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Research paper

The Mesoproterozoic to early Neoproterozoic passive margin Lajeado Group and Apiaí Gabbro, Southeastern Brazil

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ABSTRACT

The Lajeado Group in the Ribeira Belt, southeastern Brazil, corresponds to an open-sea carbonate platform, comprised of seven overlapping siliciclastic and carbonatic formations, intruded in its upper portion by the Apiaí Gabbro. These rocks have a Neoproterozoic tectonometamorphic overprint related to arc magmatism and the Brasiliano collisional orogeny. Geochronological constraints are given by new U-Pb SHRIMP and LA-ICP-MS data for Lajeado Group detrital zircons and for magmatic zircons from the Apiaí Gabbro. The youngest detrital zircons in the Lajeado Group are 1400–1200 Ma, and constrain its maximum age of deposition to be <1200 Ma, whereas the 877 ± 8 Ma age for magmatic zircons in the Apiaí Gabbro give the minimum age. Detritus source areas are mainly Paleoproterozoic (2200–1800 Ma) with some Archean and Mesoproterozoic contribution (1500–1200 Ma), with distal or tectonic stable cratonic character. The Lajeado Group should be a Stenian–Tonian carbonate platform passive margin of a continent at this time, namely the Columbia/Nuna or the Rodinia. The Apiaí Gabbro displays similar age to other intrusive basic rocks in the Lajeado and Itaiacoca groups and represents tholeiitic MORB-like magmatism that we relate to the initial break-up of a Mesoproterozoic continent and the formation of the Brasiliano oceans.

1. Introduction

The Stenian-Tonian Lajeado Group in the Ribeira Belt, southeastern Brazil (Fig. 1), corresponds to an open-sea carbonate platform and passive margin intruded in its upper portion by the Apiaí Gabbro (Petri and Suguio, 1969; Pires, 1988; Campanha and Sadowski, 1999).

Although the Ribeira Belt is considered a typical Neoproterozoic orogen, in this Southern region, especially in the so called Apiaí Terrane, most of its more representative metasedimentary sequences are older, and the Brasiliano/Panafrican cycle is expressed mainly as continental arc-related granitic magmatism and an oblique collisional tectonometamorphism and deformation (Campanha and Sadowski, 1999; Campos Neto, 2000; Heilbron et al., 2004; Faleiros et al., 2011; Campanha et al., 2015; Henrique-Pinto et al., 2015).

Passive margins are widespread in the geologic time since at least the Neoarchean. They are abundant in some periods, like the end of the Neoproterozoic, but they are scarce in the Mesoproterozoic (Grotzinger and James, 2000; Bradley, 2008, 2011). This is exemplified in the case of the Gondwana, where carbonate platforms and passive margins are widespread during the Neoproterozoic (mainly in the Ediacaran), but are significantly less known from the Mesoproterozoic. The periods with abundance of passive margins are usually associated with the dispersion of the supercontinents, like the Pangea break-out with the classic Atlantic type margins. On the other hand, the periods of supercontinent amalgamation are correlated with extensive active and orogenic margin development.

The Mesoproterozoic is dominated by the break-up of the Columbia supercontinent (also known as Nuna), and the formation of the Rodinia supercontinent at the end of the

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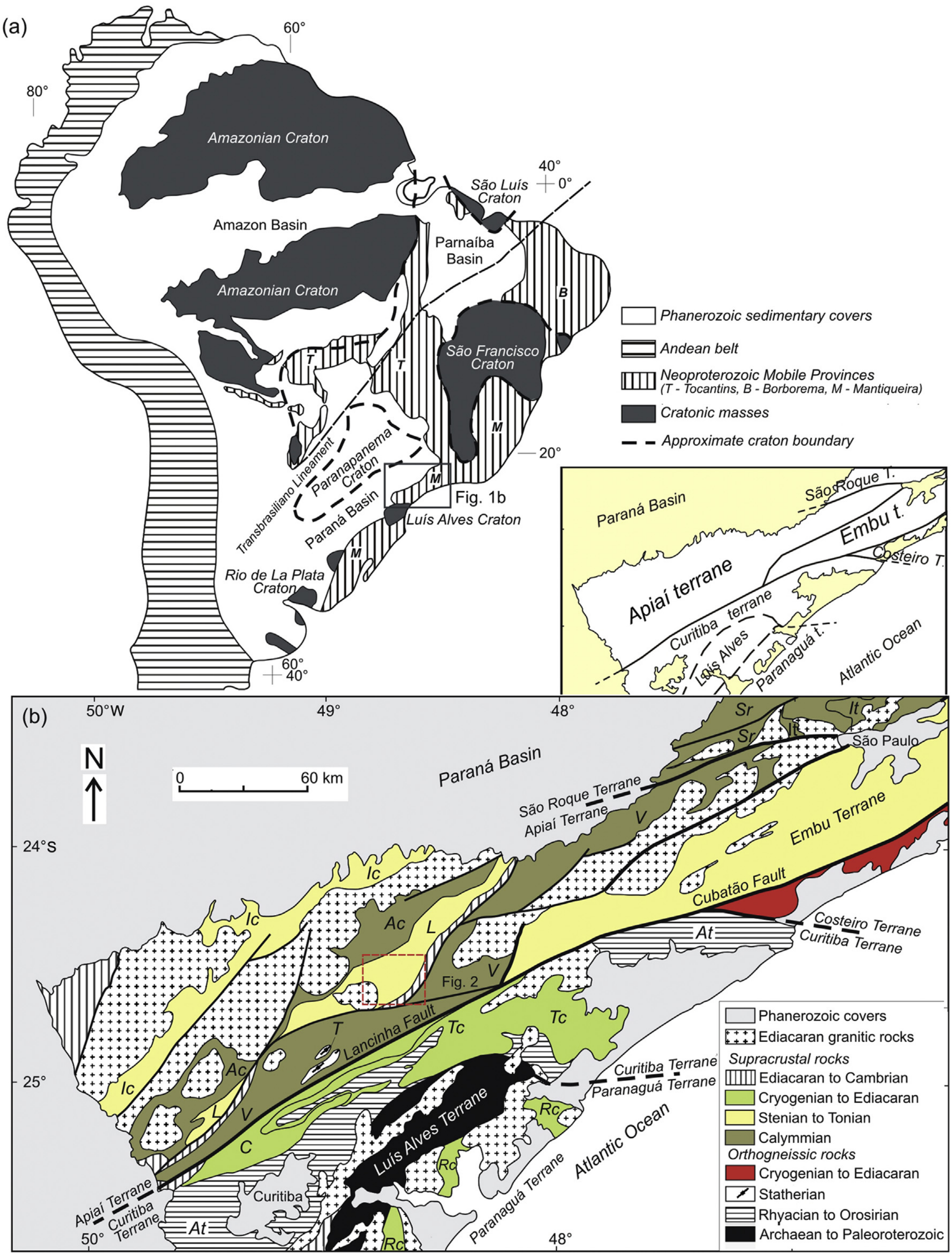

Figure 1. Simplified geotectonic map of part of South America (a), and simplified geological map of the southern portion of the Ribeira Belt (b) (after Campanha et al., 2015). Geological units: Itaiacoca Group (Ic), Água Clara Formation (Ac), Lajeado Group (L), Votuverava Group (V), São Roque Group (Sr), Serra do Itaberaba Group (It), Tigre Gneiss (T), Capirú Formation (C), Turvo-Cajati Formation (Tc), Rio das Cobras Formation (Rc), Atuba Complex (At).

Mesoproterozoic and the beginning of the Neoproterozoic (Rogers and Santosh, 2009; Roberts et al., 2015), although some authors suggested that Columbia may have been converted to Rodinia without a true dispersal (Piper, 2013; Roberts, 2013). In this context the characterization of a Mesoproterozoic to early Neoproterozoic open-sea carbonate platform and passive margin provides important information regarding configuration of pre-Gondwana continents.

In this paper we present new U-Pb SHRIMP and LA-ICP-MS data for Lajeado Group detrital zircons and for magmatic zircons from the Apiaí Gabbro, and discuss their regional correlations and implications for Gondwana and pre-Gondwana paleogeographies.

2. Regional geology

The Lajeado Group belongs to the Apiaí terrane of the Ribeira Belt in southeastern Brazil. The Ribeira Belt is a NE-trending accretionary-to-collisional orogen related to the assembly of West Gondwana during the Neoproterozoic (Almeida et al., 1973; Hasui et al., 1975; Porada, 1979; Campos Neto and Figueiredo, 1995; Campanha and Sadowski, 1999; Campos Neto, 2000; Heilbron et al., 2004). Hence it is an assemblage of tectonostratigraphic terranes accreted during the late Neoproterozoic, that have been partitioned by a late, orogen-parallel, crustal-scale transcurrent shear system (e.g., Dürr and Dingeldey, 1996; Campanha, 2002; Campanha and Brito Neves, 2004; Faleiros et al., 2010, 2011) related to an oblique collision between the Paranapanema, São Francisco, Luís Alves and Congo cratons.

The southern Ribeira Belt is limited to the north by the Paranapanema craton (covered by the Paleozoic Paraná sedimentary basin) and to the south by the Luís Alves cratonic terrane. The southern Ribeira Belt can be divided into the Apiaí and the Curitiba domains or terranes, bounded by the Lancinha-Cubatão strike-slip shear zone which has been considered a late Neoproterozoic plate boundary (Fig. 1; Basei et al., 2008; Faleiros et al., 2011).

South of the Lancinha - Cubatão shear zone, the Curitiba Terrane is essentially composed of a TTG-type migmatitic orthogneiss suite (Atuba Complex) and Neoproterozoic shallow continental-shelf metasedimentary assemblages (Turvo-Cajati and Capiru Formations) (Faleiros et al., 2011).

The Apiaí Terrane comprises extensive carbonate platforms, such as the Itaiacoca and Lajeado Groups. While the Itaiacoca Group represents deposits from very shallow waters, the Lajeado Group represents gradually deepening water lithofacies. They were considered to have formed on the passive margin of the Paranapanema Craton continent (Campanha and Sadowski, 1999; Campos Neto, 2000; Fig. 1a). The Apiai Terrane also included the Votuverava Group, a Calymmian (1490 Ma) metavolcano-sedimentary composed mainly of distal turbidites with significant basic magmatism of back arc affinity (Campanha et al., 2015).

Known Ediacaran metavolcano-sedimentary units in the Apiai Terrane are restricted to the Iporanga and Abapã formations (Campanha et al., 2008a; Siga Jr. et al., 2009). In the Apiaí terrane, Neoproterozoic ages have mainly been acquired from the extensive arc-related plutonism that intrudes these sequences and for the tectono-metamorphism that affected its metasedimentary rock formations (Campanha and Sadowski, 1999). Campos Neto (2000) related this arc magmatism with the development of an Andean-style active arc on the previously passive margin of the Paranapanema Craton. This arc is represented by the few hundred kilometers long granitic batholits of Cunhaporanga, Três Córregos and Agudos Grandes (Fig. 1) composed of metaluminous, I-type suites of medium to high-K calc-alkaline affinity with ages from 630 to 600 Ma (Takahashi et al., 1986; Theodorovicz et al., 1988; Chiodi Filho et al., 1989; Wernick et al., 1990; Gimenez Filho, 1993; Reis Neto, 1994; Gimenez Filho et al., 1995; Janasi et al., 2001; Prazeres Filho, 2005). Subsequent collisional tectonics took place at 600–590 Ma followed by strike-slip, exhumation and extensional tectonics up to ca. 530 Ma (Faleiros et al., 2011).

The Apiaí terrane in the studied area (Fig. 2) comprises the Lajeado and Votuverava groups and the Iporanga Formation, as well granitic and basic intrusions (Campanha and Sadowski, 1999).

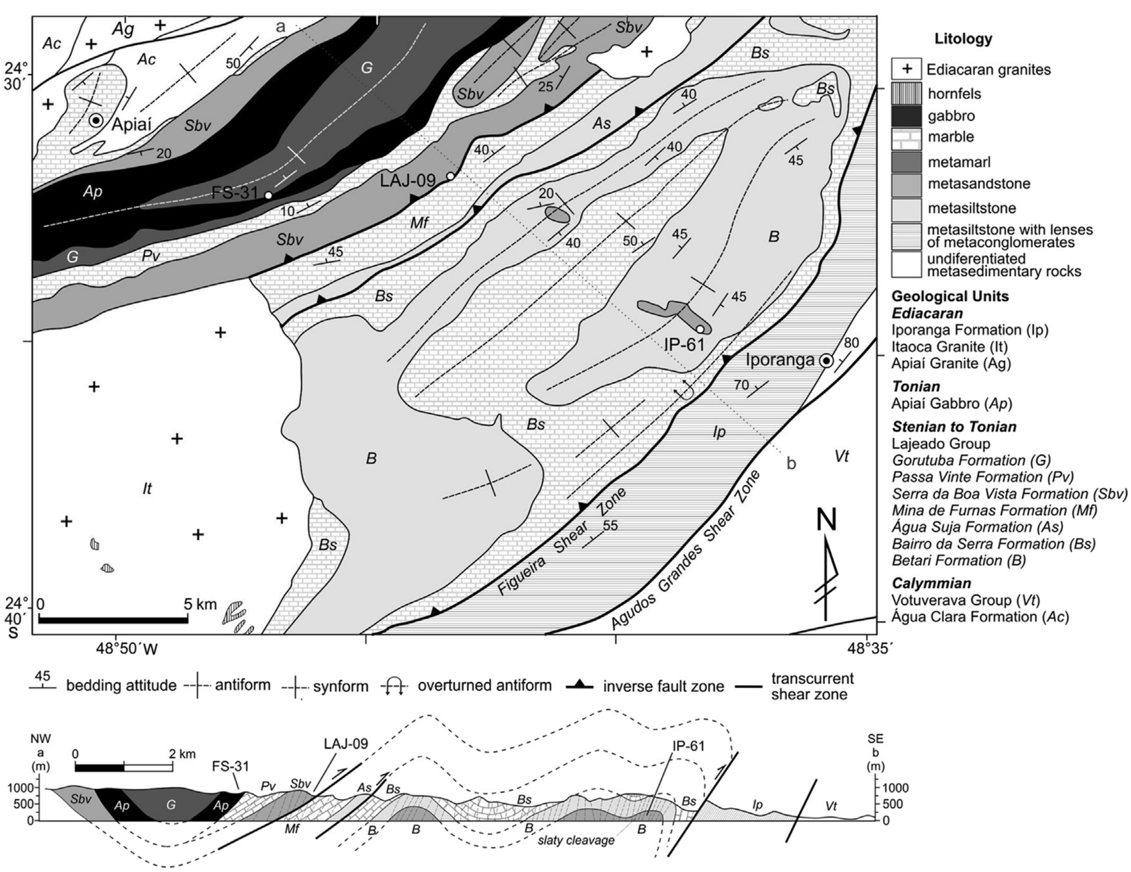

Figure 2. Simplified geological map and cross section emphasizing the Lajeado Group and its formations (modified from Campanha, 1991; Faleiros et al., 2012). Also shown are the location of studied samples.

3. The Lajeado Group

The *Lajeado Subgroup* (Campanha et al., 1985, 1986; Campanha and Sadowski, 1999), later named as *Lajeado Group* (Faleiros et al., 2012) is composed of alternating terrigenous clastic and carbonate formations, interpreted as deposited on a open-sea shelf. It corresponds to the central belt of carbonate rocks of Bigarella (1948) and Marini and Bigarella (1967), to the Açungui III Formation of Daitx et al. (1983) and MMAJ/JICA (1981, 1982, 1983). Its outcrop area extends about 130 km in a NE–SW trend and is bounded by major shear zones. The upper part of the Lajeado Group was intruded by the Apiaí Gabbro (Figs. 2 and 3).

In the studied area the southeastern limit of the Lajeado Group with the Iporanga Formation (Campanha et al., 2008a) is the Figueira shear zone. On its western side the Lajeado Group is intruded by the Itaoca Granite, developing a metamorphic aureole with quartz + muscovite + biotite + andalusite/sillimanite. Meter- to hectometer-skarn enclaves and roof pendants inside the Itaoca Granite are interpreted as derived from the Lajeado Group. To the north, the Quarenta–Oitava shear zone limits the Lajeado Group from the Três Córregos arc-related granites and the Água Clara Formation (Figs. 1 and 2). Campanha et al. (1987) and Campanha and Sadowski (1999) had correlated the Lajeado Group with the Antinha Formation (Dias and Salazar Jr., 1987), to the south in the Paraná State, although both comprise isolated transcurrent shear megalenses.

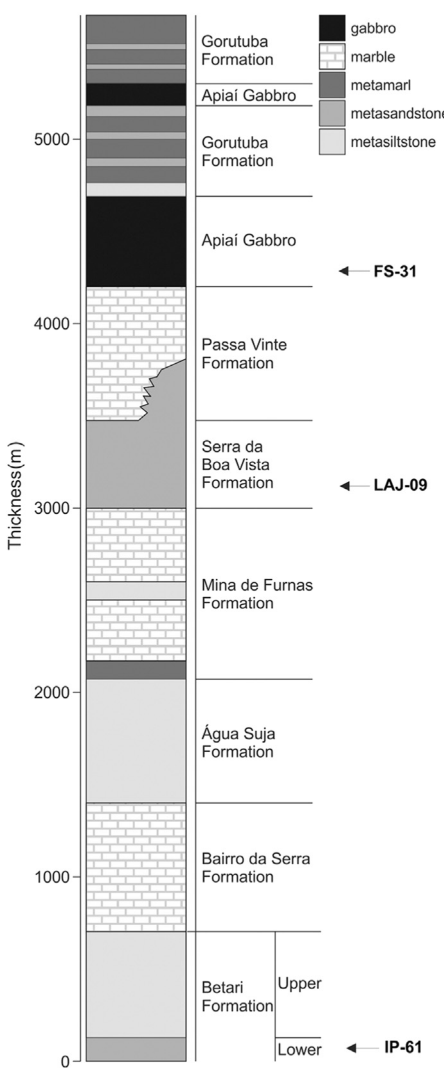

Figure 3. Lajeado Group, stratigraphic column (after Campanha et al., 1985, 1986; Campanha, 1991).

A stratigraphic subdivision for the Lajeado Group was first proposed by Barbosa (1941) and Geoffrey and Santos (1942), and has been reviewed by MMAJ/JICA (1983), Campos Neto (1983), Daitx et al. (1983), Chiodi Filho (1984), Hasui et al. (1984), Campanha et al. (1985, 1986), Pires (1988, 1990, 1991), Campanha (1991), Campanha and Sadowski (1999) and Faleiros et al. (2012). The currently accepted column is portrayed in Fig. 3. The type-section crops out along the road between Apiaí and Iporanga towns.

The geological section of the studied type area is shown in Fig. 2, where it reaches more than 5000 m in thickness. The structural style is characterized by broad open folds with subhorizontal NE-trending hinges and a steep NW-plunging axial planar slaty cleavage. Crenulation cleavages have been locally observed. Beds in the type-section are usually upright, except near the Figueira shear zone, where they are steeply overturned. Evidence of bed-parallel shearing along the contacts between the upper formations of the Lajeado Group is observed and these are suspected to be allochthonous or parautochthonous to the lower parts of the Group. Kinematic indicators show SE-directed tectonic transport. The metamorphism related to the slaty cleavage belongs to the lower chlorite zone. Chloritoid porphyroblasts are syn- to post kinematic in relation to a local S_2 crenulation cleavage.

The Lajeado Group is subdivided into seven formations (Figs. 2 and 3). The basal terrigenous *Betari Formation* starts with metasandstones and oligomitic metaconglomerates interpreted as alternating A-B turbiditic levels, grading towards the top into thinner metarythmites interpreted as a series of C-D-E turbidite levels, suggesting a transgressive sequence. It is covered by two dark-gray calcitic limestone formations, *Bairro da Serra* and *Mina de Furnas*, which are interstratified with sparse thin phyllite layers, the thickest of which was called the *Água Suja* Formation. The limestone banks show submetric hummocks, graded bedding, slump breccias and locally ripple marks. They seem to reflect a distal shelf environment but still within the reach of storm effects. The upper *Mina de Furnas* limestones are overlaid by the *Serra da Boa Vista* Formation of pale colored meter thick fine-grained sandstone banks locally with thin layers of finer clastic rocks, small ripple marks and metric sigmoidal shape banks. These sandstones are overlain by the *Passa Vinte* Formation, a limestone with restricted areal distribution, which represents the only very shallow water facies of the Lajeado Group, locally exhibiting algal mats. The upper unit is the *Gorutuba* Formation which is characterized by very thin-grained distal rhythmites including interbedded siltstones, mudstones, marls and locally limestones. Its sheared contact with the underlying Passa-Vinte limestone and the apparent incompatibility between the sedimentary facies suggests that the Gorotuba Formation could be allochtonous.

Petri and Suguio (1969) considered that the sequences now called the Lajeado Group were deposited in a neritic platform environment far from the coast and suggested that the oligomitic metaconglomerates from the base of the Group constitute proximal turbidites or fluxturbidites. Campanha et al. (1985, 1986, 1987), Campanha and Sadowski (1999) also considered a paleogeography of continental shelf, slope and abyssal plain, respectively for the Lajeado Group, the Iporanga Formation and the Votuverava Group. Later, the last two are demonstrated to have distinct depositional ages, Ediacaran for Iporanga Formation and Calymmian for the Votuverava Group (Campanha et al., 2008a,b, 2015). Pires (1988) considered the Lajeado Group as a succession of turbiditic systems, where the variation of the sea level would be the main factor for the accumulation of sediments, as was also stated by Barbour et al. (1990) for whom the tectonic environment was also a continental shelf. Pires (1991) considered the carbonate sequence as programational in character and related to a regressive episode, represented by wave-influenced, shallow platform to slope (carbonate ramp) sediments. A passive margin was assumed by Campanha and Sadowski (1999) and Campos Neto (2000), related to the Paranapanema continent to the NW. The paleocurrent directions in Lajeado Group (Petri and Suguio, 1969; Campanha et al., 1985, 1986; Pires, 1988, 1990, 1991; Campanha, 1991) support this assertion. Heavy minerals provenance study showed textural and mineralogical maturity suggesting a distal or tectonically stable source area, in a passive margin with cratonic source areas (Nobrega et al., 2006). The large thickness of the entire column, the facies distribution and lateral variability are more consistent with a passive margin environment than a cratonic shallow sedimentary cover.

4. The Apiaí Gabbro

The Apiaí Gabbro (Morgental et al., 1975; Campanha, 1991; Campanha and Sadowski, 1999; Archanjo et al., 2012; Faleiros et al., 2012; Oliveira et al., 2012) forms a lopolith-like intrusion emplaced in the upper units of the Lajeado Group, especially the Gorutuba Formation, with an exposed area about 30 km^2. Similar metabasic rocks intrude others formations of the Lajeado Group south of the studied area (Maniesi, 1997; Maniesi and Oliveira, 2000, 2002; Oliveira et al., 2002). It is composed of gabbro, diabase or microgabbro with augite + hypersthene + andesine-labradorite plagioclase and accessory magnetite and ilmenite. The rocks show equigranular, nonfoliated and medium-grained ophitic to subophitic textures. Intergrowth of hornblende and biotite in corroded edges of augite and hypersthene and the occurrence of chlorite veinlets are evidence of late incipient hydrothermal activity. The rocks have SiO_2 of 49–52 wt.%, positive ε_{Nd} values and can be classified as subalkaline tholeiitic basalts with closer compositional similarities to MORB (Frascá et al., 1997; Oliveira et al., 2002, 2012). Due its typical magmatic microstructure and nonaltered mineralogy, Campanha and Sadowski (1999) proposed that the Apiaí pluton could be a post-tectonic intrusion. On the other hand, Archanjo et al. (2012) provided evidence from magnetic fabric and textural studies that it is a pre-tectonic folded sill-like body. The contacts of the Apiaí Gabbro with the country rocks are mainly concordant but locally discordant. Contact metamorphism is observed mainly with the Gorutuba Formation where a meter-scale hornfels zone is developed, mainly in metamarls, with randonly oriented millimetric euhedral crystals of diopside, actinolite, calcite, epidote, quartz.

5. Geochronology

5.1. Former geochronological data

As volcanic intercalations in the Lajeado Group are not known, there is not a direct absolute age for its deposition. Granite intrusions on the Lajeado Group gave ages of 612 ± 3 Ma (Itaóca Granite, U-Pb SHRIMP, Salazar et al., 2013) and 605.4 ± 3.5 Ma (Apiaí Granite, U-Pb, Hackspacher et al., 2000). Geochronological studies for the Apiaí Gabbro had yielded different results. Amaral et al. (1966) reported a 123.5 Ma K/Ar age, although the geological evidence pointed for a Precambrian age. Silva et al. (1981) presented a 675 ± 41 Ma plagioclase K/Ar age. Daitx et al. (1983) reported that six samples have ages between 800 and 3000 Ma, probably due to excess Argon. Daitx et al. (1990) presented Rb/Sr isochron providing a 850 ± 85 Ma age with initial $^{87}Sr/^{86}Sr$ ratio of 0.705, and interpreted this as the intrusion age. Hackspacher et al. (2000) provided a U-Pb age for one zircon and one monazite fraction yielding discordant ages with a lower intercept of 617 ± 4 Ma and an upper of around 2100 Ma, the latter being interpreted as showing pre-magmatic inheritance. Oliveira et al. (2002) presented a Sm/Nd isochron using whole rock, plagioclase and pyroxene which yielded 885 ± 53 Ma for the Apiaí Gabbro and 820 ± 84 Ma for the Adrianópolis metabasite which is a correlated body. They also recalculated the Daitx et al. (1990) Rb/Sr isocron age giving 839 ± 85 Ma. Tassinari et al. (1990) analysed former and new Pb and Sr isotope data for hydrothermal galena veins cutting the Lajeado Group limestones, suggesting the formation of these veins by remobilization from crustal sources due a metamorphic event around 1100–1400 Ma.

5.2. Analytical methods

Zircons were extracted from 100–200 mesh fractions using standard isodynamic, gravimetric and magnetic techniques. The grains were hand-picked using a binocular microscope. Cathodoluminescence (CL) and scanning electron microscope (SEM) images were used to identify the best points for U-Pb analysis, avoiding fractures, inclusions or metamict areas that may have experienced Pb loss.

SHRIMP U-Pb data were obtained using a ~25 μm diameter spot. Details of the analytical procedure, as well as of the calculations of the analytical errors are presented in Stern (1998) and Williams (1998). The decay constants and current $^{238}U/^{235}U$ of Steiger and Jager (1977) has been used to calculate ages. U concentrations were calculated using the SL13 standard (U = 238 ppm) and $^{206}Pb/^{238}U$ ratios were calibrated using the FC1 standard (concordant, 1099 Ma). U–Pb analyses by LA-MC-ICP-MS were carried out using the Finnigan Neptune coupled to an eximer ArF laser (193 nm) ablation system. The mounts containing zircons were cleaned in a HNO_3 solution (3%) and in ultraclean water bath. The ablation was done with spot size of 29 μm, at a frequency of 6 Hz and an intensity of 6 mJ. The ablated material was carried by Ar (~0.7 L/min) and He (~0.6 L/min) and analysis was undertaken in 60 cycles of 1 s. Unknowns were bracketed by measurements of the international standard GJ-1, following the sequence 2 blanks, 3 standards, 13 unknowns, 2 blanks, and 2 standards. Raw data were reduced off-line with corrections for background, instrumental mass bias drift and common Pb.

The ages for Neoproterozoic zircons are derived from $^{206}Pb/^{238}U$ ratios, following correction for common Pb by the ^{207}Pb method (Compston et al., 1984) and use of the Cumming and Richards (1975) model Pb composition for the likely age of the zircons. For inherited cores of >1000 Ma zircon, $^{207}Pb/^{206}Pb$ dates are presented, following correction for common Pb based on measured ^{204}Pb. Dates calculated in this paper are weighted mean $^{206}Pb/^{238}U$

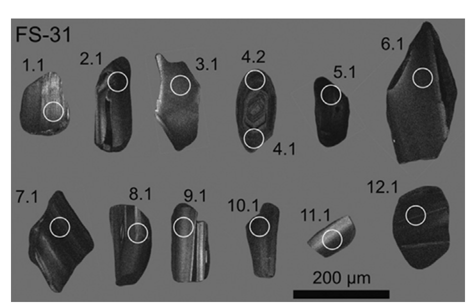

Figure 4. Cathodoluminescence image of dated zircons from the sample FS-31 of Apiaí Gabbro.

Table 1
Analytical results for sample FS31 of the Apiaí Gabbro (Beijing SHRIMP Center).

Labels	Site	U (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{206}Pb/^{238}U	Error (1σ)	^{207}Pb/^{235}U	Error (1σ)	^{207}Pb/^{206}Pb	Error (1σ)	Age (Ma)				Conc (%)
												^{206}Pb/^{238}U	Error	^{207}Pb/^{206}Pb	Error	
1.1	fr,m,hd	194.5	1.07	34	13	0.14325	0.00559	1.3506	0.08622	0.06838	0.00314	863	32	880	98	98
2.1	p,m,hd	504.2	1.52	97	13	0.14608	0.00486	1.39781	0.05261	0.0694	0.00097	879	27	911	29	97
3.1	an,e,hd	176.0	1.29	33	28	0.15077	0.00511	1.43799	0.09329	0.06917	0.00355	905	29	904	109	100
4.1	r,e,osc	1002.9	0.21	87	64	0.09358	0.00377	0.76437	0.0361	0.05924	0.0012	577	22	576	45	100
4.2	r,e,osc	975.2	0.21	86	62	0.09274	0.00366	0.76961	0.03575	0.06019	0.00121	572	22	610	44	94
5.1	fr,e,hd	1013.5	0.96	75	77	0.06376	0.00306	0.4993	0.0412	0.05679	0.00349	398	19	484	142	82
6.1	an,m,hd	183.8	1.24	34	13	0.14686	0.005	1.37198	0.0802	0.06776	0.00295	883	28	861	93	103
7.1	eq,m,sz	658.2	1.37	119	24	0.14264	0.00668	1.31854	0.06712	0.06704	0.001	860	38	839	31	102
8.1	an,m,sz	241.8	1.39	45	25	0.1465	0.00519	1.34194	0.06304	0.06644	0.00178	881	29	820	57	108
9.1	p,e,sz	273.2	1.13	47	21	0.14208	0.00486	1.33549	0.06794	0.06817	0.00229	856	28	874	71	98
10.1	an,e,d	625.1	1.51	118	28	0.14459	0.00515	1.38289	0.05543	0.06936	0.00101	871	29	910	30	96
11.1	fr,m,sz	446.8	1.19	80	31	0.14526	0.00397	1.37568	0.05374	0.06869	0.0017	874	22	889	52	98
12.1	r,m,sz	746.0	1.70	139	10	0.13764	0.00736	1.31029	0.0762	0.06904	0.00118	831	42	900	36	92

x.y: grain number followed by analysis number.
Grain habit: p = prism, eq = equant, fr = fragment.
Site: e = end or edge, m = middle, r = rim/overgrowth.
CL image microstructure: osc = oscillatory zoning, h = homogeneous (d = dark or b = bright); sz = sector zoned.
U-Pb data corrected for non-radiogenic Pb based on measured ^{204}Pb and 900 Ma model Pb of Cumming and Richards (1975).
All uncertainties are 1σ.

dates (analyses inverse-variance weighted, 95% confidence and rounded to the nearest million year), based on grouping of sites interpreted from CL images to belong to one generation of zircon. The dates were calculated using the program Isoplot (Ludwig, 1999). Results are summarized as ^{207}Pb/^{206}Pb – ^{206}Pb/^{238}U Tera-Wasserburg plots.

5.3. Results

The Apiaí Gabbro gave a small yield of prismatic to angular-anhedral zircons with lamellar to oscillatory zoning (Fig. 4). Apart from two analyses on the margins of grain 4, other sites had moderate U content with high Th/U > 1, typical of zircons grown from gabbroic magma. Twelve zircons from a sample of the Apiaí Gabbro (sample FS-31, Table 1) were analysed by SHRIMP at the Beijing SHRIMP Center. Ten zircons give concordant ages with a weighted mean ^{206}Pb/^{238}U age of 877 ± 8 Ma (Fig. 5 and Table 1), interpreted as the time of magmatic emplacement. Two sites at edges of a single grain (4.1 and 4.2) showed younger ages (about 600 Ma) with lower Th/U, and are interpreted as indicating a metamorphic and/or hydrothermal event. A high-U site on grain 5 gave discordant ages.

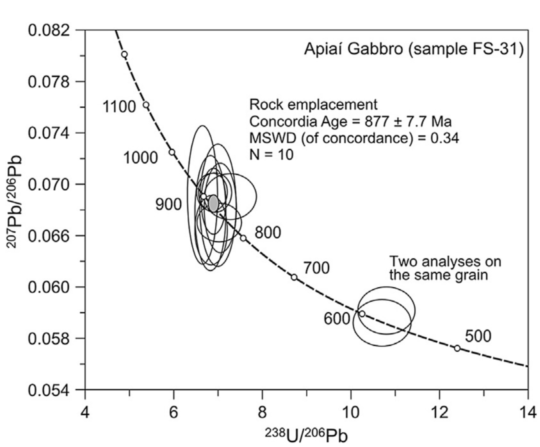

Figure 5. Tera-Wasserburg ^{238}U/^{206}Pb versus ^{207}Pb/^{206}Pb diagram for zircons from sample FS31 of the Apiaí Gabbro.

Detrital zircons of two Lajeado Group metasedimentary rocks (IP-61 and LAJ-09) were analysed. The grains in both samples show variable degrees of roundness, indicated by truncation of oscillatory zoning at their margins (Figs. 6 and 7). This shows that at least some grains underwent protracted recycling in surficial systems. Sample LAJ-09 is a metasandstone from one of the upper units, the Serra da Boa Vista Formation (Figs. 2 and 3). Sixty four zircons were analysed by LA-ICP-MS at the University of São Paulo. Most analyses

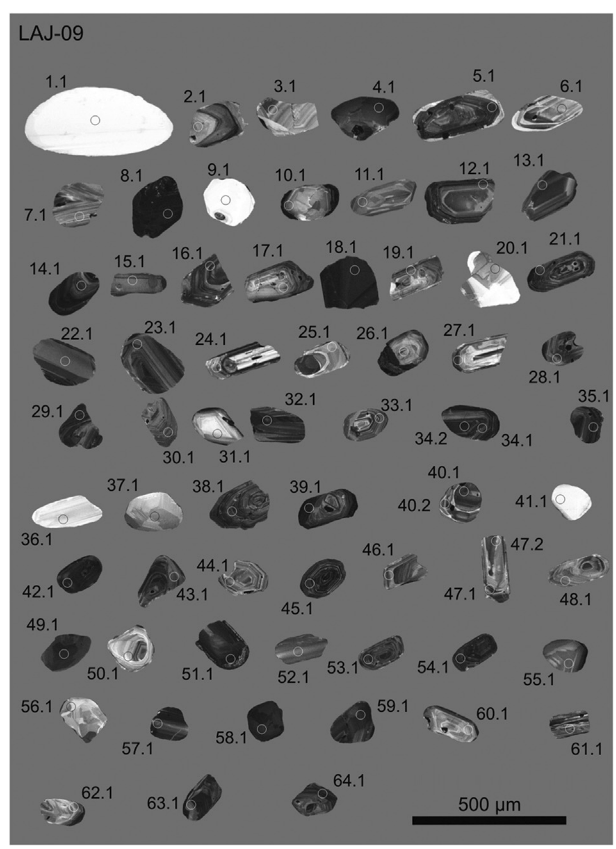

Figure 6. Cathodoluminescence image of the detritic zircons from metasandstone sample LAJ-09 from the Serra da Boa Vista Formation, Lajeado Group.

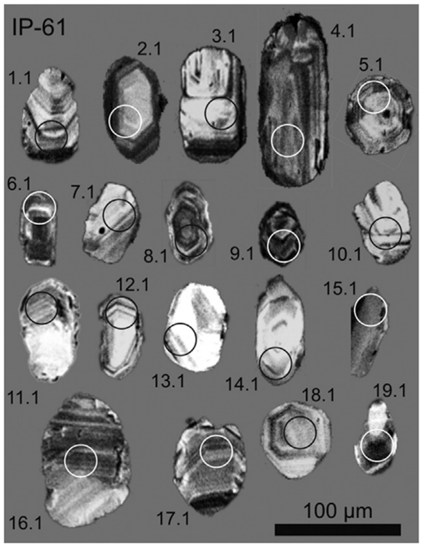

Figure 7. Cathodoluminescence image of the detrital zircons from sample IP061, a metaconglomerate from the Betari Formation, Lajeado Group.

yielded close to concordant ages (Fig. 8a,b, Table 2). There is a dominant population with ages of 2200–2000 Ma. There are a few older grains up to Mesoarchaean age (maximum 3300 Ma), plus a minor population at 1800–1700 Ma. A single grain (analysis 31.1) gives an age of ~1200 Ma, which is the youngest detritical zircon obtained. Sample IP-61 is from a metaconglomerate of the Lajeado basal unit, the Betari Formation (Figs. 2 and 3). Nineteen zircons (Fig. 8c,d) were analysed by SHRIMP at the Australian National University. The majority of the grains showed ages between 1750 and 2000 Ma, one grain (20.1) yielded a ~2740 Ma age and two others (10.1 and 16.1) have Mesoproterozoic ages (~1500–1400 Ma; Fig. 8c,d, Table 3).

6. Discussion

The youngest detrital zircons in the Lajeado Group indicate deposition after 1400–1200 Ma, whereas the 877 ± 8 Ma age on the Apiaí Gabbro, gives the minimum age of deposition. The analyses of detrital zircon grains presented here show the importance of Palaeoproterozoic source areas (2200–1800 Ma) with some Archean and Mesoproterozoic (1500–1200 Ma) contributions. These results are compatible with those presented by Basei et al. (2005) and Siga Jr. et al. (2011) for the Ribeira Belt, south of the present area.

The presence of some ~1400 Ma detrital zircons could suggest provenance of some detritus from the neighboring Votuverava Group (Campanha et al., 2008b; Siga Jr. et al., 2011; Campanha et al., 2015). However zircons of this age in the Votuverava Group are derived from metabasic rocks and are notably different from the detrital rounded zircons from the Lajeado Group. Previous publications showed that detrital zircons from the Apiai terrane are Palaeoproterozoic and Archaean with a main peak at ~2.2 Ga. Basei et al. (2008) proposed “African” and a “South American” signatures with different detrital zircon ages across West Gondwana. While the Ribeira (understanding “Ribeira” mainly as the Apiaí terrane) sources are only Palaeoproterozoic and Archaean, the sources for the southern Dom Feliciano belt and the African Damara and

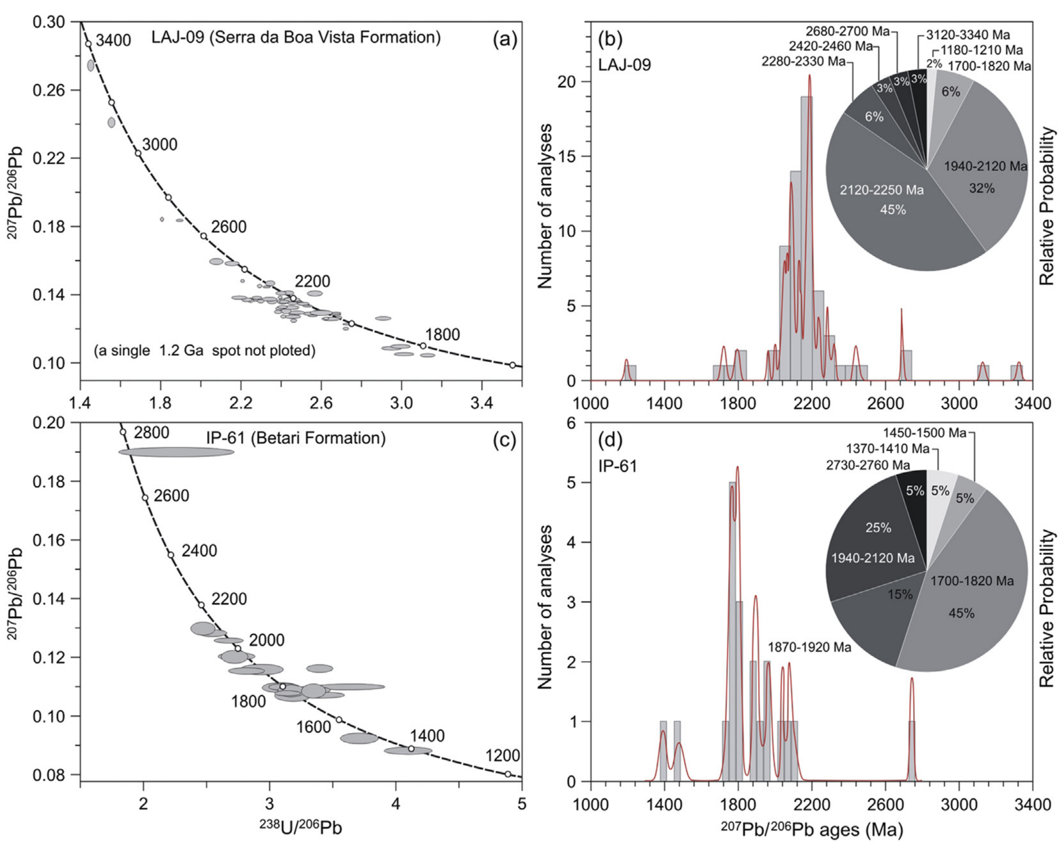

Figure 8. Tera-Wasserburg $^{238}U/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ diagram and frequency diagrams for detrital zircon grains from samples LAJ-09 (a metasandstone from the Serra da Boa Vista Formation) (a,b) and IP-61 (a metaconglomerate from the Betari Formation) (c,d).

Table 2
Analytical results for detrital zircons of sample LAJ09 from Lajeado Group, Serra da Boa Vista Formation.

Labels	Site	Ratios											Ages (Ma)				Concord.
LAJ-09		$^{207}Pb/^{235}U$	Error	$^{206}Pb/^{238}U$	Error	Error corr.	$^{238}U/^{206}Pb$	Error	$^{207}Pb/^{206}Pb$	Error	$^{208}Pb/^{206}Pb$	Error	$^{206}Pb/^{238}U$	Error	$^{207}Pb/^{206}Pb$	Error	%
1.1		4.6303	0.0570	0.3195	0.0024	0.61	3.1298	0.0235	0.1047	0.0006	0.4196	0.1337	1787	0.012	1714	0.011	104
2.1		8.4404	0.1021	0.4485	0.0033	0.61	2.2296	0.0165	0.1372	0.0006	0.2840	0.0933	2389	0.015	2188	0.008	109
3.1		6.8414	0.0885	0.3850	0.0031	0.63	2.5971	0.0210	0.1303	0.0006	0.2427	0.0826	2100	0.014	2099	0.008	100
4.1		7.2100	0.0848	0.4048	0.0028	0.58	2.4701	0.0168	0.1296	0.0006	0.1977	0.0696	2191	0.013	2089	0.008	105
5.1		7.4002	0.0939	0.3984	0.0032	0.62	2.5102	0.0199	0.1349	0.0007	0.2544	0.0929	2162	0.015	2159	0.008	100
6.1		7.9831	0.1042	0.4108	0.0032	0.59	2.4342	0.0188	0.1413	0.0008	0.4215	0.1600	2219	0.015	2238	0.010	99
7.1		6.8618	0.0821	0.3864	0.0027	0.58	2.5883	0.0180	0.1290	0.0006	0.2763	0.1084	2106	0.012	2082	0.008	101
8.1		7.5822	0.0909	0.4152	0.0029	0.58	2.4082	0.0168	0.1330	0.0006	0.0530	0.0218	2239	0.013	2134	0.008	105
9.1		10.4964	0.1537	0.4811	0.0050	0.71	2.0787	0.0216	0.1597	0.0012	0.9968	0.4277	2532	0.022	2449	0.013	103
10.1		7.7306	0.0928	0.4140	0.0029	0.59	2.4156	0.0172	0.1361	0.0006	0.2512	0.1126	2233	0.013	2174	0.008	103
11.1		8.3601	0.0990	0.4385	0.0030	0.58	2.2805	0.0157	0.1385	0.0006	0.1966	0.0923	2344	0.014	2204	0.008	106
12.1		8.0765	0.0971	0.4163	0.0029	0.58	2.4019	0.0168	0.1412	0.0007	0.4046	0.1994	2244	0.013	2237	0.008	100
13.1		7.5424	0.0892	0.4070	0.0027	0.57	2.4568	0.0166	0.1353	0.0006	0.2983	0.1548	2201	0.013	2164	0.008	102
14.1		6.8844	0.0511	0.3909	0.0024	0.82	2.5580	0.0156	0.1279	0.0003	0.2401	0.1147	2127	0.011	2067	0.004	103
15.1		7.5550	0.0562	0.4027	0.0025	0.82	2.4833	0.0152	0.1363	0.0003	0.2879	0.1332	2181	0.011	2177	0.004	100
16.1		7.2559	0.0541	0.3948	0.0024	0.82	2.5329	0.0155	0.1336	0.0003	0.2472	0.1108	2145	0.011	2142	0.004	100
17.1		7.7664	0.0583	0.4113	0.0025	0.81	2.4312	0.0148	0.1371	0.0003	0.3245	0.1411	2221	0.011	2186	0.004	102
18.1		8.3558	0.0623	0.4416	0.0027	0.81	2.2644	0.0137	0.1374	0.0003	0.2111	0.0891	2358	0.012	2191	0.004	108
19.1		6.1717	0.0511	0.3657	0.0026	0.85	2.7348	0.0193	0.1230	0.0004	0.3496	0.1434	2009	0.012	2000	0.005	100
20.1		6.6879	0.0504	0.3741	0.0023	0.82	2.6734	0.0166	0.1295	0.0004	0.5390	0.2158	2048	0.011	2088	0.005	98
22.1		7.7867	0.0583	0.4102	0.0025	0.82	2.4379	0.0151	0.1381	0.0003	0.3113	0.1177	2216	0.012	2199	0.004	101
24.1		6.6269	0.0512	0.3742	0.0023	0.80	2.6720	0.0165	0.1288	0.0003	0.4194	0.1507	2049	0.011	2078	0.004	99
25.1		8.5533	0.0637	0.4294	0.0026	0.82	2.3288	0.0143	0.1449	0.0004	0.5171	0.1813	2303	0.012	2282	0.004	101
26.1		7.4881	0.0560	0.4111	0.0025	0.82	2.4328	0.0149	0.1326	0.0003	0.7332	0.2510	2220	0.011	2129	0.004	104
27.1		7.7491	0.0465	0.4101	0.0013	0.52	2.4385	0.0077	0.1378	0.0006	0.4957	0.1396	2215	0.006	2196	0.007	101
28.1		7.8572	0.0491	0.4173	0.0013	0.48	2.3965	0.0072	0.1387	0.0006	0.3729	0.1061	2248	0.006	2207	0.007	102
29.1		6.4744	0.0387	0.3722	0.0014	0.63	2.6866	0.0102	0.1268	0.0005	0.2581	0.0742	2040	0.007	2052	0.007	99
30.1		13.9890	0.0779	0.5533	0.0015	0.50	1.8074	0.0050	0.1843	0.0007	0.3362	0.0977	2839	0.006	2694	0.007	105
32.1		6.0893	0.0353	0.3674	0.0012	0.56	2.7221	0.0088	0.1204	0.0005	0.4457	0.1326	2017	0.006	1962	0.007	103
33.1		8.7091	0.0535	0.4362	0.0014	0.53	2.2927	0.0074	0.1453	0.0006	0.1554	0.0466	2333	0.006	2287	0.007	102
34.1		6.6257	0.0390	0.3808	0.0012	0.54	2.6257	0.0083	0.1264	0.0005	0.2646	0.0804	2080	0.006	2046	0.007	102
34.2		7.2248	0.0437	0.4147	0.0015	0.60	2.4111	0.0088	0.1275	0.0005	0.2400	0.0737	2237	0.007	2062	0.007	108
35.1		9.2033	0.0555	0.4528	0.0015	0.53	2.2085	0.0071	0.1484	0.0006	0.3486	0.1083	2408	0.006	2323	0.007	104
36.1		7.9804	0.1117	0.4246	0.0030	0.50	2.3550	0.0165	0.1366	0.0011	0.5108	0.2577	2281	0.013	2180	0.013	105
37.1		7.7716	0.1078	0.4152	0.0028	0.49	2.4088	0.0165	0.1362	0.0010	0.4453	0.2159	2238	0.013	2175	0.013	103
38.1		7.4452	0.1035	0.4122	0.0029	0.50	2.4262	0.0168	0.1308	0.0010	0.2301	0.1074	2225	0.013	2105	0.013	106
39.1		6.8574	0.1280	0.3845	0.0054	0.75	2.6009	0.0363	0.1296	0.0010	0.2560	0.1152	2097	0.025	2089	0.013	100
40.1		8.6036	0.1189	0.4261	0.0029	0.50	2.3469	0.0161	0.1469	0.0011	0.3499	0.1519	2288	0.013	2306	0.013	99
40.2		7.5488	0.1243	0.3893	0.0038	0.59	2.5686	0.0249	0.1409	0.0011	0.1709	0.0718	2120	0.017	2234	0.013	95
43.1		7.2217	0.0997	0.4055	0.0028	0.50	2.4661	0.0172	0.1291	0.0010	0.3080	0.1173	2194	0.013	2083	0.013	105
44.1		7.6189	0.0682	0.4176	0.0023	0.62	2.3944	0.0133	0.1322	0.0007	0.1971	0.0176	2250	0.011	2125	0.009	106
46.1		8.0941	0.0685	0.4350	0.0020	0.54	2.2990	0.0104	0.1365	0.0007	0.2065	0.0185	2328	0.009	2179	0.008	107
47.1		5.9139	0.0743	0.3439	0.0030	0.70	2.9076	0.0255	0.1264	0.0007	0.2518	0.0226	1906	0.014	2046	0.009	93
47.2		7.4895	0.0651	0.4190	0.0020	0.56	2.3866	0.0116	0.1303	0.0006	0.2220	0.0201	2256	0.009	2099	0.008	107
48.1		8.3055	0.0696	0.4446	0.0019	0.52	2.2491	0.0098	0.1367	0.0007	0.1714	0.0154	2371	0.009	2182	0.008	109
49.1		6.9450	0.0584	0.4058	0.0017	0.51	2.4644	0.0106	0.1251	0.0006	0.2900	0.0261	2196	0.008	2028	0.008	108
50.1		8.3810	0.0711	0.4445	0.0020	0.53	2.2497	0.0102	0.1373	0.0007	0.4106	0.0371	2371	0.009	2189	0.009	108
51.1		8.2724	0.0693	0.4397	0.0019	0.53	2.2741	0.0100	0.1373	0.0006	0.1906	0.0172	2349	0.009	2190	0.008	107
52.1		5.0809	0.0580	0.3340	0.0036	0.95	2.9940	0.0325	0.1099	0.0006	0.8154	0.6869	1858	0.017	1801	0.010	103
53.1		7.2109	0.0821	0.4035	0.0043	0.94	2.4781	0.0266	0.1297	0.0007	0.7852	0.6276	2185	0.020	2091	0.009	104
54.1		10.1091	0.1206	0.4637	0.0052	0.94	2.1564	0.0242	0.1585	0.0009	0.0452	0.0351	2456	0.023	2436	0.009	101
55.1		4.8068	0.0544	0.3318	0.0035	0.94	3.0137	0.0322	0.1055	0.0006	0.5143	0.3728	1847	0.017	1727	0.010	107
56.1		7.5046	0.0861	0.4085	0.0045	0.95	2.4481	0.0267	0.1327	0.0008	0.6873	0.4762	2208	0.020	2131	0.010	104
57.1		8.6834	0.1037	0.4562	0.0052	0.95	2.1920	0.0248	0.1386	0.0008	1.0043	0.6663	2423	0.023	2205	0.009	110
58.1		8.0824	0.0911	0.4268	0.0046	0.95	2.3432	0.0250	0.1376	0.0008	0.6535	0.4182	2291	0.021	2193	0.009	104
59.1		7.7039	0.0876	0.4072	0.0044	0.95	2.4559	0.0265	0.1375	0.0008	0.7806	0.4772	2202	0.020	2192	0.009	100
60.1		5.0678	0.0578	0.3389	0.0037	0.95	2.9505	0.0321	0.1089	0.0006	0.6619	0.3894	1881	0.018	1785	0.010	105
61.1		7.6115	0.0920	0.4062	0.0046	0.94	2.4619	0.0279	0.1363	0.0008	0.6401	0.3632	2197	0.021	2177	0.010	101
62.1		6.9350	0.0782	0.3918	0.0042	0.94	2.5522	0.0272	0.1291	0.0007	0.8153	0.4460	2131	0.019	2084	0.010	102
63.1		6.6243	0.0806	0.3778	0.0043	0.93	2.6470	0.0301	0.1261	0.0007	0.3901	0.2062	2066	0.020	2043	0.010	101
64.1		7.1045	0.0808	0.4069	0.0044	0.94	2.4579	0.0263	0.1273	0.0007	0.3973	0.2031	2201	0.020	2059	0.010	107
31.1		2.3569	0.0152	0.2163	0.0009	0.67	4.6235	0.0201	0.0796	0.0004	0.7490	0.2202	1262	0.005	1192	0.010	106
23.1		13.2793	0.1000	0.5270	0.0033	0.83	1.8977	0.0118	0.1836	0.0004	0.7500	0.2763	2729	0.014	2688	0.004	102
41.1		21.1689	0.2980	0.6416	0.0047	0.52	1.5585	0.0114	0.2411	0.0018	0.2305	0.0940	3195	0.018	3130	0.012	102
42.1		25.8409	0.3646	0.6871	0.0049	0.50	1.4555	0.0104	0.2745	0.0021	0.4137	0.1626	3371	0.019	3327	0.012	101
45.1		5.5590	0.0663	0.3198	0.0022	0.57	3.1271	0.0211	0.1268	0.0007	0.1589	0.0142	1789	0.011	2052	0.010	87
21.1		4.4308	0.0866	0.2647	0.0045	0.87	3.7777	0.0641	0.1216	0.0005	0.4247	0.1649	1514	0.023	1979	0.008	76

Last two analyses are not used due to discordance.
Legend as Table 1.

Table 3
U-Pb SHRIMP analytical results for detrital zircons from sample IP061 of the Lajeado Group, Betari Formation.

Labels	Sites	U (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{206}Pb/^{238}U	Error (1σ)	^{207}Pb/^{235}U	Error (1σ)	^{207}Pb/^{206}Pb	Error (1σ)	Age (Ma)				% Conc
												6/38	Error	7/6	Error	
1.1	e.osc.r	214.0	0.62	80	2	0.33997	0.01298	5.43811	0.22162	0.11601	0.00119	1887	63	1896	19	100
3.1	e.osc.p	305.8	0.48	117	2	0.35472	0.01182	5.65316	0.19673	0.11559	0.00077	1957	57	1889	12	104
4.1	e.osc.rp	209.5	0.83	76	0	0.31374	0.00923	4.62976	0.15178	0.10703	0.0012	1759	45	1749	21	101
5.1	e.osc.eq	132.2	0.76	46	0	0.29828	0.00565	4.46873	0.11241	0.10866	0.00156	1683	28	1777	26	95
7.1	e.osc.fr	211.3	0.51	73	4	0.32371	0.00994	4.90242	0.16472	0.10984	0.00114	1808	49	1797	19	101
8.1	e.osc.p	379.8	0.75	163	7	0.37308	0.01077	6.47213	0.19321	0.12582	0.0006	2044	51	2040	8	100
10.1	e.osc.fr	130.4	0.81	40	3	0.26926	0.00716	3.43569	0.10673	0.09254	0.00121	1537	36	1479	25	104
11.1	e.osc.p	129.5	0.96	57	0	0.36694	0.00931	6.08829	0.18075	0.12034	0.00151	2015	44	1961	23	103
12.1	e.osc.p	131.3	0.64	60	1	0.40413	0.0103	7.24322	0.21168	0.12999	0.00149	2188	47	2098	20	104
13.1	e.osc.r	125.6	0.72	43	0	0.30124	0.00982	4.52439	0.15607	0.10893	0.00086	1697	49	1782	14	95
15.1	e.h.fr	460.7	0.67	190	1	0.36461	0.01276	6.06085	0.22133	0.12056	0.00084	2004	61	1965	12	102
16.1	m.osc.r	167.8	0.40	42	2	0.24376	0.00749	2.96961	0.09924	0.08836	0.00087	1406	39	1390	19	101
17.1	m.osc.r	243.6	0.86	91	1	0.32073	0.00837	4.86994	0.13457	0.11012	0.00071	1793	41	1801	12	100
18.1	m.hb.eq	151.2	0.41	50	0	0.31464	0.00708	4.71635	0.12687	0.10872	0.00132	1763	35	1778	22	99
19.1	e.osc.fr	348.1	1.00	133	1	0.31794	0.00688	4.73461	0.1092	0.108	0.00062	1780	34	1766	11	101
20.1	e.hd.fr	224.2	0.69	117	4	0.44108	0.05892	11.5633	1.55401	0.19014	0.00107	2355	269	2743	9	86
2.1	e.osc.p	803.8	0.67	249	16	0.27497	0.01406	4.17537	0.21748	0.11013	0.00059	1566	72	1802	10	87
6.1	e.h.p	495.3	0.69	161	21	0.29334	0.01065	4.34009	0.16283	0.10731	0.00064	1658	53	1754	11	95
9.1	e.osc.p	570.8	0.73	190	24	0.29404	0.00587	4.71923	0.10454	0.1164	0.00086	1662	29	1902	13	87
14.1	e.osc.p	286.8	0.39	120	16	0.39176	0.01128	6.93707	0.20895	0.12843	0.00076	2131	52	2077	11	103

x.y: grain number followed by analysis number.
Grain habit: p = prism, eq = equant, fr = fragment, r = rounded, rp = rounded prism.
Site: e = end or edge, m = middle, r = rim/overgrowth.
CL image microstructure: osc = oscillatory zoning, h = homogeneous (d = dark or b = bright).
U-Pb data corrected for non-radiogenic Pb based on measured ^{204}Pb and 2000 Ma model Pb of Cumming and Richards (1975).
All uncertainties are 1σ.

Gariep–Rocha belts include Neoproterozoic zircons, suggesting a major suture; it was proposed that the sources for the "Ribeira basin" was essentially derived from the Paranapanema and Rio de la Plata cratons, whereas for the Damara and Gariep–Rocha belts source areas were from the Namaqua Belt. Henrique-Pinto et al. (2015) also demonstrated the Paleoproterozoic and Archean sources for the Ribeira belt (São Roque Group) detrital zircons, without Neoproterozoic ages, as well an essentially continental (cratonic) provenance. But they suggested that the Ribeira Belt is part of the reworked border of the São Francisco paleoplate, displaced southwestward as a result of significant dextral orogen-parallel tectonics during the Neoproterozoic collision (Campanha and Brito Neves, 2004) instead of a Paranapanema continent border as proposed for example by Campos Neto (2000).

Although most of the Precambrian carbonate platforms in the West Gondwana, like the Bambui and Corumba groups show Criogenian to Ediacarian ages (Boggiani et al., 2005; Babinski et al., 2008; Campanha et al., 2010, 2011; Pimentel el al., 2011), the results presented here stress that the Lajeado Group in the Southern Ribeira Belt must be deposited earlier, in the Tonian-Stenian interval. For Bradley (2008, 2011), only two passive margins are known from ca. 1200 to 1050 Ma, in the borders of Siberian and Baltic cratons. Especially thick terrigenous-carbonate successions occur at southeastern margin of the Siberian platform, the lower Riphean (1650–1350 Ma) Uchur Group, the middle Riphean (1350–1000 Ma) Aimchan and Kerpyl groups, the upper Riphean (1000–650 Ma) Lakhanda and Uy groups, and the Vendian Yudoma Group (Khudoley et al., 2001).

Mesoproterozoic depositional ages in the Brazilian Shield are known mainly for the Espinhaço Supergroup, which is composed essentially by continental sediments comprising metasandstones, metapelites and metaconglomerates with subordinate metavolcanic and carbonate rocks deposited as an intracontinental rift-sag basin covering the São Francisco Craton and affected by the marginal portion of the Neoproteroic Araçuai belt (Chemale Jr. et al., 2012). Similar ages are also found in the Sunsás–Aguapeí province (1.20–0.95 Ga), in the SW border of the Amazonian Craton. Its evolution can be delineated into three steps: (1) a passive margin represented by the Sunsás and Vibosi groups (<1.2 Ga); (2) the collisional stage (1.11–1.00 Ga) related to the Greenvilian Amazonian – Laurentia collision; and (3) the post-tectonic and anorogenic events (Litherland et al., 1986, 1989; Sadowski and Bettencourt, 1996; Teixeira el al., 2010). In the absence of evidence for Greenvilian tectonometamorphism in the Ribeira belt, despite some suggestion in Campanha et al. (2015), it is hard to correlate the Apiaí terrane with the Sunsás-Aguapeí province.

Thus the Lajeado Group as a Stenian–Tonian passive margin carbonate platform should be at the margin of Columbia/Nuna or the Rodinia. Alternatively it may represent a passive margin in a back-arc sea, as an oceanic back-arc setting has been proposed for the regional neighboring Votuverava and São Roque groups (Hackspacher et al., 2000; Tassinari et al., 2001; Campanha et al., 2015) in the Apiaí terrane. But its proper position in a Mesoproterozoic/Early Neoproterozoic paleocontinent configuration is hard to stablish due the lack of paleomagnetic poles in the surrounding cratons (Paranapanema, Luís Alves) and the allochtonous character of the Apiaí terrane. The Paranapanema Craton (Campos Neto, 2000; Mantovani and Brito Neves, 2005) is completely covered by Paleozoic sedimentary rocks and was recognized by data from deep boreholes and geophysical studies, hampering the understanding of its geotectonic relationships. On the other hand, the suggestion that the Ribeira (Apiaí) belt is part of the reworked border of the São Francisco paleoplate (Henrique-Pinto et al., 2015) is possible but still speculative.

The SHRIMP U-Pb zircon age obtained for the Apiaí Gabbro (877 ± 8 Ma) is coincident with the much less precise former Sm/Nd (885 ± 53 Ma) and Rb/Sr (850 ± 85 Ma) isochron ages (Daitx et al., 1990; Oliveira et al., 2002) and is interpreted as the emplacement age. Two rim sites on the edge of grain 4 with ages at around 600 Ma and low Th/U ratios are roughly coeval with a former discordant U-Pb age in one zircon grain and monazite fraction, (Hackspacher et al., 2000) as well as the timing of emplacement of neighboring granite intrusions (Hackspacher et al., 2000; Salazar et al., 2013) and are probably associated with the slight hydrothermal alteration observed in the gabbro. The Apiaí Gabbro displays similar age to other intrusive basic rocks in the Lajeado (Maniesi, 1997; Maniesi and Oliveira, 2000, 2002; Oliveira et al., 2002) and Itaiacoca (Siga Jr. et al., 2009) groups. They represent a tholeiitic magmatism possibly related to the initial break-up of the Rodinia continent and the formation of the Brasiliano oceans.

7. Conclusions

(1) The maximum age of deposition for the Lajeado Group is given by the youngest detrital zircons with ages of 1400–1200 Ma, whereas its youngest age is constrained by the Apiaí Gabbro intrusion at 877 ± 8 Ma. This gives a Stenian–Tonian age interval for its deposition.
(2) The source areas for the Lajeado Group are mainly Palaeoproterozoic (2200–1800 Ma) with some Archean and Mesoproterozoic (1500–1200 Ma) and of distal or tectonic stable cratonic character.
(3) The passive margin sequence represented by the Lajeado Group thus formed in late Mesoproterozoic to the early Neoproterozoic, and is markedly older than the more widespread Gondwanan late Neoproteroic passive margin and carbonate platforms sequences formed upon the breakup of Rodinia.
(4) The Stenian–Tonian Lajeado Group represents a carbonate platform passive margin of a continent at this time, namely Columbia/Nuna or Rodinia.
(5) The Apiaí Gabbro and other similar intrusive basic rocks in the Lajeado and Itaiacoca groups represent tholeiitic magmatism possibly related to the initial break-up of the Rodinia continent and the formation of the Brasiliano oceans.

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