Within plate, arc, and collisional Neoproterozoic granitic magmatism in the Araxá Group, Southern Brasília belt, Minas Gerais, Brazil

Magmatismo granítico Neoproterozoico de ambientes intraplaca, arco e colisão no Grupo Araxá, Faixa Brasília Meridional, Minas Gerais, Brasil

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ABSTRACT: Three Neoproterozoic granitic episodes associated with the Araxá Group, in Southern Brasília Belt between the cities of Araxá and Cascalho Rico, Minas Gerais State, Brazil, are characterized from the geologic, geochemical, and geochronological points of view. The earliest episode, of 833 Ma, generated in a within-plate environment, is represented by the Quebra Anzol Granite, which has: low $^{87}\text{Sr}/^{86}\text{Sr} = 0.706$ ratios and $\epsilon_{\text{Nd}(833)} = -3.98$; high levels of SiO_2 , Na_2O , MnO , Nb , Y and Co ; and low concentrations of Sr and Ba , with the absence of anorthite and presence of diopside, acmite, and positive Eu anomaly, therefore it may have been originated from mantle sources with small crustal contamination. The second episode, of 790 Ma, is represented by the pre-collisional Monte Carmelo Granitic Complex, which was partially remobilized in a collisional event around 630 Ma. It is metaluminous to peraluminous with low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.706, high light rare earth elements fractionation relative to heavy rare earth elements, and negative Nb , Ta , Sr , P , and Ti anomalies. Their $\epsilon_{\text{Nd}(790)} = -2.218$, with $T_{\text{DM}} = 1.29$ Ga, indicate an origin from juvenile sources and reveal the existence of a late Mesoproterozoic magmatic arc in this region. The last granitic episode has taken place in a collisional tectonic environment between 642 and 630 Ma, generating peraluminous granites with muscovite, garnet, and tourmaline denominated Serra Velha, Tamanduá, Pirapetinga, Galheirinho, Perdizes, Estrela do Sul, and Cascalho Rico. They have negative ϵ_{Nd} , Nd model ages from Neo to Mesoproterozoic, and variable rare Earth elements enrichment patterns, with strong negative Eu anomalies.

KEYWORDS: Southern Brasília Belt; Araxá Group; Neoproterozoic; within plate granites; arc granites; collisional granites.

RESUMO: Três episódios de granitogênese Neoproterozoica associados com o Grupo Araxá, na Faixa Brasília Meridional, são caracterizados geológica, geoquímica e geocronologicamente entre Araxá e Cascalho Rico, em Minas Gerais, no Brasil. O episódio mais antigo, de 833 Ma, gerado em ambiente intraplaca, é representado pelo Granito peralcalino Quebra Anzol, que possui: baixas razões $^{87}\text{Sr}/^{86}\text{Sr}$ de 0,706 e $\epsilon_{\text{Nd}(833)} = -3,98$, com elevados valores de SiO_2 , Na_2O , MnO , Nb , Y e Co e baixas concentrações de Sr e Ba , tendo ausência de anortita e presença de acmita e diopsídio e anomalia Eu positiva, o que indica sua origem a partir de fontes mantélicas com pequena contaminação crustal. O segundo episódio, de 790 Ma, é representado pelo Complexo Granítico Monte Carmelo, que é pré-colisional e parcialmente remobilizado em evento colisional de 630 Ma. É metaluminoso a peraluminoso, com baixas razões $^{87}\text{Sr}/^{86}\text{Sr}$ de 0,706, elevado fracionamento de terras raras leves e anomalias negativas de Nb , Ta , Sr , P e Ti . Seu $\epsilon_{\text{Nd}(790)}$ de -2,218 e sua T_{DM} de 1,29 Ga indicam origem a partir de fontes juvenis do final do Mesoproterozoico, de modo similar à dos granitos do Arco Magmático de Goiás, sendo representante de um arco magmático nesta região. O último episódio ocorreu em contexto colisional, entre 642 e 630 Ma, gerando os granitos peraluminosos com muscovita, granada e turmalina, chamados de Serra Velha, Tamanduá, Pirapetinga, Galheirinho, Perdizes, Estrela do Sul e Cascalho Rico. Possuem ϵ_{Nd} negativos, idades modelos de Nd Neo a Mesoproterozoicas e padrões de enriquecimento de terras raras variáveis, com fortes anomalias negativas de Eu .

PALAVRAS-CHAVE: Faixa Brasília Meridional; Grupo Araxá; Neoproterozoico; granitos intraplaca; granitos de arco; granitos colisionais.

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Manuscrito ID 28703. Recebido em: 28/08/2012. Aprovado em: 12/04/2013

INTRODUCTION

Granitic rocks that are intrusive into quartz-mica schist and amphibolites of the Araxá Group, Southern Brasília Belt (SBB), usually occur between the cities of Araxá and Cascaltho Rico, Minas Gerais State, in Brazil (Fig. 1). The earliest reference to these granites is by Barbosa (1937). After some time, Barbosa *et al.* (1970) drew the attention to the existence of granites and gneisses from the region of Araxá up to Estrela do Sul and Abadia dos Dourados. Hasui and Almeida (1970) performed the first K-Ar dating of granites and metamorphic rocks of this area, while Besang *et al.* (1977) studied the Quebra Anzol and Monte Carmelo granites by Rb-Sr geochronology. Brod *et al.* (1991) described intrusive granites into mica schists and metabasic rocks of Araxá Group near Abadia dos Dourados. The first results related to granites associated with the Araxá Group in its type region were performed by Seer (1999), Seer and Dardenne (2000) and Seer *et al.* (2001). Valeriano *et al.* (2004b) presented the first U-Pb dating of an Araxá granite obtaining the age of 637 Ma, which confirm its relation with the Brasiliano Cycle in the region. Seer *et al.* (2005) detailed the geology, petrography, and geochemistry of intrusive granites into the Araxá Group

in Araxá linking them to collisional magmatism. In 2008, Seer *et al.* reported the first U-Pb dating of Estrela do Sul Granite, whereas in 2010 the preliminary results of geochronological analyses through the U-Pb and Sm-Nd methods of eight granite samples situated between Monte Carmelo and Araxá were presented. In Catalão, Klein (2008), to the North-western area discussed in this work, studied orthogneiss and granite combining U-Pb geochronology and Sm-Nd to the whole-rock chemistry.

These works bring to light an evolutionary scenario for the Neoproterozoic SBB showing two main magmatic peaks, one at ca. 790 Ma and the other at ca. 630 Ma, reinforcing the evidence raised by other authors in the state of Goiás (Pimentel e Fuck 1992, Pimentel *et al.* 1992, 1999a, Laux *et al.* 2005). However, the discovery of Nova Aurora orthogneiss terrain with 1.2 Ga (Klein 2008), in South-eastern Goiás, tectonically placed beside more younger terrains, and within plate granites of 833 Ma in the region of Araxá, reinforces the suggestion that the SBB resulted from the amalgamation of tectonostratigraphic terrains with distinct ages and origins, as suggested by Seer (1999). This work presented and discussed the results of chemical analyses, U-Pb dating and Sm-Nd analyses of granites

Figure 1. Geological map of Southeast portion of the Brasília Belt showing the granitoids in the Araxá Group.

from Araxá Group starting in Araxá to Monte Carmelo and Cascalho Rico regions, on the border of Minas Gerais and Goiás States (Figs. 2 and 3).

REGIONAL GEOLOGY

Between Abadia dos Dourados and Cascalho Rico, the rocks of Araxá Group compose three thrust slices

separated by NW-striking shear zones (Seer *et al.* 2007), as see in Fig. 2. The Western thrust, characterized as upper and that is in tectonic contact with Nova Aurora orthogneisses to the West (Klein 2008), is represented by inter-bedded mafic igneous, ultramafic and clastic sedimentary rocks metamorphosed in amphibolite facies conditions. The lithological types include mica schists including varying proportions of garnet, muscovite, and biotite, with variable amounts of quartz, fine quartzite,

Figure 2. Geological map of Monte Carmelo and Abadia dos Dourados regions with localization of studied samples.

Figure 3. Geological map of the Araxá Nappe region with localization of studied samples.

coarse- and medium-grained amphibolite, garnet amphibolite, serpentinite, talc-chlorite and tremolite-actinolite schists. They are intruded by several pegmatites and granitic rocks, such as the Estrela do Sul and Cascalho Rico granites (Fig. 2). Medium- and coarse-grained amphibolites and amphibole-chlorite schist intruded by pegmatites and granites are predominant in the intermediate thrust. Monte Carmelo Granitic Complex (Fig. 2), with batholithic proportions and that is deformed, is part of this thrust. The Eastern one is the lower thrust and makes contact with chlorite schists of the Ibiá Group to the East.

The Eastern thrust is a volcanosedimentary sequence of Abadia dos Dourados (Brod *et al.* 1991), characterized by intercalations of medium to fine amphibolites (metabasalt chemically similar to oceanic ridge basalts), quartz-mica schist (acid metavolcanic with bi-pyramidal quartz), garnet-quartz-mica schist, carbonaceous schist, quartzite and ferruginous meta-chert, intruded by granites and pegmatites of smaller size and number compared to others. The three tectonic slices represent ophiolitic and magmatic arc terrains dismembered and intruded by granitoids and, although deformed, their rocks are relatively well preserved compared to the Araxá Group in the Araxá Nappe (Simões e Navarro 1996), as seen in Fig. 3.

The granitoids show intense deformation, but are well preserved in the inner portions. In most outcrops a major shallow-dipping foliation was identified, commonly associated with mineral and/or stretching lineation and small isoclinal folds. Kinematic indicators show top-to-the-ESE tectonic transport. A subvertical foliation, related to the development of NW-striking, sinistral transcurrent faults associated with open folds, interfere on the previous structures. The metamorphic and deformational styles in the region of Monte Carmelo are similar to those of the Araxá Nappe (Seer 1999) and to the tectonic compartments of Southeast Goiás (Simões 2005, Klein 2008). In the Araxá Nappe, the sub-horizontal shear deformation and retro-metamorphism, generated during tectonic transport, were more intense, being the individualization of tectonic thrust slices more difficult to identify. Yet, there is a regional zoning, in which ultramafic rocks occur more to the West, and the volcanosedimentary ones farther to the East like in the Monte Carmelo region. Sincollisional granites are predominant in relation to within-plate ones.

ANALYTICAL PROCEDURES

Nine samples of granitic bodies called Quebra Anzol, Pirapetinga, Tamanduá, Galheirinho, Perdizes, Estrela do Sul, Cascalho Rico, following Seer's (1999) nomenclature

(Seer *et al.* 2007, 2008), and Monte Carmelo Granitic Complex (Besang *et al.* 1977, Pereira *et al.* 1983), were examined using the U-Pb and Sm-Nd methods (Tab. 1). The zircon concentrates were extracted by means of gravimetric and magnetic conventional separation techniques and selected by hand picking with binocular microscope. The U-Pb analyzes were performed using the laser ablation inductively coupled plasma mass spectrometry (LA-MC-ICPMS) and the Neptune spectrometer (thermo Finnigan Neptune multi-collector ICPMS) of the Geochronology Laboratory of the University of Brasília, following the method described by Bühren *et al.* (2009). Nine samples of granite were selected for Sm-Nd analyzes in whole-rock, carried out in the same place mentioned, using a mass spectrometer Finnigan MAT262 Multicollector, following the method described by Gioia and Pimentel (2000) and detailed by Della Giustina *et al.* (2011). Model ages were calculated applying the De Paolo's (1981) model. Some samples were also analyzed for major and minor elements in the Acme Analytical Laboratories Ltd. (Canada) in order to complement the data obtained by Seer (1999).

RESULTS

The results of the chemical analyzes are presented in Tab. 2. Sm-Nd outcomes are in Tab. 3 and the U-Pb ones are in Tabs. 4 to 10. For the Quebra Anzol Granite, the FB-113 sample was investigated for its Sm-Nd since it did not possess zircon, while the samples QA-15-1 and QA-15-2 were analyzed only by U-Pb method. Unpublished Sm-Nd analyzes (initiative of professor doctor Reinhard A. Fuck) of a garnet mica schist and a fine amphibolite (metabasalt) from the volcanosedimentary sequence Abadia dos Dourados (AD-40 and AD-46), a coarse metagabbro of the Chapada das Perdizes Complex (AD-13) hosting the Monte Carmelo Granitic Complex, were added in this paper. Each granitic body was separately described.

Quebra Anzol Granite

Quebra Anzol Granite is an elongated and deformed body that occurs in the frontal part of the Araxá Nappe and is associated with significant volume of fine to coarse amphibolites (gabbros to basalts) and meta-chert (Seer 1999), as seen in Figs. 1 and 3. It is equigranular to porphyritic, from light to pinkish grey, with orthoclase phenocrysts up to 2 cm in matrix of quartz, orthoclase and microcline, plagioclase, and biotite. Hornblende, zircon, titanite, and opaque occur as accessories. Albite, sericite, fluorite, chlorite, epidote, carbonate, tourmaline and leucocoxen as secondaries of hydrothermal and/or metamorphic

Table 1. Studied samples with indication of coordinates, modal classification, and analytical procedures

Sample	E coord	N coord	Name/Unit	Modal classification	Chem An	U-Pb	Sm-Nd
FB-15	250258	7867987	Perdizes	sienogranite		x	x
FB-48	245832	7922351	Monte Carmelo	sienogranite	x	x	x
FB-60	247406	7925122	Monte Carmelo	monzogranite	x		
FB-86	231824	7934524	Monte Carmelo	tonalite	x	x	x
FB-98	213621	7951587	Monte Carmelo	granodiorite	x		
FB-106	216088	7925046	Estrêla do Sul	sienogranite	x	x	x
FB-108	195824	7941548	Cascalho Rico	monzogranite	x	x	x
FB-112	273162	7845530	Galheirinho	alkali-granite	x	x	x
FB-113	330434	7832718	Quebra Anzol	granodiorite			x
FB-114	313040	7837435	Pirapetinga	alkali-granite	x	x	x
FB-116	308140	7837435	Tamanduá	sienogranite		x	x
QA-15	329643	7830019	Quebra Anzol	granodiorite		x	
AD-6	239394	7932910	Monte Carmelo	granite			x
AD-12	245334	7952530	Monte Carmelo	granite			x
AD-13	240234	7947520	Chapada Perdizes	amphibolite			x
AD-40	254559	7954837	VSAD	garnet-mica schist			x
AD-46	243538	7955389	VSAD	amphibolite			x
HS-56a	330800	7805600	Quebra Anzol	monzogranite	x		
HS-205a	331200	7805600	Quebra Anzol	alkali-granite	x		
HS-285b	330100	7805700	Quebra Anzol	granite	x		
HS-425a	329200	7806500	Quebra Anzol	alkali-granite	x		
HS-460a	299400	7822500	Serra Velha	monzogranite	x		
HS-486b	300200	7818000	Serra Velha	monzogranite	x	x	

FB samples were analyzed at Acme Laboratories Ltd. and HS ones at the Geochemistry Laboratory at Universidade de Brasília (Seer 1999). U-Pb and Sm-Nd analyses were done in the Geochronology Laboratory at Universidade de Brasília, VSAD: volcano-sedimentary sequence Abadia dos Dourados

origins. Garnet happens as broken xenocrysts, with atoll texture and biotite cores. It contains petrographic facies ranging from granodiorite to monzogranite and alkali-granite (Fig. 4), generally displayed from protomylonitic to mylonitic textures. It features rare mafic microgranular enclaves and has levels of SiO₂ from 73.2 to 74.69% and Al₂O₃ from 11.89 to 12.47%, quite consistent, high Na₂O, K₂O and CaO, including acmite, diopside and normative titanite and absence of anorthite (Tab. 2).

The low values of TiO₂, and high ones of MnO, and variable Na₂O/K₂O ratios from 0.58 to 2.03, high Nb, Y and Co and low Sr, Ba, Cr and V (Figs. 5 and 6) stand out. In the AnxAbxOr diagram, the HS-285b sample plots in the field of trondjemites on the boundary of granodiorites, possibly due to the high Na₂O content and abundant albite, and others in the field of granite (Fig. 7). Two samples have peralkaline character, one is in a transition to metaluminous and the other is metaluminous (Fig. 8). The light rare earth elements (LREE) have low fractionation in relation to the heavy rare earth elements – HREE (La_N/Yb_N = 21.39 to 21.74) and the Eu/Eu* ratio = 1.71, representing slight positive Eu anomaly (Fig. 9). In the multi-element diagram, although some elements have not been analyzed, the higher values of Nb indicate the

absence of subduction zone component (Fig. 10). It is plotted in the field of anorogenic granites in the R1xR2 diagram (Fig. 11) and in that of within plate granites in the Nb_xY diagram (Fig. 12). Based on Barbarin (1999), it may be classified as PAG type (peralkaline and alkaline granite). Four zircon grains from the QA-15-1 sample provided a concordia age of 834 ± 6.1 Ma and, in the QA-15-2 sample, four ones provided 831.9 ± 4.5 Ma (Fig. 13, which was interpreted as an average age of 833 Ma for the body crystallization. Its low ⁸⁷Sr/⁸⁶Sr ratio of 0.706 (Besang *et al.* 1977), ε_{Nd(833)} of -3.98, and geochemical data indicate that it may have been originated from mantle sources with little crustal contamination, although it was affected by post-magmatic hydrothermal alteration and mylonitization.

Monte Carmelo Granitic Complex

Monte Carmelo Granitic Complex comprises a batholith between the cities of Monte Carmelo and Abadia dos Dourados (Figs. 1 and 2). It is associated with large volume of medium to coarse amphibolites (Chapada das Perdizes Complex, Brod *et al.* 1991) and is intensely deformed mainly on its borders. Four significant samples of this batholith were investigated and two were analyzed only for Sm-Nd. In the FB-86 and FB-98, the granites were

Table 2. Chemistry analysis results and calculated normative minerals

Sample	FB - 48	FB - 60	FB - 86	FB - 98	FB - 106	FB - 108	FB - 112	FB - 114	HS- 460a	HS- 486b	HS- 56b	HS- 205a	HS- 285b	HS- 425a
SiO ₂	70.94	69.39	70.41	66.05	72.37	66.45	75.68	70.66	73.98	75.74	74.69	74.60	73.97	73.20
TiO ₂	0.24	0.62	0.36	1.13	0.27	0.87	0.07	0.31	0.16	0.32	0.05	0.06	0.3	0.24
Al ₂ O ₃	15.03	14.81	14.59	15.45	14.15	15.21	13.14	14.6	11.83	12.19	12.4	12.47	11.89	12.08
Fe ₂ O ₃	2.04	3.32	2.58	3.97	1.66	4.27	1.65	2.07	2.22	3.17	0.96	1.10	2.23	2.18
MnO	0.06	0.05	0.06	0.03	0.04	0.05	0.02	0.04	0.05	0.05	0.18	0.18	0.02	0.12
MgO	0.49	0.82	0.81	0.99	0.34	0.97	0.16	0.5	0.57	0.72	0.06	0.10	0.79	0.42
CaO	1.78	1.72	2.85	2.89	1.19	2.36	0.1	0.39	0.63	0.89	0.66	0.33	2.81	0.63
Na ₂ O	3.64	2.54	4.13	3.11	2.75	3.04	1.97	1.25	2.72	2.43	4.81	5.19	3.76	3.41
K ₂ O	4.87	5.12	2.54	3.89	6.05	4.58	5.49	8.35	5.03	4.58	4.26	5.21	1.85	5.79
P ₂ O ₅	0.14	0.24	0.1	0.4	0.14	0.34	0.05	0.32	0.26	0.1	0.03	0.03	0.06	0.12
LOI	0.6	1.1	1.4	1.7	0.9	1.3	1.7	1.3	1.72	1.82	1.0	0.7	1.64	1.1
TOTAL	99.82	99.74	99.85	99.64	99.82	99.42	100	99.75	99.01	99.13	99.01	99.90	99.17	99.10
Rb	197.3	289.4	88.4	180.6	327.2	204.7	562.6	338.9	-	-	-	-	-	-
Ba	871	1216	871	1932	1032	2585	69	1623	59	116	60	15	398	425
Sr	383.1	330.3	440.6	458.5	233.9	1159.9	17.1	223.5	13	79	4	4	177	188
V	25	46	40	56	14	75	8	29	7	18	5	4	30	16
Ni	2.7	3.7	2.2	6.8	1.5	3.8	0.5	1.8	5	2	5	5	12	5
Zr	136.7	318.7	180.6	446.4	191.9	490.2	76.2	177.6	86	116	70	103	135	170
Sc	3	5	3	4	2	4	3	4	-	-	-	-	-	-
Cu	3.5	4.5	2.5	5.1	4.2	20	0.8	1.7	4	5	3	3	6	2
Ce	62.5	161.4	70.6	131.1	116.2	311.4	33.3	122.9	21.13	48.41	-	-	21.21	-
Co	3.6	6.3	6.1	8.1	2.8	8.1	1.7	4.1	77	-	-	113	113	110
Dy	1.26	4.45	1.2	2.73	1.46	2.77	5.58	3.96	4.5	5.26	-	-	1.01	-
Cs	9.2	15	2.3	3.2	22	2.1	16.2	18.9	-	-	-	-	-	-
Er	0.67	1.8	0.68	0.63	0.32	0.96	2.74	1.84	2.98	3.22	-	-	0.89	-
Eu	0.74	1.78	0.72	2.43	1.19	2.25	0.14	1.2	0.29	0.87	-	-	1.04	-
Ga	18.8	23.3	20.4	26.4	22.6	22	20	20.6	-	-	-	-	-	-
Gd	2.28	8.1	1.98	7.09	4.59	7.6	4.15	6.15	3.82	5.46	-	-	2.13	-
Hf	4.2	9.5	5.1	11.9	6	11.8	2.9	6	-	-	-	-	-	-
Ho	0.24	0.69	0.24	0.34	0.16	0.4	0.99	0.68	1.14	1.32	-	-	0.33	-
La	34.7	73.2	41.7	66.3	52.2	160.8	13.9	55.2	5.5	17.94	-	-	9.64	-
Lu	0.06	0.28	0.09	0.04	0.03	0.11	0.31	0.22	0.27	0.44	-	-	0.06	-
Nb	10.4	23	9.8	23.3	16	18.8	11.6	14.2	15	14	187	202	11	62
Nd	21	72.2	22	61.2	51.5	109.4	14.2	53	10.7	23.92	-	-	8.93	-
Pr	6.65	18.87	6.97	15.81	13.31	31.51	4.07	14.16	-	-	-	-	-	-
Sm	3.7	12.27	2.77	9.94	8.28	14.11	4.04	9.22	2.78	4.35	-	-	1.62	-
Sn	9	6	1	1	6	1	12	6	-	-	-	-	-	-
Ta	1	2.5	0.8	1.1	1.7	0.8	2	1.7	-	-	-	-	-	-
Tb	0.33	1.06	0.28	0.85	0.49	0.86	0.92	0.88	-	-	-	-	-	-
Th	13.8	29.7	10.6	17.2	20.7	37.7	15.7	21.8	-	-	-	-	-	-
Tm	0.09	0.31	0.1	0.07	0.04	0.14	0.42	0.28	-	-	-	-	-	-
U	1.9	5.5	0.9	1.5	4.8	1.6	4.6	8.3	-	-	-	-	-	-
W	0.5	1.1	0.5	0.5	0.7	0.5	6.9	1.9	-	-	-	-	-	-
Y	8.2	23.8	8.2	15	6.1	13.9	32.9	23.3	28	31	38	43	4	15
Yb	0.35	2.12	0.58	0.22	0.16	0.66	2.49	1.59	-	-	-	-	0.3	-
q	26.98	30.79	29.63	26.53	30.56	25.7	42.9	30.76	37.44	41.38	29.8	27.69	38.73	29.96
or	28.78	30.26	15.01	22.99	35.75	27.07	32.44	49.34	29.72	27.07	25.17	30.79	10.93	34.22
ab	30.8	21.49	34.95	26.32	23.27	25.72	16.67	10.58	23.02	20.56	40.06	35.13	31.82	28.85
an	7.92	6.96	13.49	11.72	4.99	9.49	0.17	0	1.43	3.76	0	0	10.1	0.55
c	0.87	2.54	0.1	1.83	1.25	1.77	3.89	3.56	1.39	1.86	0	0	0	0
ac	0	0	0	0	0	0	0	0	0	0	0.56	3.18	0	0
di	0	0	0	0	0	0	0	0	0	0	0.32	0.98	1.93	1.11
hy	1.22	2.04	2.02	2.47	0.85	2.42	0.4	1.25	1.42	1.79	0	1.04	1.07	0.53
wo	0	0	0	0	0	0	0	0	0	0	1.11	0.11	0	0
mt	0	0	0	0	0	0	0	0	0	0	0.44	0	0	0
hem	2.04	3.32	2.58	3.97	1.66	4.27	1.65	2.07	2.22	3.17	0.46	0	2.23	2.18
il	0.13	0.11	0.13	0.06	0.09	0.11	0.04	0.09	0.11	0.11	0.09	0.11	0.04	0.26
ru	0.22	0.72	0.37	1.4	0.29	1.04	0.06	0.34	0.13	0.34	0	0	0	0
tn	0	0	0	0	0	0	0	0	0	0	0	0	0.68	0.26
ap	0.32	0	0.23	0.93	0.32	0.79	0.12	0.74	0.6	0.23	0.07	0.07	0.14	0.28
Total	99.28	98.79	98.51	98.21	99.02	98.37	98.34	98.6	97.48	100.3	98.1	99.27	97.67	98.2

Table 3. Sm-Nd isotopic results

Sample	Sm	Nd	$^{143}\text{Nd}/^{144}\text{Nd}$	$^{147}\text{Sm}/^{144}\text{Nd}$	$\epsilon_{(0)}$	$\epsilon_{(T)}$	$T_{DM}(\text{Ga})$
FB-15	1.563	6.105	0.512061	0.1548	-11.25	-10.545	–
FB-48	2.505	15.229	0.511962	0.0994	-13.19	-5.359	1.43
FB-86	2.837	20.085	0.511948	0.0854	-13.46	-2.218	1.29
FB-106	6.079	32.495	0.511922	0.1131	-13.97	-7.224	1.68
FB-108	5.956	35.607	0.511939	0.1011	-13.63	-5.909	1.48
FB-112	3.486	11.764	0.512176	0.1791	-9.02	-7.605	–
FB-113	1.119	3.003	0.512582	0.2252	-1.10	-3.980	–
FB-114	9.183	52.498	0.511805	0.1057	-16.26	-8.934	1.73
FB-116	3.019	16.333	0.511990	0.1117	-12.64	-5.728	1.56
AD-6	3.448	57.436	0.512211	0.0363	-8.32	4.596	0.72
AD-12	8.975	50.78	0.511856	0.1068	-15.0	-8.027	1.68
AD-40	10.40	53.33	0.511716	0.1179	-17.99	-8.931	2.10
AD-13	5.282	24.523	0.512263	0.1302	-7.31	–	1.41
AD-46	3.332	12.490	0.512341	0.1613	-5.05	–	–

Table 4. Representative results of zircon analyses from Quebra Anzol Granite

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
15-1-010-Z08	720	0.06802	3.6	1.2727	4.0	0.13570	1.7	869.1	72.9	833.6	22.5	820.3	13.6	0.67
15-1-015-Z11	689	0.06877	1.4	1.3464	2.4	0.14199	1.9	891.8	27.7	866.0	13.7	855.9	15.5	0.81
15-1-027-Z21	1422	0.06767	3.0	1.3195	4.4	0.14142	3.2	858.5	63.1	854.3	25.5	852.7	25.5	0.72
15-1-026-Z20	9324	0.06567	1.1	1.2485	1.6	0.13788	1.1	796.0	23.2	822.7	8.8	832.7	8.6	0.86
15-2-005-Z03	28151	0.06558	1.0	1.2648	1.4	0.13987	1.0	793.1	21.1	830.1	8.1	843.9	8.1	0.69
15-2-013-Z09	5916	0.06657	0.6	1.2511	2.3	0.13631	2.2	824.3	12.3	823.9	13.0	823.7	17.2	0.97
15-2-020-Z16	6703	0.06639	1.5	1.2531	2.0	0.13690	1.3	818.6	31.2	824.8	11.0	827.1	9.7	0.83
15-2-027-Z21	930	0.06826	2.9	1.3003	3.1	0.13815	1.2	876.5	59.1	845.8	17.8	834.2	9.4	0.38

Table 5. Representative results of zircon analyses from Monte Carmelo Granitic Complex

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
FB 48														
22 Z14	53676	0.06154	1.1	0.7993	0.9	0.09420	0.6	658.0	23.1	596.4	4.0	580.3	3.4	0.62
21 Z13	56593	0.06114	2.1	0.8031	1.7	0.09527	1.3	644.1	44.3	598.6	7.4	586.6	7.2	0.72
09 Z3	100710	0.06079	2.1	0.8135	1.5	0.09706	1.4	631.7	44.2	604.4	7.0	597.2	8.0	0.90
24 Z16	42852	0.06244	1.1	0.8222	1.0	0.09550	0.6	689.3	23.5	609.3	4.4	588.0	3.2	0.48
11 Z5	8588	0.06427	3.2	0.8334	2.9	0.09405	1.2	750.4	65.8	615.5	13.5	579.4	6.7	0.36
20 Z12	7229	0.06208	2.8	0.8438	2.5	0.09858	1.2	676.7	58.7	621.2	11.6	606.1	7.2	0.49
25 Z17	1913	0.06397	4.3	0.8329	3.2	0.09442	2.8	740.7	87.6	615.2	14.8	581.6	15.5	0.86
18 Z10	25920	0.06433	0.9	1.1237	1.4	0.12667	1.0	752.7	18.9	764.7	7.4	768.9	7.5	0.74
04 Z1C	52363	0.06462	0.7	1.1476	1.1	0.12879	0.9	762.1	14.8	776.1	6.2	781.0	6.6	0.73
10 Z4	42786	0.06428	1.1	1.1540	2.7	0.13021	2.4	750.8	23.3	779.1	14.6	789.1	18.2	0.91
12 Z6	41781	0.06255	3.5	1.1588	3.9	0.13435	1.7	693.1	75.4	781.4	21.5	812.6	13.2	0.43
06 Z2C	38436	0.06587	1.0	1.1890	2.5	0.13091	2.3	802.3	21.3	795.5	13.8	793.1	17.0	0.88
15 Z9	17296	0.06611	2.9	1.1944	2.6	0.13103	1.1	809.9	58.6	798.0	14.5	793.8	8.2	0.40
13 Z7	2288	0.06933	1.5	1.2538	1.2	0.13118	0.8	908.4	30.1	825.1	6.8	794.6	6.2	0.64
14 Z8	38901	0.07241	4.0	1.3819	3.7	0.13841	1.5	997.6	79.4	881.3	21.6	835.6	11.9	0.39
19 Z11	41225	0.08135	4.1	1.4743	3.1	0.13143	2.6	1230.0	77.5	919.9	18.4	796.0	19.7	0.86
FB 86														
08 Z4	17241	0.06300	2.0	1.14317	2.1	0.13159	0.8	708.4	41.7	774.0	11.6	797.0	6.3	0.34
31 Z15	22079	0.06394	1.4	1.146681	1.7	0.13006	1.0	739.8	29.1	775.7	9.1	788.2	7.1	0.52
40 Z20	33759	0.06419	1.4	1.154574	1.6	0.13045	0.9	747.9	28.9	779.4	8.8	790.4	6.5	0.45
48 Z24	36004	0.06525	1.4	1.193318	2.0	0.13264	1.5	782.4	28.4	797.5	11.0	802.9	11.1	0.66
03 Z1	17293	0.06853	1.8	1.213215	1.6	0.12840	0.9	884.6	37.3	806.7	8.7	778.7	6.8	0.52
13 Z7	13538	0.06973	2.7	1.24786	2.5	0.12980	0.9	920.3	53.7	822.4	14.0	786.7	6.8	0.32

Table 6. Representative results of zircon analyses from Perdizes Granite

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
40 Z20	48875	0.05796	5.8	0.8244	5.9	0.10317	0.7	528.2	127.5	610.5	26.9	632.9	4.3	0.12
08 Z4	70947	0.06034	3.2	0.8531	3.3	0.10255	0.7	615.7	69.4	626.4	15.3	629.3	4.0	0.20
32 Z16	78955	0.05990	2.2	0.8589	2.4	0.10398	1.0	600.1	47.1	629.5	11.2	637.7	6.1	0.41
04 Z2	49779	0.06138	1.3	0.8679	1.1	0.10255	0.8	652.5	27.8	634.4	5.0	629.4	4.5	0.59
07 Z3	61956	0.06032	0.8	0.8680	2.1	0.10436	1.9	615.0	18.1	634.5	9.7	639.9	11.5	0.92
12 Z6	38875	0.06151	1.1	0.8739	1.0	0.10305	0.6	656.9	24.2	637.7	4.6	632.3	3.6	0.52
39 Z19	74074	0.06074	0.9	0.8867	1.0	0.10589	0.5	629.9	18.3	644.6	4.6	648.8	2.8	0.34
47 Z23	108789	0.06097	0.6	0.8889	1.2	0.10573	1.0	638.3	12.2	645.8	5.7	647.9	6.4	0.79
44 Z22	54830	0.06145	1.1	0.8910	0.9	0.10516	0.7	655.1	23.9	646.9	4.3	644.6	4.1	0.66
31 Z15	77481	0.06166	1.1	0.8913	0.9	0.10484	0.6	662.4	22.6	647.1	4.1	642.7	3.7	0.59
20 Z10	50473	0.06212	1.4	0.8928	1.1	0.10424	0.9	678.3	30.5	647.9	5.4	639.2	5.5	0.72
24 Z12	37472	0.06609	2.7	0.9480	2.5	0.10403	1.0	809.3	55.2	677.1	12.2	638.0	6.1	0.38
43 Z21	6690	0.07309	1.8	1.0482	1.7	0.10401	0.5	1016.4	35.3	728.0	8.7	637.9	3.1	0.21

Table 7. Representative results of zircon analyses from Estrela do Sul Granite

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
06 Z9	56616	0.06224	2.0	0.8313	1.5	0.09687	1.3	682.5	41.7	614.4	6.9	596.0	7.4	0.83
11 Z6	5610	0.05958	0.8	0.8822	1.3	0.10738	1.0	588.4	16.4	642.1	6.1	657.5	6.5	0.78
13 Z8	7028	0.06961	2.9	1.0472	2.3	0.10911	1.9	916.9	59.2	727.5	11.7	667.6	11.8	0.83

Table 8. Representative results of zircon analyses from Cascalho Rico Granite

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
39 Z19	138305	0.06089	1.9262	0.858925	1.5240	0.10231	1.1779	635.4	40.9	629.5	7.1	627.9	7.0	0.76
44 Z22	111231	0.06099	1.3287	0.86334	1.1187	0.10266	0.7166	639.0	28.3	631.9	5.2	630.0	4.3	0.52
45 Z23	80525	0.06095	1.4594	0.865517	1.2073	0.10299	0.8196	637.6	31.1	633.1	5.7	631.9	4.9	0.59
23 Z11	13721	0.06562	1.1190	1.188622	1.3274	0.13137	0.7142	794.4	23.5	795.3	7.3	795.7	5.3	0.41
46 Z24	16340	0.06534	1.2297	1.201305	1.4687	0.13334	0.8031	785.4	25.8	801.2	8.1	806.9	6.1	0.40
24 Z12	22582	0.06748	2.6745	1.213402	2.4226	0.13041	1.1322	852.7	54.6	806.8	13.4	790.2	8.4	0.43
08 Z4	12979	0.06568	5.1510	1.213496	6.0181	0.13399	3.1120	796.3	108.0	806.8	33.5	810.6	23.7	0.51
32 Z16	31901	0.06571	1.6334	1.220105	1.8506	0.13467	0.8699	797.1	34.2	809.8	10.3	814.5	6.7	0.35
16 Z8	19084	0.06760	3.8498	1.238962	3.1559	0.13293	2.2028	856.3	78.0	818.4	17.6	804.6	16.7	0.66
43 Z21	19954	0.09719	3.3654	3.525266	2.4978	0.26308	2.2536	1570.8	61.7	1532.9	19.6	1505.6	30.2	0.91
20 Z10	15192	0.09412	1.2828	3.534071	1.9659	0.27233	1.4897	1510.5	24.2	1534.9	15.6	1552.6	20.6	0.74
04 Z2	27948	0.11475	1.6435	5.214779	1.3197	0.32960	0.9789	1875.9	29.3	1855.0	11.2	1836.4	15.6	0.70
35 Z17	16142	0.12280	1.7893	6.131792	1.5301	0.36215	0.9267	1997.3	31.5	1994.8	13.3	1992.4	15.9	0.52
12 Z6	28341	0.12184	0.8823	6.858978	1.7656	0.40828	1.5294	1983.4	15.7	2093.4	15.6	2207.1	28.6	0.87

Table 9. Representative results of zircon analyses from Galheirinho Granite

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
24 Z12	19441	0.05754	2.7	0.8561	2.9	0.10790	1.0	512.3	59.7	628.0	13.6	660.6	6.3	0.34
15 Z7	42318	0.06073	0.7	0.8595	0.9	0.10264	0.6	629.8	15.6	629.8	4.4	629.8	3.5	0.56
19 Z9	24185	0.06013	0.8	0.8639	1.2	0.10420	0.9	608.2	17.2	632.3	5.5	639.0	5.2	0.72
20 Z10	19202	0.06034	0.8	0.8844	1.1	0.10631	0.6	615.8	18.3	643.4	5.0	651.3	3.9	0.52
23 Z11	36537	0.05982	0.7	0.8855	1.0	0.10737	0.7	597.0	15.3	644.0	4.7	657.4	4.4	0.66
27 Z13	89306	0.06070	0.7	0.9049	1.1	0.10812	0.8	628.6	14.8	654.3	5.2	661.8	5.2	0.73
07 Z3	22394	0.06425	3.5	0.9907	3.0	0.11183	1.9	749.8	72.9	699.1	15.0	683.4	12.1	0.61
08 Z4	77375	0.06293	1.2	1.0546	3.4	0.12155	3.2	705.8	26.2	731.2	17.9	739.5	22.4	0.92

Table 10. Representative results of zircon analyses from Pirapetinga Granite

Sample	6/4	7/6	1s(%)	7/5	1s(%)	6/8	1s(%)	Age 7/6	1s(My)	Age 7/5	1s(My)	Age 6/8	1s(My)	Rho
25 Z14	3057	0.06451	0.7	0.2088	2.4	0.02347	2.3	758.5	14.5	192.5	4.2	149.6	3.4	0.96
47 Z25	12877	0.07352	0.7	0.4180	4.0	0.04124	4.0	1028.2	13.5	354.6	12.1	260.5	10.2	0.99
23 Z12	303	0.14080	1.6	0.4234	3.6	0.02181	3.3	2237.1	27.6	358.5	11.0	139.1	4.5	0.90
32 Z19	65157	0.06610	0.7	0.4524	9.7	0.04964	9.6	809.5	14.5	379.0	30.6	312.3	29.4	1.00
39Z21B	17933	0.07300	1.8	0.4954	2.8	0.04922	2.2	1013.9	37.0	408.6	9.5	309.7	6.5	0.76
07 Z3	20613	0.06836	0.5	0.5128	4.4	0.05441	4.3	879.5	10.7	420.4	15.0	341.5	14.4	1.00
12 Z6	578	0.07125	1.9	0.5143	8.2	0.05235	8.0	964.6	39.5	421.3	28.4	328.9	25.7	0.97
48 Z26	54085	0.06742	1.3	0.8504	5.0	0.09149	4.8	850.6	26.4	624.9	23.2	564.3	26.0	0.96
19 Z10	344898	0.15969	3.5	0.8685	11.7	0.03945	11.2	2452.3	58.7	634.8	55.4	249.4	27.4	0.96
14 Z8	45750	0.07420	0.8	0.8935	3.5	0.08733	3.4	1047.0	15.8	648.3	16.8	539.7	17.7	0.97
46 Z24	128630	0.06663	0.6	0.9635	1.6	0.10488	1.5	826.1	12.2	685.1	7.9	642.9	9.0	0.94
13 Z7	29856	0.06771	0.7	0.9763	2.6	0.10458	2.6	859.6	14.3	691.7	13.3	641.2	15.6	0.97
24 Z13	380121	0.07402	0.5	0.9814	1.1	0.09616	1.0	1042.1	11.1	694.3	5.6	591.9	5.5	0.86
40Z21N	120951	0.06330	0.6	0.9951	1.5	0.11402	1.4	718.2	13.0	701.3	7.6	696.1	9.0	0.93
41Z22B	89110	0.07946	1.4	0.9990	2.0	0.09119	1.5	1183.5	27.6	703.3	10.2	562.6	7.8	0.72
42Z22N	89357	0.06676	0.6	1.0043	1.8	0.10910	1.6	830.4	13.4	706.0	8.9	667.5	10.3	0.91
05 Z1	75737	0.06533	0.6	1.0087	1.3	0.11198	1.2	785.0	11.6	708.2	6.7	684.2	7.7	0.92
45 Z23	295659	0.10013	1.5	1.0095	3.2	0.07312	2.8	1626.6	27.5	708.6	16.1	454.9	12.2	0.89
06 Z2	237508	0.06814	0.5	1.0224	0.9	0.10882	0.8	872.9	9.9	715.1	4.8	665.9	5.1	0.86
11 Z5	267655	0.08099	1.1	1.0769	2.9	0.09644	2.7	1221.3	21.6	742.1	15.4	593.5	15.4	0.93
30 Z17	68643	0.06707	3.5	1.0840	5.5	0.11722	4.2	839.8	73.9	745.6	28.9	714.6	28.1	0.76
08 Z4	93332	0.06649	0.8	1.1114	2.3	0.12123	2.2	821.8	16.1	758.9	12.5	737.7	15.4	0.93
26 Z15	3893	0.08077	2.2	1.1268	3.7	0.10118	2.9	1215.8	43.3	766.2	19.8	621.3	17.4	0.79
31 Z18	83813	0.06590	0.5	1.1313	1.7	0.12452	1.6	803.1	11.3	768.4	9.1	756.5	11.4	0.96
20 Z11	52554	0.06977	0.9	1.1586	2.4	0.12044	2.3	921.7	19.0	781.3	13.3	733.1	15.7	0.92
29 Z16	59290	0.06477	0.6	1.1704	1.5	0.13106	1.4	766.8	12.0	786.8	8.2	793.9	10.3	0.93
18 Z9	150863	0.06477	0.6	1.2635	1.7	0.14148	1.6	766.9	12.8	829.5	9.4	853.0	12.4	0.94

equigranular, fine to medium light grey and slightly deformed, consisting of quartz, orthoclase, plagioclase, biotite, titanite, apatite, and zircon with epidote and sericite as secondary minerals formed over feldspars. This fact indicates hydrothermal alteration. They are classified as tonalite and granodiorite.

However, in the FB-48 and FB-60 samples, the granites have porphyritic and equigranular textures and besides the mentioned minerals, they also present muscovite and garnet being classified as syenogranite and monzogranite respectively (Fig. 4). Chemically, the two groups have notable differences, being more evident the high levels of TiO_2 , CaO, MgO, Ni and Zr in the FB-98 sample and high CaO and MgO in the FB-86 (Figs. 5 and 6). Ta and Rb are high in FB-60 and Cr in the FB-48. All present normative corundum that is lower in the FB-86, whose alumina saturation index is of 0.99 being, therefore, metaluminous, and the others peraluminous (Fig. 8). The $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios are higher than one in FB-86, and smaller than one in the others. In the AnxAbxOr diagram they are classified as granodiorite and granite (Fig. 7). The LREE have a high fractionation compared to HREE ($\text{La}_N/\text{Yb}_N = 67.02$ and 203.68) in the samples FB-86 and

Figure 4. Modal QAP diagram for granitoids from Araxá Group.

FB-98, and lower ones in FB-60 and FB-48 ($\text{La}_N/\text{Yb}_N = 23.28$ to 48.56). The Eu/Eu^* ratios range from 0.88 to

Figure 5. Bivariate oxide-oxide major element plots for the granitoids from Araxá Group. Simbology at Fig. 4.

0.94 in FB-98 and FB-86, and from 0.54 to 0.78 in FB-60 and FB-48. Therefore, only the FB-60 sample presents slight negative Eu anomaly (Fig. 9). FB-98 stands out with the highest fractions of LREE in relation to HREE. In the multi-element diagram, all samples have subduction zone component (negative anomalies of Nb and Ta) and present

negative anomalies of Sr, P and Ti (Fig. 10). The similarity between the curves in the FB-48 and FB-86 samples is remarkable, and they plot in the field of collisional granites in the R1xR2 diagram (Fig. 11); collisional granites and volcanic arc in the NbX/Y (Fig. 12); collisional granite and volcanic arc in the RbX/Y+Nb (Fig. 14); and volcanic arc

Figure 6. Bivariate oxide-oxide minor and trace element plots for the granitoids from Araxá Group. Simbology at Fig. 4.

Figure 7. Or:Ab:Na diagram for Araxá Group granitoids (adapted from Barker 1979 *apud* Rollinson 1993). Simbology at Fig. 4.

Figure 8. Shand Index (Maniar & Piccoli 1989) for granitoids from Araxá Group. Simbology at Fig. 4.

Figure 9. Rare earth elements patterns for Araxá Group granitoids. Normalization based on Sun and McDonough (1989) *apud* Rollinson (1993). Simbology at Fig. 4.

Figure 10. Spider diagrams for Araxá Group granitoids. Normalization based on Thompson (1982) *apud* Rollinson (1993). Simbology at Fig. 4.

Figure 11. R1xR2 diagram (Batchelor & Bowden 1985) for Araxá Group granitoids. Simbology at Fig. 4.

granites in the Hf/Rb/30x3Ta one (Fig. 15). They are similar to the I and III granite types in the Rb/Zr/SiO₂ and TaxNb diagrams (Figs. 16 and 17).

The FB-60 sample plots in the transition to the second granites type. They are, therefore, collisional granites

Figure 12. Nb/Y tectonic discriminant diagram (Pearce *et al.* 1984) for some Araxá Group granitoids. Simbology at Fig. 4.

originated by the melting of volcanic arc rocks. FB-86 and FB-98 samples instead suggest an origin in the pre-collisional volcanic arc as shown in the mentioned diagrams.

Figure 13. Rb/Y + Nb tectonic discriminant diagram (Pearce *et al.* 1984) for some Araxá Group granitoids. Simbology as Fig. 4.

Figure 14. Hf x Rb/30 x 3Ta tectonic discriminant diagram (Harris *et al.* 1986) for some Araxá Group granitoids. Simbology at Fig. 4.

Figure 15. Rb/Zr x SiO₂ tectonic discriminant diagram (Harris *et al.* 1986) for some Araxá Group granitoids. Simbology at Fig. 4 and fields like Fig. 14.

Figure 16. TaxNb tectonic discriminant diagram (Harris *et al.* 1986) for some Araxá Group granitoids. Simbology as Fig. 4 and fields like Fig. 14.

Figure 17. Concordia diagram for Quebra Anzol Granite.

The FB-48 sample has zircon grains with much loss of lead, probably that happened during the transport of nappes. Nevertheless, it is possible to identify two populations. The most reliable result is the age of 6/8 of 586 ± 22 Ma and inheritance nearly 790 Ma (Fig. 18). The crystallization age should be around 630 Ma, and the inheritance may be from the granites of 790 Ma. Its $\epsilon_{\text{Nd}(630)}$ is of -5.359 and its T_{DM} of 1.43 Ga, indicating reworking of crustal sources. The FB-86 sample seems to have incorporation of lead, as the majority (20 out of 26) of the grains present high ratios of $^{206}\text{Pb}/^{204}\text{Pb}$, not being useful for the age calculation. Other six grains are of about 790 Ma, by Tera-Wasserburg's method (Fig. 19), and the average is of 6/8, which is interpreted as the time of body crystallization. Its $\epsilon_{\text{Nd}(790)}$ is -2.218 and its T_{DM} is 1.29 Ga. This shows an origin from juvenile sources at the end of the Mesoproterozoic period. In the $\epsilon_{\text{Nd}(790)} \times T$ diagram (Fig. 20), the evolution curve of Nd is similar to the granites of the Goiás Magmatic Arc. Two samples were investigated for Sm-Nd: AD-06 is a porphyritic light grey, slightly deformed granite, with K-feldspar, quartz and biotite, with $\epsilon_{\text{Nd}(630)}$ of 4.596 and 0.72 Ga for T_{DM} , while AD-12 is a porphyritic, coarse, deformed granite, with K-feldspar, quartz, biotite and accessory muscovite with garnet of up to 1 mm. Its $\epsilon_{\text{Nd}(630)}$ is -8.027 and its T_{DM} is 1.68 Ga. Besides these data, Besang *et al.* (1977) obtained low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.706 for this batholith.

Perdizes Granite

The Perdizes Granite is a NW elongated granitic body that occurs to the NW of the city of Perdizes (Figs. 1 and 3). It is intruded in garnet-mica-quartz schist and amphibolite and displays pegmatitic facies with quartz, muscovite, K-feldspar, and tourmaline. It is porphyritic with K-feldspar phenocrysts of up to 3 cm, from medium to pegmatitic, white, very deformed, with quartz (20.43%), orthoclase and microcline (67.88%), plagioclase (11.68%), and rare muscovite. Garnet and zircon act as accessories, and the epidote happens secondarily. This Granite is classified as syenogranite, and presents very bad metamictic zircons. There is one concordant grain of about 680 Ma, but the most reliable age of crystallisation is an average of the 6/8 ages 642 ± 59 Ma (Fig. 21). Regarding the Nd, it has a very high $^{147}\text{Sm}/^{144}\text{Nd}$ ratio, therefore it is not possible to calculate its T_{DM} age. However, its $\epsilon_{\text{Nd}(642)}$ is -10.535, indicating an origin by melting of crustal sources.

Estrela do Sul Granite

Estrela do Sul Granite is a small elliptical granitic body in Estrela do Sul (Figs. 1 and 2). It is intruded in garnet-mica-quartz and amphibolite and talc-amphibole schists, in which pegmatites were seen. It is deformed at the edges

Figure 18. (A) Means of 6/8 ages ($^{206}\text{Pb}/^{238}\text{U}$) for the FB-48 sample from Monte Carmelo Granitic Complex; (B) Diagram represents crystallization age and (C) represents influence of the collisional episode.

and well preserved from deformation in the inner portions. An equigranular facies predominates, which is light grey, from fine to medium, with quartz, orthoclase and microcline, oligoclase, biotite, muscovite, and opaques and as accessories, zircon (two populations, one of prismatic and clear

crystals and another of rounded and clear crystals), apatite, garnet and tourmaline and secondarily sericite, epidote, and carbonate. It can be classified as syenogranite, and has monzogranitic and alkali granite facies (Fig. 4). It plots in the granite field in the AnxAbxOr diagram (Fig. 7), being rich in Rb and Cs and depleted of Nb and Y (Fig. 6). Estrela do Sul Granite displays $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio of 0.487 and normative corundum, having a peraluminous character (Fig. 8). Its strong fractionation between the LREE and HREE is represented by the La_N/Yb_N ratio = 221.55 (Fig. 9). Its Eu/Eu^* ratio = 0.59 shows a weak Eu anomaly.

In a multi-element diagram (Fig. 10), it has a subduction zone component and negative anomalies of Sr, P, and Ti like the Monte Carmelo Granitic Complex samples. It plots in the field of the collisional granites in the R1xR2 (Fig. 11) and RbxY+Nb diagrams (Fig. 14). In Nb x Y (Fig. 12), it plots in the fields of the collisional and volcanic arc granites and in the $\text{Hf x Rb}/30\text{xTa}$ diagram (Fig. 15), on the boundary among the fields of collisional and post-collisional granites.

According to Barbarin's classification, in 1999, this can be named peraluminous muscovite granite (MPG). It is on the boundaries among the I, II, and III granites (Fig. 16) in the $\text{Rb}/\text{Zr x SiO}_2$ diagram, and in the field of type II granites (Fig. 17) in the TaxNb . It presents many zircon grains (11/24) with high levels of common lead ($^{206}\text{Pb}/^{204}\text{Pb}$) and another seven ones with Pb loss. Only six grains were used to determine a concordia age of 632.4 ± 3.4 Ma (Fig. 22), interpreted as the time of crystallization of this body. Its $\epsilon_{\text{Nd}(632)}$ is -7.224 and its T_{DM} is 1.68 Ga, indicating an origin by the reworking of Mesoproterozoic crustal sources. Muscovite of this granite dated using the K-Ar method (Hasui & Almeida 1970) provided the age of 615 ± 1 Ma, which is seen as the cooling age of mica and is consistent with the age of crystallization and cooling of the body.

Cascalho Rico Granite

Cascalho Rico Granite is near the Cascalho Rico town (Figs. 1 and 2), forming an irregular body of small dimensions associated with Goiandira gneisses (Klein 2008). It is equigranular, medium, grey, with quartz, orthoclase, plagioclase, and biotite. Zircon, apatite, and ilmenite act as accessories, and albite and muscovite are secondary. It is a syenogranite in the QAP diagram, where Q is quartz; A is alkaline feldspar; and P is plagioclase (Fig. 4). It has $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio of 0.663 and high values of MgO, Sr, Th, V, Zr and Ba (Figs. 5 and 6). In the AnxAbxOr diagram, it plots in the field of the granites (Fig. 7), has normative corundum, and it is peraluminous (Fig. 8).

Cascalho Rico Granite shows strong fractionation between the LREE and HREE, reaching $\text{La}_N/\text{Yb}_N = 164.14$

Figure 19. Tera-Wasserburg's diagram for FB-86 sample of Monte Carmelo Granitic Complex and mean of 6/8 ages.

and Eu/Eu^* ratio = 0.66, with weak negative Eu anomaly (Fig. 9). In the multi-element diagram, it has subduction zone component and negative anomalies of Sr, Ti and P, which are similar to the Estrela do Sul Granite (Fig. 10). This plots in the field of collisional granites in the R1xR2

(Fig. 11) diagram, collisional granites and volcanic arc in the Nb_xY one (Fig. 12), and in the volcanic arc granites in the Rb_xY+Nb (Fig. 14) and Hf_xRb/30x3Ta diagrams (Fig. 15). In the Rb/Zr_xSiO₂ and TaxNb diagrams, it plots in the field of types I and III granites (Figs. 16 and 17). Most zircon grains from the FB-108 sample have very low 6/4 ratios, and other very discordant ones. The most reliable age is obtained from the average of 6/8 in three grains with 633 ± 58 Ma, given its probable age of crystallization (Fig. 23). It displays T_{DM} of 1.48 Ga and $\epsilon_{Nd(633)}$ of -5.909, interpreted as a body originated by the melting of Mesoproterozoic crustal sources.

Galheirinho Granite

Galheirinho Granite outcrops badly on the BR-452 highway, between the towns of Araxá and Perdizes (Figs. 1 and 3), forming an irregular body with small dimensions, intruded in garnet-mica-quartz schist and amphibolite. This is equigranular, fine to medium, light grey, deformed, with quartz, orthoclase and microcline, plagioclase, biotite,

and muscovite and zircon, apatite, garnet, and tourmaline as accessories. From the modal point of view, it is an alkali granite (Fig. 4). Its low TiO₂, CaO, MgO, P₂O₅, Sr and Ba values are remarkable, with high Rb and Y (Figs. 5 and 6). Its Na₂O/K₂O ratio is equal to 0.358, which demonstrates the high level of K₂O in relation to Na₂O, and the normative corundum value is the highest among the studied granites, having strong peraluminous character (Fig. 8). In the AnxAbxOr diagram, Galheirinho is classified as granite (Fig. 7). It has smooth pattern of LREE in relation to the HREE with La_N/Yb_N ratio = 3.76 and Eu/Eu* ratio = 0.1, indicating strong negative Eu anomaly (Fig. 9).

In the multi-element diagram, strong negative anomalies of Ba, Nb, Sr, P and Ti are seen (Fig. 10). It plots in the field of collisional granites in the R1xR2 (Fig. 11), Rb_xY+Nb (Fig. 14) and Hf x R/30 Tax3 diagrams (Fig. 15), collisional granites and volcanic arc in the Nb_xY diagram (Fig. 12) and in the Rb/Zr_xSiO₂ and TaxNb diagrams plots in the field of type II granites (Figs. 16 and 17). According to Barbarin's classification, in 1999, it can be called MPG. Some zircon grains of the FB-112 sample

Figure 20. Epsilon Nd_t vs T evolution diagram for granitoids and a garnet-mica schist from Araxá Group (Goiás Magmatic Arc after Pimentel & Fuck 1992), Goiás Archean Gneisses and Paleoproterozoic São Francisco Craton after Pimentel et al. 1996, Goiandira and Ipameri orthogneisses after Klein (2008).

Figure 22. Concordia diagram for six zircon grains from Estrela do Sul Granite.

Figure 21. Mean of 6/8 ages for five zircon grains from Perdizes Granite.

Figure 23. Mean of 6/8 ages ($^{206}\text{Pb}/^{238}\text{U}$) for three zircon grains from Cascalho Rico Granite.

have high common Pb. However, four ones show a good concordia age of 631 ± 3 Ma (Fig. 24), which indicates the crystallization time of this body. Several zircon grains show Paleoproterozoic inheritance (1836.4 and 2207.1 Ma), Mesoproterozoic (1505.6 and 1552.6 Ma), and Neoproterozoic (~ 800 Ma), being the latter the most significant one. The $^{147}\text{Sm}/^{144}\text{Nd}$ ratio is quite high not making it possible to calculate a model age. Its $\epsilon_{\text{Nd}(631)}$ is -7.605 indicating reworking of crustal sources. Among the bodies investigated, this is the one that shows the oldest heritages.

Pirapetinga Granite

Pirapetinga Granite is a folded tabular body that occurs on the NE border of the Araxá Nappe (Figs. 1 and 3). It is intrusive into garnet-mica-quartz schist and amphibolite, and presents abundant pegmatitic facies constituted of quartz, muscovite, K-feldspar, and tourmaline. It is equigranular, medium, light grey, deformed, with quartz, orthoclase and microcline, muscovite and biotite, and rare grains of plagioclase. Zircon, tourmaline and apatite are accessories. It is an alkali granite from the modal point of view (Fig. 4). Chemically, it stands out for its high level of K_2O , high Rb and very low Na_2O , which reflected in the low $\text{Na}_2\text{O}/\text{K}_2\text{O}$ 0.149 ratio (Figs. 5 and 6) and in the AnxAbxOr diagram, where it plots near the apex of Or, being compatible with the high modal percentage of orthoclase (51.38%), as seen in Fig. 7.

This Granite has high normative corundum and peraluminous character (Fig. 8). Its $\text{La}_\text{N}/\text{Yb}_\text{N} = 23.42$ ratio reflects a low-enriched pattern in LREE compared to HREE and its Eu/Eu^* ratio = 0.49, indicating a significant negative Eu anomaly (Fig. 9). In the multi-element diagram, its negative anomalies of Nb, Sr and Ti stand out (Fig. 10). It plots on the boundary between the fields of collisional and anorogenic granites in the R1xR2 diagrams (Fig. 11), and volcanic arc and collisional granites in the YxNb (Fig. 12) and HfxR/30x3Ta diagrams (Fig. 15) and collisional in RbxY+Nb (Fig. 14). According to Barbarin's classification, in 1999, it can be called MPG. In the Rb/ZrxSiO₂ and ZrxTaxNb diagrams (Figs. 16 and 17), it plots on the boundary among the fields of granites types I, II and III. Its zircons present high isotopic imbalances, which may indicate hydrothermal alteration and unreliability in the chemical analysis. The FB-114 sample has only eight zircon grains with reasonable results, also there is the incorporation of Pb (reverse) with a discordia age of 623 ± 41 Ma. However, there is a concordant grain of about 630 Ma (Fig. 25) that could be its crystallization age. Its T_{DM} is 1.73 Ga, the highest model age among the studied bodies. Its $\epsilon_{\text{Nd}(630)}$ is -8.934, indicating reworking of crustal sources.

Figure 24. (A) Concordia diagrams for zircons from Galheirinho Granite; (B) More significant heritages; (C) Concordia age.

Serra Velha Granite

Serra Velha Granite is a small NW lenticular body situated to the North of Araxá (Figs. 1 and 3). It is intruded in garnet-mica-quartz schist and amphibolite, and is intensely deformed with concordant tectonic foliation with the

hosting rocks, presenting gneiss aspect. It is equigranular, fine to medium, light grey to white, with quartz, orthoclase, microcline, plagioclase, biotite and muscovite, and garnet, tourmaline, monazite, apatite and zircon as accessories. Sericite, biotite, albite and chlorite secondary act as retro-metamorphic minerals. From the modal point of view, it is a granite (Fig. 4). Samples of this body analyzed by Seer (1999) are classified as granite in the AnxAbxOr diagram (Fig. 7), presenting normative corundum and being peraluminous (Fig. 8), with low Ba, V and Sr and high Y (Fig. 6). It may also have been formed by melting of pelitic metasediments. They present low La_N/Yb_N ratios ranging from 2.13 to 6.8 and Eu/Eu^* ones from 0.27 to 0.54 (Fig. 9). In the multi-element diagram, its resemblance to the Galheirinho Granite is remarkable (Fig. 10). It plots in the field of collisional granites in the R1xR2 (Fig. 11) and RbxY+Nb diagrams (Fig. 14), collisional granites and volcanic arc in the NbX diagram (Fig. 12). According to Barbarin's classification, in 1999, it can be called MPG. Zircon dating by isotopic dilution – thermal ionization mass spectrometer – ID-TIMS (Valeriano *et al.* 2004a) provided concordant age of 637 ± 1 Ma, considered the crystallization age of this body (Fig. 26). Some zircon inherited from the source area provided the age of 830 Ma.

Tamanduá Granite

Tamanduá Granite (FB-116 sample) is an NW elongated body in the Araxá Nappe, beside the Serra Velha Granite (Figs. 1 and 3). It is intrusive into garnet-mica-quartz schist, quartzite and amphibolite and has pegmatitic facies formed by quartz, muscovite, K-feldspar, and tourmaline. It has abundant xenoliths of amphibolite, schist, and quartzite on its edge. It is dominantly equigranular, medium, light grey, deformed, with quartz (26.76%), orthoclase and microcline (45.49%), plagioclase (17.15%), biotite (6.17%), muscovite (4.41%). Apatite and zircon are accessories. Secondary muscovite occurs on the K-feldspar. In the QAP diagram, it is classified as syenogranite. Isotopically, its zircons are completely unbalanced, not being possible to obtain the U-Pb age. It is believed that this body has undergone strong post-magmatic hydrothermal alteration, a fact corroborated by the abundant presence of pegmatites. Taking into account only the Nd data and using a crystallization age of 637 Ma (~Serra Velha granite), its $\epsilon_{Nd(637)}$ is -5.728 with T_{DM} of 1.56 Ga, values that match the other samples.

DISCUSSION

Field studies and petrographic, geochemical, and geochronological data make it possible to claim that the

intrusive granites into the metasedimentary, mafic and ultramafic metaigneous rocks of the Araxá Group, between Araxá and Cascalho Rico towns, represent three episodes of Neoproterozoic granitic magmatism, each one related to a distinct environment. The first one is related to the Quebra Anzol Granite, aged 833 Ma, which was originated in within-plate environment and is associated with a large volume of amphibolite. The mafic rocks and granite can be interpreted as an accreted terrain that would represent the first magmatic manifestations in a within-plate environment. Tholeiitic amphibolites associated with the Araxá Group in the Anápolis region (Piuzana *et al.* 2003) aged 838 ± 20 Ma and $\epsilon_{Nd} + 5.1$ represent a fragment of oceanic crust of the SBB, and may be co-related to the Araxá Nappe and to the region of Ipameri-Catalão, which are characterized as tholeiites of mid-ocean ridge (Seer 1999, Klein, 2008). This age represents therefore an extensional event in SBB and is compatible with that of the Quebra Anzol Granite.

Figure 25. Concordia age for one zircon grain from Pirapetinga Granite.

Figure 26. Concordia diagram for monazite and zircon grains from Serra Velha Granite (Valeriano *et al.* 2004a).

Of a bit younger age, around 790 Ma, are the Pires Belo and Davinópolis granites in Catalão, which Klein (2008) interpreted as being of extensional origin. Such fact suggests that the events generating granites of this age would have persisted for at least 48 Ma. In contrast, a little to the NW, Pimentel *et al.* (1992) obtained the age of 790 Ma for the Maratá Granite interpreting it as being collisional. The second magmatic episode is represented by granites aged 790 Ma. Geological, geochemical, and isotopic evidence suggest that the Monte Carmelo Granitic Complex and associated amphibolites may represent the root of a magmatic arc, whose volcanosedimentary counterpart would be represented by the volcanosedimentary sequence of Abadia dos Dourados. The Nd isotopic data ($\epsilon_{\text{Nd}(790)}$ of -2.218 and T_{DM} of 1.29) reinforce this hypothesis, showing its similarity to the isotopic pattern of the rocks of Goiás Magmatic Arc (Fig. 20, Laux *et al.* 2005). Associated with this complex, bodies of peraluminous granites happen with garnet and muscovite, typically collisional and may represent the melting of arc granites around 630 Ma, since they contain zircon populations inherited from 790 Ma and similar patterns of REE. The third episode between 642 and 630 Ma is represented by the collisional magmatism, which is already well characterized in the region and with metamorphic peak between 640 and 637 Ma (Seer *et al.* 2010). This is represented by granitic bodies of Serra Velha, Tamanduá, Pirapetinga, Galheirinho, Perdizes, Estrela do Sul and Cascalho Rico, generated from the reworking of continental neo and mesoproterozoic crusts. These ages are similar to the Goiandira orthogneisses (Klein 2008) to the Firminópolis and Palminópolis ones, and in this case also to the evolution pattern of Nd (Laux *et al.* 2005) and to lenticular anatetic bodies of the Passos Nappe (Valeriano *et al.* 2004a).

The Nd evolution pattern of the collisional granites of Araxá and Monte Carmelo is very similar to the metasediments of the Araxá Group, both for the sample of Volcanosedimentary Sequence Abadia dos Dourados and for that of Anápolis and Goiânia region (Pimentel *et al.* 1999b). However, very different from the patterns of the Goiandira - Ipameri gneisses, indicating that the Araxá and Monte Carmelo granites may have been originated by the melting of sediments with low crustal residence, perhaps having been generated in forearc basins. An exotic terrain of magmatic arc formed at the end of the Mesoproterozoic in SBB, with an age of 1.2 Ga, represented by the Nova Aurora orthogneisses, was recently characterized (Klein 2008). This age shows the existence of a fourth and the oldest episode of granitic magmatism in the SBB. In the tectonic evolution context of SBB, the data presented here conform to the original idea of Pimentel *et al.* (1999a) and

Laux *et al.* (2005), who discussed the possibility that several intra-oceanic arcs would have developed independently and were accreted during the evolution of SBB. But, it also reaffirms the possibility of tectono-stratigraphic terrain accretion that differ in both their ages and geochemical and isotopic patterns.

The collisional process occurred between 640 and 630 Ma, well marked by granitic magmatism, joined several terrains of within-plate, ophiolitic melanges and of magmatic arc and generated sincolisional sedimentary (Dias *et al.* 2011) or forearc basins (Pimentel *et al.* 2011), later deformed, juxtaposing themselves in nappe systems through extensive subhorizontal and subvertical shear zones, whose exhumation and cooling would have occurred up to 605 Ma (Valeriano *et al.* 2004b).

CONCLUSIONS

The data presented show the existence of three episodes of granites generation in distinct tectonic environments in the SBB, between Araxá and Cascalho Rico, Minas Gerais State, in Brazil. The earliest episode is represented by the Quebra Anzol Granite, aged 833 Ma, with low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.706 and $\epsilon_{\text{Nd}(833)} = -3.98$. Its peralcalinity, high SiO_2 , Na_2O , MnO , Nb, Y and Co values and low Sr and Ba, absence of anorthite and presence of acmite and diopside indicate that it may have been originated from mantle sources with little crustal contamination, although it was affected by post-magmatic hydrothermal alteration and mylonitization. In the tectonic discrimination diagrams, it associates with the field of within-plate granites. The second magmatic episode is represented by Monte Carmelo Granitic Complex, aged 790 Ma, and partly remobilized around 630 Ma. It is metaluminous to peraluminous, with low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.706, high fractionation of LREE in relation to HREE and negative anomalies of Nb, Ta, Sr, P and Ti. Its $\epsilon_{\text{Nd}(790)}$ is -2.218 and its T_{DM} is 1.29 Ga, indicating an origin from juvenile sources at the end of the Mesoproterozoic. Its Nd evolution curve in relation to time is similar to that of Goiás Magmatic Arc granites.

From the tectonic point of view, the granites aged 790 Ma were formed in a pre-collisional magmatic arc environment, and they are associated with collisional granites generated around 630 Ma. These are products of remobilization of older granites, a fact which is proved both by the presence of inherited zircons of 790 Ma and similarity of the REE patterns, although other older crustal components may also have participated in the process as demonstrated by Mesoproterozoic zircons and Nd model ages. The last episode is represented by Serra Velha, Tamanduá, Pirapetinga,

Galheirinho, Perdizes, Estrela do Sul, and Cascalho Rico granites whose crystallization ages range from 642 to 630 Ma. They are peraluminous granites, mostly with muscovite and garnet, as well as tourmaline, with negative ϵ_{Nd} , model ages of Nd from Neo to Mesoproterozoic, enrichment patterns of LREE in relation to HREE variable according to the melting of igneous or sedimentary sources. In this case, with weak enrichment in REE and strong negative anomalies of Eu. In discriminant diagram, they plot in the field of collisional granites. These three episodes of granitic magmatism of different ages show that the collisional process that occurred around 640 to 630 Ma in this area of the SBB amalgamated tectono-stratigraphic terrains generated in within-plate, forearc, and magmatic arc tectonic environments.

ACKNOWLEDGEMENTS

This study was financially supported by *Fundação de Amparo à Pesquisa do Estado de Minas Gerais* – FAPEMIG (process 139-04) to which the authors are grateful. We thank professors José Affonso Brod (Federal University of Goiás) for his support in carrying out some chemical analysis of granites, Reinhard Adolf Fuck (University of Brasília) for his support in performing some Sm-Nd analysis, Sergio Luis Junges (Federal University of Rio Grande do Sul) for the discussions on the geochronological data, and Valda Sánchez (Araxá Cultura Inglesa) for the English version of the original manuscript. We are also grateful to the BJG proofreaders.

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