CAPÍTULO III

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Two Neoproterozoic Crustal Accretion Events in the Brasília Belt, Central Brazil

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Abstract

New U-Pb and Sm-Nd isotopic data for orthogneiss and granitoid rocks from the Neoproterozoic Goiás Magmatic Arc in western Goiás further constrain the geological evolution of this juvenile crust in the western Brasília Belt. Orthogneiss rock samples have U-Pb crystallization ages of 804 ± 6 Ma, 669 ± 3 Ma, 662 ± 12 Ma, 634 ± 8 Ma, 630 ± 5, and 637 ± 20 Ma, and show ε_{Nd}(T) values varying between +2.8 and -15.1. Rock units with negative ε_{Nd}(T) are more frequent in the eastern part of the studied area, to the south of Anicuns, indicating the presence of older continental crust in that part of the arc. Metagranitoids have ages of 821 ± 10 Ma, 810 ± 10 Ma, 792 ± 5 Ma, 790 ± 12, 782 ± 14 Ma, 748 ± 4 Ma, and 614 ± 5 Ma, and ε_{Nd}(T) values between +5.1 and -3.7. These data presented here combined with those in the literature suggest that igneous activity in the Goiás Magmatic Arc took place in two episodes: between ca. 0.89 and 0.8 Ga, probably in intraoceanic settings, and between ca. 0.66 and 0.60 Ga, most likely in an active continental margin at the end of the Brasiliano orogeny.

3.1 INTRODUCTION

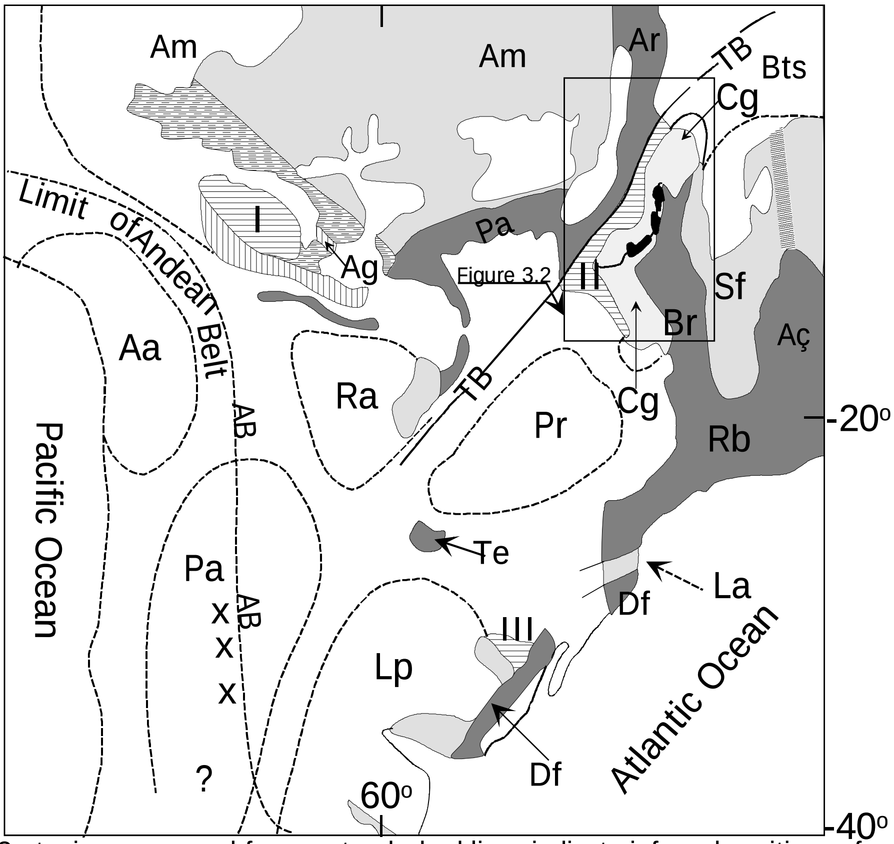
During the last decade, several studies have demonstrated that the Goiás Magmatic Arc in the western part of the Brasília Belt, in central Brazil, represents a large area of Neoproterozoic juvenile continental crust formed during plate convergence, roughly between ca. 900 and 630 Ma (Pimentel and Fuck, 1992; Pimentel et al., 1991, 1997; Junges et al., 2002). The available data, however, are neither sufficient to reconstruct in detail the history of arc magmatism and terrane accretion, and the tectonic setting in which the different rock units were formed (intraoceanic arc, continental arc, back arc, etc.), nor do they delineate the precise areal extent of these juvenile terrains and the nature of the limits with adjacent tectonic units.

This paper presents new ID-TIMS and SHRIMP geochronological data and Nd isotopic characteristics for several metatonalitic and granitic units from the southern part of the arc in western Goiás, which demonstrate that Neoproterozoic juvenile rocks underlie a much larger area then previously thought. In this region, the Goiás Magmatic Arc is exposed along the northern border of the Phanerozoic Paraná Basin, occupying an area at least 200 km wide (Fig. 3.1 and 3.2).

The U-Pb and Sm-Nd data, combined with data from the literature, also suggest that crustal accretion, represented by the generation of tonalitic to granitic magmas, took place during two main episodes: the first, most probably in an intraoceanic setting occurred between ca. 0.89 – 0.80 Ga, while the second , at ca. 0.66 – 0.60 Ga, likely took place in an active continental margin.

3.2 REGIONAL GEOLOGICAL SETTING

The Tocantins Province is a large Brasiliano/Pan-African orogen that was developed between three major continental blocks: the Amazon, São Francisco, and Paranapanema cratons (Fig. 3.1). The province comprises three main fold belts: the Paraguay Belt in the southwest, the Araguaia Belt in the northwest, and the Brasília Belt, which underlies underlying large areas of the eastern Tocantins Province along the western margin of the São Francisco Craton (for a review see Pimentel et al., 2000a) (Fig. 3.1).



Cratonic masses and fragments; dashed lines indicate inferred positions of major cratonic fragments below Phanerozoic cover: Aa- Arequipa/Antofalla; Am- Amazonia;Bts- BorboremaTrans-Sahara; Cg - Central Goiás; La- Luis Alves; Lp- Rio de la Plata; Pa- Pampia; Pr- Paranapanema; Ra- Rio Apa; Sf- São Francisco.

Late Neoproterozoic mobile belts: Aç- Araçuaí; Ar-Araguaia; Br- Brasília; Df- Dom Feliciano; Pa- Paraguay; Rb- Ribeira; Te- Tebicuary river área.

Juvenile granitoid rocks of intra-oceanic magmatic arcs: I - Pensamiento; II- Goiás; III- São Gabriel.

Espinhaço aulacogen within the São Francisco craton.

Rondonian-San Ignacio mobile belt.

Mafic-ultramafic layered complexes within Central Goiás massif: from north to south, Cana Brava, Niquelândia and Barro Alto.

Sunsás orogenic belt, including Aguapeí formation (Ag).

Phanerozoic cover.

X Outcrops of Neoproterozoic granitoids of the Pampean orogen. Tb- Transbrasiliano lineament; AB - limits of tectonic influence of Andean belt

Figure 3.1 - Precambrian tectonic framework of Central South America (after Kröner and Cordani, 2003; Cordani et al., 2003).

The Brasília Belt is one of the best preserved and the most complete Neoproterozoic orogen in Brazil, comprising: (i) a thick Meso-Neoproterozoic sedimentary pile that includes the Paranoá, Canastra, Araxá, Ibiá, Vazante, and Bambuí groups, overlying Paleoproterozoic and minor Archean basement (Almeida et al., 1981; Fuck et al., 1993, 1994, 2001; Pimentel et al., 2000a, b); (ii) the Goiás Massif a possible micro-plate or allochthonous sialic terrain, composed of Archean rock units (the Crixás-Goiás granite-greenstones) and associated Proterozoic formations, and (iii) a large Neoproterozoic juvenile arc in the west (Goiás Magmatic Arc) (Figs. 3.2 and 3.3).

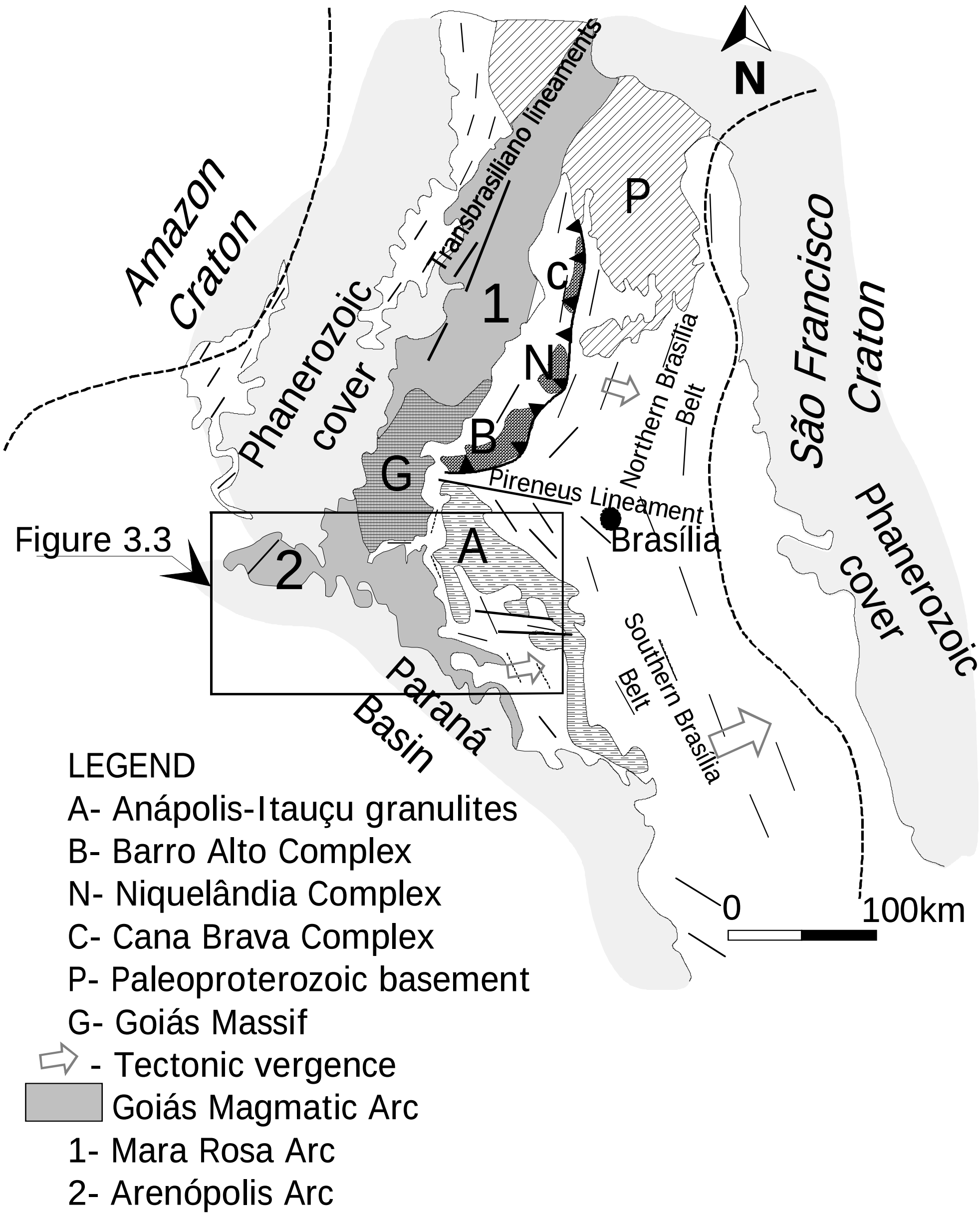


Figure 3.2 - Geological sketch map of the Brasília Belt in the eastern part of Tocantins Province, central Brazil (after Pimentel et al., 2003).

The several sedimentary/metasedimentary units, which occur in the eastern part of the Brasília Belt, display tectonic vergence to the east, towards the São Francisco Craton. They are more intensely deformed and metamorphosed towards the west, reaching amphibolite and granulite facies conditions in the central part of the belt (Fuck et al., 1993, 1994; Dardenne, 2000, Piuzana et al., 2003a).

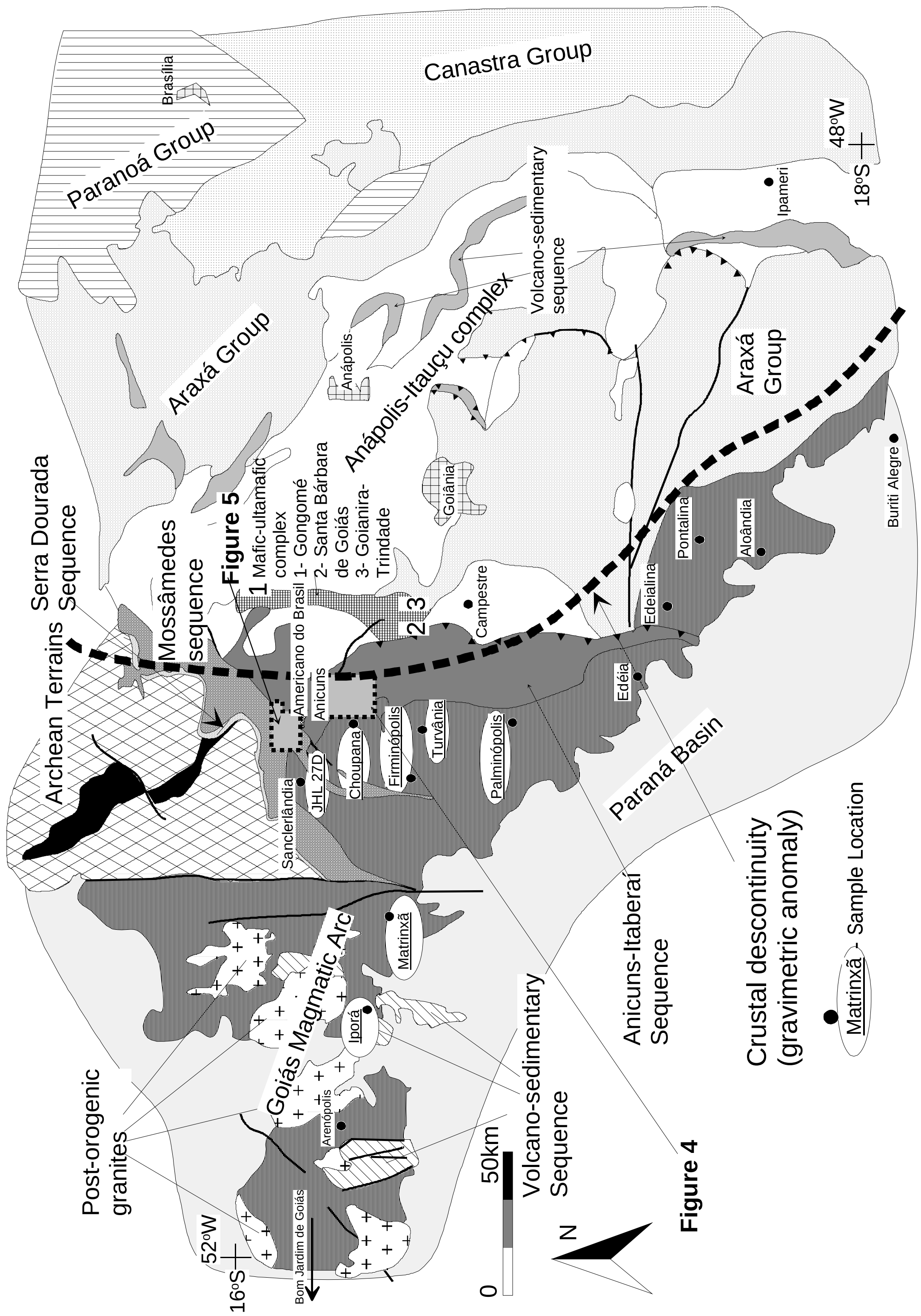


Figure 3.3 - Geological sketch map of the southern part of the Goiás Magmatic Arc, with the location of the studied areas (after Pimentel et al., 2000a).

Metasedimentary rocks belonging to the Araxá and Canastra groups underlie large areas in the central-southern part of the Brasília Belt (Figs. 3.2 and 3.3). Nappes and thrust sheets of these units overlie Paleoproterozoic basement represented by 2.1 Ga volcano-sedimentary sequences (e.g. Silvânia and Rio do Peixe sequences) and associated granites (e.g. Jurubatuba granite 2.0 Ga) (Fischel et al., 2001a, b; Piuzana et al., 2003a).

High-grade rocks of the Anápolis-Itauçu Complex are exposed in the central-southern part of the belt (Figs. 3.2 and 3.3). They include para- and orthogranulites, as well as strongly deformed intrusive granites. Recent data have shown that the Nd isotopic signatures and metamorphic ages of the Araxá metasediments, Anápolis-Itauçu felsic granulites, and intrusive granites are all very similar (TDM 1.1 – 1.3 and 1.9 – 2.3) (Fischel et al., 1998, 1999; Pimentel et al., 1999, 2001; Seer, 1999; Piuzana et al., 2003b), suggesting that at least part of the aluminous granulites of the Anápolis-Itauçu Complex may represent high-grade equivalents of the Araxá metasedimentary rocks.

The Goiás Massif, in the central part of the Brasília Belt (Fig. 3.2) is represented by: (i) Archean greenstone belts and TTG orthogneisses; (ii) Paleoproterozoic orthogneisses largely covered by younger supracrustal rocks; and (iii) mafic-ultramafic layered complexes of Barro Alto, Niquelândia, and Cana Brava and associated volcano-sedimentary sequences. The eastern margin of the Goiás Massif is marked by a regional gravimetric discontinuity typical of suture zones (Haralyi and Hasui, 1981, Marangoni et al., 1995). Therefore, the Goiás Massif is interpreted as an allochtonous block accreted to the Brasília Belt during the Neoproterozoic (Brito Neves and Cordani, 1991; Pimentel et al., 2000a).

The Neoproterozoic juvenile arc (Goiás Magmatic Arc) is composed of volcano-sedimentary sequences associated with calcic to calc-alkaline tonalite/granodiorite gneisses (Figs. 3.2 and 3.3). It is exposed in two sections separated by the Archaean terranes of the Goiás Massif (Fig. 3.2). The southern sector (the object of this study) is known informally as the Arenópolis Arc, and the northern sector, in northern Goiás and southwestern Tocantins, is known as the Mara Rosa Arc (Pimentel et al., 2000a). Both areas first evolved as intraoceanic island arcs with the crystallization of very primitive tholeiitic to calc-alkaline volcanics and associated tonalites/granodiorites at ca. 890-860 Ma. These rocks have $\varepsilon_{Nd}(T)$ values between +3.0 and +6.0 and T_{DM} values mostly between ca. 0.8 and 1.1 Ga (Pimentel et al., 1991, 1997, 2000b; Pimentel and Fuck, 1992). Geochemical and isotopic data (Pimentel, 1991; Pimentel et al., 1997) suggest that the original tonalitic/andesitic magmas were similar to modern adakites, normally formed above subduction zones where young, hot oceanic lithosphere is subducted under oceanic lithosphere (Martin 1987). Calc-alkaline igneous activity was recurrent during the Neoproterozoic and lasted until ca. 640 Ma, with younger magmas becoming progressively more evolved. The main metamorphic episode occurred at ca. 630 Ma, as indicated by U-Pb titanite and Sm-Nd garnet ages (for a review, see Pimentel et al., 2000a), when final ocean closure probably took place.

There has been considerable debate on the areal distribution of these juvenile terrains, since geochronological and isotopic data are still sparse. However, preliminary U-Pb and Sm-Nd data have shown that the juvenile arc extends to the southeast and northeast under the Phanerozoic Paraná and Parnaíba basins, respectively (Figs. 3.2 and 3.3). They underlie, therefore an area that constitutes a significant part of the Brasília Belt (Pimentel et al., 2000a; Fuck et al., 2001).

3.3 ORTHOGNEISSES OF THE ARENÓPOLIS ARC

The Arenópolis Arc in the southern part of the Goiás Magmatic Arc (Figs. 3.2 and 3.3) underlies large areas of western and southwestern Goiás, extending from the vicinity of Bom Jardim de Goiás in the west to Turvânia in the east (Fig. 3.3). The supracrustal and orthogneissic units that comprise this section of juvenile Neoproterozoic continental crust are juxtaposed along important NNE to NNW strike-slip faults.

The orthogneisses are dominantly hornblende- and biotite-bearing metadiorites, metatonalites and metagranodiorites. They show mineral assemblages indicative of metamorphism under amphibolite facies conditions, they locally display relict igneous textures and structures, but show features of strong deformation and metamorphism such as mylonitic textures and migmatitic structures. Major element data suggest that the igneous protoliths were metaluminous, and calcic- to calc-alkaline with typically low K contents (Pimentel and Fuck, 1986, 1987). The Arenópolis, Sanclerlândia and Firminópolis gneisses are typical of these rocks and have been compared with primitive M-type granitoids of intraoceanic island arcs, whereas the Matrinxã granodioritic rocks show characterisitics of both I- and M-type rocks (Pimentel and Fuck, 1986, 1987, 1992; Rodrigues et al., 1999).

U-Pb, Sm-Nd, and Rb-Sr isotopic determinations give ages between ca. 940 and 630 Ma. Initial $^{87}Sr/^{86}Sr$ ratios are low (<0.705) and $\varepsilon_{Nd}(T)$ values are positive, indicating the juvenile character of the original magmas (Pimentel and Fuck, 1986, 1987; Rodrigues et al., 1999). A summary of isotopic and geochronological data for some of these orthogneisses is given in Tables 3.1 and 3.2.

Table 3.1 Summary of previous age data for rocks of the Arenópolis Arc.

Rocha	Age (Ma)	$(^{87}Sr/^{86}Sr)_i$	T_{DM} (Ga)	$\varepsilon_{Nd}(T)$	Refer.
Arenópolis Gneiss	899±7 [a] 818±57[b] 637 [c]	0.7042	1.0-1.2	+1.9/+3.2	1,2
Matrinxã Gneiss	ca. 895[b]	0.7026	0.9	+ 6.0	2
Sanclerlândia Gneiss	ca. 940[b] 820±7 [a]	0.7025	0.9-1.0	+4.0/+6.0	2 4
Firminópolis Gneiss	628±65[d]		1.1-1.2	-1.7	3

a –Zircon U-Pb age; b – whole-rock Rb-Sr isochron; c – Titanite U-Pb age; d – whole-rock Sm-Nd isochron age. References: 1 – Pimentel et al. (1991); 2 – Pimentel and Fuck (1994); 3 – Gioia (1997); 4- Motta-Araújo and Pimentel (2003).

Hornblende-bearing gneisses exposed in the vicinities of Choupana and Turvânia, in the easternmost part of the Goiás Magmatic Arc, have T_{DM} model ages between ca. 0.94 and 1.13 Ga. A whole rock Sm-Nd isochron gives an age of 863 ± 97 Ma and $\varepsilon_{Nd}(T)$ of +4.1 for the Choupana granite-gneiss, indicating the juvenile nature of the protolith (Rodrigues et al., 1999; Pimentel et al., 2000b). To the south of Turvânia, however, orthogneisses have Paleoproterozoic model ages (1.89 to 2.27 Ga), indicating the presence of older sialic crust between the Neoproterozoic juvenile rocks. Examples of such intervening blocks of older rocks have been described in previous studies of the Arenópolis Arc (Pimentel and Fuck, 1986, 1987; Rodrigues et al., 1999).

Table 3.2 Results and previous Sm-Nd data for rocks of the Arenópolis Arc.

Sample	Sm	Nd	$^{143}Nd/^{144}Nd$ (±2SE)	$^{147}Sm/^{144}Nd$	$\varepsilon_{(0)}$	$\varepsilon_{(T)}$	T_{DM}(Ga)
Gneisses							
Iporá	6.68	42.00	0.512126(±13)	0.0963	-9.9	0.3	1.18
Matrinxã	2.39	12.82	0.512381(±31)	0.1126	-5.0	2.2	0.99
Firminópolis	3.49	20.86	0.512007(±32)	0.1013	-12.3	-4.6	1.39
Turvânia	4.08	21.54	0.512318(±17)	0.1147	-6.2	0.3	1.11
Turvânia-1A*	1.92	10.22	0.512395(±09)	0.1140	-4.7	1.9	0.99
Turvânia-1E*	1.75	10.89	0.512320(±08)	0.0970	-6.2	1.8	0.94
Turvânia-2A*	3.60	19.47	0.512342(±15)	0.1140	-5.7	0.9	1.07
Palminópolis	6.63	37.19	0.511497(±19)	0.1079	-22.3	-15.1	2.21
Palminópolis	5.18	32.83	0.511887(±12)	0.0954	-14.6	-6.4	1.48
Palminópolis-1A*	4.47	22.75	0.511626(±23)	0.1190	-19.7	-13.4	2.27
Palminópolis -1B*	5.70	31.32	0.511548(±09)	0.1100	-21.2	-14.2	2.19
Palminópolis -2A*	3.62	16.47	0.512504(±14)	0.1330	-2.6	2.6	0.98
Palminópolis -2B*	6.90	47.32	0.512010(±13)	0.0880	-12.2	-3.4	1.25
Choupana Granite-1*	2.47	11.71	0.512426(±10)	0.1280	-4.1	1.7	1.09
Choupana Granite-4*	1.78	7.452	0.512559(±20)	0.1450	-1.5	2.8	1.07
Choupana Granite-5*	1.65	7.023	0.512540(±21)	0.1420	-1.9	2.7	1.06
Aloândia-1*	5.89	27.70	0.512219(±20)	0.1280	-8.2	---	1.45
Aloândia –2*	3.77	18.68	0.512365(±12)	0.1220	-5.3	---	1.12
Edéia-1C*	7.78	35.93	0.511926(±08)	0.1300	-13.8	---	2.00
Edéia-2A*	10.49	51.43	0.511818(±08)	0.1230	-16.0	---	2.04
Indianópolis-1A*	18.85	99.56	0.511798(±09)	0.1140	-16.4	---	1.89
Granites							
JHL 5a	4.53	29.95	0.512260(±23)	0.0915	-7.4	---	0.97
JHL 06	122.69	538.06	0.512588(±08)	0.1378	-0.9	5.1	0.91
JHL 07	7.34	33.35	0.512571(±11)	0.1330	-1.3	4.8	0.89
JHL 10	3.20	15.57	0.512173(±12)	0.1245	-9.1	-1.8	1.47
JHL12	8.15	33.63	0.512568(±11)	0.1466	-1.3	3.6	1.07
JHL27c	5.42	26.91	0.512088(±39)	0.1218	-10.7	---	1.57
JHL27d	4.28	25.14	0.512046(±24)	0.1030	-11.5	-1.7	1.36
JHL 29a	10.90	72.01	0.512059(±18)	0.0915	-11.3	---	1.22
JHL 29c	4.64	20.09	0.512491(±19)	0.1396	-2.8	---	1.13
JHL 30a	2.27	14.69	0.511993(±33)	0.0934	-12.6	---	1.32
JHL 30c	4.10	19.91	0.512376(±08)	0.1245	-5.1	---	1.13
JHL 32	3.45	22.20	0.512065(±17)	0.0940	-11.2	-3.1	1.24
JHL 33	4.01	25.48	0.512037(±12)	0.0952	-11.7	-3.7	1.29
JHL 35	5.75	24.26	0.512556(±19)	0.1434	-1.59	3.8	1.05

*Samples from Pimentel et. al. (2000b).

3.4 GRANITIC ROCKS OF THE ARENÓPOLIS ARC

Two major groups of granites are recognized within the Arenópolis Arc based on their field and structural characteristics: (i) small, extremely deformed bodies of pre- to syn-tectonic character, and (ii) larger intrusions of K-rich late- to post-orogenic bimodal diorite-granite suites and associated dykes of porphyritic microgranites. Very little is known about the first group. They typically form narrow, elongate bodies that display mylonitic textures and a vertical mylonitic foliation best developed along contacts with adjacent rock units. In the Iporá area, whole-rock Rb-Sr isochrons give poorly constrained ages between ca. 470 and 690 Ma, and low $^{87}Sr/^{86}Sr$ initial ratios (<0.705; Rodrigues et al., 1999).

The second group of granites, which is better known because of better exposure, show initial $^{87}Sr/^{86}Sr$ ratios that range from 0.7032 to 0.71030 and $\varepsilon_{Nd}(T)$ values between –4.6 and +3.0 (Pimentel et al., 1996). Their isotopic and chemical characteristics suggest that the parental granitic magmas were derived by re-melting the older tonalitic arc rocks in response to the emplacement of large volumes of mafic magmas into the lower/middle continental crust during final uplift and extension (Pimentel et al., 1996). Granites of this group are mostly exposed in the western half of the Arenópolis Arc. In the Anicuns area (Fig. 3.4 and 3.5) most granitic rocks are strongly deformed, displaying protomylonitic to mylonitic textures along shear zones.

3.5 ANALYTICAL PROCEDURES

Zircon concentrates were extracted from ca. 10 kg rock samples using conventional gravimetric (DENSITEST®) and magnetic (Frantz isodynamic separator) techniques. Final purification was achieved by hand picking using a binocular microscope. All zircon grains selected for analysis were free of inclusions and fractures and were separated from the least magnetic fraction.

For the conventional U-Pb analyses, fractions were dissolved in concentrated HF and HNO_3 ($HF:HNO_3$ = 4:1) using microcapsules in Parr-type bombs. A mixed ^{205}Pb-^{235}U spike was used. Chemical extraction followed standard anion exchange technique, using Teflon microcolumns, following procedures modified from Krogh (1973). Pb and U were loaded together on single Re filaments with H_3PO_4 and Si gel, and isotopic analyses were carried out on a Finnigan MAT-262 multi-collector mass spectrometer equipped with secondary electron multiplier-ion counting at the Geochronology Laboratory of the University of Brasília. Procedure blanks for Pb at the time of analyses were better than 20 pg. PBDAT (Ludwig, 1993) and ISOPLOT-Ex (Ludwig, 2001a) were used for data reduction and age calculation. Errors for isotopic ratios are 2σ.

Ion microprobe analyses were carried out using SHRIMP I at the Research School of Earth Sciences, Australian National University, Canberra, Australia. Zircon grains were mounted in epoxy resin and polished. Transmitted and reflected light microscopy, as well as scanning electron microscope cathodoluminescence imagery, was used to investigate the internal structures of the zircon crystals prior to analysis. Data were collected and reduced as described by Williams and Claesson (1987) and Compston et al. (1992). Uncertainties are given at 1σ level and final age quoted at 95% confidence level. Reduction of raw data was carried out using Squid 1.02 (Ludwig, 2001b). U/Pb ratios were referenced to the RSES standard zircon AS3 (1099 Ma, $^{*206}Pb/^{238}U$ = 0.1859, Paces and Miller 1993). U and Th concentrations were determined relative to those measured in the RSES standard SL13.

Sm-Nd isotopic analyses followed the method described by Gioia and Pimentel (2000) and were carried out at the Geochronology Laboratory of the University of Brasília. Whole rock powders (ca. 50 mg) were mixed with ^{149}Sm-^{150}Nd spike solution and dissolved in Savillex capsules. Sm and Nd extraction of whole-rock samples followed conventional cation exchange techniques, using Teflon columns containing LN-Spec resin (HDEHP – diethylhexil phosphoric acid supported on PTFE powder). Sm and Nd samples were loaded on Re evaporation filaments of double filament assemblies and the isotopic measurements were carried out on a multi-collector Finnigan MAT 262 mass spectrometer in static mode. Uncertainties for Sm/Nd and

$^{143}Nd/^{144}Nd$ ratios are less than ±0.4% (1σ) and ±0.005% (1σ) respectively, based on repeated analyses of international rock standards BHVO-1 and BCR-1. $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd$ of 0.7219 and the decay constant used was 6.54×10^{-12} a^{-1}. T_{DM} values were calculated using DePaolo's (1981) model.

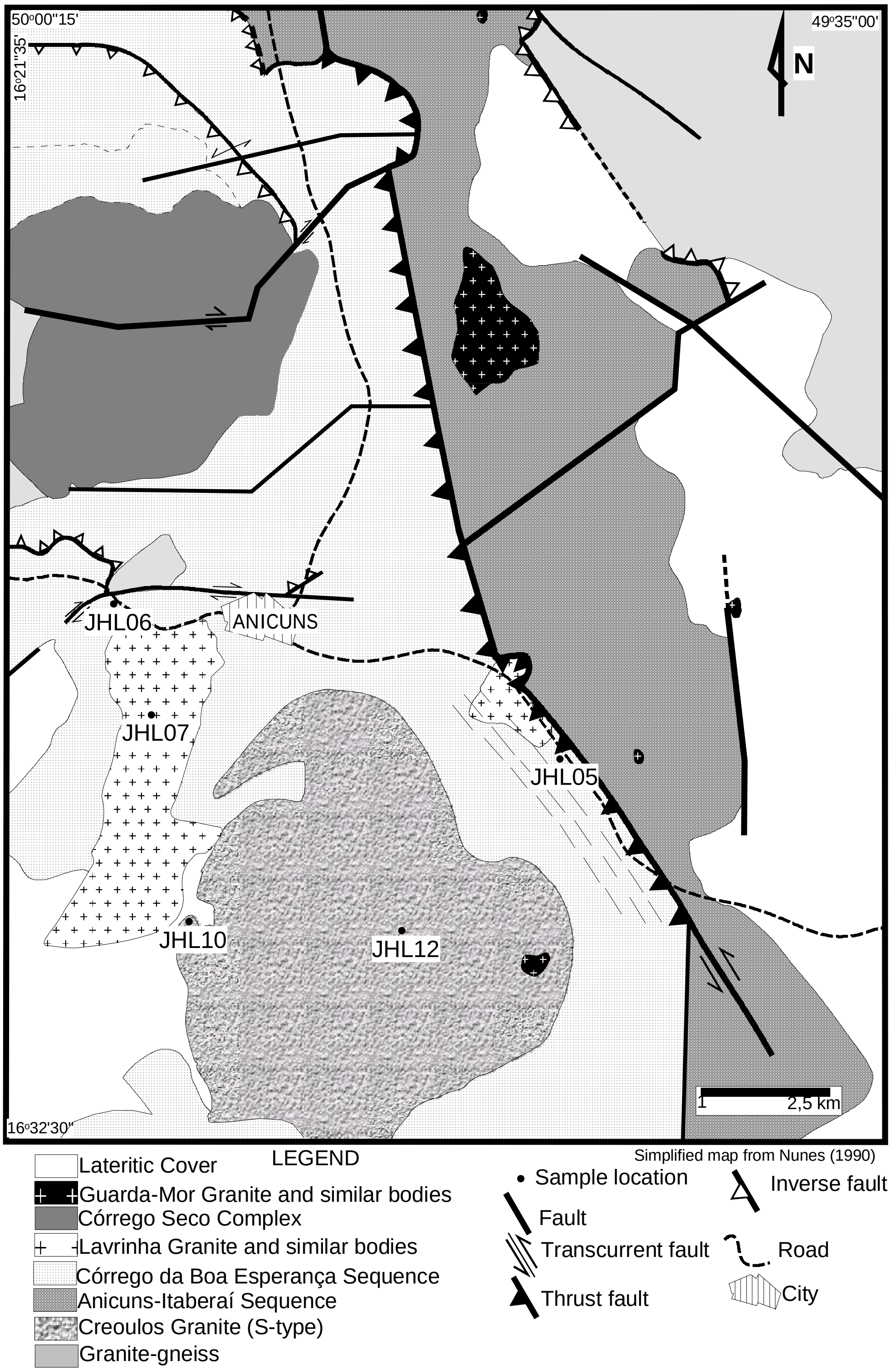


Figure 3.4 - Geological map of the Anicuns region with locations of studied samples (simplified from Nunes, 1990).

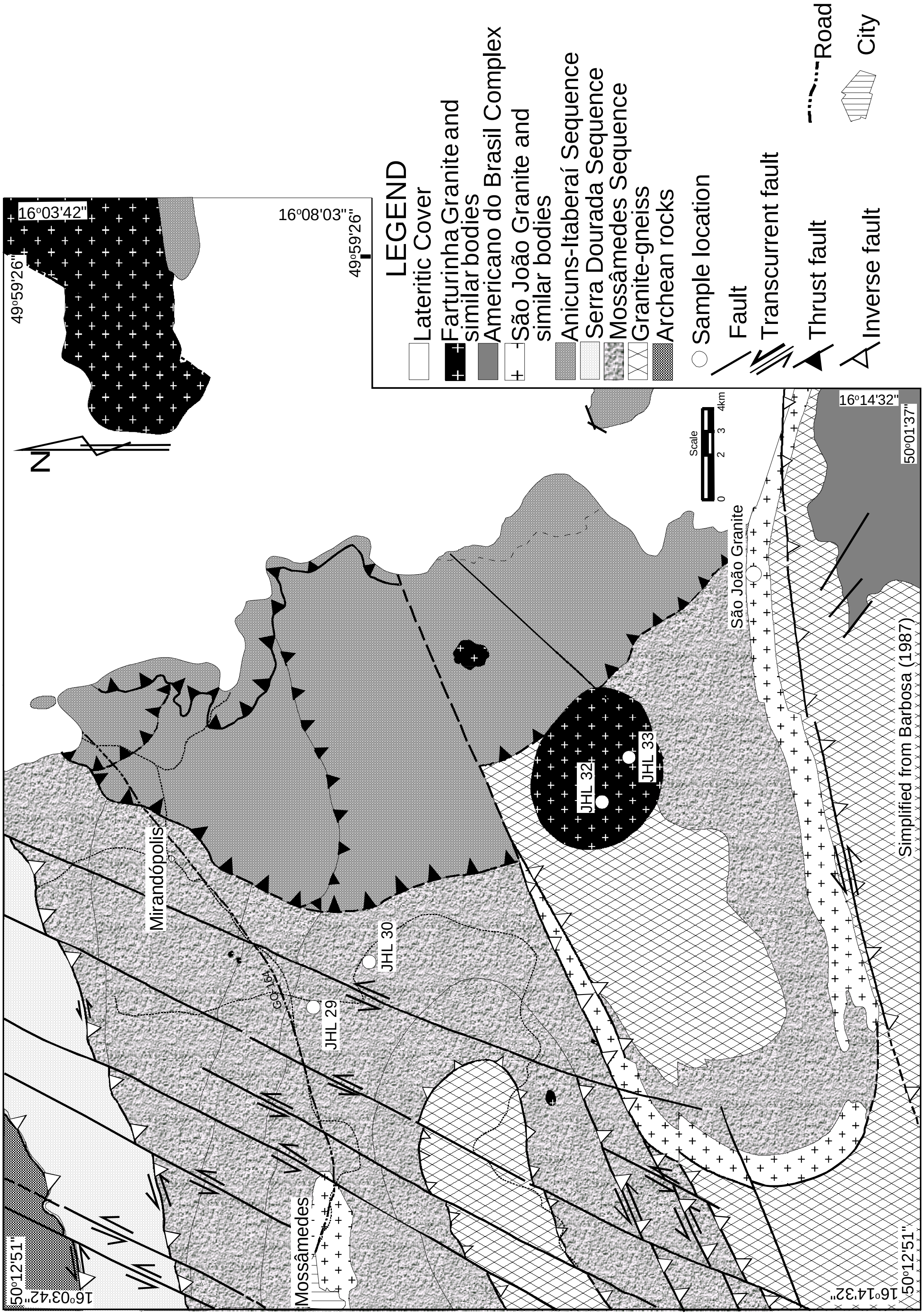


Figure 3.5 - Geological map of the area east of Mossâmedes, Goiás (after Barbosa 1987).

3.6 RESULTS AND DISCUSSION

Six orthogneiss and seven granite samples from the southern part of the Goiás

Magmatic Arc were analyzed by the ID-TIMS U-Pb method and one orthogneiss sample (the Palminópolis gneiss) had zircon grains investigated by SHRIMP. Samples were investigated for their Nd isotopic characteristics and the new results were interpreted together with Nd isotopic data published previously. Sm-Nd data are in Table 3.2 and U-Pb results are in Tables 3.3 to 3.5.

3.6.1 Orthogneisses

Zircon grains from the Iporá, Matrinxã, Firminópolis, Turvânia, and Palminópolis gneisses and from the Choupana granite-gneiss (Fig. 3.3) form simple populations of well-formed, prismatic, pink crystals, without visible core-overgrowth relationships. They are optically similar to the zircon grains in the Palminópolis gneiss, which have been studied by cathodoluminescence and show well-developed oscillatory zoning (Fig. 3.6).

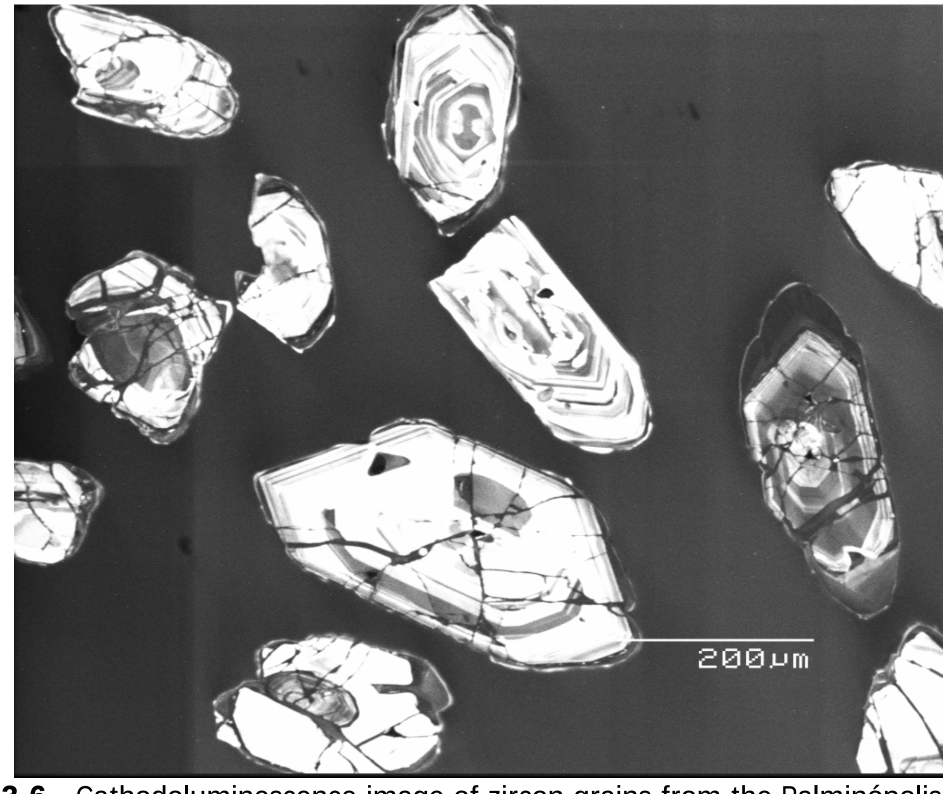


Figure 3.6 - Cathodoluminescence image of zircon grains from the Palminópolis Gneiss.

Iporá Gneiss – This is a pink, finely banded biotite gneiss of granodioritic composition. Analysis of zircon grains from this sample yielded a discordia (MSWD = 0.61) with an upper intercept age of 804 ± 6 Ma with 1 concordant point (Fig 3.7a, Table 3.3). This is interpreted to be the age of crystallization of the igneous protolith. Sm-Nd isotopic data from the same sample give a T_{DM} model age of 1.18 Ga and a slightly positive $\varepsilon_{Nd}(T)$ of +0.3 (Table 3.2).

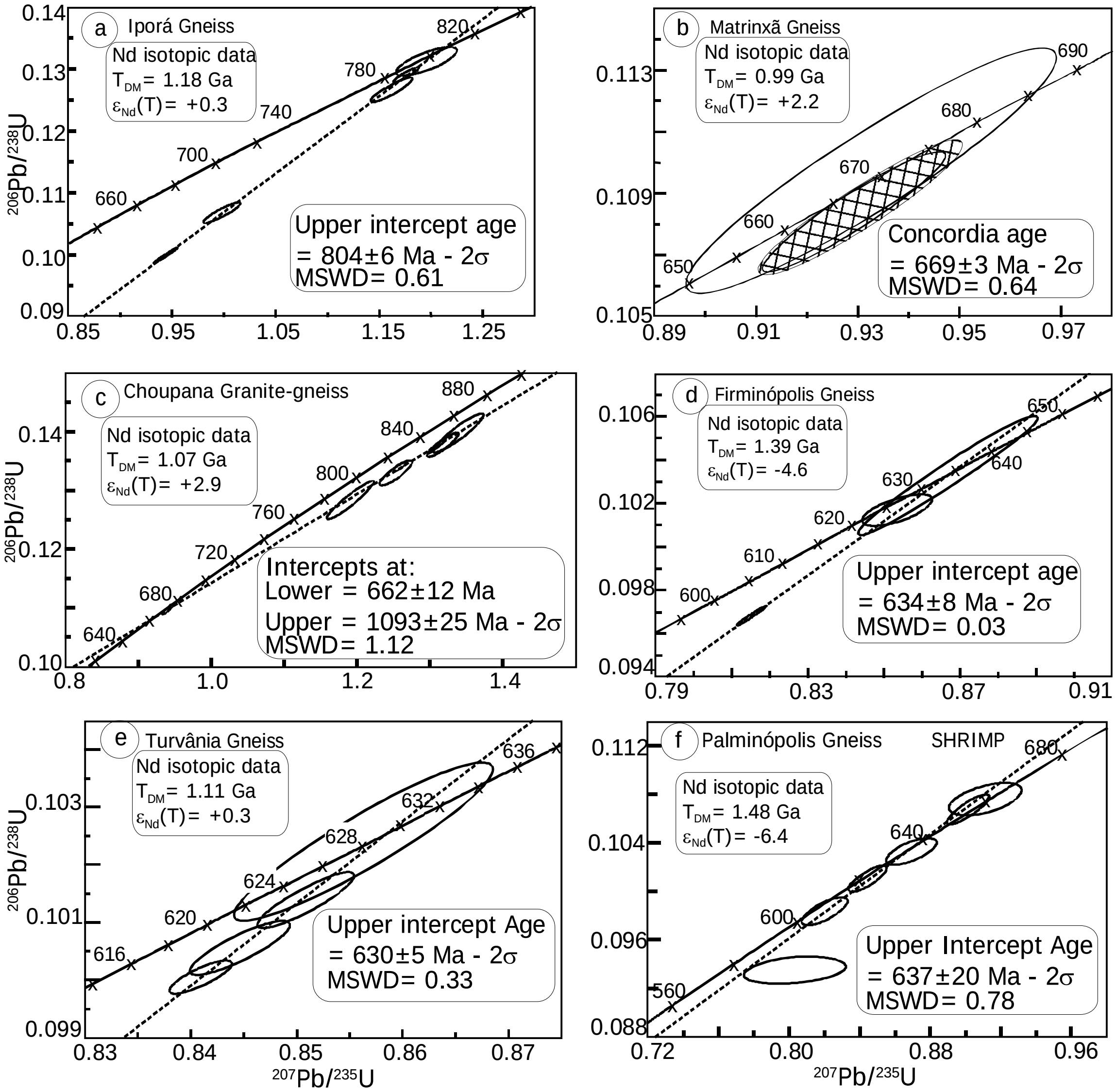


Figure 3.7 - ID-TIMS and SHRIMP U-Pb concordia diagrams for orthogneisses from the Goiás Magmatic Arc.

Matrinxã Gneiss – This is a grey, medium- to coarse-grained biotite- and hornblende-bearing metagranitoid varying in composition from tonalite to granite. Two concordant zircon analyses produced a concordia age of 669 ± 3 Ma (Fig. 3.7b, Table 3.3), significantly younger than that of the Iporá orthogneiss. The Nd isotopic composition indicates a T_{DM} model age of 0.99 Ga and $\varepsilon_{Nd}(T)$ of +2.2 (Table 3.1), pointing to the juvenile character of the parental magma.

Choupana Granite-gneiss – This is a grey, medium- to coarse-grained biotite- and hornblende-bearing metagranodiorite. The seven U-Pb zircon analyses resulted in mostly discordant compositions, with only one nearly concordant analytical point indicating the $^{206}Pb/^{238}U$ age of 671 Ma. The discordant analytical points are interpreted to indicate an important inherited component, although older cores are not optically obvious in the zircon grains analysed. The discordia through the seven analytical points defines a lower intercept age of 662 ± 12 Ma, that we interpret to be the best estimate for the crystallization age of the igneous protolith (Fig. 3.7c, Table 3.3). The upper intercept age of ca. 1.09 Ga may be slightly overestimated since the T_{DM} model ages of three samples of this rock unit are between 1.09 and 1.06 Ga. $\varepsilon_{Nd}(T)$ values are positive (+1.7 to +2.8) (Table 3.2), indicating the primitive nature of the magma.

Firminópolis Gneiss – This is a hornblende-bearing, epidote-rich banded to homogeneous grey gneiss of dioritic to tonalitic composition. Analyses of zircon grains from this rock yield a discordia (with two concordant points) with an upper intercept age of 634 ± 8 Ma (Fig. 3.7d, Table 3.3). This agrees, within error, with a previous Sm-Nd whole-rock isochron that yielded an age of ca. 628 Ma and $\varepsilon_{Nd}(T)$ of –1.7 (Gioia, 1997, Pimentel and Gioia, 1997). T_{DM} ages vary between ca. 1.1 and 1.4 Ga (Table 3.2). The Nd isotopic data indicate, therefore, a small degree of contamination with older crust during the evolution of the parental magma.

Turvânia Gneiss – This is a banded biotite gneiss with well developed mylonitic textures. Four zircon fractions were investigated and produced a discordia with an upper intercept age of 630 ± 5 Ma (Fig 3.7e, Table 3.3). Nd isotopic compositions indicate T_{DM} ages between 0.99 and 1.11 Ga and positive $\varepsilon_{Nd}(T)$ values between +0.3 and +1.9 (Table 3.2).

Palminópolis Gneiss – This is petrographically very similar to the Turvânia gneiss and is of tonalitic composition. This rock unit is extremely deformed and locally migmatized. Zircon grains are pink, prismatic, and show well developed oscillatory zoning (Fig. 3.6). Six grains were analysed with the SHRIMP and produced a discordia with an upper intercept age of 637 ± 20 Ma (MSWD = 0.78) (Fig. 3.7f, Table 3.4). T_{DM} model ages vary over a large interval between 0.98 and 2.27 Ga, clearly indicating contamination of older crust during the evolution of the magma. This is also evident from the ε_{Nd}(T) values, which can be as negative as –6.51 (Table 3.2).

The parental magmas of the Firminópolis, Turvânia, and Palminópolis gneisses are, therefore, roughly coeval (~630 Ma) and these rock units seem to form a distinctly younger block of continental crust in the eastern part of the Arenópolis Arc (Fig. 3.3). Nd isotopic data for the Firminópolis and Palminópolis rocks suggest that their parental magmas were contaminated with older continental crust (Fig. 3.8), and might have been formed in a continental arc setting. Other gneissic units in the same block (the Aloândia and Edéia gneisses, for example) show the same characteristics and ε_{Nd}(T =630 Ma) values ranging from 0 to –10 (Pimentel et al., 2000b).

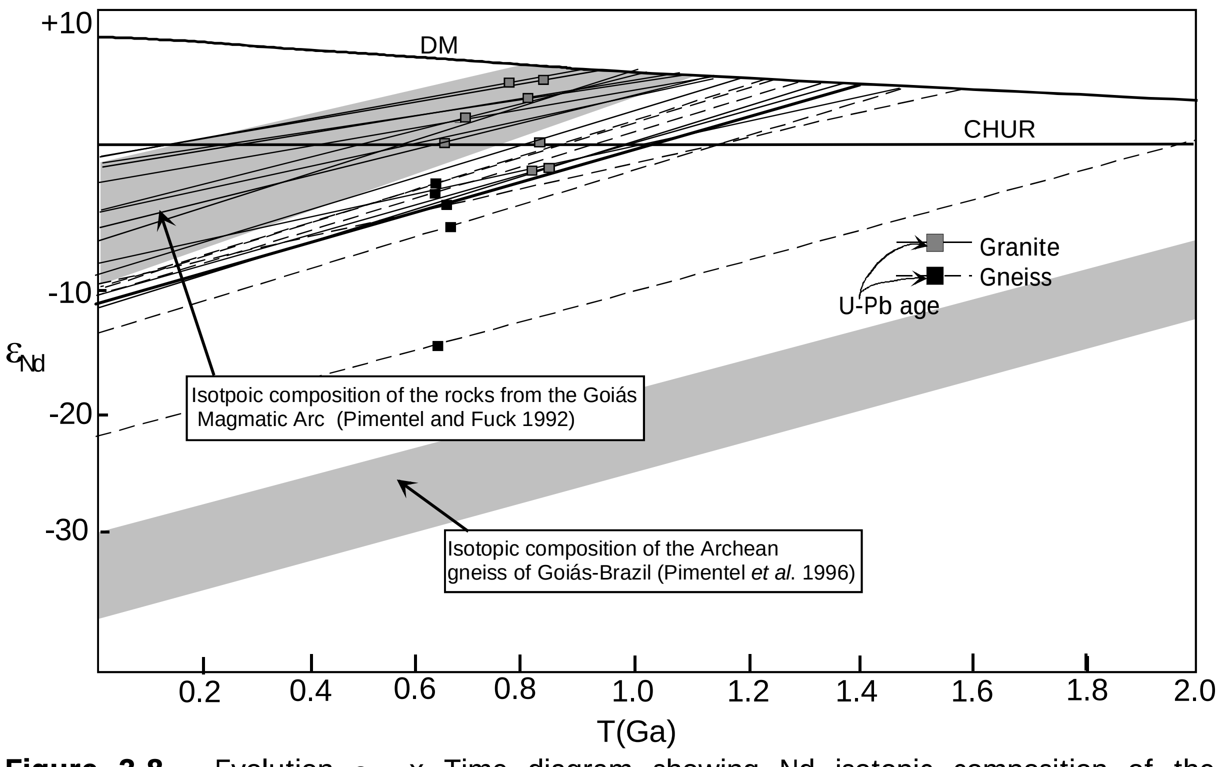


Figure 3.8 - Evolution ε_{Nd} x Time diagram showing Nd isotopic composition of the orthogneiss and granite samples studied. Nd isotopic composition of the Goiás Magmatic Arc is from Pimentel and Fuck (1992) and that of Archean gneisses of Goiás is from Pimentel et al. (1996). U-Pb ages are shown for the individual samples. Note that there is a trend in which the younger rocks tend to have more negative ε_{Nd}(T) values.

3.6.2 Granites

Sample JHL 27D (Fig. 3.3) – This is a grey, undeformed, fine-grained biotite granite exposed to the southeast of Sanclerlândia. Zircon grains investigated form short orange prisms. Four fractions have been analyzed and are very discordant. The upper intercept age of 821 ± 10 Ma (Fig. 3.9a, Table 3.5) is interpreted to be the best estimate for the age of igneous crystallization.

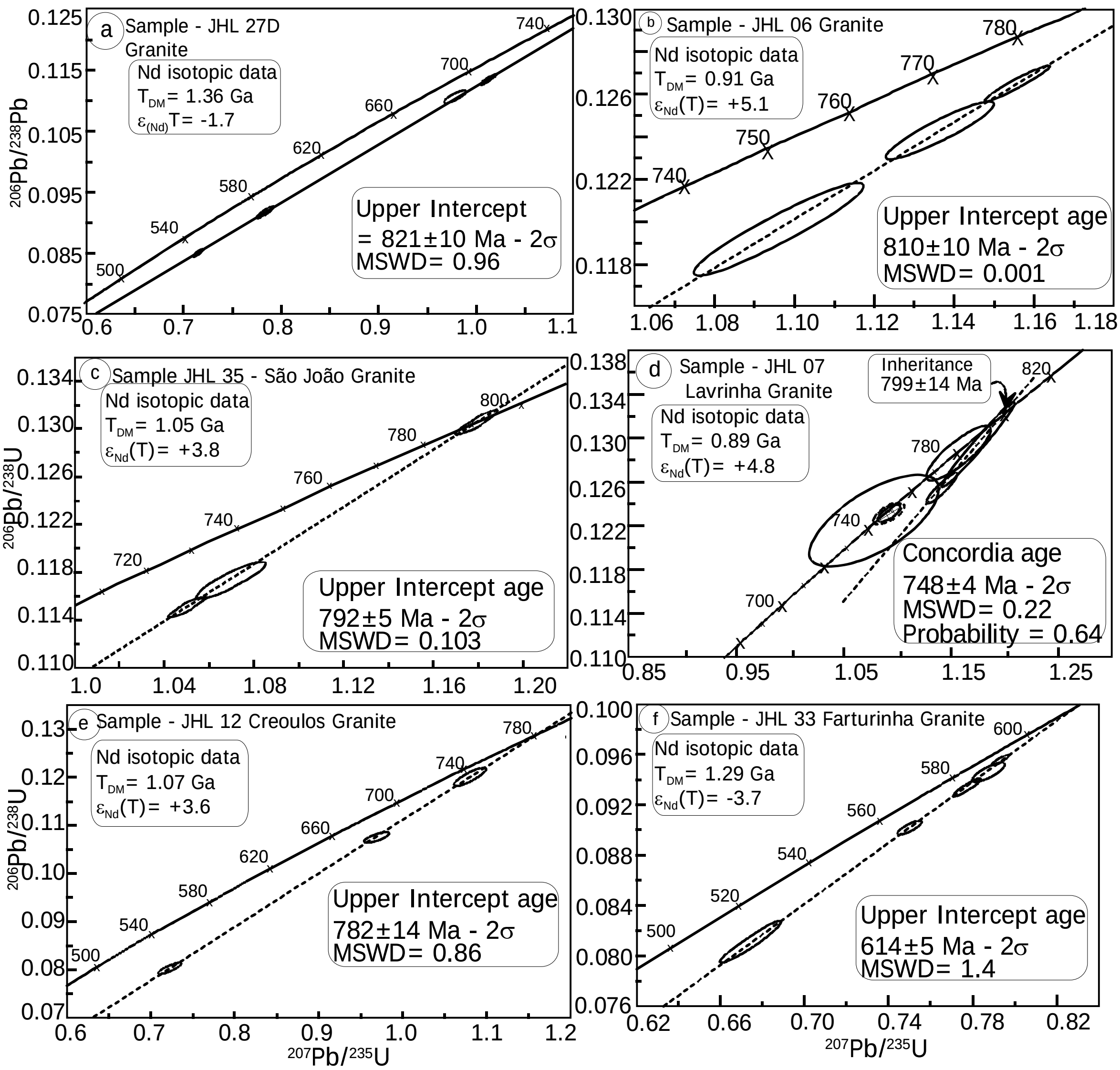


Figure 3.9 - ID-TIMS U-Pb concordia diagrams for granitic rocks of the Anicuns area.

Sample JHL 06 (Fig. 3.4) – This is a light grey granite, with local mylonitic structure, intrusive into metasedimentary rocks of the Córrego da Boa Esperança sequence. Zircon grains occur as short brown prisms. Three fractions analyzed are discordant and form a discordia with an upper intercept age of 810 ± 10 Ma (Fig. 3.9b, Table 3.5).

São João Granite (Sample JHL 35) – The São João Granite is a red porphyritic biotite granite which forms a very elongate E-W body, just to the north of the Americano do Brasil layered intrusion (Fig. 3.5). Three zircon fractions were analyzed, with one concordant analytical point with a $^{207}Pb/^{206}Pb$ age of 791 Ma. The upper intercept age of the discordia is 792 ± 5 Ma (Fig. 3.9c, Table 3.5), interpreted to be the crystallization age of the original granitic magma.

Lavrinha Granite (Sample JHL 07) – This is medium-grained, pink coloured mylonitic granite exposed as an elongate N-S body, just to the southwest of Anicuns (Fig. 3.4). Two distinct zircon populations were identified. One is characterized by long yellowish prismatic crystals from which three analyses define a discordia with an upper intercept age of 799 ± 14 Ma (Fig. 3.9d, Table 3.5). The other more abundant population is made up of short prismatic crystals. Two concordant data points from this population give a concordia age of 748 ± 4 Ma (Fig. 3.9d, Table 3.5). This age is interpreted to date the crystallization of the granitic magma, whereas the older, less abundant population is most likely inherited zircon grains.

Sample JHL-10 – This is a muscovite-bearing augen granite-gneiss, forming a dome-like circular structure to the south of Anicuns (Fig. 3.4). Analysed zircon grains are prismatic and colourless, and the six fractions investigated are very discordant, forming a discordia with an upper intercept age of 790 ± 12 Ma (Fig. 3.10, Table 3.5), which is interpreted to be the best estimate for the crystallization age of the granite.

Creoulos Granite (Sample JHL-12) (Fig. 3.4) – This is a pink porphyritic granite that takes the form of a metre-scale sheet, emplaced into JHL 10 granite-gneiss, parallel to the regional gneissic foliation. Analysed zircon grains are pink, well-formed prisms. The three zircon fractions analysed are discordant and form a discordia with an upper intercept age of 782 ± 14 Ma (Fig. 3.9e, Table 3.5).

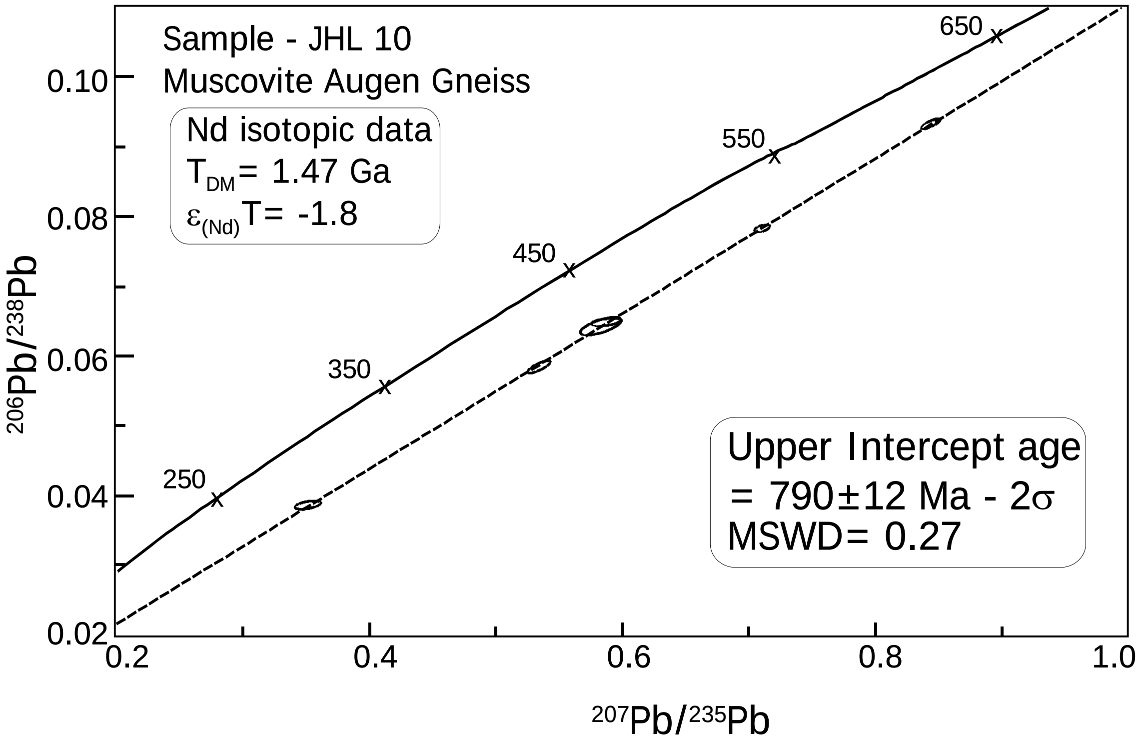


Figure 3.10 – ID-TIMS U-Pb concordia diagram for sample JHL 10.

Farturinha Granite (Sample JHL 33) – This is a undeformed, fine-grained to porphyritic grey granite exposed as circular body approximately 4 km to the north of the São João Granite (Fig. 3.5). Zircon occurs as yellowish, well-formed prismatic crystals. Five zircon fractions were analyzed and form a discordia with an upper intercept age of 614 ± 5 Ma (Fig. 3.9f, Table 3.5), which is interpreted to be the crystallization age of the granite magma and is compatible with its post-tectonic character.

Sm-Nd isotopic analyses for most of these granitoid rocks give positive values for ε_{Nd}(T). The ca. 800 Ma-old granites have ε_{Nd}(T) values of around +4.5 and T_{DM} ages of approximately 1.0 Ga (Fig. 3.8, Table 3.2), similar to other juvenile rock units of the Goiás Magmatic Arc (Fig. 3.8), and indicating an important crustal accretion event at that time. The ca. 614 Ma old Farturinha granite, together with leucogranites (possibly peraluminous) JHL 27D and JHL 10, have Nd isotopic compositions that indicate an older continental crustal component in the origin of the parental magmas. T_{DM} model ages are around 1.3 Ga and ε_{Nd}(T) values are negative, between –2.0 and –4.0. (Fig. 3.8, Table 3.2). Additional samples of undated granitic rocks have Nd isotopic compositions that fall in both groups described above (Table 3.2, Fig. 3.8).

The U-Pb zircon data also suggest two main episodes of igneous rock-forming events in the Arenópolis Arc took place, an older episode between ca. 890 and 790, and a younger episode between ca. 670 and 615 Ma (Fig 3.11). The available data, however, are neither sufficient to reconstruct in detail the history of arc magmatism and terrane accretion, and the tectonic setting in which the different rock units were formed.

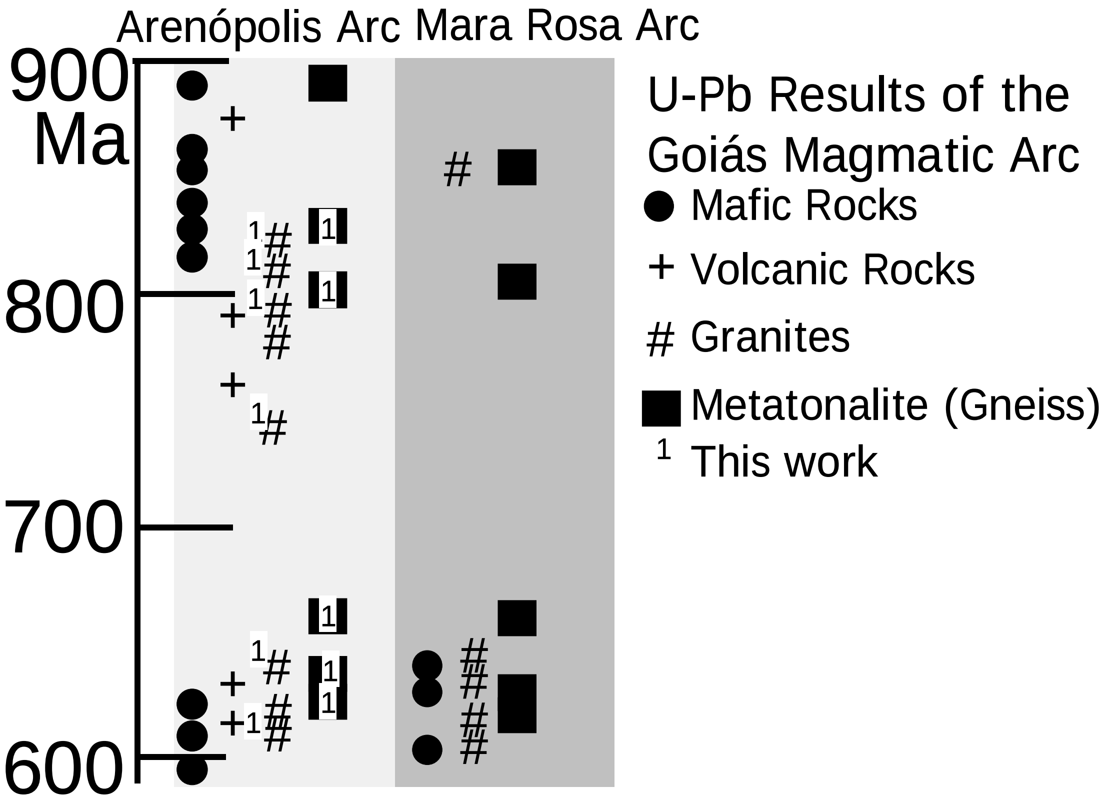


Figure 3.11 – Summary of the previous age data from the Goiás Magmatic Arc documents two distinct crustal accretion events (Data from Pimentel et al., 1991, 1997, 2003; Pimentel and Fuck, 1992; Viana et al., 1995; Rodrigues et al., 1999; Fischel et al., 2001b; Dantas et al., 2001; Piuzana et al., 2001, 2003a, b; Junges et al., 2002, 2003; Laux et al., 2002a, b, 2003a, b, 2004a; Motta-Araújo and Pimentel, 2003).

3.7 CONCLUSIONS

The new U-Pb and Sm-Nd data presented here, combined with data from the literature, demonstrates that the Arenópolis Arc underlies a very large area of western Goiás extending from Bom Jardim de Goiás, in the west to the vicinity of Anicuns in the east; a continuous 200 km-wide exposure of juvenile Neoproterozoic rocks.

The data presented here also confirm two major periods of crustal accretion in the Arenópolis Arc. The older period is represented by orthogneisses and granitoids with emplacement ages between ca. 821 and 782, whereas the younger one records the crystallization of metatonalites and metagranitic rocks between ca. 669 and 630 Ma. The older event, which may also include rock units that are even older than those studied here (Arenópolis and Sanclerlândia gneisses – ca. 890 Ma) and is dominated by very primitive, island arc-type magmatism represented by the protoliths of the Iporá, Arenópolis, Sanclerlândia orthogneisses, the Americano do Brasil country rocks, granitoids JHL-12, JHL-06, and the São João and Lavrinha granites. T_{DM} model ages for these rock units are dominantly around 1 Ga and ε_{Nd} values are positive.

Units that comprise the younger rock-forming event appear to indicate a larger degree of contamination with older crust, as indicated by both the zircon Meso- to Neoproterozoic inheritance pattern (e.g. Choupana granite-gneiss and Lavrinha granite) an the older T_{DM} model ages (e.g. Palminópolis and Firminópolis gneisses).

This study also suggests that representatives of the younger episode are concentrated in the eastern part of the Goiás Magmatic Arc, forming a continuous gneissic block between Firminópolis and Palminópolis. Within this block, the igneous protoliths of the gneissic rocks appear to have been more intensely contaminated with older sialic crust during ascent and crystallization, probably indicating proximity to, or participation of, the edge of the São Francisco continental plate.

The two rock-forming events the Arenópolis Arc were also observed in a previous study (Laux et al., 2004a), which demonstrated that mafic intrusive rocks (mostly amphibolites, metagabbros and gabbrodiorites) formed in two distinct time intervals that broadly coincide with those discussed above (Fig. 3.11); the older event includes gabbros and amphibolites, with crystallization ages between 890 and

800 Ma (Pimentel et al., 2003, Laux et al., 2004a), while the younger includes mafic intrusives formed between 650 and 600 Ma, including small layered mafic-ultramafic complexes. Hence, the crustal accretion events in the Arenópolis Arc recorded by the emplacement of tonalites, granodiorites and granites were accompanied by important mafic igneous activity. Similarly Junges et al., (2003) have recently demonstrated that two phases of tonalite/diorite formation exist in the northern half of the Goiás Magmatic Arc, in the Mara Rosa area.

Table 3.3. Summary of ID-TIMS U-Pb data for the orthogneisses.

Sample/ Fraction	Size (mg)	U ppm	Pb ppm	Th ppm	Pb^{206}/Pb^{204}	Pb^{207*}/Pb^{235}	(pct)	Pb^{206*}/U^{238}	(pct)	Correl. Coeff. (rho)	Pb^{207*}/Pb^{206*}	(pct)	Pb^{206*}/U^{238} Age	$Pb^{207}/^{*}U^{235}$ Age	$Pb^{207}/^{*}Pb^{206*}$ Age	(Ma)	Quant.
Iporá D	0.030	168.8	22.4	36.3	718.65	1.162	1.40	0.126	1.27	0.911	0.0665	0.57	768	782	824	12	1
Iporá A	0.036	208.2	100.4	30.2	1654.54	0.998	1.42	0.106	1.27	0.899	0.0678	0.62	653	703	863	13	5
Iporá E	0.032	352.7	197.3	34.0	1714.84	0.944	1.01	0.099	1.01	0.994	0.0685	0.11	613	675	885	2.3	2
Iporá 9	0.025	297.6	42.3	43.5	715.78	1.176	0.85	0.129	0.78	0.926	0.0661	0.32	782	789	809	6.7	1
Iporá 3	0.021	91.6	14.4	51.8	342.18	1.196	2.00	0.131	1.43	0.760	0.0661	1.30	794	798	810	27	1
Matrinxã E7	0.013	183.2	19.6	83.7	557.85	0.929	1.59	0.108	1.48	0.938	0.0622	0.54	662	667	682	12	3
Matrinxã E8	0.011	102.8	11.3	98.9	277.99	0.932	3.21	0.109	2.95	0.932	0.0616	1.16	671	668	659	25	3
Choupana L	0.036	243.6	34.9	262.3	825.07	1.310	0.77	0.137	0.75	0.969	0.0690	0.19	831	850	899	3.9	1
Choupana K2	0.031	87.6	12.5	35.1	437.58	1.339	2.10	0.139	1.95	0.927	0.0695	0.78	843	862	913	16	1
Choupana M	0.019	77.4	10.7	57.3	599.99	1.253	1.49	0.133	1.33	0.889	0.0684	0.68	804	824	880	14	2
Choupana J	0.028	77.1	11.2	38.8	502.74	1.318	1.37	0.137	1.25	0.914	0.0694	0.55	831	853	910	11	3
Choupana N	0.038	45.7	6.2	27.9	1836.88	1.258	0.54	0.134	0.46	0.859	0.0681	0.27	810	827	872	5.7	2
Choupana E1	0.026	184.7	19.4	41.8	931.33	0.942	0.75	0.109	0.72	0.963	0.0622	0.20	671	673	680	4.3	2
Choupana E4	0.015	92.5	12.0	72.5	419.58	1.191	2.21	0.128	2.08	0.949	0.0673	0.69	778	796	846	14	1
Firminópolis H	0.020	381.0	38.2	54.4	1771.08	0.853	0.87	0.102	0.59	0.686	0.0608	0.63	624	626	634	14	1
Firminópolis I	0.024	203.1	23.5	45.3	544.35	0.866	2.23	0.103	2.17	0.974	0.0686	0.50	633	633	634	11	2
Firminópolis M	0.039	266.6	25.1	28.6	3986.16	0.815	0.39	0.096	0.39	0.989	0.0611	0.05	595	605	641	1.2	3
Turvânia E	0.164	128.9	13.71	6.6	16216.02	0.841	0.28	0.100	0.23	0.821	0.0609	0.16	614	619	637	3.5	1
Turvânia N	0.082	194.9	21.54	13.3	2477.08	0.844	0.46	0.100	0.39	0.844	0.0609	0.24	617	621	636	5.3	1
Turvânia D9	0.126	207.0	22.33	8.6	4730.13	0.851	0.44	0.101	0.39	0.886	0.0608	0.20	622	625	634	4.3	1
Turvânia 2	0.056	247.1	29.74	19.4	929.02	0.856	1.17	0.102	1.09	0.927	0.0606	0.44	628	628	626	9.5	1

Table 3.4. Summary of SHRIMP U-Pb data for Palminópolis gneiss.

Grain Spot	U ppm	Th ppm	$^{206*}Pb/^{204}Pb$	$^{(1)206}Pb/^{238}U$ Age	1σ err	$^{(1)207}Pb/^{206}Pb$ Age	1σ err	% Discordant	Total $^{238}U/^{206}Pb$	% err	Total $^{207}Pb/^{206}Pb$	% err	$^{(1)207*}Pb/^{206*}Pb$	% err	$^{(1)207*}Pb/^{235}U$	% err	$^{(1)206*}Pb/^{238}U$	% err	err corr
Palminópolis 1.1	350	422	1011.2	631.9	6.4	599	210	-6	9.54	0.9	0.0742	4.2	0.0599	9.7	0.85	9.8	0.1030	1.1	0.109
Palminópolis 2.1	242	198	1131.8	605.3	5.6	644	123	6	10.00	0.9	0.0739	3.5	0.0611	5.7	0.83	5.8	0.0984	1.0	0.168
Palminópolis 2.2	528	3	2320.0	576.1	4.5	624	79	8	10.62	0.8	0.0668	2.0	0.0606	3.6	0.78	3.7	0.0935	0.8	0.217
Palminópolis 3.1	1368	5	8607.7	634.1	4.2	621	27	-2	9.66	0.7	0.0622	0.8	0.0605	1.3	0.86	1.4	0.1034	0.7	0.489
Palminópolis 3.2	183	144	883.1	614.8	6.7	480	208	-28	9.79	1.0	0.0732	4.2	0.0567	9.4	0.78	9.5	0.1001	1.1	0.120
Palminópolis 4.1	1760	7	6379.9	620.5	4.1	581	18	-7	9.87	0.7	0.0617	0.5	0.0594	0.8	0.83	1.1	0.1010	0.7	0.648
Palminópolis 5.1	1864	6	5126.0	604.8	4.5	579	25	-5	10.13	0.8	0.0621	0.7	0.0593	1.1	0.80	1.4	0.0984	0.8	0.568
Palminópolis 6.1	1314	9	2801.7	657.2	5.5	554	96	-19	9.26	0.8	0.0638	1.2	0.0586	4.4	0.87	4.5	0.1073	0.9	0.195
Palminópolis 7.1	2197	3	17728.2	653.9	4.6	626	13	-4	9.36	0.7	0.0615	0.5	0.0606	0.6	0.89	1.0	0.1068	0.7	0.773
Palminópolis 6.2	215	137	1261.1	606.9	5.7	600	96	-1	9.99	0.9	0.0714	1.7	0.0599	4.4	0.82	4.5	0.0987	1.0	0.219
Palminópolis 8.1	474	427	2239.2	614.2	4.8	621	51	1	9.92	0.8	0.0670	0.9	0.0605	2.4	0.83	2.5	0.1000	0.8	0.324

(1) Common Pb corrected using measured ^{204}Pb.

Error in Standard calibration was 1.11% (not included in above errors but required when comparing data from different mounts).

Table 3.5. Summary of ID-TIMS U-Pb data for the granitic rocks.

Sample/ Fraction	Size (mg)	U ppm	Pb ppm	Th ppm	Pb^{206}/Pb^{204}	Pb^{207*}/Pb^{235}	(pct)	Pb^{206*}/U^{238}	(pct)	Correl. Coeff. (rho)	Pb^{207*}/Pb^{206*}	(pct)	Pb^{206*}/U^{238} Age	$Pb^{207}/^{*}U^{235}$ Age	$Pb^{207}/^{*}Pb^{206*}$ Age	(Ma)	Quant.
JHL 27D D7	0.024	91.6	10.7	45.3	735.25	0.979	0.95	0.111	0.78	0.849	0.0642	0.50	676	693	747	11	1
JHL 27D D8	0.040	390.1	31.9	27.2	1149.68	0.715	0.61	0.085	0.57	0.943	0.0609	0.20	526	547	638	4.4	1
JHL 27D D9	0.030	212.3	19.5	36.3	1078.87	0.784	0.91	0.092	0.84	0.932	0.0619	0.33	565	587	674	7.1	1
JHL 27D D10	0.018	294.6	34.3	60.4	903.75	1.013	0.65	0.113	0.62	0.955	0.0647	0.19	693	710	765	4.1	1
JHL 06 V	0.020	104.6	13.1	54.4	627.66	1.096	1.59	0.119	1.48	0.943	0.0664	0.53	728	751	819	11	8
JHL 06 Y	0.021	157.3	20.5	51.8	955.11	1.136	0.98	0.124	0.91	0.923	0.0663	0.38	755	770	816	7.9	7
JHL 06 Z	0.013	221.5	29.8	83.7	1369.79	1.156	0.56	0.126	0.55	0.975	0.0662	0.12	768	780	814	2.6	6
São João D13	0.027	189.4	25.7	40.3	1751.23	1.179	0.65	0.130	0.61	0.950	0.0655	0.20	790	791	791	4.2	1
São João 14	0.031	348.4	41.9	35.1	680.62	1.049	0.66	0.115	0.62	0.932	0.0662	0.24	701	728	812	5	1
São João 15	0.012	275.6	34.1	90.7	680.77	1.069	1.18	0.117	1.06	0.897	0.0661	0.52	714	738	811	11	1
JHL 07 D	0.012	301.7	39.3	90.7	505.93	1.078	4.62	0.122	2.79	0.675	0.0639	3.42	744	742	738	72	6
JHL 07 A	0.051	129.7	16.9	21.3	1555.77	1.092	0.82	0.123	0.52	0.688	0.0643	0.59	748	749	752	13	14
JHL 07 C*	0.027	178.4	23.6	40.3	1462.91	1.148	0.88	0.126	0.76	0.875	0.0658	0.43	768	776	800	6	9
JHL 07 D13*	0.023	151.5	24.8	47.3	205.60	1.157	2.07	0.128	1.57	0.797	0.0652	1.25	780	780	782	26	8
JHL 07 D12*	0.027	101.6	13.7	40.3	466.68	1.179	2.13	0.129	2.08	0.979	0.0658	0.43	787	791	800	9	9
JHL 10 K	0.018	876.1	92.7	60.4	618.26	0.844	0.73	0.093	0.60	0.842	0.0656	0.39	574	621	795	8	3
JHL 10 L	0.022	757.1	55.5	49.4	457.35	0.583	2.34	0.064	1.59	0.718	0.0666	1.63	402	466	795	34	7
JHL 10 M	0.013	1310.4	72.2	83.7	154.57	0.351	2.44	0.038	1.14	0.563	0.0659	2.03	244	305	805	42	5
JHL 10 O	0.026	991.6	92.1	41.8	452.34	0.711	0.70	0.078	0.53	0.785	0.0658	0.43	486	545	800	9	7
JHL 10 H	0.012	1327.3	112.1	90.6	235.61	0.587	1.66	0.0652	0.79	0.554	0.0656	1.39	405	469	793	29	3
JHL 10 G	0.019	1094.7	79.9	57.3	282.46	0.534	1.25	0.058	1.12	0.898	0.0660	0.55	367	434	807	12	3
JHL 12 I	0.012	697.2	67.8	90.7	289.71	0.723	1.52	0.080	1.21	0.828	0.0653	0.85	497	552	785	18	1
JHL 12 H	0.019	450.1	57.9	57.3	622.65	1.081	1.44	0.120	1.25	0.886	0.0652	0.66	731	744	780	14	2
JHL 12 D11	0.030	254.0	32.2	36.3	3552.52	0.969	1.21	0.107	0.87	0.763	0.0653	0.78	658	688	786	16	2
JHL 33 E11	0.015	568.9	53.9	72.5	1048.50	0.750	0.62	0.090	0.50	0.821	0.0603	0.35	556	568	616	7.7	5
JHL 33 E12	0.018	765.5	71.8	60.4	1151.77	0.777	0.68	0.093	0.64	0.940	0.0604	0.23	575	583	618	5.1	1
JHL 33 E13	0.020	1455.0	130.8	54.4	2339.76	0.787	0.80	0.094	0.65	0.823	0.0604	0.45	582	589	617	9.8	1
JHL 33 E15	0.019	819.7	77.3	57.3	1984.31	0.793	0.41	0.095	0.35	0.865	0.0602	0.21	587	592	613	4.4	1
JHL 33 8	0.013	418.2	34.2	83.7	384.26	0.674	1.75	0.081	1.6	0.961	0.0603	0.48	502	523	615	10	6

* Inheritance.