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Paleoproterozoic Crustal Evolution of the São Luís Craton, Brazil: Evidence from Zircon Geochronology and Sm-Nd Isotopes

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Abstract

The São Luís Craton, northern Brazil, is composed of a few granitoid suites and a metavolcano-sedimentary succession. New single zircon Pb evaporation ages and Nd isotope data, combined with other available information, show that the metavolcano-sedimentary succession developed from 2240 Ma to approximately 2200–2180 Ma from juvenile protoliths. The subduction-related calc-alkaline suites of granitoids, spatially associated with the metavolcano-sedimentary sequence, formed in an oceanic island arc setting between 2168–2147 Ma. Most of these granitoids are tonalitic and formed from juvenile, mantle- or oceanic plate-derived protoliths, whereas minor true granites are the product of the reworking of the juvenile island arc material. These arc-related successions represent an accretionary event around 2.20 ± 0.05 Ga, which is coincident with one of the main periods of crustal growth in the South American Platform. This accretionary orogen has subsequently been involved in a collision episode, at ca. 2100–2080 Ma, which is mainly recorded in the nearby Gurupi Belt. The rock associations, inferred geological settings, and the crustal evolution detected in the São Luís Craton are similar to what is described in Paleoproterozoic domains of major geotectonic units of the South American Platform, such as part of the São Francisco Craton, southeastern Guyana Shield, and of the West African Craton.

Key words: São Luís Craton, Paleoproterozoic, geochronology, Nd isotopes, crustal growth.

Introduction

The São Luís Craton, as defined by Almeida et al. (1976), is that part of the Precambrian continental crust that crops out at the border of the states of Pará and Maranhão in northern Brazil, whose rocks have not been affected by geological events after ca. 1900 Ma, as suggested by Rb-Sr and K-Ar geochronological data (Hurley et al., 1967, 1968; Almeida et al., 1968; Cordani et al., 1968; Almaraz and Cordani, 1969). This geotectonic unit is bordered to the south by the Gurupi Belt (Fig. 1), which, in turn, records the imprinting of Neoproterozoic events.

More than two decades of intermittent regional mapping programs outlined the present-day cartography (Fig. 2) and fostered the debate on the lithostratigraphy and tectonic evolution of the São Luís Craton (Costa et al., 1977; Abreu et al., 1980; Hasui et al., 1984; Pastana, 1995; Almeida, 2000; Costa, 2000), always based on the Rb-Sr and K-Ar dataset. A precise time positioning of each unit has not been attained, with some units being considered as having Archean-to-Paleoproterozoic age. Only recently, zircon geochronology (Gorayeb et al., 1999; Klein and Moura, 2001, 2003; Palheta, 2001) improved this chronostratigraphic framework, and the chronology of the regional units is now relatively well established. However, the fundamental question that has not yet been addressed is the crustal evolution, that is, are the rocks of the São Luís Craton juvenile or are they the products of recycling of an older, pre-existing crust? It is the aim of this paper to constrain this question. We provide: (1) a review of relevant aspects of the São Luís Craton (structure, limits, lithostratigraphy, geochronology); (2) new single zircon Pb evaporation data for the major suite of granitoids (Tromaí Intrusive Suite); and (3) Sm-Nd isotope compositions of granitoids and supracrustal rocks. The integration of this study with the available information enables us to outline the crustal evolution of the rocks belonging to the São Luís Craton, taking into account its present-day configuration (Fig. 1), that is, the portion that has not been affected by Neoproterozoic events.

In addition, the São Luís Craton has been considered as a fragment of the West African Craton that was left behind in the South American Platform (Fig. 3) after the breakup of the Pangea supercontinent (Hurley et al., 1967; Torquato and Cordani, 1981; Lesquer et al., 1984; Brito Neves et al., 2001). Therefore, the study of the evolution of the São Luís Craton is important to the understanding of the crustal evolution of the South American and African continents.

Geological Overview

Geographical extent, boundaries and structure

The São Luís Craton extends from about 400 km in east-west direction and up to 120 km in north-south direction, covering parts of the Pará and Maranhão states in northern Brazil. Despite this extension, the rocks of the craton crop out as highly discontinuous erosive and tectonic windows within the Phanerozoic sedimentary cover (Figs. 1 and 2), which makes it difficult to recognize the boundaries of the craton. The westernmost exposed rocks attributed to the cratonic area are the granitoids of the Tracuateua Intrusive Suite (Fig. 2), and the eastern limit lies possibly a few tens of kilometers east of São Luís town (Fig. 1), since the basement rocks of the Phanerozoic formations show a Neoproterozoic imprint. The south-southwestern boundary of the craton is considered to be the NNW-SSE-trending, sinistral, strike-slip Tentugal Shear Zone (Hasui et al., 1984), which is also visible in remote-sensing imagery and is highlighted by a geophysical discontinuity (Lesquer et al., 1984; Abreu and Lesquer, 1985; Ribeiro, 2002). This boundary is characterized by the gradation from undeformed or weakly foliated tonalites to rocks showing mylonitic fabric. The timing of the establishment of the shear zone is not clear yet, but it is likely that it has been active in the Paleoproterozoic and that it has been reactivated at the end of the Brasiliano/Pan-African cycle (Hasui et al., 1984; Klein and Moura, 2001, 2003). To the north, the Precambrian rocks of the São Luís Craton crop out towards the present-day coastline, where they disappear below the Phanerozoic coastal basins.

Throughout the craton, the structural trends are randomly distributed, in contrast to the strongly linear and elongated pattern displayed by most of the rock bodies to the south in the adjoining Gurupi Belt. Nevertheless, NNE-SSW and WNW-ESE-trending structures are more

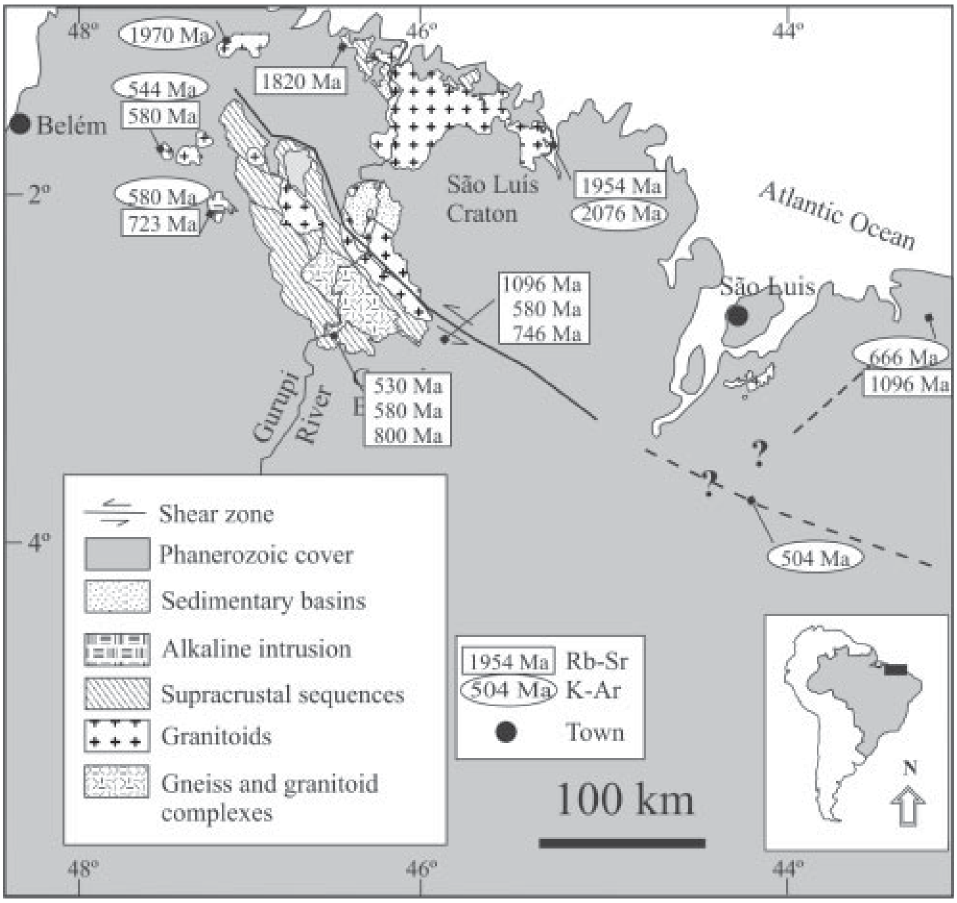

Fig. 1. Location map and simplified geological map of the São Luís Craton and Gurupi Belt, showing also the location of the main previous Rb-Sr and K-Ar data.

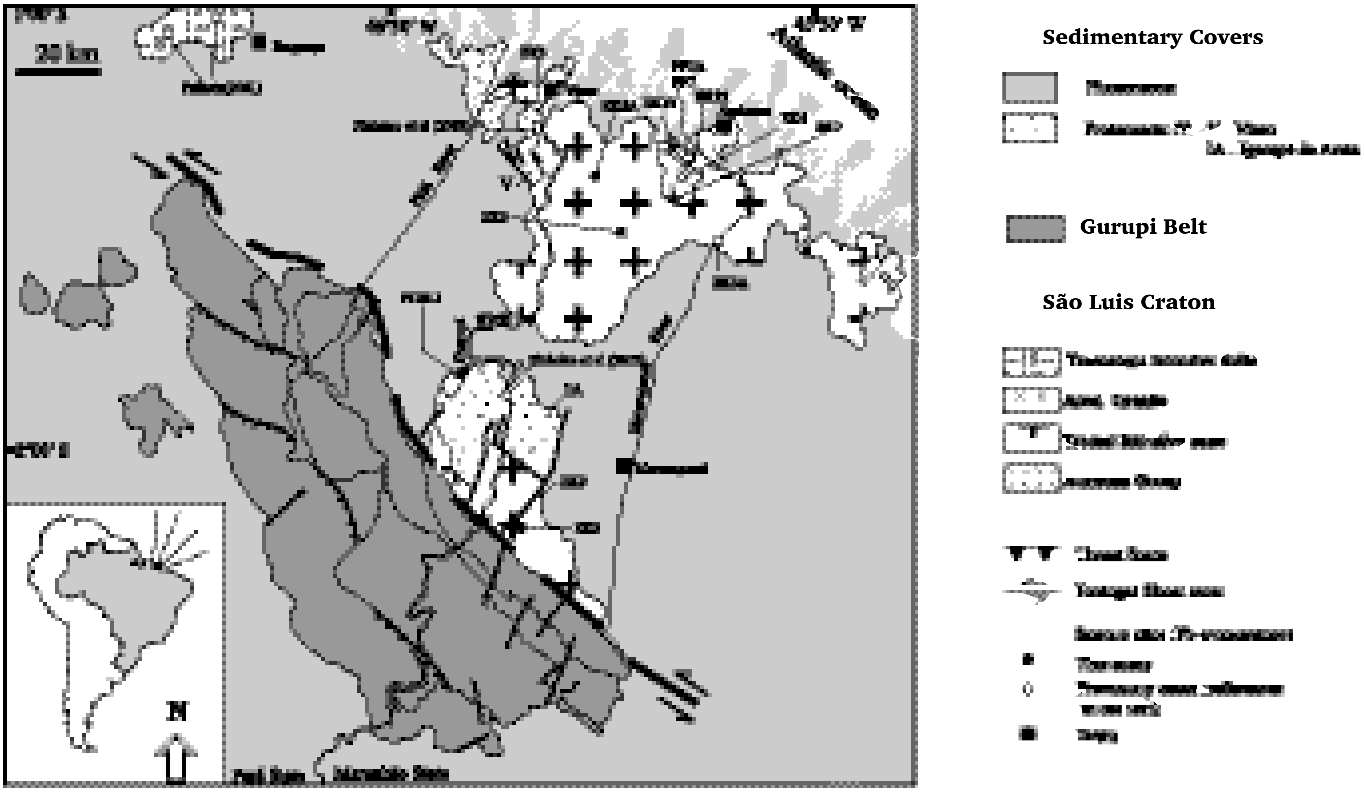

Fig. 2. Simplified geological map of the São Luís Craton in the study area, showing the sites of rocks dated by the single zircon Pb evaporation method in this and in previous studies.

commonly observed. In the field, the main structural element that can be recognized is the regional foliation of the metavolcano-sedimentary sequence, which also overprints part of the granitoids. This foliation strikes variably NE-SW and NW-SE, and dips in general at moderate to high angles. Discrete shear zones, up to a few tens of meters wide and a few kilometers long, are widespread and cross-cut both granitoids and supracrustal rocks. These discrete shear zones are economically important, since they host most, if not all of the known gold deposits and occurrences of the São Luís Craton.

Lithostratigraphy and previous geochronology

The São Luís Craton is composed of a few suites of granitoids with distinct field association, petrography and geochemical characteristics, in addition to a less voluminous metavolcano-sedimentary sequence. These successions are covered by younger sedimentary basins (Figs. 1 and 2). The cratonic lithostratigraphy has been reviewed by Klein and Moura (2001; 2003) and is summarized below.

Schists of variable compositions, metavolcanic and metapyroclastic rocks, as well as subordinate quartzite, metachert and metamafic-ultramafic rocks form the metavolcano-sedimentary succession of the Aurizona Group (Pastana, 1995). This sequence records greenschist facies metamorphism, attaining locally the lower amphibolite facies. The rocks show a well-developed schistosity that strikes N15°–70°W, and dips steeply (>70°) to the NE. Field relationships show that the Areal Granite intruded the supracrustal sequence. To date, only one sample of a metapyroclastic rock has been dated by Pb evaporation in zircon, yielding an age of 2240±5 Ma with inheritance of 2260 Ma (Klein and Moura, 2001).

The Tromaí Intrusive Suite is the largest unit of the craton (Fig. 2), forming composite batholiths of tonalite, trondhjemite, granodiorite and minor monzogranite with variable textural and structural aspects. The rocks are porphyritic to equigranular and either foliated or massive. They show well-preserved primary (igneous) mineralogy and textures, such as zoned plagioclase and granular hypidiomorphic texture, despite late hydrothermal/metamorphic overprint. Field relationships show that the granitoids contain centimeter- to meter-scale, lens-shaped, foliated or not, microgranular enclaves of mafic to dominantly intermediate composition. Single zircon Pb evaporation ages vary between 2149±3 Ma and 2165±2 Ma (Klein and Moura, 2001).

Pastana (1995) and Klein (2004) described the Tromaí Intrusive Suite as metaluminous and sodic rocks, with low to moderate K_2O contents. The rare earth (REE) and other minor and trace element patterns display a calc-alkaline signature. The Tromaí granitoids show also low Rb/Sr and moderate to high Ba/La and Sr/Y ratios, which led Klein (2004) to interpret the Tromaí Intrusive Suite as having characteristics of both calc-alkaline and TTG suites, formed in intra-oceanic island arcs with protoliths derived from the mantle wedge and/or subducted oceanic crust.

Another association of granitoids showing field and petrographic aspects similar to those described for the Tromaí Intrusive Suite crops out near the easternmost boundary of the cratonic area, southeast of São Luís town (Fig. 1). These granitoids were grouped by Rodrigues et al. (1994) in the Rosário Intrusive Suite, and Gorayeb et al. (1999) reported Pb evaporation ages in the 2075–2146 Ma range. Since these ages have been determined using the single filament array of the Pb evaporation method, it is likely that they represent only minimum ages and that their real ages are close to those determined for the Tromaí Intrusive Suite. Sato (1998) provided a Sm-Nd model age (T_{DM}) of 2.1 Ga with εNd(t) of +2.5.

Dacite and rhyodacite occurrences have also been reported and considered as extrusive equivalents of the granitoids of the Tromaí Intrusive Suite (Costa et al., 1977; Pastana, 1995). However, these rocks have never been defined on geological maps, at any scale. In fact, they have been found in the field only as isolated blocks, without visible contact relationships, and locally as dikes that cut across the granitoids. These volcanic rocks differ from the metavolcanic rocks of the Aurizona Group in that they are not metamorphosed and generally undeformed. In places, they show well-preserved volcanic structures and textures, such as magmatic flow and corroded quartz phenochrysts. No geochronological data are available for these rocks, and in this paper they will generically be considered as "volcanic unit".

The Areal Granite is composed of pink-colored syenogranites and monzogranites that are restricted to a single stock that crops out in the northern central portion of the craton, south of Aurizona township (Fig. 2). These granites are porphyritic to equigranular and do not show tectonic deformation, except along discrete (cm-wide) brittle-ductile shear zones. They contain large enclaves of supracrustal rocks, possibly related to the Aurizona Group in which they were intruded. Single zircon Pb evaporation ages of 2149±4 Ma and 2152±3 Ma have been obtained by Klein and Moura (2003). The Areal Granite is also calc-alkaline, but more evolved than the

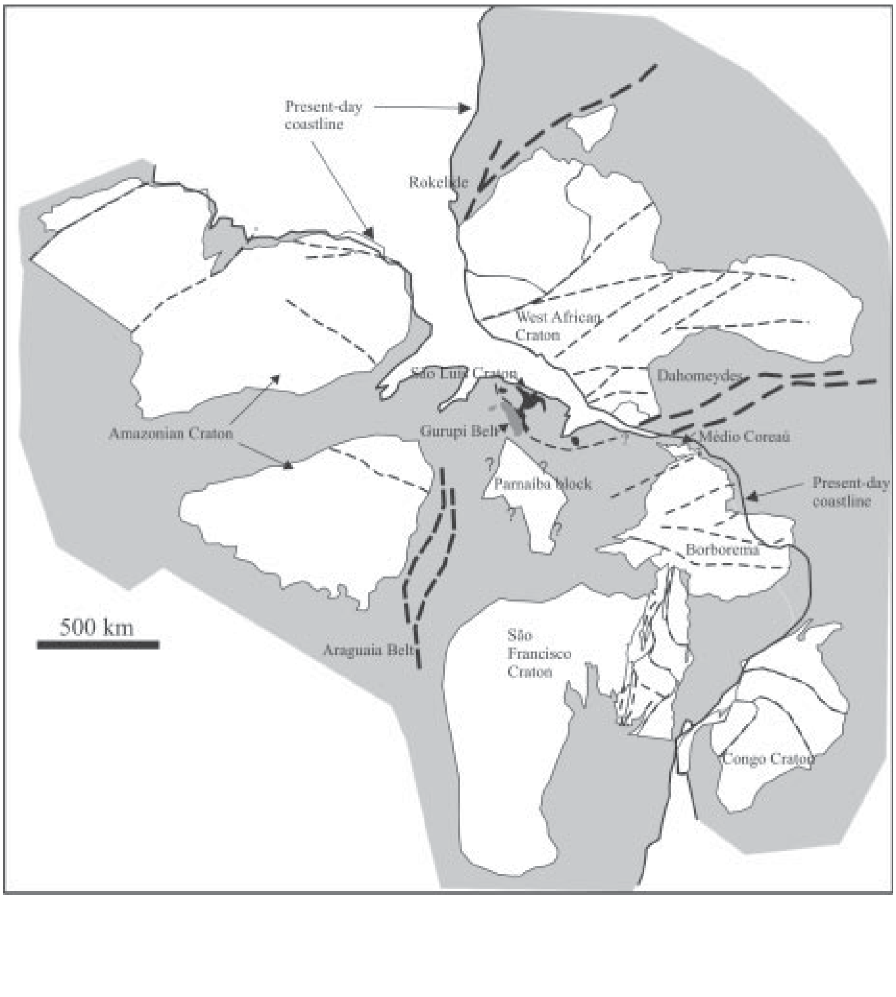

Fig. 3. Sketch map (not a paleogeographic reconstruction) showing the position of the São Luís Craton in relation to major geotectonic units of the South American Platform and western Africa.

Tromaí granitoids, and shows a less fractionated REE pattern with weak Eu anomalies, and higher K_2O, Rb, and Ba contents, in addition to higher Rb/Sr ratios (Pastana, 1995; Klein, 2004).

Two-mica granites, cropping out in the northwestern portion of the area near Bragança (Fig. 2), and containing enclaves of migmatite and supracrustal rocks, were grouped in the Tracuateua Intrusive Suite by Costa (2000). Petrographic and geochemical characteristics point to S-type, strongly peraluminous granitoids, derived from the partial melting of crustal rocks (Lowell, 1985; Costa, 2000). Palheta (2001) presented single zircon Pb evaporation ages of 2086±10 Ma and 2091±5 Ma, and Sm-Nd model ages (T_{DM}) varying between 2.31 and 2.50 Ga, with εNd(t) values ranging from –1.33 to +1.15.

Viseu and Igarapé de Areia are sedimentary formations deposited in small, fault-bounded extensional basins, overlying rocks of the São Luís Craton (Fig. 2). The basins comprise sandstones, arkoses and conglomerates, with subordinate occurrences of pelites, representing continental clastic sediments deposited in semi-arid conditions (Abreu et al., 1980; Pastana, 1995). The rocks are only weakly metamorphosed (sub-greenschist conditions) and show well-preserved sedimentary structures, but large-scale open folds and an incipient subvertical axial plane foliation are present. This foliation strikes variably NW-SE and NE-SW in the Viseu Basin, following the general pattern of the cratonic rocks, and only NW-SE in the Igarapé de Areia Basin (Abreu, 1990), following the structural pattern of the nearby Gurupi Belt. Recent dating of detrital zircons (Pinheiro et al., 2003) showed ages between 1950 and 2170 Ma with a well defined peak around 2100 Ma for the Viseu Formation. For the Igarapé de Areia Formation Pinheiro et al. (2003) determined two age populations: an older population with ages between 2100 and 2160 Ma; and a younger population with ages between 500 and 700 Ma and a well defined peak at 600–650 Ma.

Geochronology and Sm-Nd isotopes

Analytical procedures

All the isotopic ratios were measured in a Finnigan Mat 262 mass spectrometer at the Laboratório de Geologia Isotópica (Pará-Iso) of the Universidade Federal do Pará, Belém, Brazil. Zircons were dated by the Pb evaporation method (Kober, 1986, 1987), using the double filament array, and data were acquired in the dynamic mode using the ion-counting system of the instrument. For each step of evaporation, a step age is calculated from the average of the $^{207}Pb/^{206}Pb$ ratios. When different steps yield similar ages, all are included in the calculation of the crystal age. If distinct crystals furnish similar mean ages, then a mean age is calculated for the sample. Crystals or steps showing lower ages probably reflect Pb loss after crystallization (e.g., Vanderhaeghe et al., 1998) and are not included in sample age calculation. Common Pb corrections were made according to Stacey and Kramers (1975) and only blocks with $^{206}Pb/^{204}Pb$ ratios higher than 2500 were used for age calculations. $^{207}Pb/^{206}Pb$ ratios were corrected for mass fractionation by a factor of 0.12% per a.m.u, given by repeated analysis of the NBS-982 standard, and analytical uncertainties are given at the 2σ level.

For Sm-Nd analysis, rock powders (~100mg) were dissolved in teflon reaction vessels at 220°C for one week in a mixture of $HF+HNO_3$. After evaporation, the separation of Sm and Nd was carried out in two steps. Initially, the REE were separated from other elements by cation exchange chromatography, then, Sm and Nd were separated from the REE by anion exchange chromatography. A mixed ^{150}Nd –^{149}Sm spike was used and the Nd data were normalized to a $^{146}Nd/^{144}Nd$ ratio of 0.7219. During the period of analysis a $^{143}Nd/^{144}Nd$ ratio of 0.511843±12 was obtained for the LaJolla Nd standard. Sm and Nd concentrations for BCR-01 were 6.56 ppm and 28.58 ppm, respectively. Procedural blanks were <110 pg for Sm and <240 pg for Nd. The crustal residence ages were calculated using the values of DePaolo (1988) for the depleted mantle (T_{DM}).

Single zircon Pb evaporation

Four samples of the Tromaí Intrusive Suite (EK5A, EK6A, EK8, and PCSL1) were dated. Sampling locations are displayed in figure 2, and the analytical results are shown in table 1. Sample EK5A is a gray, foliated tonalite. It is composed of sericitized plagioclase, anhedral and interstitial quartz, amphibole showing brownish to greenish pleochroism, and minor K-feldspar. Accessory phases are titanite, zircon, and apatite. The zircon crystals are weakly fractured, pink colored, and prismatic, with rather rounded terminations. They are 0.13 mm to 0.20 mm long and show inclusions of an acicular, transparent mineral, probably apatite. Four zircon crystals yielded ages ranging from 2144 to 2150 Ma, which overlap within uncertainties, and define a mean age of 2147±3 Ma for this sample (Table 1).

The sample EK6A is a greenish, foliated tonalite, containing mafic microgranular enclaves. It is composed of saussuritized plagioclase, quartz, amphibole, biotite and K-feldspar, with minor opaque minerals, epidote, rutile and zircon. The zircon crystals are brownish to yellowish, with a few mineral inclusions, and fractured in their external parts. They form subhedral, prismatic and bipyramidal crystals that range from 0.20 to 0.30 mm in the longest dimension. Four zircon crystals defined a mean age of 2168±4 Ma, varying from 2164 to 2170 Ma in individual crystals (Table 1).

Sample EK8 is a weakly foliated, greenish to yellowish granodiorite, composed of plagioclase, quartz, amphibole and K-feldspar. Euhedral and prismatic zircon grains have a brownish color, and range from 0.22 to 0.33 mm in the longest dimension. Only two zircon crystals yielded suitable Pb signal for analysis and defined a mean age of 2156±10 Ma (Table 1). Despite the small number of analyzed crystals and the larger analytical uncertainty, the $^{206}Pb/^{204}Pb$ ratios are high (Table 1) and the resulting mean age falls into the same range of ages obtained for other samples of the Tromaí Suite, i.e., this age can be considered as significant.

Sample PCSL1 is a tonalite composed of plagioclase, quartz, amphibole, and minor K-feldspar in addition to accessory and alteration phases. It is locally foliated and contains enclaves of mafic rocks. The dated zircon crystals are pinkish to brownish, more or less fractured and prismatic individuals that range from 0.25 to 0.55 mm in the longest dimension. Seven crystals, with individual ages ranging from 2154 Ma to 2164 Ma, defined a mean age of 2160±2 Ma (Table 1).

Sm-Nd isotopes

Sm-Nd isotope compositions were determined in granitoids belonging to the Tromaí Intrusive Suite and Areal Granite, in metavolcanic and metasedimentary rocks of the Aurizona Group, and in a volcanic rock of the volcanic unit (Table 2). Two samples from the Aurizona Group were analyzed. A metamorphosed and foliated dacite, which is spatially associated with the metapyroclastic rock dated at 2240 Ma (Klein and Moura, 2001), show a model age (T_{DM}) of 2.48 Ga and εNd(t) value of +0.8. A quartz-mica schist yielded a T_{DM} age of 2.21 Ga, with εNd(t) of +3.5. Three samples of the Tromaí Intrusive Suite show model ages (T_{DM}) between 2.22 and 2.26 Ga, with slightly positive (about +2) values of εNd(t). The two samples of the Areal Granite show similar T_{DM} values of 2.23 and 2.26 Ga and also positive (about +2) εNd(t) values (Table 2), which are in the same range of values displayed by most of the Tromaí granitoid samples. The undeformed dacite of the volcanic unit shows a Sm-Nd model age (T_{DM}) of 2.42 Ga, with an εNd(t) value of +0.16.

Discussion

The new zircon ages obtained by the Pb evaporation technique for granitoids of the Tromaí Intrusive Suite (2147–2168 Ma) confirmed the same narrow (<20 Ma) range of ages previously obtained for this suite (2149–2165 Ma). The apparent ages obtained by the single zircon evaporation method should be considered as minimum ages, since it is not possible to evaluate the degree of

Table 1. Isotopic data obtained by Pb evaporation on zircon from granitoids of the Tromaí Intrusive Suite.

Zircon	Evap. T (ºC)	No. of ratios	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	2σ	$^{207}Pb/^{206}Pb$*	2σ	Step age (Ma)	Mean age (Ma)
EK5A	tonalite								
1	1500	34	>10000	0.08277	0.00040	0.13389	0.00155	2150±20	
4	1500	78	>10000	0.10616	0.00085	0.13382	0.00033	2149±4	
7	1500	36	>10000	0.09247	0.00040	0.13346	0.00048	2144±6	
13	1500	64	>10000	0.08362	0.00030	0.13351	0.00028	2145±4	2147±3
EK6A	tonalite								
1	1500	36	>10000	0.07921	0.00090	0.13544	0.00047	2170±6	
2	1450	34	5618	0.07011	0.00052	0.13434	0.00042	2164±9	
4	1500	8	8130	0.07912	0.00075	0.13539	0.00173	2169±22	
5	1500	38	>10000	0.07632	0.00034	0.13531	0.00046	2168±6	2168±4
EK8	tonalite								
1	1500	18	>10000	0.15238	0.00089	0.13480	0.00053	2162±7	
3	1550	36	>10000	0.11946	0.00078	0.13402	0.00044	2152±6	2156±10
PCSL1	tonalite								
2	1500	84	>10000	0.09902	0.00025	0.13461	0.00018	2159±2	
	1550	18	>10000	0.11704	0.00081	0.13423	0.00044	2154±6	
3	1500	90	>10000	0.07845	0.00022	0.13492	0.00046	2163±6	
4	1500	78	>10000	0.09450	0.00115	0.13478	0.00025	2161±3	
5	1450	66	9900	0.08487	0.00066	0.13503	0.00043	2165±6	
	1500	88	>10000	0.10046	0.00146	0.13461	0.00021	2159±3	
6	1500	76	>10000	0.08985	0.00065	0.13495	0.00035	2164±4	
7	1500	88	>10000	0.12809	0.00055	0.13449	0.00021	2158±3	
8	1450	12	3185	0.09198	0.00106	0.13468	0.00069	2160±9	
	1500	88	>10000	0.10059	0.00284	0.13477	0.00026	2161±3	2160±2

*corrected ratio (according to Stacey and Kramers, 1975).

Table 2. Whole-rock Sm-Nd isotopic data.

Sample	Rock type	Age* (Ma)	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	2σ (10^{-5})	$^{143}Nd/^{144}Nd$	2σ (10^{-6})	εNd(0)	εNd(t)	T_{DM} (Ga)
Tromaí Intrusive Suite											
EK3A	monzogranite	2163[B]	3.44	20.14	0.10319	3	0.511441	6	–23.35	+2.65	2.22
EK5A	tonalite	2149[A]	2.47	17.24	0.08669	4	0.511180	7	–28.44	+1.94	2.24
EK6A	tonalite	2164[A]	3.04	15.51	0.11851	5	0.511635	11	–19.57	+2.22	2.26
Volcanic unit											
EK12	dacite	2160[D]	2.80	14.92	0.11330	4	0.511457	4	–23.04	+0.16	2.42
Areal Granite											
EK4	monzogranite	2152[C]	3.35	19.36	0.10472	4	0.511450	9	–23.17	+2.27	2.23
EK7	syenogranite	2149[C]	2.40	13.30	0.10899	4	0.511496	5	–22.28	+1.95	2.26
Aurizona Group											
PF1A	metadacite	2240[D]	1.94	8.62	0.13627	7	0.511789	12	–16.56	+0.84	2.48
EK13	schist	2240[D]	2.08	10.24	0.12283	5	0.511727	14	–17.77	+3.51	2.21

*key for zircon ages: [A]this study; [B]Klein and Moura (2001); [C]Klein and Moura (2003); [D]estimated age (see text).

discordance of the dated zircons. Nevertheless, the good reproducibility of step ages in most of the samples indicates that the determined ages are close to the true crystallization ages (see also Vanderhaeghe et al., 1998; Dogherty-Page and Bartlett, 1999). Furthermore, the determined time interval is compatible with the magmatic evolution of an igneous suite such as the Tromaí Intrusive Suite.

The Sm-Nd isotopic data of the granitoid rocks of the Tromaí Intrusive Suite are in the 2.22–2.26 Ga range and show positive εNd values. These results, combined with the crystallization ages, the absence of inherited zircons, and the petrologic characteristics of the granitoids, indicate juvenile, mantle- and/or subducted plate-derived sources for these rocks. The zircon ages and Sm-Nd isotope results for the Areal Granite are in the same range of those presented by the Tromaí Suite. However, the presence of enclaves of supracrustal rocks and the petrologic characteristics suggest that crustal sources have also been involved in the genesis of the Areal magmas. Nevertheless, these sources are most likely of Paleoproterozoic age and not much older than the Areal Granite.

Sm-Nd results of rocks from the metavolcano-sedimentary Aurizona Group showed two different situations. The data indicate that the sources from the clastic sediments were dominantly, if not exclusively, of Paleoproterozoic age. The felsic metavolcanic rock shows an older model age of 2.48 Ga, which is, nevertheless compatible with juvenile sources (see geological evolution below), and is similar to that of the undeformed dacite of the volcanic unit.

Crustal evolution of the São Luís Craton

The results presented in this paper, combined with pre-existing geochronological, isotopic, geochemical and geological information allow us to infer that the São Luís Craton, in its present-day configuration, consists of Paleoproterozoic igneous and metamorphic rocks that formed in at least three (not necessarily unique) well defined periods: ~2240 Ma, 2168–2147 Ma, and 2090 Ma. The data also show that these Paleoproterozoic rocks are mostly (about 90%) derived from juvenile protoliths (Fig. 4). Only very subordinate relics of a remobilized Archean crust have been indicated by Sm-Nd model ages of S-type granites (Palheta, 2001). Archean rocks or inherited Archean ages in Paleoproterozoic rocks have not been identified to date. Juvenile sources are basically the oceanic crust (ophiolites), oceanic plateaus (komatiites) and arc settings (island arc, continental margins) (Condie, 1997). The absence of mafic rocks and the association of juvenile volcano-sedimentary rocks with large masses of also juvenile calc-alkaline/TTG granitoids strongly indicate an intra-oceanic, arc-related subduction setting for the Tromaí Intrusive Suite, Areal Granite and Aurizona Group.

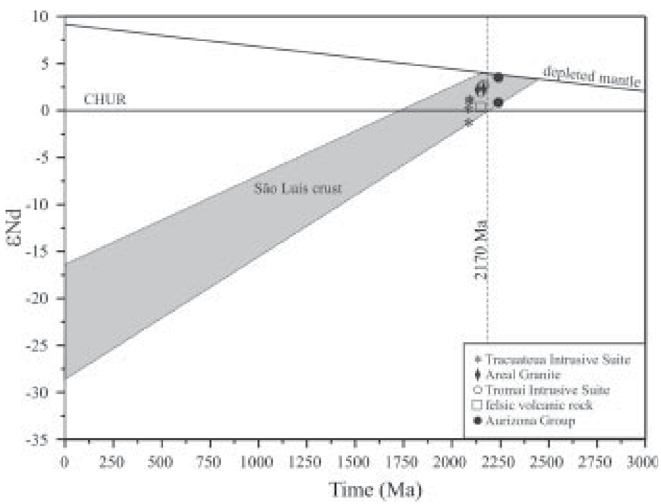

Fig. 4. Nd evolution diagram for rocks from the São Luís Craton.

The combination of zircon geochronology and Sm-Nd isotopic data suggests that the orogenic evolution of the São Luís Craton started sometime before 2240–2260 Ma, which is recorded in zircon ages of a metapyroclastic rock belonging to the Aurizona Group. Furthermore, an ocean basin may have formed approximately at the Archean-Paleoproterozoic boundary and the model ages of the metadacite and dacite (2.48 Ga and 2.42 Ga, respectively) likely record the age of the mafic protoliths (oceanic crust) that formed at that time and that were subsequently melted. Moreover, based on the model age of a sedimentary-derived schist associated with the Aurizona Group (2.21 Ga), it is likely that this supracrustal sequence had a long-lived evolution (until 2.20–2.18 Ga), similarly to what is described for the metavolcano-sedimentary rocks in the southeastern Guyana Shield (e.g., Delor et al., 2003).

Large masses of calc-alkaline/TTG granitoids of the Tromaí Intrusive Suite, related to mantle wedge and/or oceanic plate subduction, were produced between 2168 and 2147 Ma. Despite the lack of geochronological constraints, but based on the data of the metavolcanic rocks of the Gurupi Belt (Klein and Moura, 2001), the felsic to intermediate volcanism (volcanic unit) is probably associated with this period. Field association, geochemistry, age patterns, and Nd isotope evidence all indicate that the Areal Granite formed through the reworking of early phases of the volcano-sedimentary rocks in an arc system, and from parental magmas similar to those that produced the Tromaí granitoids.

Muscovite-bearing granitoids (Tracuateua Suite), produced by melting of pre-existing crustal material, were emplaced at about 2100 Ma, which corresponds to the main period of collision-type plutonism recorded in the Gurupi Belt (Klein and Moura, 2001; Palheta, 2001).

The extensional sedimentary basins (Viseu, Igarapé de Areia) formed in grabens that opened after cratonization. Since Neoproterozoic detrital zircons have been found in the sedimentary rocks of the Igarapé de Areia Basin, this basin formed obviously in the Neoproterozoic/Early Cambrian and is not related with the orogenic evolution of the São Luís Craton. The data of the Viseu basin are not yet conclusive. The sedimentologic, metamorphic and structural similarities that this basin shares with the Igarapé de Areia Basin led Pinheiro et al. (2003) to suggest a correlation between these two basins, despite the absence of Neoproterozoic detrital zircons in the studied samples of the Viseu Formation. This could, however, be explained by the participation only of Paleoproterozoic rock sources, and the weak deformation and anchimetamorphism could be related to distal effects of the Neoproterozoic orogeny that occurred in the Gurupi Belt. Alternatively, Viseu could represent one of the Paleoproterozoic cratonic covers, which are well documented in the Amazonian Craton (see Brito Neves, 2002), with anchimetamorphism and structures being related to the late stage evolution of the São Luís Craton.

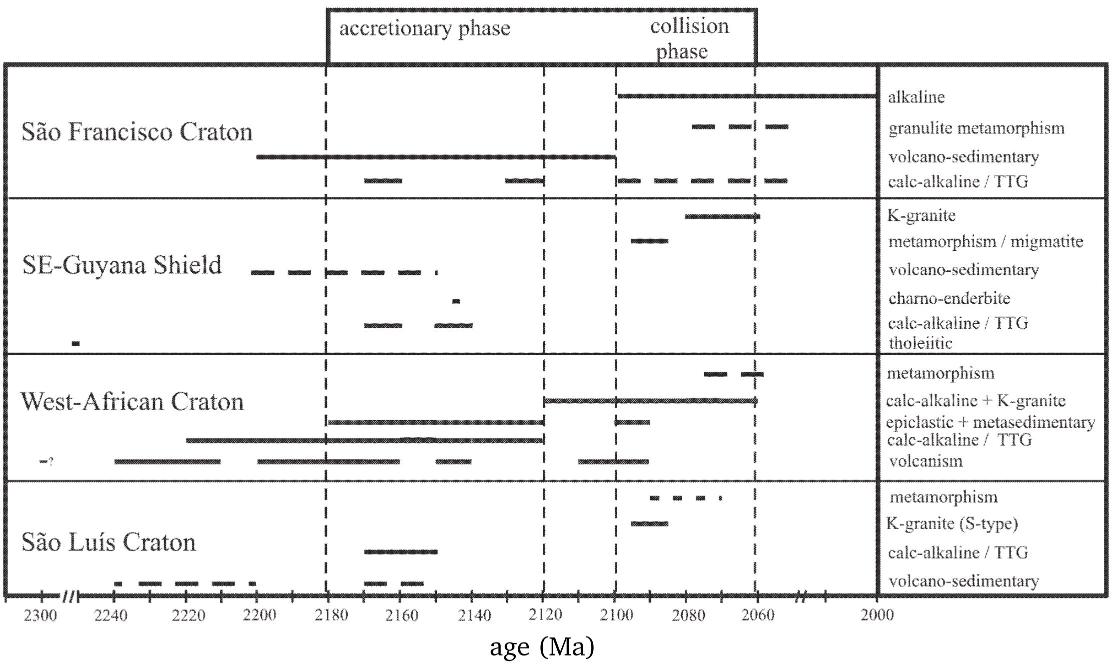

Fig. 5. Diagram comparing the geochronology of the São Luís Craton with that of the main Paleoproterozoic successions of the SE-Guyana Shield, São Francisco Craton, and West-African Craton. References in the text.

Implications for the Paleoproterozoic Orogenies

The São Luís Craton evolved from c.a. 2240 Ma to c.a. 2090 Ma, with the main calc-alkaline activity recorded around 2160 Ma, and subordinate collision-type magmatism at 2090 Ma. The period around 2150–2160 Ma corresponds to important events of crustal growth in the South American platform (Sato and Siga Jr., 2002), whereas the period around 2100–2080 Ma corresponds to the main collisional events in that platform. Both are associated with the widespread Transamazonian cycle of orogenies (cf. Brito Neves, 1999; Hartmann, 2002). In addition to this geochronological coincidence, the rock association, inferred tectonic setting, and geological evolution proposed here for the São Luís Craton are in good agreement with what is described for other Paleoproterozoic domains (Fig. 5), such as the southeastern Guyana Shield (Delor et al., 2003; Rosa-Costa et al., 2003), and part of the northern portion of the São Francisco Craton (Teixeira et al., 2000). The same features are also recognized in the West African Craton (Abouchami et al., 1990; Boehr et al., 1992; Hirdes et al., 1996; Doumbia et al., 1998; Egal et al., 2002; Gasquet et al., 2003) as the Eburnean orogenic cycle. It is possible that all these Paleoproterozoic landmasses have been more or less contiguous, which is in keeping with the idea of the Atlantica supercontinent (Ledru et al., 1994; Rogers, 1996; Hartmann, 2002) that eventually participated in the agglutination of West-Gondwana.

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