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Paleoproterozoic source contributions to the São Roque Group sedimentation: LA-MC-ICPMS U-Pb dating and Sm-Nd systematics of clasts from metaconglomerates of the Boturuna Formation

Contribuições de fontes Paleoproterozoicas para a sedimentação do Grupo São Roque: datação U-Pb LA-MC-ICPMS e sistemática Sm-Nd dos clastos dos metaconglomerados da Formação Boturuna

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Abstract

The São Roque Group is characterized by volcano-sedimentary sequences, in which deposition probably started in the late Paleoproterozoic. U-Pb dating by LA-MC-ICPMS of zircons extracted from predominantly equigranular monzogranites clasts from Morro Doce and Morro do Polvilho regions, yield paleoproterozoic ages of 2199 ± 8.5 Ma and 2247 ± 13 Ma, respectively. These represent the ages for the main source of granite for the metaconglomerates from the Boturuna Formation (basal unit of São Roque Group). Its polycyclic history is reinforced by the presence of inherited Archean zircons (2694 ± 29 Ma) found within the clasts. Moreover, these clasts have also been affected by the Neoproterozoic overprinting event as indicated by their lower intercept Concordia ages. Sm-Nd isotope data for the main clast varieties from the Morro Doce metaconglomerates yield T_{DM} ages of 2.6 to 2.7 Ga, demonstrating that these granites are the recycling products of an Archean crustal component. The metaconglomerate arkosean framework yields slightly lower $\varepsilon_{Nd(t)}$ values than those for the clasts, indicating that a younger and/or more primitive source also contributed to the Boturuna Formation.

Keywords: São Roque Group; Metaconglomerates; U-Pb dating; Sm-Nd data; Provenance.

Resumo

O Grupo São Roque é caracterizado por uma sequência vulcanossedimentar com deposição provavelmente iniciada no Paleoproterozoico tardio. Datações U-Pb obtidas por LA-MC-ICPMS de zircões extraídos das variedades predominantes dos clastos de monzogranitos equigranulares, das regiões do Morro Doce e Morro do Polvilho, mostram idades paleoproterozoicas de 2199 ± 8,5 Ma e 2247 ± 13 Ma, respectivamente. Estas representam as idades da principal fonte de granito da Formação Boturuna (unidade basal do Grupo São Roque). A história policíclica deste domínio é reforçada pela presença de zircões arqueanos herdados (2694 ± 29 Ma), encontrados nos clastos. Além disso, tais clastos também foram afetados pelo evento Neoproterozoico, conforme indicado pelo intercepto inferior das idades concórdia. Dados isotópicos Sm-Nd para os principais clastos do metaconglomerado do Morro Doce têm idades T_{DM} entre 2,6 a 2,7 Ga, demonstrando que estes granitos são produtos da reciclagem de um componente crustal arqueano. O arcabouço dos metaconglomerados, quando comparado com os clastos, mostra valores mais baixos de $\varepsilon_{Nd(t)}$, indicando contribuições de fontes mais jovens e/ou primitivas para a Formação Boturuna.

Palavras-chave: Grupo São Roque; Metaconglomerados; Datação U-Pb; Dados Sm-Nd; Proveniência.

INTRODUCTION

The depositional age and geological significance of the São Roque Group (SRG) (Mantiqueira Tectonic Province, in Southeast Brazil) remain the focus of considerable debate in the geological literature. Several meta volcano-sedimentary sequences have been recognized in the so-called São Roque Domain. This includes the Serra do Itaberaba Group, which has been recognized as a medium-grade metamorphic sequence with a depositional age of ~1.5 Ga (Juliani et al., 2000), and is distinct relative to the lower-grade sequences that are commonly grouped into the SRG. The SRG itself is considered by some authors (Juliani, 1993; Martin, 2000) as a younger sequence, in view of its lower-grade metamorphism and proposed erosional contact marked by the presence, in metaconglomerates from its basal sequence (Boturuna Formation), of clasts and volcanic fragments, which are correlated to the Serra do Itaberaba Group (SIG). However, U-Pb zircon dating of acid and basic metavolcanic rocks from the Boturuna Formation has yielded consistently older ages (1790 ± 14 Ma; van Schmus et al., 1986; 1750 ± 40 Ma; Oliveira et al., 2008), strongly suggesting that SRG in fact corresponds, at least in part, to an older sequence (Henrique-Pinto and Janasi, 2010).

The metaconglomerates study from the SRG basal sequence has a long history, with the pioneering study by Derby (1882), who first documented the occurrence of such rocks in Brazil. A subsequent study by Coutinho (1955) reported a detailed description of the metaconglomerates, which are characterized by pebbles and boulders largely granitic in nature within an arkosean framework. These occur as meter to hectometre-sized lenses within a dominantly psammitic sequence. The intercalated bimodal suite of metavolcanic rocks that was used to determine the age of deposition occurs as thin layers and is characterized by a within-plate geochemical signature (Henrique-Pinto, 2008).

We have reported here the results of LA-MC-ICPMS U-Pb zircon dating of granitic clasts and Sm-Nd isotope determinations for granitic and amphibolite clasts, and for the framework of the metaconglomerates. Together with the previously reported geochemical data, these new results are used to aid in elucidating the provenance of the SRG and therefore contribute for understanding its tectonic significance.

TECTONIC SETTING

The São Roque Domain is a tectonic block that is located between the high-metamorphic grade Socorro-Guaxupé Nappe to the north (currently interpreted as related to the evolution of the southern branch of the Brasília Fold Belt), and the Embu Domain to the south (related to the Ribeira Fold Belt), as observed in Figure 1. In the tectonic model of Campos Neto (2000), the São Roque Domain is part of a larger block dominated by meta-volcano-sedimentary sequences metamorphosed to low-to-medium-grade conditions (the Apiaí-São Roque Domain). When together with the Socorro-Guaxupé Nappe, these correspond to a magmatic arc domain developed at the border of an older cratonic nucleus, which is mostly concealed beneath the Phanerozoic Paraná sedimentary basin, the Paranapanema Craton (Mantovani and Brito Neves, 2005).

The first stratigraphic division of the SRG was proposed by Hasui (1976). Subsequently, a two-fold one was proposed, with the basal Boturuna Formation consisting of phyllites with quartzite and metacarbonate intercalations, whereas the upper Piragibu Formation is composed of rhythmic metapsammites succeeded by phyllites that are interbedded with quartzite. This sequence is interpreted to possibly represent turbidity current deposits in a marine environment (Carneiro, 1983; Campos Neto et al., 1983; Dantas, 1990).

Later studies recognized a distinctive volcano-sedimentary sequence in the Serra do Itaberaba region (Coutinho et al., 1982), composed of basic to intermediate tuffs, volcanic and subvolcanic rocks interbedded with chert, banded iron formation (BIF), and detrital sediments. This sequence was later defined as SIG (Juliani et al., 1986), and distinguished from the SRG, based on its higher (amphibolite-facies) metamorphic grade, and the presumed existence of an erosional contact. The latter is delineated by the presence of clasts and volcanic fragments from the SIG in metaconglomerates located at SRG base (Juliani, 1993; Martin, 2000). SIG was dated, by Juliani et al. (2000), by U-Pb zircon in metavolcanic rocks at 1395 ± 10 Ma.

A different metavolcano-sedimentary sequence was described in the Pirapora region (Bistrichi, 1982; Bergmann, 1988; Tassinari et al., 2001), which is composed of tholeiitic metabasalts with pillow-lavas (Figueiredo et al., 1982) chemically similar to MORB (Lazzari, 1987; Henrique-Pinto and Janasi, 2010) and associated with pyroclastics and meta-limestones, showing stromatolite structures (Bergmann and Fairchild, 1985). Bergmann (1988) interpreted the Pirapora Formation as the representation of passive margin volcanic centers surrounded by stromatolites. U-Pb zircon (608 ± 7 Ma) and monazite (628 ± 9 Ma) dates (Hackspacker et al., 1999; 2000) suggest a Neoproterozoic age for this sequence; however, recent U-Pb zircon dating for possible correlative metavolcanic rocks in the Cajamar region indicate an age of 1750 ± 40 Ma (Oliveira et al., 2008).

The possibility that the SRG base is older than the overlying layers was stated by Van Schmus et al. (1986), based

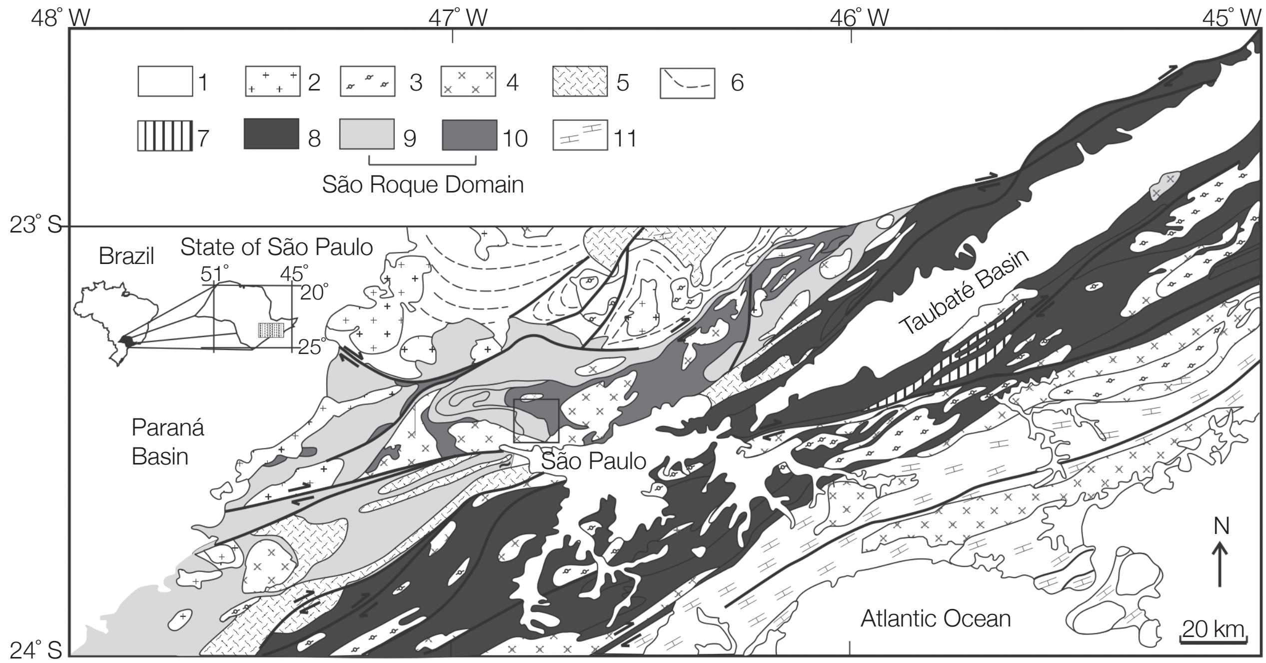


Figure 1. Simplified geotectonic map of the region near the city of São Paulo (modified from Campos Neto, 2000). 1: Phanerozoic cover and intrusive rocks; 2: late and post-tectonic granites; 3: (garnet)-(muscovite)-biotite granites; 4: porphyritic biotite granites; 5: porphyritic (hornblende)-biotite granites; 6: Socorro-Guaxupé domain; 7: Paleoproterozoic gneisses (basement to Embu Domain metasupracrustals); 8: Embu Domain metasupracrustal sequences; 9: São Roque Group and Votuverava Formation; 10: Serra do Itaberaba Group; 11: Costeiro complex. The small box shows the location of Figure 2.

on U-Pb zircon age of 1790 ± 14 Ma obtained for acid metavolcanic rocks, which are characterized by a within-plate geochemical signature from the Morro do Polvilho region (Henrique-Pinto and Janasi, 2010).

LOCAL GEOLOGY

A simplified geological map of the study area is presented in Figure 2, where most of the metaconglomerate occurrences from the Boturuna Formation are indicated. The basal unit of the SRG identified by Coutinho (1955) was referred as Morro Doce Formation (Juliani et al., 1999); part of this sequence was also positioned as lower by Cordani et al. (1961) and classified as 'impure metapsammitic' unit (Carneiro, 1983), or 'basal siliciclastic association' (Fernandes da Silva, 2004). However, these studies were conducted in different geographical locations.

The Boturuna Formation crops out predominantly northwest of the city of São Paulo (Figure 2). It is characterized by the predominance of interfingered metarkoses and polymictic metaconglomerates with pebbles and cobbles encased by hard-recrystallized framework. In topographically higher regions (the Jaraguá Peak), occurrences of metasandstones and feldspathic metasandstones ones are present. Small bodies of metavolcanic rocks are intercalated with metarkoses; those are represented by basic metavolcanic rocks (e.g. small lenses of basaltic trachyandesite within the metarkoses), and porphyritic meta-trachydacite (in the Morro do Polvilho region). The meta-trachydacites define a chemical signature typical of within-plate magmatism, with low mg#, high Zr, Y, Nb, and low Sr (Henrique-Pinto and Janasi, 2010).

The Jaraguá amphibolite, with an approximate exposure area of 1.5 x 2.5 km, occurs in apparent discordance in relation to detrital metasediments (Gomes, 1962). It shares the MORB-like signature of the volcanics from the Pirapora Formation, like low concentrations of incompatible elements such as Rb, Nb and Th (Henrique-Pinto and Janasi, 2010). Small occurrences of impure metalimestones surrounding the main body further suggest a correlation with the Pirapora Formation.

The occurrences of calc-silicate rocks appearing in the north-central portion of the studied area (Cordani et al., 1963) belong to SIG, as probably do the scattered occurrences of staurolite-mica schist that appear as windows within the area consisting predominantly of metarkoses from the Boturuna Formation.

The southern portion of the study area (Figure 2) is dominated by Neoproterozoic granitic rocks from Itaqui and Cantareira plutons; the small Fazenda Ithayê Granite, intruding the metarkose unit in the center of the area is

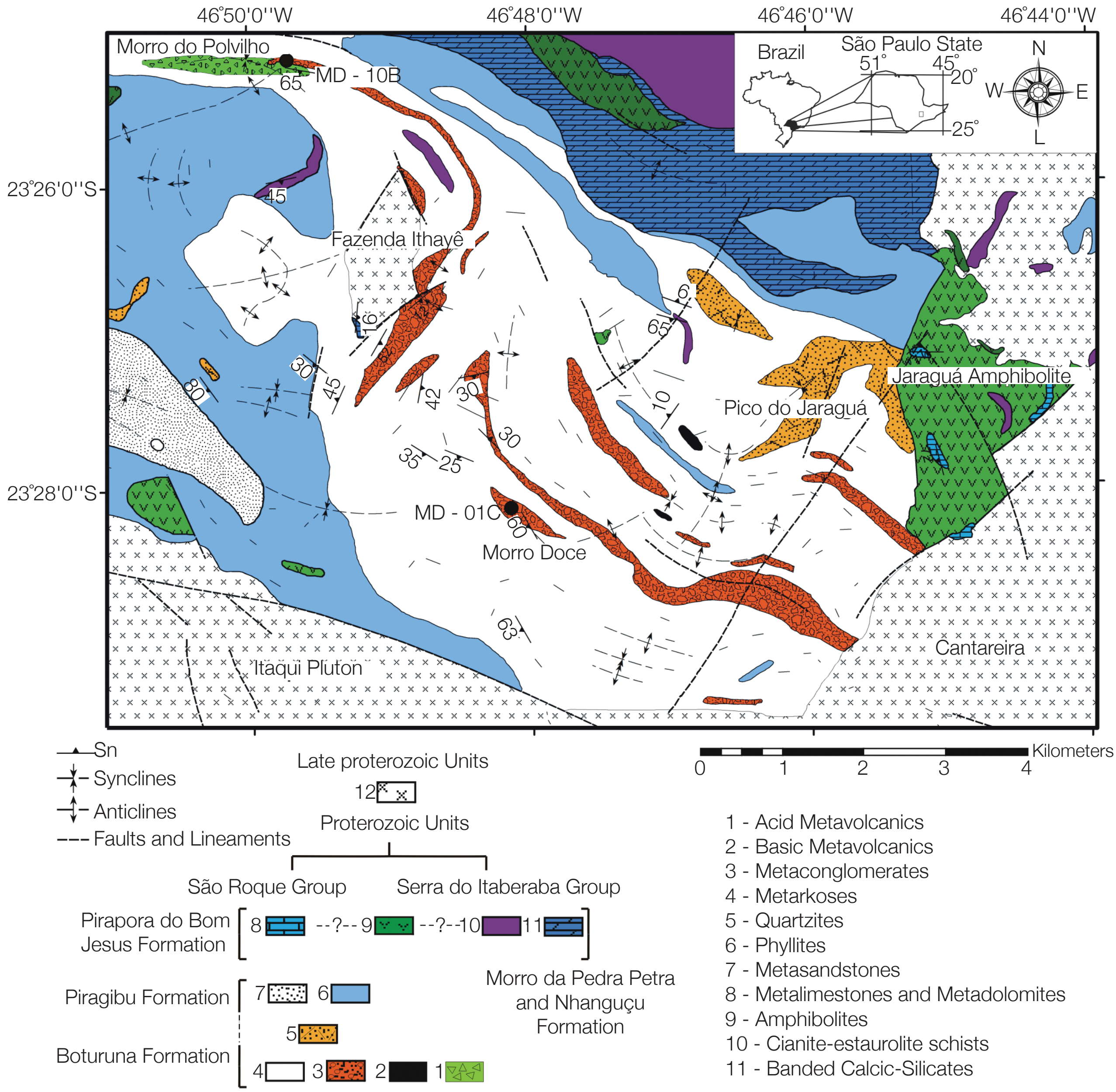


Figure 2. Geological map of São Roque Domain NW of the city of São Paulo (modified from IPT, 1983).

petrographically similar, being dominated by porphyritic biotite (± hornblende) granites. In contrast, the Tico-Tico Granite, part of which appears in the extreme north of the study area, is intrusive in SIG, and consists of two mica leucogranites. Tourmaline-bearing pegmatite and aplite dikes are scattered over most of the area.

Tassinari et al. (1985) obtained a Rb-Sr isochron age of 1200 ± 75 Ma for granitic pebbles from a metaconglomerate of Boturuna Formation. The evolution of the Sr isotopic ratio was used to suggest that the source of pebbles formed at ~2.4 Ga K-Ar ages for groundmass biotite range between 800 to 750 Ma, and they were interpreted as representing the last metamorphic event that affected these rocks (Tassinari, 1988).

It is possible that the basal unit (*sensu* Coutinho, 1955) was deposited in a deep-sea environment (Odman, 1955), which was affected by proximal arkosean terrigenous or even conglomeratic sediments. Petrographic study of granites clasts for SRG metaconglomerates (Henrique-Pinto, 2008; Henrique-Pinto and Janasi, 2010) allowed the identification of four petrographic varieties: porphyritic biotite monzogranite, inequigranular monzogranite, equigranular monzogranite, and inequigranular leucogranite. The clasts appear to be broadly comagmatic, as suggested by their definition of a single geochemical evolution trend consistent with normal differentiation in granitic magmas.

The metarkoses show clear chemical affinities with the granitic pebbles from the metaconglomerate; their REE patterns, although similar to the clasts, are characterized by a smaller negative Eu anomaly suggestive of an additional source. This possibly corresponds to a mafic igneous source as indicated by their higher Cr/Th, Ti/Zr, and Co/Th ratios (Henrique-Pinto and Janasi, 2010).

ANALYTICAL METHODS

Zircon separation

Zircon crystals for U-Pb geochronological dating were extracted from two clasts of equigranular muscovite-biotite monzogranite, which represent the most typical variety found in the metaconglomerate at the Morro Doce (MD-01C) and Morro do Polvilho (MD-10B) localities.

The samples were crushed in a steel jaw-crusher and subsequently in a disk mill. The concentrates were obtained in the Mineral Separation Laboratory of Instituto de Geociências, Universidade de São Paulo, in Brazil, by standard procedures involving a vibrating table (Wilfley) and heavy liquids (bromoform and methylene iodide).

Microscopic studies of the heavy mineral concentrates were conducted in transmitted light using a *Zeiss Axioplan* microscope. The concentrates were then submitted to magnetic separation procedures using a Frantz™ type isodynamic magnetic separator, initially with +10º side and 15º forward dip. Zircons were concentrated in the nonmagnetic fraction at 1.5 A. The different magnetic fractions of zircons were then split by varying the inclination angle of the separator from +6º to lower values, until the last sizeable fraction was obtained. Handpicking involved the selection of the least magnetic crystals with well-preserved prismatic faces, vitreous luster, and least amount of inclusions as possible.

LA-ICPMS U-Pb dating

Isotopic determinations were conducted at the Department of Earth and Atmospheric Sciences, University of Alberta (Edmonton, Canada), by LA-MC-ICPMS using a Nu Plasma mass spectrometer equipped with three ion counters and 12 Faraday detectors; this instrument was coupled to a Nd:YAG UP213 nm New Wave laser ablation system. The accuracy and precision of analyses were validated by analysing zircon standards BR266 and 91500. A spot size of 20 μm was used for the laser ablation runs given in general the high total Pb contents of the zircons. This resulted in adequate U and Pb ion signal intensities and allowed spots to be located in areas free of fractures and inclusions. Details of the analytical protocol employed here are given in Simonetti et al. (2005).

Sm-Nd analyses

Sm-Nd isotope analyses were performed at the *Centro de Pesquisas Geocronológicas* (CPGeo), Instituto de Geociências, Universidade de São Paulo, Brazil, following the procedures described by Sato et al. (1995). The Nd isotopic ratios were obtained using a multicollector Finnigan MAT-262 mass spectrometer, whereas the Sm ones were obtained using a single collector VG-354 mass spectrometer. The average $^{143}Nd/^{144}Nd$ values measured for the La Jolla and BCR-1 Nd standards during the period of this study are 0.511849 ± 0.000025 and 0.512662 ± 0.000027 (yearly 1σ variation), respectively. The maximum measured errors were 0.09% for the $^{147}Sm/^{144}Nd$ ratio and ± 0.00002 for $^{143}Nd/^{144}Nd$ (2σ precision level). ε_{Nd} calculations assume present CHUR ratios of $^{143}Nd/^{144}Nd$ = 0.512638 and $^{147}Sm/^{144}Nd$ = 0.1967. The constant used decay was 6.54 x 10^{-12} years^{-1}. T_{DM} calculations are made using the method of DePaolo (1988). Details of the analytical protocol employed here are given in Sato et al. (1995).

RESULTS OF LA-ICPMS U-PB DATING

Sample MD-01C

Thirty-nine analyses were conducted for sample MD-01C (Table 1). Eight points are essentially concordant (discordance < 3%) and yield an average date of 2199 ± 9 Ma. This is interpreted as the age of magmatic crystallization for this granitic clast. Two analyses from crystal 6b, although discordant, are clearly inherited and define discordia with an upper intercept age of 2694 ± 29 Ma (lower intercept ~zero), which is indicative of an Archean inheritance (Figure 3). The remaining analyses define a single discordia and yield an upper intercept age of 2209 ± 14 Ma, which is within uncertainty to the average age (2199 ± 9 Ma), defined by the concordant crystals. The lower intercept age at 527 ± 72 Ma reflects the overprint associated with the Neoproterozoic thermal event (Figure 3).

Sample MD-10B

Thirty-two analyses were conducted for sample MD-10B (Morro do Polvilho region), of which six were excluded from regression because of for their complex zoning and multiple age domains (Table 2). The remaining 26 points

Table 1. U-Pb zircon LA-MC-ICPMS data from biotite monzogranite clast MD-01C (Boturuna Formation, São Roque Group). The grey underlain-data correspond to the concordant results.

Sample MD- 01C									$^{207}Pb/^{206}Pb$		$^{206}Pb/^{238}U$		
Anal#	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	2σ error	$^{207}Pb/^{235}U$	2σ error	$^{206}Pb/^{238}U$	2σ error	rho	age (Ma)	2σ error	age (Ma)	2σ error	discord.%
17	58	0.13046	0.00257	4.8970	0.2985	0.2894	0.0169	0.947	2104	35	1639	96	22.1
16A	24363	0.13796	0.00150	7.5495	0.3196	0.3972	0.0167	0.967	2202	19	2156	91	2.1
16A-2	32623	0.13243	0.00140	6.4784	0.3948	0.3555	0.0216	0.985	2130	18	1961	119	8.0
16B	45091	0.13870	0.00143	7.9798	0.4076	0.4181	0.0213	0.980	2211	18	2252	115	-1.9
16C	92997	0.13276	0.00168	6.2366	0.2316	0.3430	0.0125	0.941	2135	22	1901	69	10.9
18A	infinite	0.13633	0.00142	6.8290	0.3716	0.3648	0.0198	0.982	2181	18	2005	109	8.1
18A-2	infinite	0.13553	0.00138	6.2825	0.2570	0.3368	0.0138	0.969	2171	18	1871	76	13.8
19A	infinite	0.13951	0.00148	6.5903	0.3131	0.3434	0.0163	0.975	2221	18	1903	90	14.3
19B	infinite	0.13816	0.00141	7.8975	0.4352	0.4157	0.0229	0.983	2204	18	2241	123	-1.7
20A	infinite	0.13877	0.00151	7.0230	0.2992	0.3681	0.0156	0.967	2212	19	2021	86	8.6
20B	infinite	0.13440	0.00153	5.8613	0.4257	0.3164	0.0229	0.988	2156	20	1772	128	17.8
20C	infinite	0.13851	0.00140	7.9505	0.5602	0.4178	0.0294	0.990	2209	18	2250	159	-1.9
20C-2	infinite	0.13871	0.00142	8.0426	0.5378	0.4217	0.0282	0.988	2211	18	2268	152	-2.6
20D	infinite	0.13631	0.00139	7.7332	0.4547	0.4121	0.0242	0.985	2181	18	2224	131	-2.0
21A	infinite	0.13668	0.00148	7.1387	0.2807	0.3790	0.0148	0.962	2185	19	2072	81	5.2
21A rim	35968	0.12561	0.00161	4.8755	0.3942	0.2822	0.0227	0.987	2037	23	1603	129	21.3
21B	infinite	0.13949	0.00153	8.1547	0.6071	0.4246	0.0316	0.989	2221	19	2281	170	-2.7
21C	infinite	0.13719	0.00145	7.4912	0.3199	0.3974	0.0169	0.969	2192	18	2157	92	1.6
22A	4114	0.13557	0.00168	6.0926	0.3749	0.3262	0.0199	0.980	2171	22	1820	111	16.2
22B	infinite	0.13400	0.00161	5.7331	0.5094	0.3096	0.0274	0.991	2151	21	1739	154	19.2
8	infinite	0.13850	0.00140	7.3340	0.3454	0.3850	0.0181	0.977	2209	17	2100	99	4.9
9	infinite	0.12952	0.00141	5.4160	0.3665	0.3010	0.0203	0.987	2091	19	1696	115	18.9
10	414	0.13745	0.00147	7.0039	0.6011	0.3704	0.0318	0.992	2195	19	2031	174	7.5
11A	1289	0.13606	0.00179	6.3585	0.4031	0.3353	0.0211	0.978	2178	23	1864	117	14.4
11A rim	4910	0.11589	0.00302	3.4386	0.1969	0.2143	0.0111	0.891	1894	47	1252	65	33.9
11B	586546	0.13865	0.00143	6.8275	0.3623	0.3580	0.0190	0.981	2210	18	1973	105	10.7
12A	16566	0.12187	0.00341	4.2791	0.6604	0.2465	0.0375	0.983	1984	50	1420	216	28.4
12B	19774	0.13430	0.00171	6.2210	0.3775	0.3367	0.0203	0.978	2155	22	1871	113	13.2
13A	infinite	0.13146	0.00142	5.6359	0.2858	0.3142	0.0159	0.977	2118	19	1761	89	16.8
14A core	449	0.11520	0.00160	2.9270	0.2082	0.1848	0.0130	0.981	1883	25	1093	77	42.0
14B	infinite	0.13123	0.00153	5.7118	0.3614	0.3158	0.0199	0.983	2115	20	1769	111	16.3
14C	634	0.13070	0.00262	5.0862	0.2268	0.2899	0.0119	0.893	2107	35	1641	67	22.1
15A	15141	0.13492	0.00196	6.5115	0.2780	0.3528	0.0146	0.941	2163	25	1948	81	9.9
6A	infinite	0.13223	0.00177	5.1356	0.2263	0.2819	0.0122	0.953	2128	23	1601	69	24.8
6B	infinite	0.18448	0.00200	11.8762	0.3974	0.4695	0.0156	0.947	2694	18	2481	82	7.9
6B-2	infinite	0.18232	0.00189	9.7803	0.3281	0.3916	0.0131	0.952	2674	17	2130	71	20.3
5	infinite	0.13788	0.00141	6.4512	0.2614	0.3402	0.0138	0.968	2201	18	1888	76	14.2
4	5645	0.12448	0.00266	4.5894	0.2737	0.2641	0.0149	0.934	2021	38	1511	85	25.3
3	138	0.12691	0.00222	3.8382	0.3331	0.2348	0.0201	0.979	2056	31	1360	116	33.9

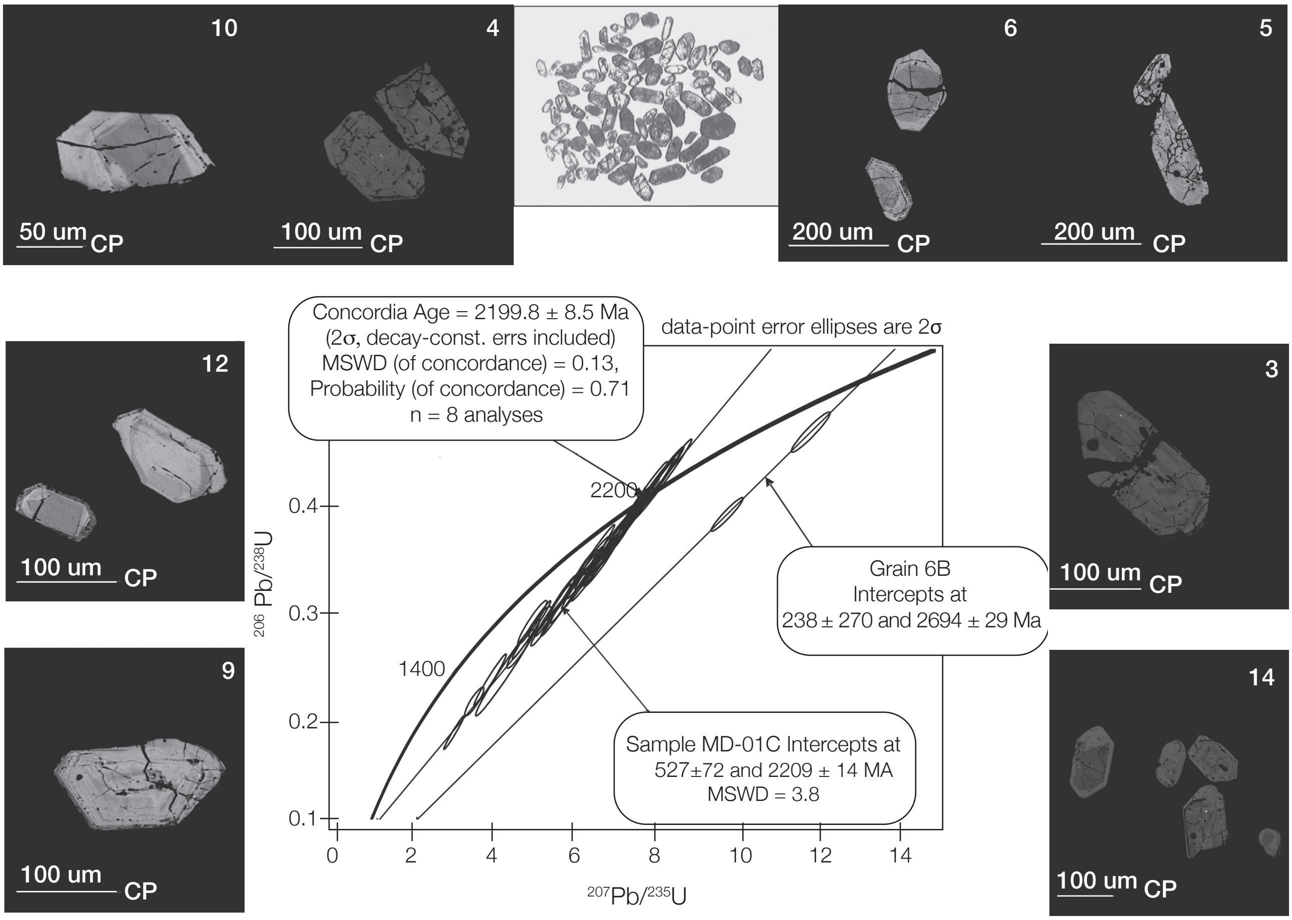


Figure 3. Concordia plot for LA-MC-ICPMS U-Pb zircon dating of sample MD-01C, a biotite monzogranite clast from the Morro Doce region. Backscattering images obtained by scanning electron microscopy with numbers linked to Table 1.

indicate variable degrees of discordance, between 4 and 22%, and define a discordia with an upper intercept age at 2247 ± 13 Ma; which is interpreted as the magmatic crystallization age for this granite clast. The lower intercept age at 637 ± 84 Ma once again reflects the overprint associated with the Neoproterozoic thermal event (Figure 4).

Sm-Nd Data

Sm-Nd isotope data were obtained from six representative samples of the main clast varieties of the Morro Doce metaconglomerate, all from outcrop MD-01. Results are listed in Table 3 and illustrated in Figure 5. Given a 2.2 Ga magmatic crystallization age, $\varepsilon_{Nd(t)}$ values are all negative and appear to cluster between values from -3.1 to -4.3; an exception is the inequigranular granite sample MD-01D that is characterized by a more negative value of -6.7. The metarkose framework is slightly less negative ($\varepsilon_{Nd(t)}$ = -2.3), suggesting contribution from a distinct source, perhaps of mafic character, a feature also suggested by whole-rock chemistry (Henrique-Pinto and Janasi, 2010). Interestingly, the amphibolite clast does not seem to equate to this same source since its $\varepsilon_{Nd(t)}$ (-3.6) at t = 2.2 Ga is within the same range for most of the granite clasts.

The Sm-Nd T_{DM} ages of the granitic clasts and the metarkose framework cluster at 2.6 to 2.7 Ga (Figure 5), combined with the inherited age (2694 ± 29 Ma) reported in sample MD-01C, reinforces the idea that these granites are products of remelting a ~2.7 Ga crustal component. The older TDM age (3.2 Ga, Table 3) defined by the inequigranular leucogranite MD-01D can be a reflection of its higher $^{147}Sm/^{144}Nd$ ratio (0.135), and may result from LREE fractionation during magma evolution (Henrique-Pinto and Janasi, 2010). Hence, this older TDM age most probably does not have any geological significance. The $^{147}Sm/^{144}Nd$ ratio of the metabasic clast (0.126) is typical for this rock type, its T_{DM} age (2.8 Ga) is slightly older than those of the typical granite clasts.

DISCUSSION

The metaconglomerates from the Boturuna Formation (basal unit of SRG) are part of the detrital sedimentary

Table 2. U-Pb zircon LA-MC-ICPMS data from biotite monzogranite clast MD-10B (Boturuna Formation, São Roque Group).

Sample MD-10B									$^{207}Pb/^{206}Pb$		$^{206}Pb/^{238}U$		
Anal#	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	2σ error	$^{207}Pb/^{235}U$	2σ error	$^{206}Pb/^{238}U$	2σ error	rho	age (Ma)	2σ error	age (Ma)	2σ error	discord.%
3	24120	0.13008	0.00177	5.2712	0.2636	0.2935	0.0144	0.962	2099	24	1659	82	21.0
4	12041	0.13708	0.00144	7.0345	0.3261	0.3741	0.0173	0.974	2191	18	2049	95	6.5
6	12997	0.13764	0.00148	7.3443	0.3198	0.3864	0.0168	0.969	2198	19	2106	91	4.2
6B	49618	0.13581	0.00140	6.2804	0.2902	0.3349	0.0155	0.975	2174	18	1862	86	14.4
8A	8757	0.13791	0.00156	7.4940	0.4118	0.3938	0.0215	0.979	2201	20	2140	117	2.8
9A-2	11234	0.12422	0.00159	4.9706	0.4040	0.2892	0.0234	0.988	2018	23	1638	132	18.8
10A	33907	0.13681	0.00140	6.1561	0.3406	0.3257	0.0180	0.983	2187	18	1817	100	16.9
15A	90378	0.12408	0.00186	4.8212	0.3155	0.2778	0.0179	0.973	2016	27	1580	102	21.6
17A	29097	0.13812	0.00143	6.8434	0.2853	0.3588	0.0149	0.969	2204	18	1977	82	10.3
19A	76219	0.13600	0.00139	6.4418	0.3206	0.3432	0.0171	0.979	2177	18	1902	95	12.6
20A	31920	0.12699	0.00226	5.0017	0.1976	0.2826	0.0104	0.893	2057	31	1605	59	22.0
22A	91423	0.13785	0.00145	7.0068	0.3098	0.3681	0.0162	0.972	2200	18	2021	89	8.2
22A-2	11290	0.13652	0.00144	6.4139	0.2916	0.3402	0.0154	0.973	2184	18	1888	86	13.5
23A	48192	0.13711	0.00139	6.7619	0.3531	0.3572	0.0186	0.981	2191	18	1969	103	10.1
24A	51309	0.13784	0.00142	7.0756	0.4576	0.3716	0.0240	0.987	2200	18	2037	132	7.4
24A-2	26436	0.13576	0.00141	6.6292	0.3532	0.3536	0.0188	0.981	2174	18	1952	104	10.2
26A	19428	0.13683	0.00151	6.8769	0.3205	0.3644	0.0169	0.972	2187	19	2003	93	8.4
26A-2	32982	0.13744	0.00142	6.9506	0.4326	0.3661	0.0228	0.986	2195	18	2011	125	8.4
28A	254449	0.13941	0.00143	7.4495	0.3629	0.3872	0.0188	0.978	2220	18	2110	103	5.0
32A	27717	0.13916	0.00151	7.3358	0.3564	0.3824	0.0185	0.975	2217	19	2087	101	5.8
32A-2	28824	0.13895	0.00147	7.0713	0.3296	0.3686	0.0171	0.974	2214	18	2023	94	8.6
35A	20853	0.13344	0.00203	5.4737	0.2190	0.3005	0.0115	0.925	2144	27	1694	65	21.0
35A-2	18720	0.13596	0.00145	6.6634	0.3702	0.3550	0.0197	0.982	2176	19	1958	109	10.0
35A-3	37686	0.13807	0.00141	7.0347	0.3286	0.3692	0.0172	0.976	2203	18	2026	95	8.1
36A	105117	0.13705	0.00140	6.9537	0.4052	0.3671	0.0214	0.985	2190	18	2016	117	8.0
40A	68565	0.13927	0.00147	7.2558	0.2903	0.3774	0.0150	0.965	2218	18	2064	82	6.9
complexly zoned - multi-age													
9A	32582	0.11969	0.00123	4.4337	0.1966	0.2684	0.0119	0.973	1952	18	1532	68	21.5
13A	infinite	0.12898	0.00146	5.8125	0.2413	0.3259	0.0134	0.962	2084	20	1818	75	12.7
14A	21059	0.13365	0.00149	5.9082	0.3829	0.3230	0.0209	0.985	2146	19	1804	117	15.9
15A-2	75382	0.13169	0.00157	5.9112	0.4176	0.3233	0.0227	0.986	2121	21	1806	127	14.8
23A-2	97993	0.13203	0.00141	5.8427	0.2823	0.3234	0.0156	0.976	2125	19	1806	87	15.0
38A	8532	0.13761	0.00174	6.6580	0.3398	0.3509	0.0177	0.969	2197	22	1939	98	11.8

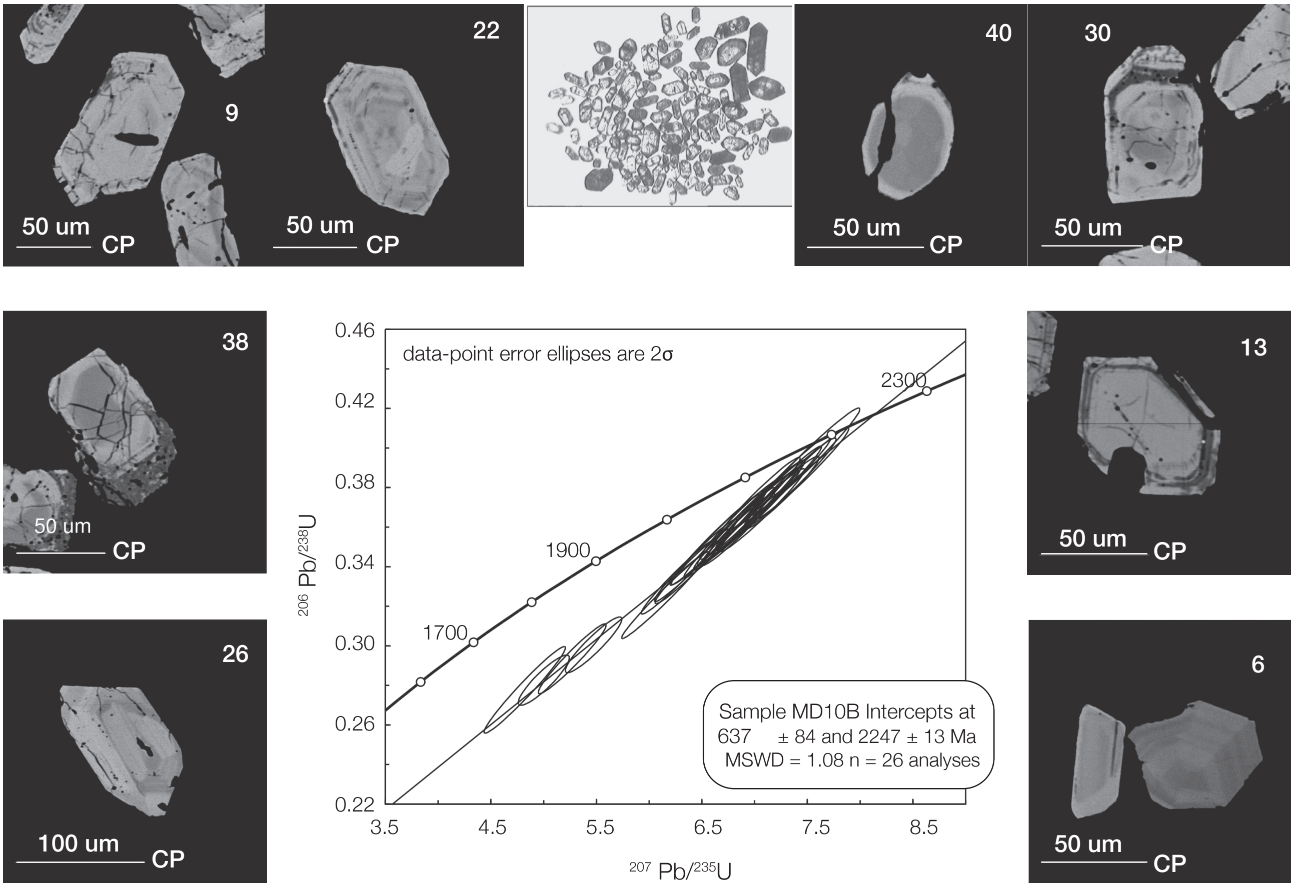


Figure 4. Concordia plot for LA-MC-ICPMS U-Pb zircon dating of sample MD-10B, a biotite monzogranite clast from the Morro do Polvilho region. Backscattering images obtained by scanning electron microscopy with numbers linked to Table 2.

Table 3. Sm-Nd isotope data for clasts and framework of metaconglomerate MD-01 (Boturuna Formation, São Roque Group).

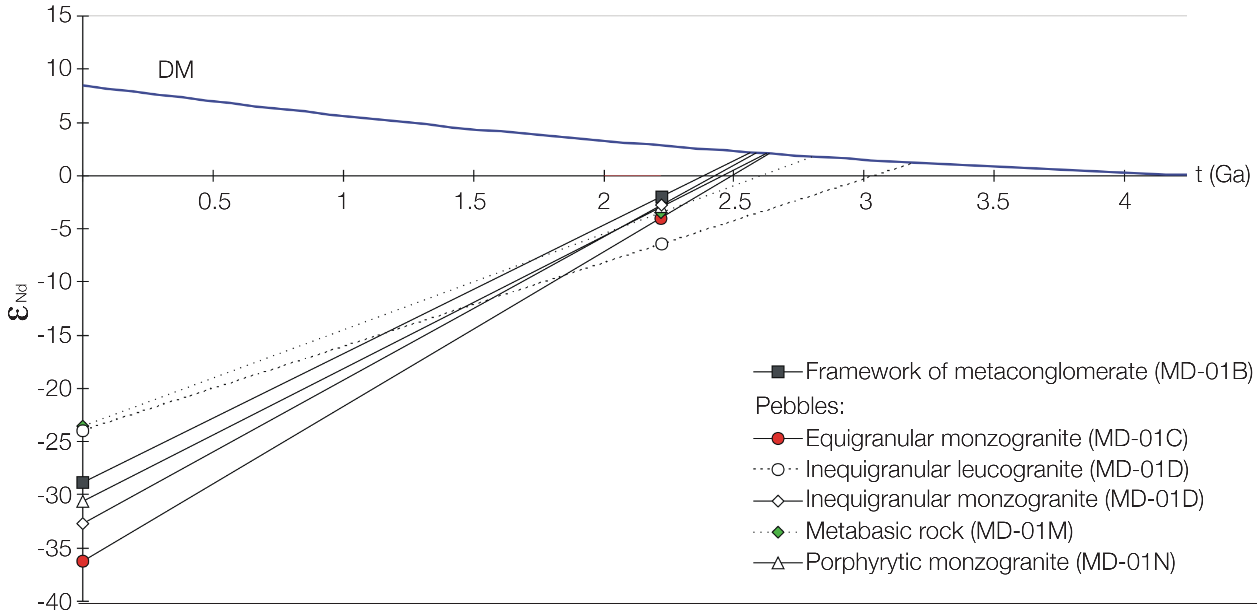
Samples	Clasts	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	Error	$^{143}Nd/^{144}Nd$	Error	T_{DM} (Ga)	$\varepsilon_{(0)}$	$\varepsilon_{(t)}$
MD-01B	Metarkose framework	5.856	34.745	0.1019	0.0006	0.511160	0.000011	2.6	-28.84	-2.25
MD-01C	Equigranular granite	5.752	42.047	0.027	0.0005	0.510779	0.000008	2.7	-36.27	-4.30
MD-01D	Inequigranular leucogranite	1.900	8.514	0.1349	0.0008	0.511409	0.000012	3.2	-23.98	-6.66
MD-01E	Inequigranular granite	6.005	39.859	0.0911	0.0005	0.510961	0.000012	2.6	-32.71	-3.09
MD-01M	Metabasic rock	1.261	6.063	0.1257	0.0007	0.511431	0.000014	2.8	-23.55	-3.64
MD-01N	Porphyritic granite	7.629	46.601	0.0990	0.0006	0.511068	0.000010	2.6	-30.62	-3.22

t = 2.2 Ga, the crystallization age of the granite clasts; T_{DM} according to DePaolo (1988).

sequences indicating proximal sources, as identified by the presence of pebbles and boulders supported by an arkosean framework. Thus, these rocks have an excellent potential for characterizing the main source for the SRG.

U-Pb dating by LA-MC-ICP-MS of zircons extracted from predominantly equigranular monzogranites clasts within the Morro Doce and Morro do Polvilho regions indicate Paleoproterozoic ages for magmatic crystallization (2199 ± 9 Ma and 2247 ± 13 Ma, respectively). Even taking into account the ~10 Ma uncertainties associated with each date, the ca. 50 Ma difference between the two ages is suggestive that these clasts, although very similar in petrography and chemistry, are not strictly comagmatic, i.e., do not derive from exactly the same source.

The polycyclic history of the zircons is reinforced by the presence of inherited grains found in the clast MD-01B in the Morro Doce occurrence (2694 ± 29 Ma). Furthermore, both dated clasts were also affected by a neoproterozoic event, as indicated by lower intercept dates in the 530 to 640 Ma range. Although imprecise, the latter dates can be attributed to the



DM: evolution line of the depleted mantle (De Paolo, 1988).

Figure 5. ε_{Nd} *versus* t(Ga) diagram of main granite clasts of Boturuna Formation.

important thermal event of metamorphism and intrusion of large amounts of granitic plutons that affected the Apiaí-São Roque Domain and the Socorro-Guaxupé Nappe, which together correspond to the reworked border of the Paranapanema Craton (Campos Neto, 2000).

The ages of the granite clasts are not documented in basement granitic rocks that occur at the southwestern margin of São Francisco craton, which are typically slightly younger and range between 2020 and 2140 Ma (Campos Neto et al., 2004). Similar ages are found in the basement of Espinhaço Supergroup in eastern São Francisco Craton (Mineiro Belt; Teixeira et al., 2008). However, correlation with some parts of the São Francisco Craton seems improbable, since the Apiaí-São Roque Domain is thought to belong to a different paleocontinent (Paranapanema). It seems more probable, therefore, that equivalents are present in the basement of the Açungui Supergroup as exposed in the Tigre, Setuva and Betari nuclei, where orthogneisses of similar age are described (Kaulfuss, 2001; Cury et al., 2002; Siga Jr. et al., 2007). Remarkably, the latter are intruded by younger (~1.75 Ga) syenogranitic orthogneisses, which are considered to represent an extensional tectonic event (Kaulfuss, 2001; Siga Jr. et al., 2011) that is possibly equivalent to the one that generated the bimodal metavolcanic sequence of within-plate geochemical signature described in the SRG (Henrique-Pinto and Janasi, 2010).

Sm-Nd isotope data from the main clast varieties from the Morro Doce metaconglomerates yield T_{DM} ages of 2.6 to 2.7 Ga, indicating that these granites are the recycling products of an Archean crust; an interpretation that is corroborated with the presence of an inherited zircon dated at ~2.7 Ga. The metaconglomerate arkosean framework yields slightly lower $\varepsilon_{Nd(t)}$ values compared to the clasts, therefore younger and/or more mafic source may contribute to the Boturuna Formation. This is in agreement with the geochemical signature of the associated metarkoses since a mafic igneous input was identified based on the whole-rock geochemistry (Henrique-Pinto and Janasi, 2010).

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