16: 119-131.
- MARINI OJ, FUCK RA, DARDENNE MA AND DANNI JCM. 1984. Província Tocantins: setores central e sudeste. In: ALMEIDA FFM AND HASUI Y. (Eds) *O Pré-Cambriano do Brasil*. São Paulo, Blücher, p. 205-264.
- MOURA MA AND BOTELHO NF. 1994. Distribuição do índio (In) na zona greisenizada principal do Maciço Estanífero Mangabeira. In: *Simp. Geol. Centro-Oeste*, 4., Res. Expand... Brasília, SBG, p. 37-39.
- PANKHURST RJ AND O'NIONS RK. 1973. Determination of Rb/Sr and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of some standard rocks and evaluation of x-ray fluorescence spectrometry in Rb-Sr geochronology. *Chem Geology* 12: 127-136.
- PIMENTEL MM AND CHARNLEY N. 1990. Intracrustal REE fractionation and implications for Sm-Nd model age calculations in late-stage granitic rocks: an example from central Brazil. *Chem Geology (Isotope Geoscience Section)* 86: 123-138.
- PIMENTEL MM, HEAMAN L, FUCK RA AND MARINI OJ. 1991. U-Pb zircon geochronology of Precambrian tin-bearing continental-type acid magmatism in central Brazil. *Precamb Res* 52: 321-335.
- REIS NETO JM. 1983. Evolução geotectônica da Bacia do Alto Tocantins, Goiás. MSc Thesis, Univ. São Paulo, São Paulo, 98p, unpublished.
- REIS NETO JM AND CORDANI UG. 1984. Influência do evento geodinâmico Brasileiro nos resultados radiométricos do centro-oeste brasileiro. In: *Cong. Bras. Geol.*, 33., Anais... Rio de Janeiro, SBG, p. 2276-2288.
- RICHARD P, SHIMIZU N AND ALLÈGRE CJ. 1976.  $^{143}\text{Nd}/^{144}\text{Nd}$ , a natural tracer: an application to oceanic basalts. *Earth Plan Sci Lett* 31: 269-278.
- ROSSI P, ANDRADE GF AND COCHERIE A. 1992. The 1.58 Ga A-type granite of Serra da Mesa (GO): an example of NYF fertile granite pegmatite. In: *Cong. Bras. Geol.*, 37., Bol. Res. Expand... São Paulo, SBG, p. 389-390.
- SONDER LJ, ENGLAND PC, WERNICKE BP AND CHRISTIANSEN RL. 1987. A physical model for Cenozoic extension of western North America. In: *Coward MP, Dewey JF and Hancock PL. (Eds) Continental Extension Tectonics*. *Geol Soc Lond Sp Public* 28: 187-201.

- SPARRENBERGER I AND TASSINARI CCG. 1998. Idade da mineralização estanífera na Subprovíncia do Rio Paranã (GO) através de datações U-Pb em cassiterita. In: Congr. Bras. Geologia, 40., Anais... Belo Horizonte, SBG, p. 143.
- TROMPETTE R. 1994. Geology of Western Gondwana (2000-500 Ma). Pan-African-Brasiliano aggregation of South America and Africa. Rotterdam: Balkema, 350 pp.
- WINDLEY BF. 1993. Proterozoic anorogenic magmatism and its orogenic connections. J Geol Society London 150: 39-50.