CHRONOLOGY OF NEOPROTEROZOIC-CAMBRIAN GRANITIC MAGMATISM IN THE ARAÇUAÍ BELT, EASTERN BRAZIL, BASED ON SINGLE ZIRCON EVAPORATION DATING

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ABSTRACT Granitic magmatism related to the orogenic stages of the Araçuaí Belt took place at 595-575 Ma, and are represented by two distinct suites. One is composed of I-type granitoids and includes the following plutons: Brasilândia (595±3 Ma), São Vitor (576±4 Ma) and Guarataia (574±2 Ma). The other suite comprises S-type granites like the Ataléia (591±5 Ma) and Wolf (582±5 Ma) plutons. After a long period of magmatic quiescence, a batholith composed of the Caladão granite and Padre Paraíso charnockite intruded at 519±2 Ma. This magmatic episode is probably associated to the collapse of the orogen.

Keywords: zircon ages, granitic magmatism, Araçuaí Belt

INTRODUCTION The Araçuaí Belt (eastern Brazil) constitutes the northern branch of a Brasiliano-Pan-African orogenic system that includes the West Congo, Ribeira, Kaoko, Dom Feliciano, Damara, and Gariep belts (*e.g.,* Trompette 1994). The evolution of the Araçuaí Belt includes several episodes of granitic magmatism associated to distinct tectonic stages. We present Pb-Pb evaporation ages of zircons from seven granitic intrusions along a roughly W-E transect in the northern sector of the belt, together with one age of a basement gneiss. These Pb-Pb ages are comparable to available U-Pb ages of similar granites elsewhere in the belt, yielding a rather precise chronology of magmatic and tectonic episodes.

GEOLOGICAL SETTING The Araçuaí Belt basement is exposed in thrust sheets and large parautochtonous metamorphic complexes. The Guanhães Complex (Fig. 1) consists of TTG gneiss and migmatite, granitic-gneiss, and volcano-sedimentary units. Archean units were reworked during the Transamazonian Orogeny (*ca.* 2.1 Ga), and intruded by anorogenic granitic plutons *ca*. 1.7 Ga (*e.g.,* Dossin 1994).

The Salinas Formation and Rio Doce Group (Fig. 1) record the passive margin stage of the Araçuaí basin, mainly comprising distal marine sediments now represented by quartz-mica schist, gneiss, and calc-silicate rock. These sequences and the Capelinha Formation (quartzite and metapelite) host several granitoid intrusions (Fig. 1). Orogenic and post-orogenic granitoid plutons have been grouped into six suites (Pedrosa-Soares *et al.* 1999).

The granitoid suites The G1 suite consists of tonalite and granodiorite, and minor granite, displaying a solid-state tectonic foliation. They are calc-alkaline, metaluminous to slightly peraluminous, I-type granitoids that evolved during pre to syncollisional stages. The Galiléia batholith of the G1 suite yielded a U-Pb crystallization age of 594±6 Ma (Nalini Jr. 1997).

The G2 suite makes up the syncollisional anatetic core of the orogen, and comprises plutons of foliated, S-type, garnet-biotite granites. One example is the Urucum pluton dated at 582±2 Ma (U-Pb age, Nalini 1997). Late to postcollisional magmatism includes the G3-I suite (high-K calc-alkaline, I-type granitoids), and the G3-S suite (peraluminous, S-type leucogranite). U-Pb, Pb-Pb evaporation and Rb-Sr data constrain the evolution of G2 and G3 suites in the interval of *ca.* 590-570 Ma (Siga Jr. 1986, Söllner *et al.* 1991, Nalini 1997, Faria 1997, Dussin *et al*. 1998).

The G4 suite comprises post-tectonic peraluminous granites dated at 530±8 Ma (Basílio 1999). The G5 suite consists of I-type, high-K calc-alkaline granitoids and charnockites that yield a U-Pb age of 513±8 Ma (Söllner *et al.* 1991).

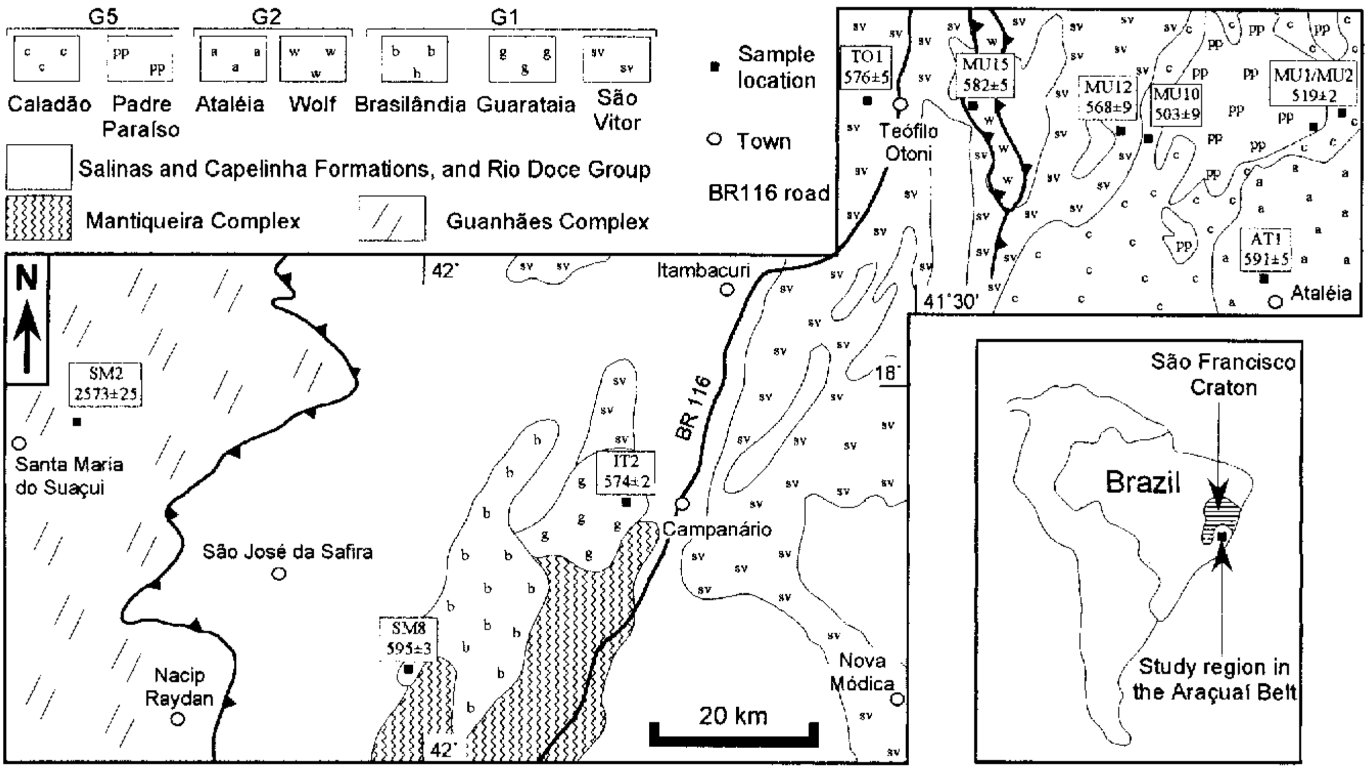

Figure 1 – Geological map of a sector of the Araçuaí Belt, simplified after Moreira (1997), Signorelli (1997), and Silva (1997)

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Pb-Pb ZIRCON GEOCHRONOLOGY Analytical techniques Each sample was collected from a single outcrop and processed by conventional methods of heavy mineral concentration. Zircon crystals were handpicked from the least magnetic fractions. Isotopic analyses were carried out with a Finnigan MAT262 mass spectrometer. Analytical procedures followed the Pb-evaporation technique introduced by Kober (1986). A zircon grain is embedded into the evaporation filament, which is heated to evaporate the Pb, which precipitates on the cold ionization filament. Three evaporation steps of five minutes each are performed at 1450º, 1500º and 1550º C, but for some crystals only lower temperature steps are completed due to low Pb-content. After each evaporation step the temperature of the ionization filament is slowly raised until Pb emission is detected and its isotopic composition measured. The ion counting collector was used for all analyses. Intensities of each Pb isotope are measured in one cycle in the mass sequence 206-207-208-206-207-204, which is repeated for ten cycles defining a block of data. The measured Pb isotopic ratios are corrected for common lead using the model of Stacey and Kramers (1975). Eighteen $^{207}Pb/^{206}Pb$ ratios are measured for each block, and five blocks are usually recorded for each evaporation step. The weighted mean $^{207}Pb/^{206}Pb$ ratio for each block is used for age calculation. Blocks yielding a mean $^{204}Pb/^{206}Pb$ ratio above 0.0004 are eliminated in order to avoid significant errors caused by inaccurate common lead correction. Blocks of data that scatter more than two standard deviations from the average plateau value are also eliminated. A more subjective data treatment is made by means of eliminating blocks, evaporation steps or zircon grains which ages contrast with the average age obtained from the highest temperature evaporation steps, assumed as the best approximation to the actual crystallization age. The calculated age for one zircon grain is the weighted mean and standard error of the accepted blocks of data, and the same is applied to the selected grains of a rock sample in order to determine its age. Isotope ratio uncertainties and age errors are listed at the two-sigma level.

Selected zircons from Brasiliano granitoids were not metamictic and most of them yield fairly constant $^{207}Pb/^{206}Pb$ ratios at different evaporation steps, and for different grains of the same sample. In this case, zircons should fall at or very close to the concordia line, and/or have only been affected by recent lead loss, meaning $^{207}Pb/^{206}Pb$ age can be considered as the age of crystallization. This is also suggested by the fact that similar mean ages were obtained for different rock samples, which would not be expected, in case $^{207}Pb/^{206}Pb$ ages were in fact minimum (or mixing) ages.

Sample description and zircon ages *GUANHÃES COMPLEX ORTHOGNEISS* Orthogneiss makes up large bodies of tonalitic to granitic composition, exhibiting migmatization features (Silva 1997). Sample SM-2b (Fig. 1) was collected from a 5-m thick vein of foliated granite intruded into coarse-grained biotite gneiss. Thin leucosome layers cut both rocks. Two zircon populations were selected for analysis. The first contains two long prismatic, subhedral crystals (1, 2), and the second, four clear and short-prismatic euhedral crystals (3-6). The weighted average of these six zircons gives an age of 2573±25 Ma (*N*=342 ratios; Fig. 2a, Table 1), interpreted as a minimum crystallization age for the granite.

BRASILÂNDIA PLUTON The Brasilândia pluton (Silva 1997) consists of diorite, tonalite, granodiorite and granite, with mafic enclaves. Sample SM-8c (Fig. 1) is a homogeneous foliated tonalite, fine- to medium-grained, cut by thin granite and pegmatite veins. The sample contains a relatively homogeneous zircon population composed mainly of colorless, transparent to translucent and long-prismatic crystals, free of inclusions but with fractures. Three zircons (1-3) were used for age calculation. The eight individual $^{207}Pb/^{206}Pb$ step-ages of these crystals range from 586±5 to 599±4 Ma, and the mean is 595±3 Ma (N=589 ratios; Fig. 2b, Table 1), assumed as the crystallization age of the tonalite. A fourth zircon gives increasing $^{207}Pb/^{206}Pb$ ratios at each step, and the corresponding age for the highest temperature step is 839±9 Ma, indicating the presence of inherited core.

SÃO VITOR PLUTON São Vitor plutons consist mainly of tonalite and granodiorite, with dominant gneissic structure although weakly deformed portions have also been reported (Signorelli 1997). Xenoliths of schist and calc-silicate rock are frequent. Sample TO-1 (Fig. 1) was collected from a large quarry near Teófilo Otoni, consisting of medium-grained biotite gneiss with minor quartz-feldspathic veins. The zircons are euhedral, prismatic (length/width ratios around 3), transparent to translucent, and colorless to light brown. A mean $^{207}Pb/^{206}Pb$ age of 576±5 Ma (*N*=976 ratios) was obtained from the analyses of 5 grains (1-5, and 7). A similar but subhedral crystal must contain inherited Pb and yields step-ages of 696 and 913 Ma.

Sample MU-12 (Fig. 1) is also a medium-grained granitic gneiss. Two short-prismatic, transparent and colorless zircon grains were analyzed (1a, 4b), yielding a mean age of 569±9 Ma (*N*=262 ratios). The mean $^{207}Pb/^{206}Pb$ age calculated for the two samples is 576±4 (Fig. 2c, Table 1), assumed as the crystallization age of the São Vitor intrusion.

GUARATAIA PLUTON The Guarataia pluton (Signorelli 1997) is a small oval-shaped granitic to granodioritic, medium- to fine-grained and weakly foliated intrusion. Sample IT-2a (Fig. 1) is a homogeneous granodiorite displaying equigranular to porphyritic textures. Three distinct zircon grains were selected. Zircon 1 is a yellow and large short-prismatic crystal, subhedral and translucent. Zircon 3 is long prismatic, euhedral, transparent and pale yellow. The six individual $^{207}Pb/^{206}Pb$ step-ages of these two crystals are very constant, ranging from 572±7 to 576±6 Ma, and the mean age is 574±2 Ma (*N*=518 ratios; Fig. 2d, Table 1). A minimum age of 938 Ma was obtained for the fractured, short-prismatic and translucent zircon 2. It must represent an inherited grain.

ATALÉIA PLUTON This pluton is mainly composed of garnet-biotite tonalite, with minor granodiorite and granite. It is strongly foliated and grades into kinzigite gneiss (Moreira 1997). Sample AT-1 (Fig. 1) is a rather homogeneous gneiss with ovoid mafic enclaves. Zircons are grouped into two types, both euhedral, prismatic (with length/width ratios ranging from 2 to 3), and transparent. One is colorless (1, 3, 5) while the other is light brown (2, 4). Four zircons, two of each type, yield a mean age of 591±5 Ma (*N*=570 ratios; Fig. 2e, Table 1). Step-ages for zircon 5 indicated a minimum age of 634 Ma, suggesting the presence of inherited core.

WOLF PLUTON It is a cordierite-garnet-biotite leucogranite (Moreira 1997), bounded by thrust faults. Sample MU-15 (Fig. 1) contains euhedral, prismatic (with length/width ratios ranging from 2 to 3), colorless to pale yellow zircons, some with visible cores. The latter were discarded for analysis. Five zircons (1, 3, 4, 6, 7) yielded a mean $^{207}Pb/^{206}Pb$ age of 582±5 Ma (*N*=710 ratios; Fig. 2f, Table 1).

CALADÃO GRANITE AND PADRE PARAÍSO CHARNOCKITE This batholith comprises megaporphyritic granite and charnockite with magmatic flow structures. The granite (sample MU-1c) is composed of K-feldspar megacrystals in a quartz-feldspar-biotite-hornblende coarse-grained matrix. The charnockite (sample MU-2) has similar texture and is typically dark green. Both samples yielded very few zircons. Zircons from Caladão granite are subhedral, short prismatic, and pink to colorless. A mean $^{207}Pb/^{206}Pb$ age of 520±2 Ma was obtained from the analyses of 4 grains (5-8). Zircons from Padre Paraíso charnockite are similar, but light yellow. One crystal was analyzed (2), and the mean age obtained from the five grains of both rocks is 519±2 Ma (*N*=904 ratios; Fig. 2g, Table 1).

GRANITE VEIN This isotropic fine-grained granite vein (sample MU-10b) cuts the Caladão granite. Zircons are long prismatic, transparent, colorless, with fractures. The mean age calculated for two zircons is 503±9 Ma (*N*=206; Fig. 2h, Table 1).

CONCLUSIONS Three episodes of Neoarchean granitic plutonism have been described in the São Francisco Craton, at *ca.* 2775 Ma, 2710 Ma and 2600 Ma (*e.g.* Noce *et al*. 1998). The Guanhães Complex orthogneiss yield a minimum age of 2573±25 Ma and could be related to the younger episode. This agrees with the suggestion that the Guanhães Complex represents an extension of the São Francisco Craton basement.

Brasilândia (595±3 Ma), São Vitor (576±4 Ma) and Guarataia (575±2 Ma) plutons are part of the G1 suite, while Ataléia (591±5 Ma) and Wolf (582±5 Ma) plutons are included into the G2 suite. These ages agree well with previous U-Pb data for similar rocks. It can be concluded that the main tectono-metamorphic-magmatic event took

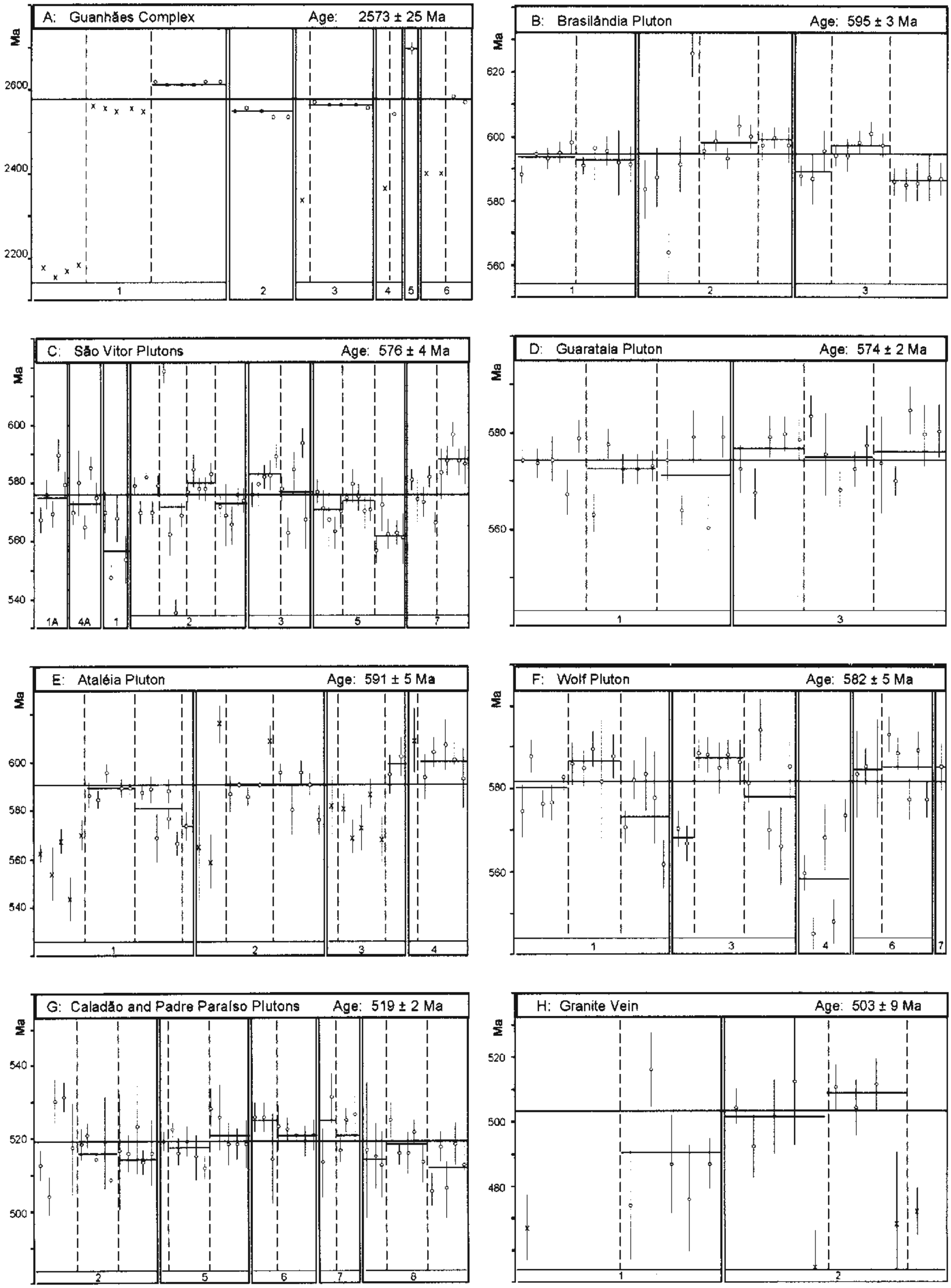

Figure 2 – Heating step versus $^{207}Pb/^{206}Pb$ age diagrams. Numbers at the bottom refer to single zircon grains. Circle: accepted blocks for age calculation; x: rejected blocks.

Table 1 - Data of $^{207}Pb/^{206}Pb$ single zircon Pb evaporation/ionization analysis

Zircon	# of ratios	$^{204}Pb/^{206}Pb$	±2σ	$^{208}Pb/^{206}Pb$	±2σ	$^{207}Pb/^{206}Pb$	±2σ	$(^{207}Pb/^{206}Pb)_c$	±2σ	Age (Ma)	±2σ
Guanhães Complex orthogneiss											
SM2b/1	102/102	0.000021	0.000010	0.06654	0.00062	0.17615	0.00049	0.17590	0.00041	2615	4
SM2b/2	86/86	0.000075	0.000005	0.09440	0.00507	0.16955	0.00119	0.16874	0.00116	2545	12
SM2b/3	86/86	0.000035	0.000002	0.15311	0.00418	0.17093	0.00031	0.17050	0.00030	2563	3
SM2b/4	18/18	0.000044	0.000006	0.10131	0.00118	0.16896	0.00043	0.16841	0.00044	2542	4
SM2b/5	14/14	0.000000	0.000000	0.15928	0.00306	0.18427	0.00356	0.18427	0.00356	2692	32
SM2b/6	36/36	0.000025	0.000004	0.15071	0.00367	0.17252	0.00126	0.17219	0.00134	2579	13
	342/342									2573	25
Brasilândia pluton											
SM8c/1	172/172	0.000010	0.000001	0.09613	0.00184	0.05984	0.00007	0.05970	0.00007	593	3
SM8c/2	191/191	0.000012	0.000003	0.10195	0.00666	0.06012	0.00009	0.05985	0.00008	599	3
SM8c/3	226/226	0.000011	0.000013	0.08859	0.03516	0.05998	0.00024	0.05969	0.00019	593	7
	589/589									595	3
São Vitor pluton											
TO1b/1	70/262	0.000109	0.000015	0.05681	0.00072	0.06025	0.00043	0.05873	0.00030	557	11
TO1b/2	292/292	0.000048	0.000008	0.08330	0.01579	0.06007	0.00017	0.05926	0.00009	577	3
TO1b/3	176/176	0.000008	0.000007	0.04817	0.02210	0.05955	0.00009	0.05941	0.00012	582	4
TO1b/5	268/268	0.000036	0.000042	0.03602	0.02447	0.06024	0.00153	0.05905	0.00021	569	8
TO1b/7	256/292	0.000017	0.000026	0.13772	0.03852	0.05959	0.00019	0.05939	0.00032	582	12
MU12/1a	88/88	0.000022	0.000003	0.17483	0.00061	0.05954	0.00022	0.05920	0.00020	575	7
MU12/4a	86/174	0.000023	0.000006	0.15525	0.00040	0.05950	0.00012	0.05916	0.00022	573	8
	1236/155									576	4
Guarataia pluton											
IT2a/1	256/256	0.000017	0.000011	0.04099	0.03336	0.05939	0.00025	0.05916	0.00007	573	2
IT2a/3	262/262	0.000011	0.000006	0.04546	0.02562	0.05957	0.00030	0.05924	0.00008	576	3
	518/518									574	2
Ataléia pluton											
AT1/1	182/266	0.000017	0.000004	0.09855	0.01977	0.05981	0.00015	0.05956	0.00018	588	6
AT1/2	178/228	0.000039	0.000026	0.13575	0.00291	0.06050	0.00053	0.05964	0.00013	591	5
AT1/3	36/144	0.000034	0.000009	0.15468	0.00056	0.06029	0.00027	0.05987	0.00030	599	11
AT1/4	84/100	0.000160	0.000008	0.11115	0.00050	0.06229	0.00015	0.05993	0.00021	601	8
	480/738									591	5
Wolf pluton											
MU15/1	260/260	0.000019	0.000009	0.02752	0.01846	0.05963	0.00007	0.05940	0.00019	582	7
MU15/3	208/208	0.000025	0.000018	0.03363	0.03872	0.05974	0.00050	0.05937	0.00032	581	12
MU15/4	82/82	0.000022	0.000005	0.05574	0.00023	0.05902	0.00023	0.05876	0.00032	559	12
MU15/6	142/142	0.000023	0.000015	0.02544	0.02621	0.05995	0.00036	0.05949	0.00014	585	5
MU15/7	18/18	0.000066	0.000006	0.11486	0.00069	0.06045	0.00032	0.05949	0.00033	585	12
	710/710									582	5
Padre Paraíso charnockite and Caladão granite											
MU1c/5	184/194	0.000013	0.000008	0.06043	0.00741	0.05796	0.00009	0.05771	0.00007	519	3
MU1c/6	144/144	0.000041	0.000026	0.08407	0.01327	0.05832	0.00040	0.05780	0.00010	522	4
MU1c/7	84/136	0.000004	0.000003	0.14635	0.00268	0.05782	0.00015	0.05777	0.00015	521	6
MU1c/8	224/224	0.000015	0.000025	0.06364	0.01643	0.05835	0.00092	0.05764	0.00011	516	4
MU2/2	268/268	0.000061	0.000075	0.23917	0.01489	0.05828	0.00084	0.05763	0.00009	516	3
	904/966									519	2
Granite vein											
MU10b/1	84/170	0.000262	0.000045	0.16670	0.00046	0.06104	0.00028	0.05696	0.00036	490	14
MU10b/2	122/192	0.000156	0.000107	0.12893	0.02502	0.05993	0.00150	0.05735	0.00020	505	8
	206/362									503	9

place at 595-575 Ma. The G1 suite may represent the root of a continental volcanic arc, while G2 suite was generated by widespread partial melting of sedimentary piles during pre to syncollisional stages (Pedrosa-Soares *et al.* 1999). Tonalitic gneiss dated at 625±11 Ma (Pb-Pb zircon age, Paes 1999) may be related to an initial stage of the magmatic arc.

The ca. 520-500 Ma Caladão and Padre Paraíso plutons, and late veins, of the G5 suite represent the last magmatic episode. This suite originated in the lowermost crust with mantle contributions (Pedrosa-Soares *et al.* 1999). The collapse of the orogen associated with magma underplating provides a suitable model for the late Cambrian magmatism.

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