UNIVERSIDADE DE BRASÍLIA
INSTITUTO DE GEOCIÊNCIAS

“Evolução do Arco Magmático de Goiás com base em dados geocronológicos U-Pb e Sm-Nd”

TESE nº 067

Tese de Doutorado

Jorge Henrique Laux

Orientador: Márcio Martins Pimentel

Brasília
2004

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Brasília - 2004

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ABSTRACT

The data presented here combined with those in the literature suggest that igneous activity in the Goiás Magmatic Arc took place in two different episodes: the older between ca. 0.89 and 0.78 Ga, probably in intraoceanic settings, and the younger between ca. 0.66 and 0.60 Ga, most likely in an active continental margin, at the end of the Brasiliano orogeny.

New U-Pb and Sm-Nd isotopic data of orthogneiss and granitoid rocks from the Neoproterozoic Goiás Magmatic Arc in western Goiás helped to better constrain the geological evolution of this large section of juvenile crust in the western part of the Brasília Belt. Orthogneiss of dominant tonalitic composition 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 present ε_{Nd}(T) values varying within a large range, between +2.8 and -15.1. Rock units with negative ε_{Nd}(T) are more frequent in the eastern part of the studied area, south of Anicuns, suggesting the presence of slivers of older continental crust in that part of the arc. Metagranites in this area have ages of 821 ± 10 Ma, 810 ± 10 Ma, 792 ± 5 Ma, 790 ± 12, 748 ± 4 Ma, 782 ± 14 Ma, and 614 ± 5 Ma, and ε_{Nd}(T) values between +5.1 and -3.7.

Mafic rocks exposed in the Anicuns region, in the eastern part of the Goiás Magmatic Arc are represented dominantly by amphibolites (metavolcanic and metaplutonic). New U-Pb results demonstrate that this association is Neoproterozoic and that mafic rocks also crystallized during two main periods: (i) between ca. 890 and 815 Ma, and (ii) between ca. 630 and 600 Ma. Metagabbro and metadiorite samples JHL-14, JHL-15, JHL-23, AMB-01, and JHL-26B have U-Pb zircon ages of 886 ± 5 Ma, 862 ± 5 Ma, 815 ± 10 Ma, 856 ± 15 Ma, and 839 ± 9 Ma, respectively, and comprise the older group. The Late Neoproterozoic intrusive Anicuns-Santa Bárbara gabbro-diorite and Americano do Brasil suites are coeval. Four samples of the first (SB-01, JHL-04, JHL-22C and JHL-19) yielded U-Pb ages of 598 ± 8 Ma, 612 ± 6 Ma,

623 ± 13 Ma and 622 ± 6 Ma, respectively, whereas zircon grains from one norite sample of the Americano do Brasil Complex yielded a concordia age of 626 ± 8 Ma. All mafic rocks investigated present T_{DM} model ages of ca. 1.0 Ga, comparable to model ages of metaigneous rocks of the Goiás Magmatic Arc. $\varepsilon_{Nd}(T)$ values are strongly positive, indicative of the depleted nature of the mantle source (MORB-like), similarly to volcanic and plutonic rocks of the arc-type volcano-sedimentary sequences exposed to the west. The lithological associations comprising the supracrustal sequences in the Anicuns area are compatible with origin in an oceanic or fore-arc setting.

The mafic samples investigated in this study correspond to tholeiitic to calc-alkaline metabasalts and display major and trace element characteristics that are compatible with an origin within an island arc setting, with LILE enrichment and HFSE depletion. In these settings, LILE enrichment is assigned to metasomatism of the mantle source due to fluids released during slab-dehydration. Amphibolite samples ANA 19A and ANA 19B, of the Bonfinópolis Sequence, associated with sedimentary rocks of the Araxá Group, to the east of the area investigated here are slightly different when compared to those of the Anicuns region, and most probably represent fragments of Neoproterozoic ocean floor.

The T_{DM} values of the sedimentary rocks of the Anicuns-Itaberaí and Córrego da Boa Esperança sequences are very distinct from each other. The Córrego da Boa Esperança Sequence sediments, with T_{DM} values between 0.8 and 1.2 Ga, were derived mostly from the erosion of the juvenile arc, whereas those of the Anicuns-Itaberaí Sequence indicate derivation from an older, mostly Paleoproterozoic source.

Based on the field, geochronological, isotopic and regional geophysical data, we suggest that the supracrustal sequence exposed in the Anicuns area might represent a arc/fore-arc sequence, marking the tectonic boundary between the Goiás Magmatic Arc and the westernmost exposures of the former São Francisco continental plate.

RESUMO

Os dados apresentados aqui, combinados com os da literatura, sugerem que a atividade ígnea no Arco Magmático de Goiás ocorreu em dois diferentes episódios: o mais antigo entre ca. 0,89 e 0,78 Ga, provavelmente em um ambiente intra-oceânico, e o mais jovem ca. 0,66 e 0,60 Ga, mais provavelmente em uma margem continental ativa, no final da orogenia Brasiliana.

Novos dados isotópicos U-Pb e Sm-Nd de ortognaisses e rochas graníticas do Arco Magmático de Goiás ajudaram a esclarecer a evolução geológica deste grande domínio de rochas juvenis da parte oeste da Faixa Brasília. Os ortognaisses, de composição dominantemente tonalítica, apresentam idades de cristalização U-Pb em zircão de 804 ± 6 Ma, 669 ± 3 Ma, 662 ± 12 Ma, 634 ± 8 Ma, 630 ± 5 e 637 ± 20 Ma, e valores de ε_{Nd}(T) em amplo intervalo, entre +2,8 e –15,1. As rochas com ε_{Nd}(T) negativo ocorrem com maior freqüência na porção leste da área estudada, a sul de Anicuns, sugerindo a participação de crosta continental antiga nesta parte do arco. Metagranitos da mesma área têm idades de cristalização de 821 ± 10 Ma, 810 ± 10 Ma, 792 ± 5 Ma, 790 ± 12, 748 ± 4 Ma, 782 ± 14 Ma e 614 ± 5 Ma, e valores de ε_{Nd}(T) entre +5,1 e –3,7.

Rochas máficas expostas na região de Anicuns, na parte leste do Arco Magmático de Goiás, estão representadas dominantemente por anfibolitos (metavulcânicas e metaplutônicas). Novos resultados U-Pb demonstram que esta associação é neoproterozóica e que as rochas máficas também cristalizaram em dois períodos principais: (i) entre ca. 890 e 815 Ma, e (ii) entre ca. 630 e 600 Ma. Cinco amostras de metagabro e metadiorito têm idade U-Pb em zircão de 886 ± 5 Ma, 862 ± 5 Ma, 815 ± 10 Ma, 856 ± 15 Ma e 839 ± 9 Ma, e representam o grupo antigo. O corpo intrusivo gabro-diorítico Anicuns-Santa Bárbara e o complexo acamadado máfico-ultramáfico de Americano do Brasil são do final do Neoproterozóico e apresentam idades semelhantes. Quatro amostras do primeiro corpo indicaram idade

U-Pb em zircão de 598 ± 8 Ma, 612 ± 6 Ma, 623 ± 13 Ma e 622 ± 6 Ma, enquanto que frações de zircão de norito do Complexo Americano do Brasil possuem idade concordante de 626 ± 8 Ma. Todas as rochas máficas apresentam idade modelo T_{DM} de ca. 1,0 Ga, comparável às idades modelo das rochas metaígneas do Arco Magmático de Goiás. Valores de $\varepsilon_{Nd}(T)$ são fortemente positivos, indicativos da natureza depletada da fonte (MORB), similar às rochas vulcânicas e plutônicas das seqüências vulcano-sedimentares do arco, expostas a oeste. A associação litológica da seqüência supracustal de Anicuns é compatível com origem em ambiente oceânico ou de *fore-arc*.

As rochas máficas investigadas neste estudo correspondem a metabasaltos toleíticos a cálcio-alcalinos. Os elementos maiores e traços mostram características compatíveis com ambiente de arco de ilha, com enriquecimento em LILE e empobrecimento em HFSE. Nestes ambientes, enriquecimento em LILE é devido ao metasomatismo do manto por fluidos derivados da desidratação da placa oceânica subductante. As amostras de anfibolito da Seqüência Bonfinópolis, associadas com rochas metasedimentares do Grupo Araxá, a leste da área investigada, diferem das de Anicuns, e, provavelmente, representam fragmentos de fundo oceânico neoproterozóico.

Os valores de T_{DM} das rochas metasedimentares das seqüências Anicuns-Itaberaí e Córrego da Boa Esperança são muito distintos um do outro. As rochas metasedimentares da Seqüência do Córrego da Boa Esperança, com valores de T_{DM} entre 0,8 e 1,2 Ga, foram derivados principalmente da erosão de rochas juvenis do arco, enquanto que os da Seqüência Anicuns-Itaberaí indicam derivação a partir de fonte antiga, mais provavelmente paleoproterozóica.

Baseados em dados de campo, geocronológicos, isotópicos e geofísica regional, sugerimos que a seqüência supracrustal exposta na região de Anicus pode constituir-se em seqüência de arco/*fore-arc*, mancando o limite tectônico entre o Arco Magmático de Goiás e a parte oeste da placa do continente São Francisco.

CAPÍTULO I

1. INTRODUÇÃO

1.1 Objetivo

Na Faixa Brasília várias são as seqüências vulcano-sedimentares de idade e significado geotectônico indefinido. A área aqui escolhida para estudo é a da Seqüência Anicuns-Itaberaí. O entendimento da sua idade e do seu contexto geológico é de fundamental importância para a compreensão da evolução geológica da Faixa Brasília no Ciclo Brasiliano.

Até o presente estudo, a idade da Seqüência Anicuns-Itaberaí, bem como das áreas adjacentes, era desconhecida. Segundo Barbosa (1987), essa seqüência corresponderia à continuidade do *greenstone belt* arqueano da Serra de Santa Rita, exposto a norte ou, alternativamente, representaria uma seqüência paleoproterozóica tal como as de Silvânia e Rio do Peixe (Lacerda Filho et al., 1991; Fischel et al., 2001b) ou ainda a Seqüência Mossâmedes (Simões, 1984; Nunes, 1990). Corresponde a uma associação metavulcano-sedimentar composta dominantemente por anfibolitos de origem vulcânica e plutônica, metapelitos, cherts, mármores, formações ferríferas e rochas ultramáficas, limitadas à oeste por ortognaisses, referidos como do embasamento, e a leste pelos granulitos do Complexo Anápolis-Itauçu.

Pesquisas mais recentes na região, e áreas circunvizinhas, têm indicado a possibilidade desta área pertencer ao Arco Magmático de Goiás (Pimentel et al., 2000a, b; Piuzana et al., 2003a, b).

O presente trabalho tem por objetivo contribuir para o conhecimento da evolução geológica da Seqüência Anicuns-Itaberaí, na região de Anicuns e sua inclusão no contexto da Faixa Brasília, por meio da datação absoluta dos eventos magmáticos e de geração de crosta.

O trabalho seguiu as seguintes etapas:

- Datações U-Pb em zircão das principais unidades geológicas, para a ordenação dos eventos magmáticos;
- Após a obtenção das idades, amostras foram selecionadas para o estudo de geoquímica e geoquímica isotópica, principalmente de rochas máficas, com o objetivo de obter informações a respeito do ambiente geotectônico de formação dos magmas originais;
- Os resultados encontrados são comparados com os dados existentes na literatura e inseridos no contexto da Faixa Brasília.

1.2 Justificativas

A área foi escolhida por:

- Ser importante para o entendimento da geologia regional da Província Tocantins, pois está localizada num setor com significativa descontinuidade gravimétrica que separa a Seqüência Anicuns-Itaberaí do Complexo Anápolis-Itauçu, podendo indicar zona de sutura entre terrenos do embasamento da Faixa Brasília e o Arco Magmático de Goiás (Figura 1.1);
- Apresentar grande variedade de tipos litológicos, incluindo gnaisses tonalíticos, tidos como embasamento da seqüência, bem como rochas máficas, seqüências máfico-ultramáficas e granitos intrusivos, desconhecidos sob o ponto de vista geocronológico;
- A Seqüência Anicuns-Itaberaí é a seqüência vulcano-sedimentar mais extensa do sul de Goiás, e sempre foi considerada uma área metalogenética estratégica.

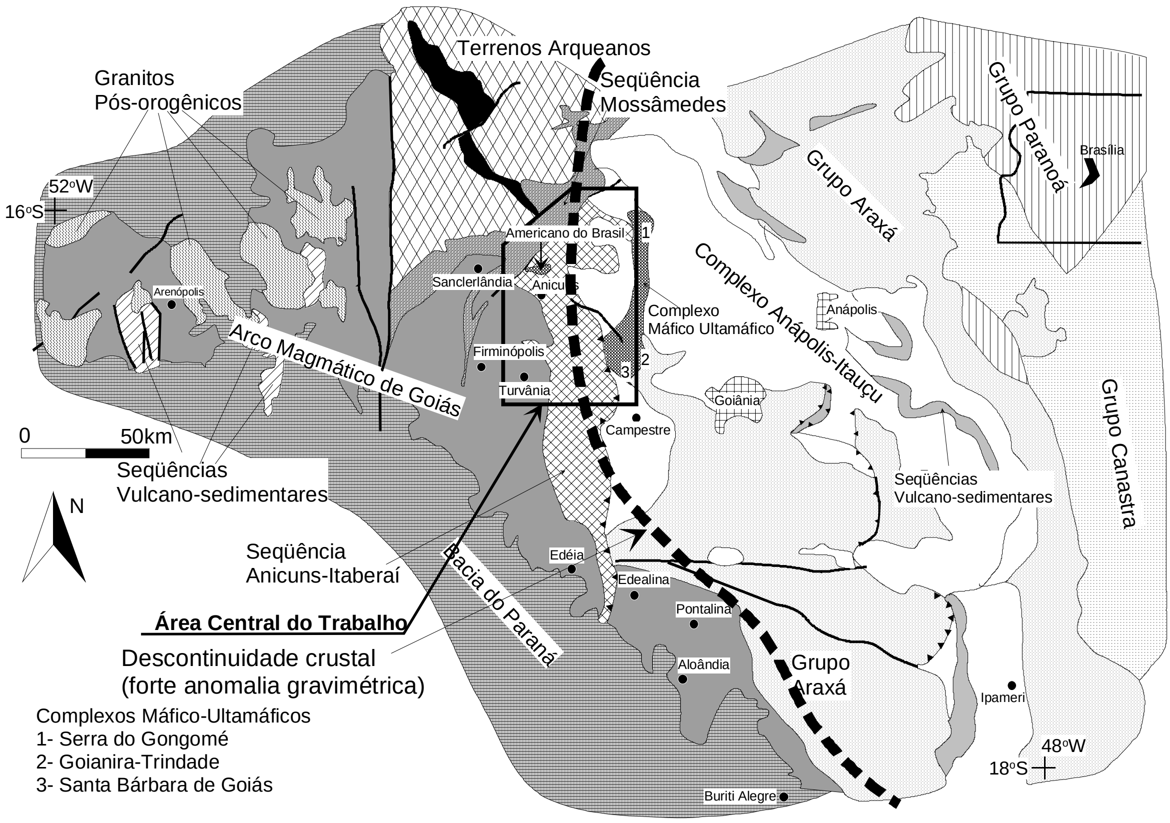

Figura 1.1. Mapa geológico esquemático do Arco Magmático de Goiás e da região compreendida neste trabalho (Pimentel et al., 2000a).

1.3 Materiais e Métodos

Foram utilizadas as bases cartográficas e geológicas das folhas 1:100.000 da CPRM – Itaberaí (Araújo, 1997), Sanclerlândia (Baêta Júnior et al., 1999) e Nazário (Baêta Júnior, 1994) (Figura 1.2), e dos trabalhos de Simões (1984) (1:25:000), Barbosa (1987) (1:25.000) e Nunes (1990) (1:25.000) (Figura 1.2).

Amostras das principais unidades geológicas identificadas nos trabalhos mencionados acima foram selecionadas para o estudo e todas analisadas para isótopos Sm-Nd. Algumas, em especial de rochas básicas, foram analisadas pelos métodos Pb-Pb, Sr-Sr e geoquímica de rocha total. As unidades geológicas mais importantes e adequadas para datação U-Pb em zircão foram escolhidas para análise. As análises foram feitas, preferencialmente, pelo método convencional, diluição isotópica no Laboratório de Geocronologia da Universidade de Brasília. Duas amostras foram analisadas pelo método SHRIMP.

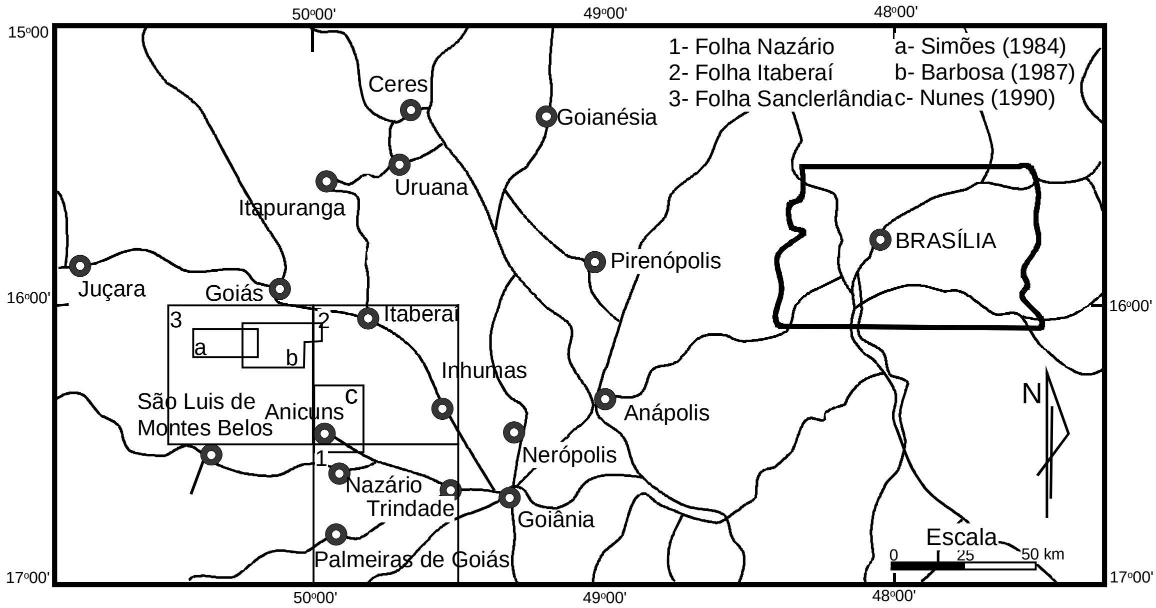

Figura 1.2. Mapa com a localização da base cartográfica e geológica usada no trabalho.

Descrições mais detalhadas dos métodos analíticos, geologia regional e local estão inseridos nos capítulos subseqüentes.

1.4 Histórico

Os primeiros trabalhos de cunho geológico na região centro-sul de Goiás se devem a Leinz e Leonardos (1936) associando os filitos e mica-xistos de uma região vizinha à cidade de Mossâmedes, à Série Minas. A mesma definição foi reafirmada por Leonardos (1938), Erichsen e Miranda (1939), Erichsen e Loefgren (1940) e Oliveira e Leonardos (1943).

Ramos (1958) correlaciona os xistos que se estendem de Mossâmedes a São Luiz dos Montes Belos à Série Araxá, assim como Hasui e Almeida (1970), Oliveira e Bittar (1971), Danni et al. (1973), Pena et al. (1975), Schobbenhaus et al. (1975), Simões (1984) e Barbosa (1987). Os trabalhos da CPRM consideram estas rochas como pertencentes à Seqüência Anicuns-Itaberaí de Barbosa (1987) (Baêta Júnior, 1994; Araújo, 1997; Baeta Júnior et al., 1999).

Hasui e Almeida (1970) obtiveram idade K/Ar de 585 Ma em xistos da borda sul da Serra Dourada. Simões (1984) divide as rochas da área em cinco unidades litoestratigráficas denominadas psamítica, psamo-pelítica, pelito-vulcânica inferior, pelito-vulcânica superior e gnáissica, além de quatro manifestações vulcânicas. Atualmente as duas primeiras unidades são colocadas como pertencentes à Seqüência Serra Dourada e a última ao Complexo Ortognáissico (Barbosa, 1987; Baêta Júnior, 1994; Araújo, 1997; Baeta Júnior et al., 1999). Simões (1984) descreveu que o vulcanismo associado ao Grupo Araxá possui característica geoquímica cálcio-alcalina, semelhante às de arcos de ilhas, mas, devido à configuração regional, sugere evolução semelhante às margens continentais ativas. Barbosa (1987) advoga filiação toleítica a cálcio-alcalina para estas rochas vulcânicas formadas em ambiente de arco de ilhas.

Pimentel et al. (1996) analisaram as rochas metavulcânicas da Unidade Pelito-vulcânica Inferior (Simões 1984), da região de Mossâmedes, e obtiveram isócrona Rb-Sr em rocha total de 1977 $\pm$ 55 Ma e razão inicial $^{87}Sr/^{86}Sr$ de 0,7023 $\pm$ 0,0003, sugerindo curta residência crustal do protolito. Análises Sm-Nd indicam T_{DM} de ca. 2,2 Ga. Um outro afloramento, da mesma seqüência, mostrou idade Rb-Sr, com quatro pontos, de 1582 $\pm$ 101 Ma e razão inicial $^{87}Sr/^{86}Sr$ de 0,7053, podendo indicar um evento de re-homogeneização isotópica do sistema Rb-Sr durante o Mesoproterozóico. Para estes autores, estas rochas não integram o Arco Magmático de Goiás, apesar de apresentarem assinatura geoquímica de arco vulcânico (Simões, 1984), nem fazem parte do Grupo Araxá, sendo melhor interpretadas como integrantes da extremidade sul do Maciço de Goiás.

1.5 Plano da Tese

A Tese foi organizada na forma de três artigos assim distribuídos:

- O primeiro intitulado: "**Mafic magmatism associated with the Goiás Magmatic Arc in the Anicuns region, Goiás, central Brazil: Sm-Nd isotopes and new ID-TIMS and SHRIMP U-Pb data**"; aceito pela revista Journal of South American Earth Sciences, e prevista para publicação no primeiro número de 2004;

- O segundo: "**Two Neoproterozoic crustal accretion events in the Brasília Belt, central Brazil**"; submetido à revista Journal of South American Earth Sciences;
- O terceiro: "**The Anicuns Volcano-Sedimentary Sequence at the limit between the juvenile Goiás Magmatic Arc and the western edge of the São Francisco Continent: new geochemical and Nd isotopic data for metabasic and metasedimentary rocks**", ainda não submetido para publicação;

O Capítulo de fechamento trará um apanhado dos principais conclusões presentes nos artigos.

CAPÍTULO II

O artigo foi aceito para publicação na revista Journal of South America Earth Sciences, com previsão para publicação no primeiro número de 2004,

Revisores: Randy Van Schmus,

Leo A. Hartmann,

Allen Fetter

Mafic Magmatism Associated with the Goiás Magmatic Arc in the Anicuns Region, Goiás, Central Brasil: Sm-Nd Isotopes and New ID-TIMS and SHRIMP U-Pb Data

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Alan Armele
Ariplinio Antônio Nilson

Abstract

Rocks exposed in the Anicuns region, in the eastern part of the Goiás Magmatic Arc are represented dominantly by amphibolites (metavolcanic and metaplutonic) and metapelitic rocks. New U-Pb results demonstrate that this association is Neoproterozoic and that mafic rocks crystallized during two main periods: (i) between ca. 890 and 815 Ma, and (ii) between ca. 630 and 600 Ma. Metagabbro and metadiorite samples JHL-14, JHL-15, JHL-23, AMB-01 and JHL-26B have U-Pb zircon ages of 886 ± 5 Ma, 862 ± 5 Ma, 815 ± 10 Ma, 856 ± 15 Ma, and 839 ± 9 Ma, respectively, and comprise the older group. The Late Neoproterozoic intrusive Anicuns-Santa Bárbara gabbro-diorite and Americano do Brasil suites are coeval. Four samples of the first (SB-01, JHL-04, JHL-22C and JHL-19) yielded U-Pb ages of 598 ± 8 Ma, 612 ± 6 Ma, 623 ± 13 Ma and 622 ± 6 Ma, respectively, whereas zircon grains from one norite sample of the Americano do Brasil Complex yielded a concordia age of 626 ± 8 Ma. All mafic rocks investigated present T_{DM} model ages of ca. 1.0 Ga, comparable to model ages of metaigneous rocks of the Goiás Magmatic Arc. $\varepsilon_{Nd}(T)$ values are strongly positive, indicative of the depleted nature of the mantle source (MORB-like), similarly to volcanic and plutonic rocks of the arc-type volcano-sedimentary sequences exposed to the west. The lithological associations comprising the supracrustal sequences in the Anicuns area, however, are compatible with origin in an oceanic or fore-arc setting, rather then in an intraoceanic arc setting (rocks of andesitic/dacitic/rhyolitic composition are absent). $^{147}Sm/^{144}Nd$ ratios for most of the mafic rocks investigated, however, are smaller than 0.19 and indicate a relative enrichment in LREE, which is not characteristic of N-MORB mafic magmas.

2.1 INTRODUCTION

The Goiás Magmatic Arc in central Brazil, consists of several arc-type metavolcano-sedimentary sequences associated with tonalitic to granitic orthogneisses, forming an extensive Neoproterozoic juvenile terrain along the western part of the Brasília Belt (Pimentel and Fuck, 1992; Pimentel et al., 2000a). Mafic volcanic and plutonic rocks are associated with voluminous calc-alkaline andesites, dacites, and rhyolites in some of these sequences (e.g. Bom Jardim de Goiás and Arenópolis; Seer, 1985; Pimentel and Fuck, 1986), but they also form bimodal associations with rhyolites in others (e.g. Iporá and Jaupaci sequences). The metavolcanic rocks typically present very primitive geochemical and isotopic characteristics, with low initial $^{87}Sr/^{86}Sr$ ratios and positive $\varepsilon_{Nd}(T)$ values. Felsic metavolcanic rocks have U-Pb zircon ages between ca. 0.9 and 0.64 Ga (Pimentel et al., 1991; Rodrigues et al., 1999). Most of the previous isotopic, geochronological and petrological studies concentrated on intermediate to felsic members of this magmatism, and little is known about the associated mafic rocks. Fine-grained amphibolites of the Arenópolis volcano-sedimentary sequence are probably the best known representatives of these Neoproterozoic mafic metavolcanic rocks. They comprise low-K tholeiites to calc-alkaline metabasalts, with primitive isotopic compositions (initial $^{87}Sr/^{86}Sr$ of ca. 0.7026 and $\varepsilon_{Nd}(T)$ of ca. +6.9; Pimentel, 1991), representing the early stages of development of an intraoceanic island arc system. Small metamorphosed gabbro-diorite intrusions are also recognized within the Arenópolis Sequence, and one has been recently dated at 890 ± 9 Ma (SHRIMP U-Pb zircon age; Pimentel et al., 2003), corresponding to plutonic/subvolcanic equivalent of the volcanic sequence.

The Anicuns-Itaberaí Sequence, exposed along the contact between the eastern part of the Goiás Magmatic Arc and the Anápolis-Itauçu high-grade terrain, is represented dominantly by amphibolites (metavolcanic and metaplutonic) and metapelitic rocks, with subordinate iron formations, cherts, marbles, and ultramafic rocks of uncertain age. It has been correlated, in the past, with the Archean Serra de Santa Rita greenstone belt, exposed to the north (Barbosa, 1987), or with Paleoproterozoic sequences such as the Silvânia Sequence within the Anápolis-Itauçu Complex (Lacerda Filho et al., 1991) and the Mossâmedes volcanics (Nunes, 1990). Recent studies based mainly on Sm-Nd isotopic characteristics of the Anicuns-Itaberaí rocks, however, suggest that they are considerably younger and might be part of the Neoproterozoic Goiás Magmatic Arc (Pimentel et al., 2000a, b; Laux et al., 2001, 2002a, b) (Tables 2.1a, b, c).

In this paper we discuss new U-Pb and Sm-Nd isotopic data from coarse-grained mafic rocks exposed within the Anicuns-Itaberaí Sequence, which demonstrate that this rock assemblage belongs to the Goiás Magmatic Arc and was formed during at least two main episodes in the Neoproterozoic.

Table 2.1a Summary of previous Sm-Nd results of the area.

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ (± 1σ)	T_{DM},(Ga)	Referen.
AMB-1	3.02	14.34	0.127	0.512396 (13)	1.13	1,2
AMB-2	3.32	15.41	0.133	0.512526 (12)	0.97	1,2
FSP-2635	1.88	07.66	0.148	0.512596 (24)	1.03	1,2
PONT-1	7.34	45.09	0.098	0.512317 (23)	0.96	2
PONT-2	8.40	41.54	0.122	0.512438 (07)	0.91	2
PONT-3	3.81	21.96	0.105	0.512296 (45)	1.06	2
PONT-4A	3.63	24.08	0.091	0.512249 (21)	0.99	2
PONT-4B	7.01	39.92	0.106	0.512164 (12)	1.23	2
PONT-4C	5.01	19.50	0.155	0.512570 (05)	1.10	2
MP-593E	11.72	72.7	0.097	0.511353(24)	2.21	3
MP-593I	10.78	66.3	0.098	0.511350(20)	2.42	3

1-Gioia (1997); 2- Pimentel et al., (2000b); 3- Pimentel et al., (1997).

Table 2.1b Summary of previous Sm-Nd whole-rock isochron age of the area.

Americano do Brasil Layered Complex	614 ± 82	0.9	+2.4	1
Pontalina	762 ± 77	3.3	+2.9	2

1-Gioia (1997); 2- Pimentel et al., (2000b).

Table 2.1c Summary of previous Rb-Sr whole-rock isochron age of the area.

Mossâmedes Sequence	1582 ± 101	0.70527	1
Mossâmedes Sequence	1978 ± 55	0.70232	1
Gongomé Intrusion	637 ± 19	0.70153	2

1- Pimentel et al., (1997); 2- Winge (1995).

2.2 REGIONAL GEOLOGICAL SETTING

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

The Brasília Belt represents one of the best preserved and the most complete Neoproterozoic orogens in Brazil, comprising: (i) a thick Meso-Neoproterozoic sedimentary pile that includes the Paranoá, Canastra, Araxá, Ibiá, Vazante, and Bambuí groups, overlying mostly 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 micro-continent (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) (Fig. 2.1).

The several sedimentary/metasedimentary rock 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 facies conditions in the central part of the belt (Fuck et al., 1993, 1994; Dardenne, 2000).

Metasedimentary rocks belonging to the Araxá and Canastra groups underlie large areas in the central-southern part of the Brasília Belt (Figs. 2.1 and 2.2). Nappes and thrust sheets of these units overlie Paleoproterozoic basement represented by 2.1 Ga volcano-sedimentary sequences and associated granites (e.g. Silvânia and Rio do Peixe sequences and Jurubatuba granite; 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. 2.1 and 2.2). They include para- and orthogranulites, as well as strongly deformed intrusive granites. Recent data have indicated that the

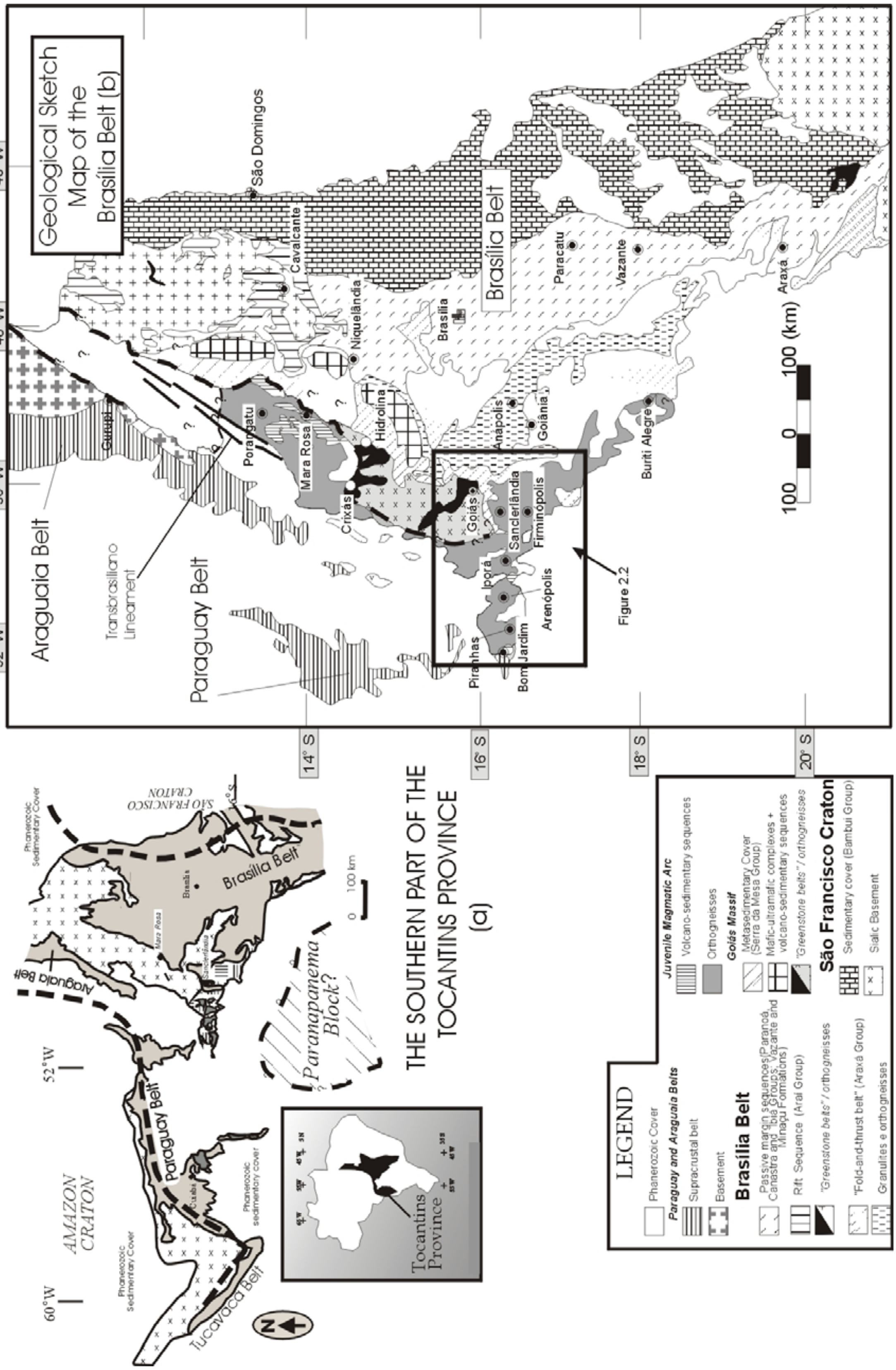


Figure 2.1 - Geological sketch map of the Brasília Belt in the eastern part of Tocantins Province, central Brazil (after Fuck et al., 1994).

Nd Isotopic signatures and metamorphic ages of the Araxá metasediments, Anápolis-Itauçu felsic granulites, and intrusive granites are all very similar (Fischel et al., 1998, 1999; Pimentel et al., 1999, 2001; Seer, 1999), demonstrating that at least part of the aluminous granulites of the Anápolis-Itauçu Complex may represent high-grade equivalents of the Araxá metasedimentary rocks. Therefore, source areas of the original Araxá sediments may have included Neoproterozoic juvenile areas such as the Goiás Magmatic Arc (Fischel et al., 1998, 1999; Pimentel et al., 1999, 2001; Piuzana et al., 2003a).

In the central part of the Brasília Belt is the Goiás Massif (Fig. 2.2), represented by: (i) Archean greenstone belts and TTG orthogneisses; (ii) Paleoproterozoic orthogneisses largely covered by younger supracrustal rocks; (iii) and mafic-ultramafic layered complexes of Barro Alto, Niquelândia, and Canabrava 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 massif is interpreted as an allochtonous block amalgamated to the Brasília Belt during the Neoproterozoic (Brito Neves and Cordani, 1991; Pimentel et al., 2000b).

The Neoproterozoic juvenile arc (Goiás Magmatic Arc) is composed of volcano-sedimentary sequences associated with calcic to calc-alkaline tonalite/granodiorite gneisses (Fig. 2.2). The main arc terranes are known as the Arenópolis and Mara Rosa arcs, located in western and northern Goiás, respectively (Pimentel and Fuck, 1992; Pimentel et al., 1991, 1997). In both areas, geological evolution started at ca. 890-860 Ma in intraoceanic island arcs with the crystallization of very primitive tholeiitic to calc-alkaline volcanics and associated tonalites/granodiorites. These rocks have $\varepsilon_{Nd}(T)$ values between ca. +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, commonly positioned above subduction zones where young and hot oceanic lithosphere was subducted under oceanic lithosphere. 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.

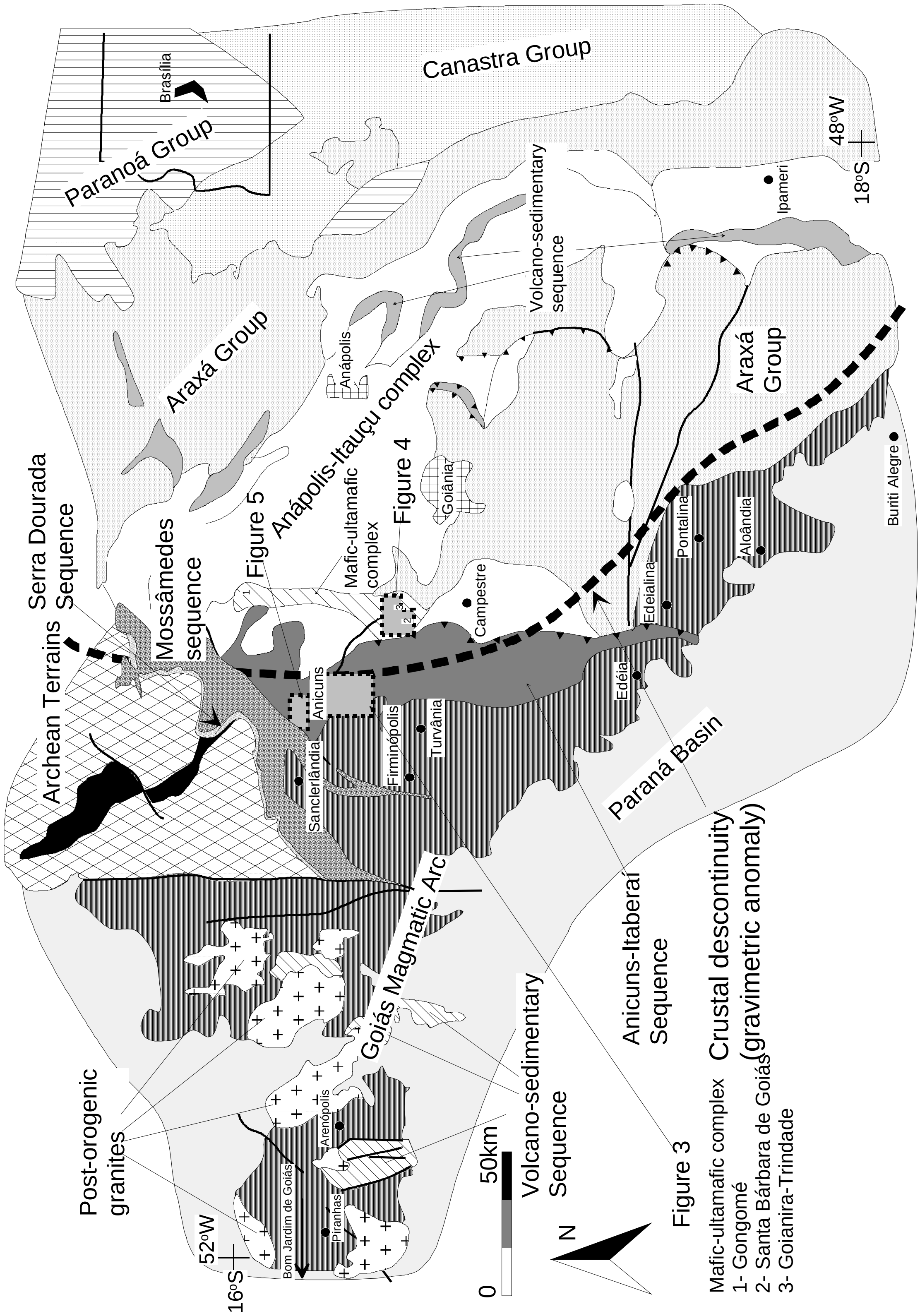


Figure 2.2 - Geological sketch map of the southern part of the Goiás Magmatic Arc, with the location of the studied areas (Pimentel et al., 2000a).

There has been considerable debate on the real areal distribution of these juvenile terrains, since geochronological and isotopic data are still sparse and insufficient. Recent U-Pb and Sm-Nd data have shown that the juvenile arc extends to the southeast and northeast, disappearing under the Paraná and Parnaíba Phanerozoic basins, respectively (Figs. 2.1 and 2.2). They underlie a very large area, which constitutes a significant portion of the Brasília Belt (Pimentel et al., 2000a; Fuck et al., 2001). In this context, the Anicuns-Itaberaí sequence represents a key geological unit for the understanding of the evolution of the Goiás Magmatic Arc and adjacent terrains because: (i) it represents one of the largest supracrustal sequences within this tectonic unit, (ii) it has been traditionally considered to be an Archean or Paleoproterozoic greenstone sequence, and (iii) it coincides with a regionally important gravimetric discontinuity, separating a gravimetric high to the west and a gravimetric low to the east (Baêta Junior, 1994). Zircon crystals from amphibolites intercalated with metasedimentary rocks of the Anicuns-Itaberaí Sequence (AIS) and from intrusive mafic-ultramafic bodies were dated mainly with conventional ID-TIMS U-Pb methods and their Nd isotopic compositions were investigated in order to provide means of comparison with mafic rock units from other sequences within the Goiás Magmatic Arc.

2.3 GEOLOGY OF THE ANICUNS REGION

In the Mossâmedes-Anicuns region (Figs. 2.2 and 2.3), Barbosa (1987) recognized three distinct supracrustal sequences and assigned different ages to them based on field relationships and structural data: (i) the Anicuns-Itaberaí Sequence (AIS) was interpreted as the southern extension of the Serra de Santa Rita (Goiás Velho) greenstone belt, (ii) the Mossâmedes Sequence (Simões, 1984), west/northwest of Anicuns, has been interpreted to be of Mesoproterozoic age, equivalent to the Araxá Group, and (iii) a younger detrital sequence (conglomerates, quartzites and schists) forming the roughly E-W Serra Dourada ridge to the north. The north/south supracrustal sequence, referred to as the Anicuns-Itaberaí Sequence

(AIS) by Barbosa (1987), has been divided into two distinct geological units by Nunes (1990): (i) the Córrego da Boa Esperança Sequence (CBES) in the west has been correlated with the Araxá Group and consists of metapelites, andesitic/dacitic meta-tuffs, and iron formation (Nunes, 1990) (Fig. 2.3); (ii) the AIS in the east, separated from the CBES by a NNW reverse fault, is composed of mafic/ultramafic metavolcanic rocks, metacherts, metarhytmites, and marble lenses. It was correlated with the Serra de Santa Rita greenstone belt (Fig. 2.2).

Both Nunes (1990) and Barbosa (1987) have suggested that the metavolcanic rocks in this region have calc-alkaline or calc-alkaline/tholeiitic nature, indicating a magmatic arc setting for their origin.

Three generations of granitic rocks, as well as small mafic and mafic-ultramafic bodies are intrusive into the supracrustal sequences. The granitoid intrusions are tonalites, granodiorites, and granites with subordinate quartz syenite, monzonites, and monzodiorites (Barbosa, 1987; Nunes, 1990).

The mafic/intermediate intrusions are collectively referred to as the Anicuns-Santa Bárbara Gabbro-Diorite Suite (Lacerda Filho and Oliveira, 1995). Two examples of this suite, the Córrego Seco (Nunes, 1990) and Santa Bárbara (Silva and Nilson, 1990) intrusions, were investigated in this study (Figs. 2.3 and 2.4). The Córrego Seco Complex (Fig. 2.3) comprises gabbro, diorite and amphibolite and, in some places, crosscutting relationships with the AIS are observed. This complex has been correlated with the Americano do Brasil intrusion, exposed to the north of the AIS (Pfrimer et al., 1981; Nunes, 1990) (Fig. 2.5). The Santa Bárbara Gabbro-Anorthosite Complex (Fig. 2.4) is made up dominantly of metagabbro and meta-anorthosite, with minor ultramafic rocks; it has been interpreted as a metamorphosed layered mafic-ultramafic intrusion (Silva and Nilson, 1990).

The Americano do Brasil Mafic-Ultramafic Suite comprises small layered bodies known as the Americano do Brasil, Mangabal I, Mangabal II, Adelândia, Fronteira do Norte, Palmeiras, and Serra do Gongomé, exposed to the north of the investigated area (Pfrimer et al., 1981; Nilson 1981, 1984; Candia and Girardi, 1985; Winge, 1995). The Americano do Brasil intrusion (Fig. 2.5) includes metagabbro, metagabbronorite, olivine gabbro, amphibolite, metadunite, metaperidotite, metapyroxenite, and hornblendite (Nilson, 1984). The Serra do Gongomé and Americano do Brasil complexes have been dated at 637 ± 19 Ma and 610 ± 50 Ma, by Rb-Sr and Sm-Nd whole-rock isochrons, respectively (Winge, 1995; Gioia, 1997) (Table 2.1b). The high initial Sr isotopic ratio of the Gongomé intrusion (0.7153) indicates interaction with older continental crust, whereas the positive $\varepsilon_{Nd}(T)$ value (approximately +2.4) of the Americano do Brasil original magma indicates little or no contamination with ancient sialic crust.

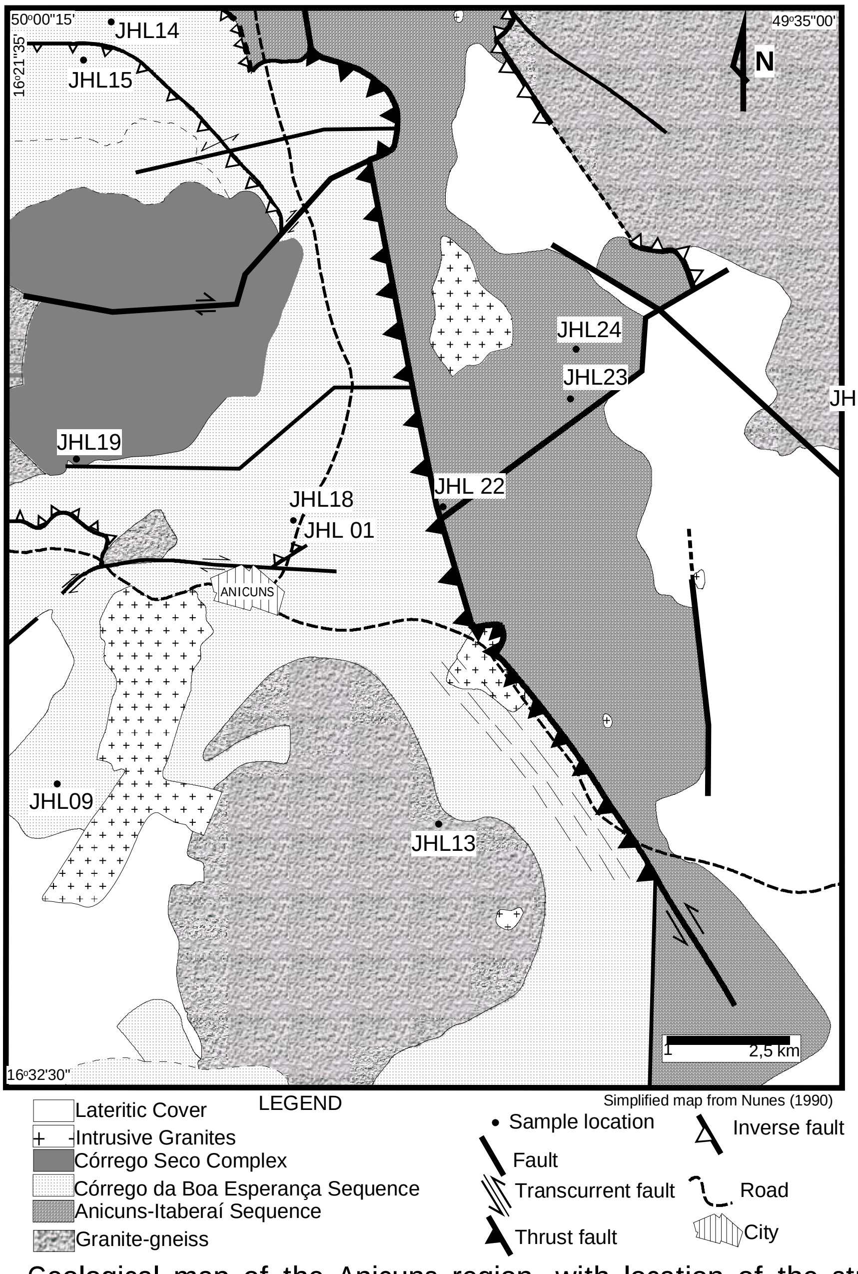


Figure 2.3 - Geological map of the Anicuns region, with location of the studied samples (simplified from Nunes, 1990).

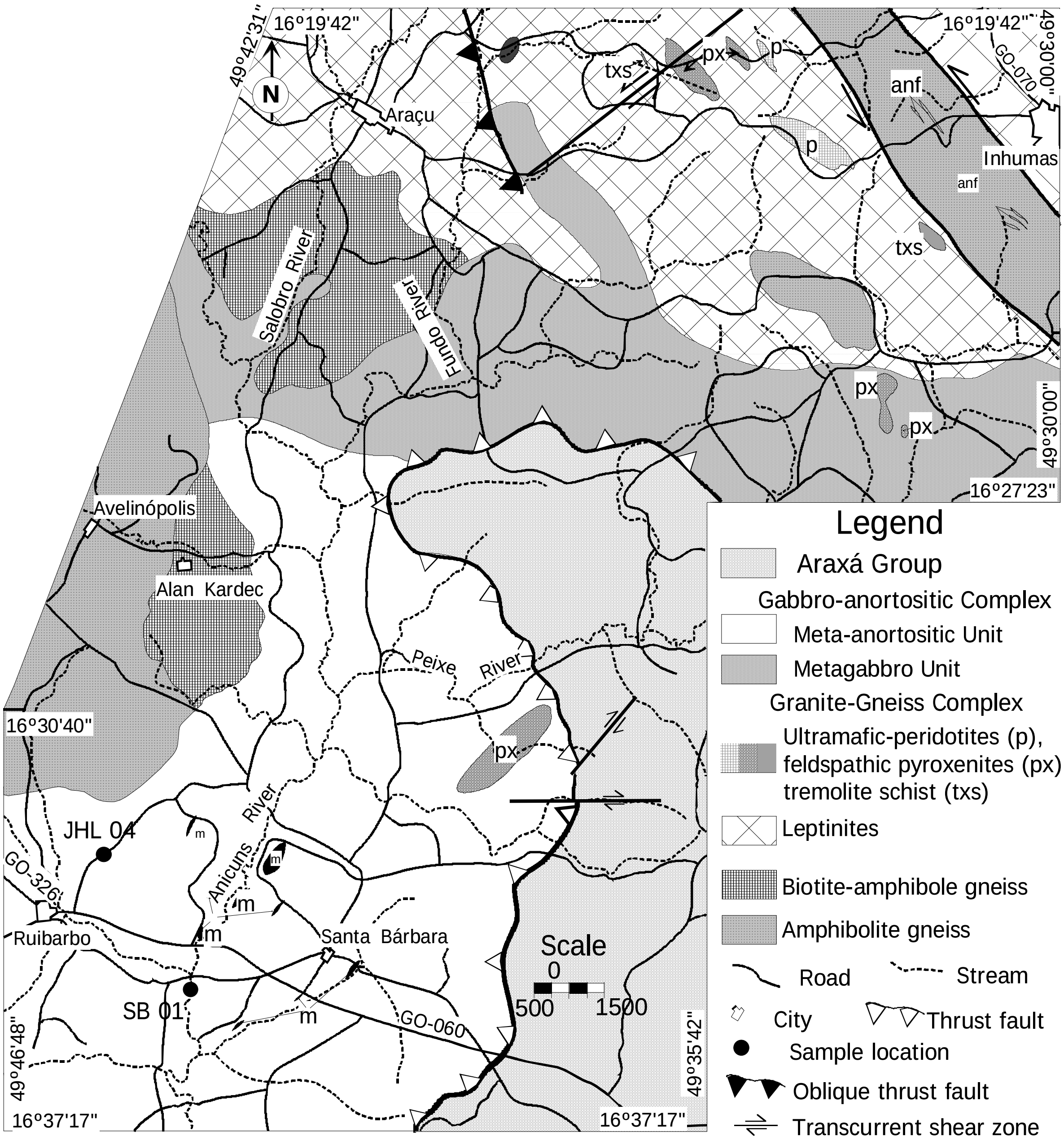


Figure 2.4 - Geological map of the Santa Bárbara de Goiás-Inhumas region, Goiás Brazil (after Silva and Nilson, 1990).

2.4 ANALYTICAL PROCEDURES

Zircon concentrates were extracted from ca. 10 kg rock samples, using conventional gravimetric (DENSITEST®) and magnetic (Frantz isodynamic separator) techniques at the Geochronology Laboratory of the University of Brasília. Final purification was achieved by hand picking using a binocular microscope.

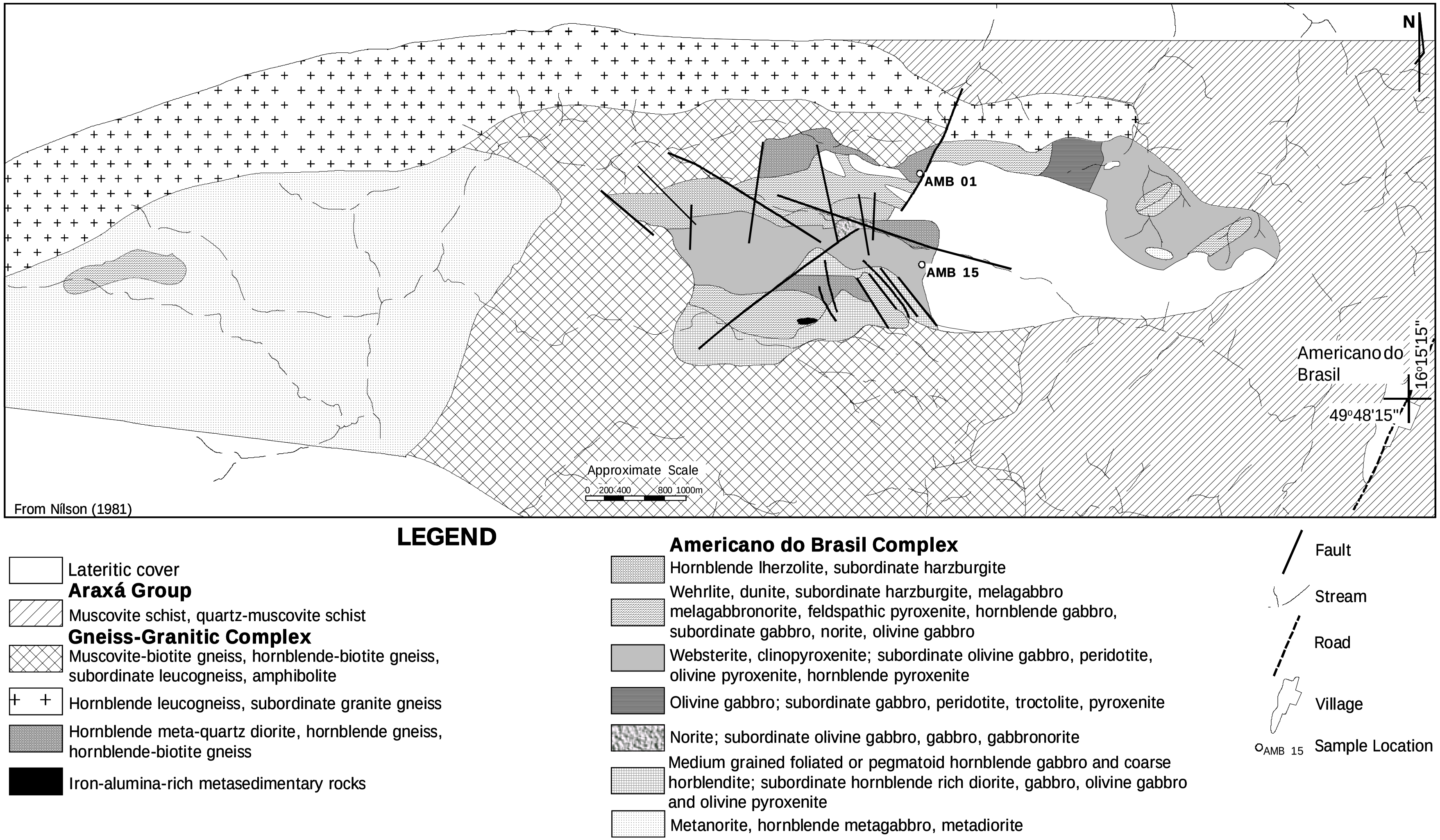


Figure 2.5 - Geological map of the Americano do Brasil Layered Complex (from Nilson, 1981).

For 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 onto single Re filaments with H_3PO_4 and silica gel, and isotopic analyses were carried out at the Geochronology Laboratory of the University of Brasília on a Finnigan MAT-262 multi-collector mass spectrometer equipped with secondary electron multiplier - ion counting. 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 levels. 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 of Sm/Nd and

$^{143}Nd/^{144}Nd$ ratios are better 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 the DePaolo (1981) model.

2.5 RESULTS AND DISCUSSION

Nine new ID-TIMS ages and one SHRIMP U-Pb age, as well as sixteen new Sm-Nd isotopic results of mafic rocks of the Anicuns region are discussed in this work (Fig. 2.6). Mafic rocks from the four main distinct geological units recognized in the area have been investigated: Córrego da Boa Esperança and Anicuns-Itaberaí sequences, the Anicuns-Santa Bárbara Gabbro-Diorite Intrusive Suite, and the Americano do Brasil intrusion. One additional diorite sample (AMB-01) representing the country-rocks of the Americano do Brasil intrusion was also studied.

2.5.1 Córrego da Boa Esperança Sequence

Zircon crystals from two amphibolite samples within the Córrego da Boa Esperança Sequence [samples JHL-14, JHL-15 (Fig 2.3) (Tables 2.2 and 2.3)] were dated by the U-Pb method. JHL-14 is an amphibole-garnet schist, most likely derived from a gabbro. Zircon grains separated from this sample were analysed using SHRIMP-RG. Cathodoluminescence images reveal that the zircon grains present well developed sector zoning typical of crystals formed from mafic magmas (Fig. 2.7b). Analyses of 13 spots on 12 zircon grains yield a concordia age of 886 ± 5 Ma (Fig. 2.7a), interpreted as the crystallization age of the original magma. The date is identical, within error, to the SHRIMP U-Pb age observed for the Morro do Baú intrusion within the Arenópolis Volcano-Sedimentary Sequence, in the western part of the Goiás Magmatic Arc (Pimentel et al., 2003). Sm-Nd isotopic analysis of the JHL-14 sample yielded a strongly positive $\varepsilon_{Nd}(T)$ of +4.4, indicative of the depleted nature of the mantle source (Table 2.4).

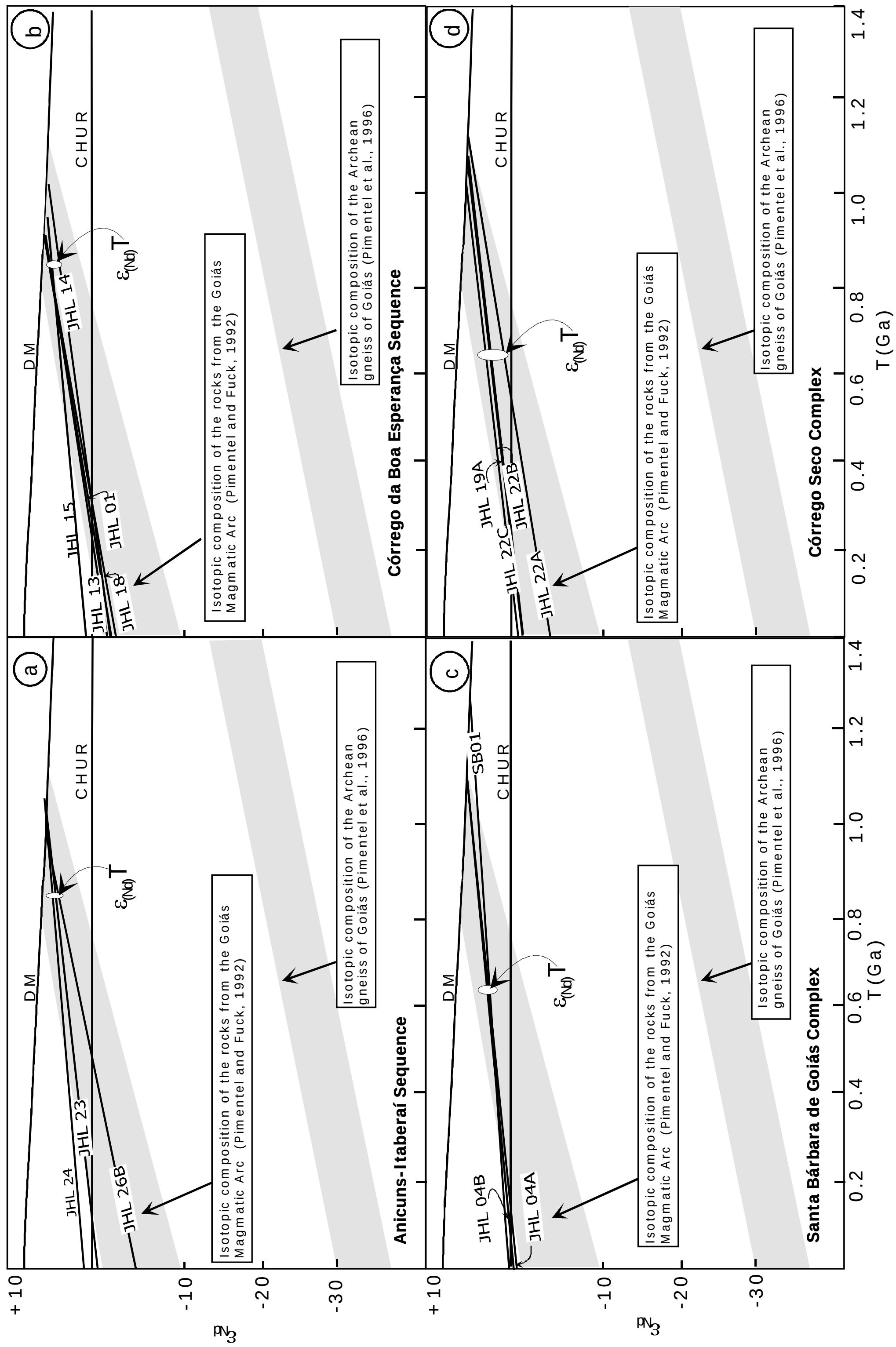
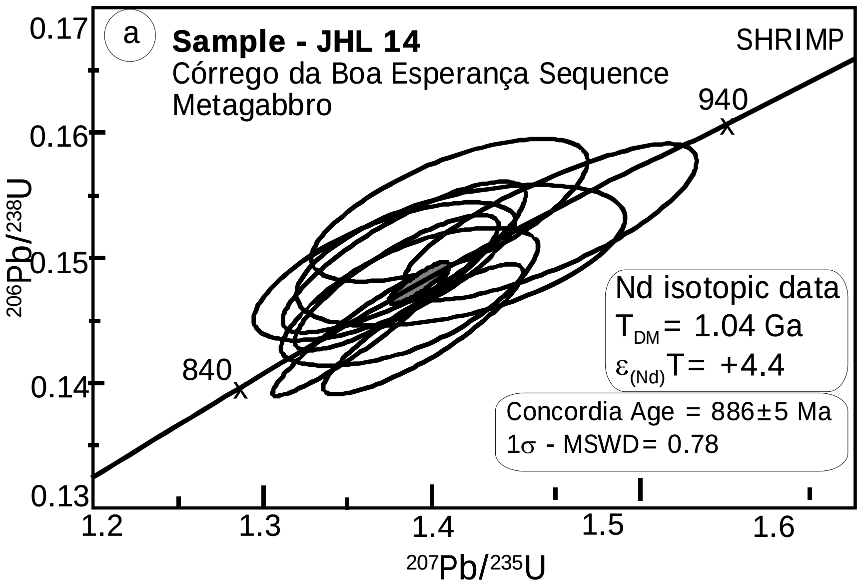


Figure 2.6 - Evolution diagram of ε_{Nd} x Time, showing patterns similar to Goiás Magmatic Arc of Pimentel and Fuck (1992); (a) Córrego da boa Esperaça Sequence, (b) Anicuns-Itaberaí Sequence, (c) Santa Bárbara de Goiás Complex, (d) Córrego Seco Complex.

Sample JHL-15 is an amphibole schist, which is most likely also derived from the metamorphism and deformation of a small plutonic or sub-volcanic intrusion. Zircon grains in this sample form yellow, long prismatic crystals. Four zircon fractions define a discordia indicating the upper intercept age of 862 ± 5 Ma (Fig. 2.8a). Sm-Nd isotopic composition of this sample also indicate derivation of the original mafic magma from a depleted mantle source, with ε_{Nd}(T) of +5.5 (Table 2.4). Other amphibolite samples associated with the Córrego da Boa Esperança Sequence, samples JHL-1, JHL-9, JHL-13, and JHL-18, also present positive ε_{Nd}(T) values between +4 and +5 at T = 830 Ma (reference Sm-Nd isochron age – Fig. 2.9), with T_{DM} values of ca. 1.0 Ga (Table 2.2). Samples JHL-1 and JHL-18 are fine-grained amphibolites/metabasalts, whereas JHL-9 and JHL-13 are metagabbros.



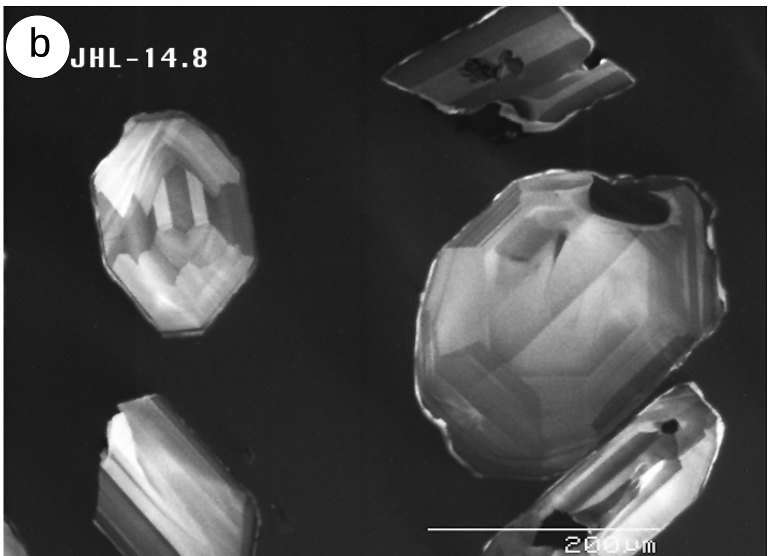


Figure 2.7 - SHRIMP U-Pb concordia diagram for sample JHL-14 (a), and zircon cathodoluminescence images (b).

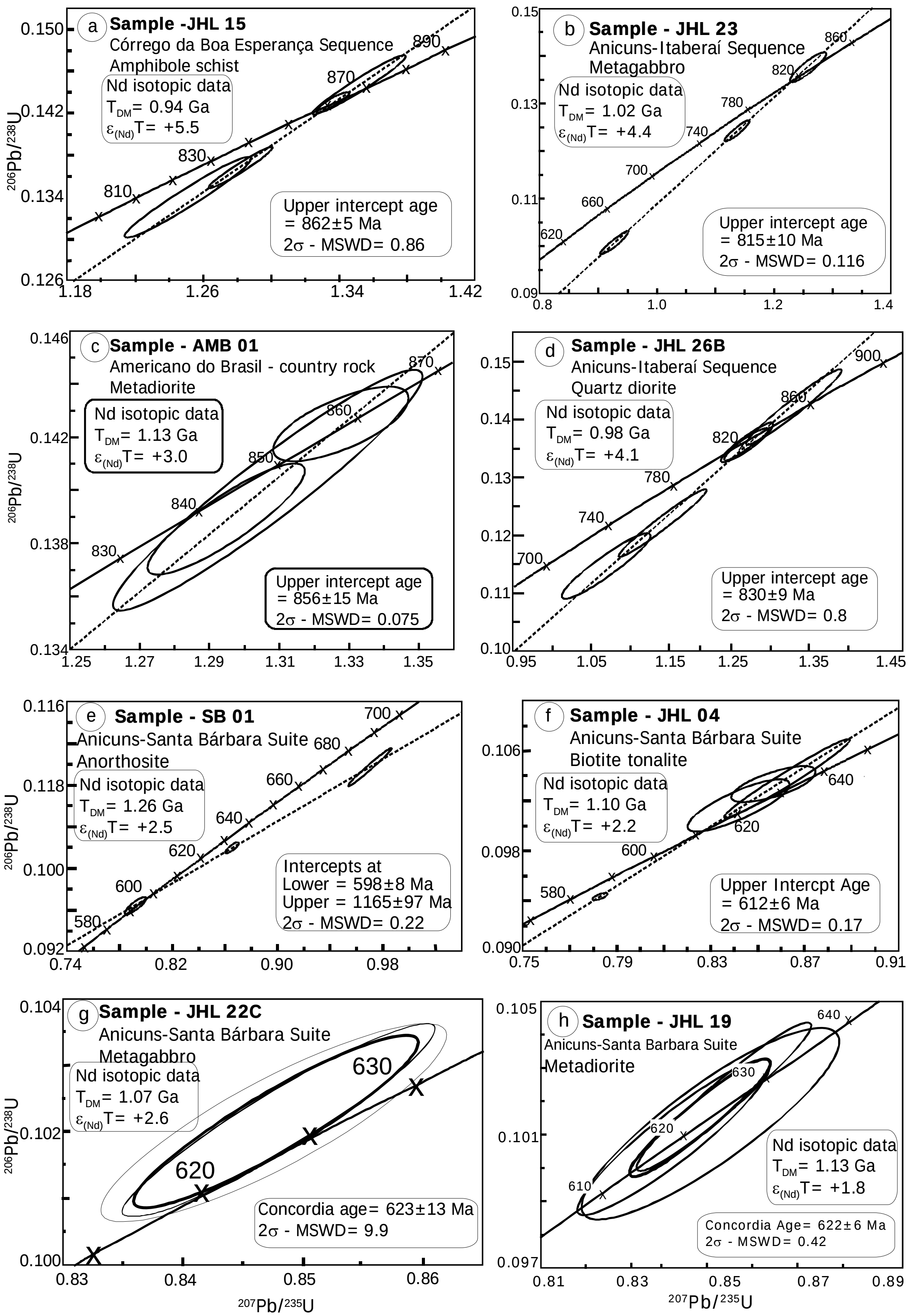


Figure 2.8 - ID-TIMS U-Pb concordia diagram for Anicuns-Itaberaí Sequence (b, d); Córrego da Boa Esperança Sequence (a); Córrego Seco Complex (g, h); Santa Bárbara de Goiás Complex (e, f); and Americano do Brasil Layered Complex dioritic country rock (c).

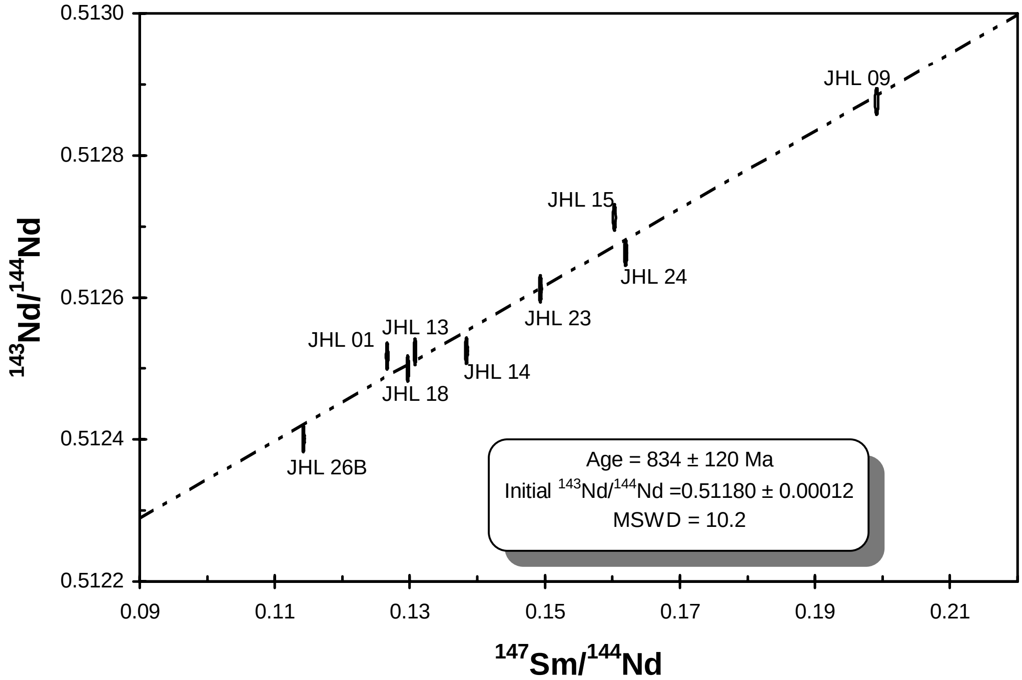


Figure 2.9 – Reference Sm-Nd whole-rock isochron for the mafic rocks.

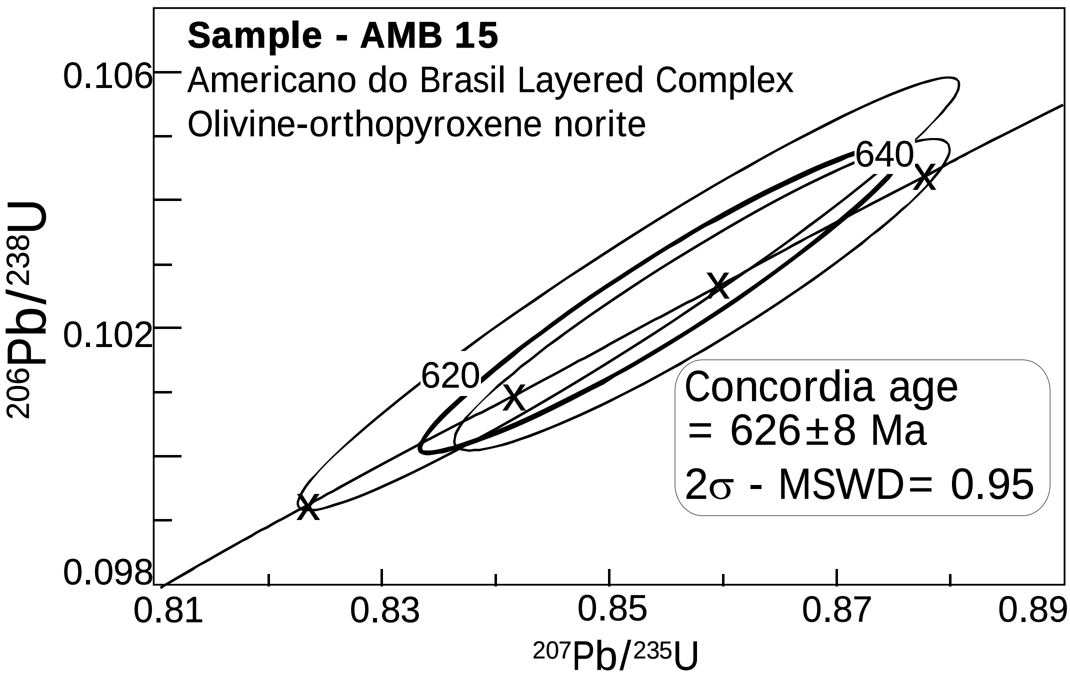


Figure 2.10 – ID-TIMS U-Pb concordia diagram for Americano do Brasil Layered Complex.

2.5.2 Anicuns-Itaberaí Sequence

Two samples from the Anicuns-Itaberaí Sequence were studied (Table 2.3). Sample JHL-26B is a quartz diorite with preserved igneous texture, whereas JHL-23 is a coarse-grained amphibolite (metagabbro). Zircon grains from JHL-26B are prismatic and yellowish, and the analyses of five zircon fractions align along a discordia indicating the upper intercept age of 830 ± 9 Ma (Fig. 2.8d). The Nd isotopic composition of this sample reveals the depleted nature of the mantle source with an ε_{Nd}(T) of +4.1 (Table 2.4).

Zircon grains separated from JHL-23 are prismatic and brownish yellow, and they yielded an upper intercept age of 815 ± 10 Ma (Fig. 2.8b), interpreted as the igneous crystallization age, and identical, within uncertainty, to the age of sample JHL-26B. The Nd isotopic composition also demonstrates origin from a depleted mantle, with an ε_{Nd}(T) of +4.4 (Table 2.4).

An additional amphibolite sample of this sequence has ε_{Nd}(850 Ma) of +4.3 and T_{DM} model age of 0.98 Ga (Table 2.4) (reference Sm-Nd isochron age – Fig. 2.9).

2.5.3 Anicuns-Santa Bárbara Gabbro-Diorite Suite

Four selected samples from the Anicuns-Santa Bárbara Gabbro-Diorite Suite were investigated (JHL-22C, JHL-19, JHL-04, SB-01; Figs. 2.3 and 2.4; Table 2.3). Sample JHL-19 corresponds to a diorite belonging to the Córrego Seco Complex, intrusive into the Córrego da Boa Esperança Sequence. Zircon crystals are colorless and needle-shaped, and yield the concordia age of 622 ± 6 Ma (Fig. 2.8h). Nd isotopic composition indicates derivation of the original magma from a depleted mantle source, with an ε_{Nd}(T) of +1.8 (Table 2.4). Sample JHL-22C is an amphibolite/metagabbro intrusive into the Anicuns-Itaberaí Sequence. Analyses of two zircon fractions are semi-concordant indicating the crystallization age of 623 ± 13 Ma (Fig. 2.8g), identical, within error, to sample JHL-19. Initial Nd isotopic characteristics also indicate a depleted mantle source (ε_{Nd}(T) = +2.6) (Table 2.4). Samples JHL-04 and SB-01 are from the Santa Bárbara de Goiás Complex (Silva and Nilson, 1990). Anorthosite SB-01 has anhedral, colorless zircon crystals. One concordant analysis indicates the $^{206}Pb/^{238}U$ age of 594 ± 10 Ma. The other two analytical points seem to have incorporated some inherited Pb. A discordia line through the three points indicates a lower intercept age of 598 ± 8 Ma, interpreted as the crystallization age, and the upper intercept age of 1165 ± 97 Ma, suggesting Mesoproterozoic inheritance (Fig. 2.8e). Sample JHL-04 is a biotite tonalite with an upper intercept zircon age of 612 ± 6 Ma (Fig. 2.8f), interpreted as the age of igneous crystallization of the original magma. Nd isotopic characteristics of Santa Bárbara samples also indicate derivation of the original magma from a depleted mantle with ε_{Nd}(T) values between +2.2 and +2.5 (Table 2.4). Sample SB-01 (Santa Bárbara de Goiás Anorthosite) displays a slightly older T_{DM} value of 1.25 Ga (Table 2.4), suggesting a small contribution from an older source, which is also indicated by the inheritance pattern observed for that sample.

Two additional samples of the Anicuns-Santa Bárbara Gabbro-Diorite Suíte (JHL-22a and b) present ε_{Nd}(T= 630 Ma) of + 0.8 and +2.6, respectively, and a T_{DM} of ca. 1.0 Ga.

2.5.4 Americano do Brasil Layered Complex

Zircon grains separated from one sample of the Americano do Brasil intrusion and one from a country-rock diorite have been investigated (Table 2.3). Sample AMB-15 is an olivine-othopyroxene norite and zircon grains separated from it are anhedral, light brown, and produced two concordant analyses with the age of 626 ± 8 Ma (Fig. 2.10). Initial Nd isotopic composition indicated by the whole-rock Sm-Nd isochron of this rock unit (Gioia, 1997) also indicates origin of the parental basic magma from a depleted mantle source (ε_{Nd}(T) of +2.4).

Sample AMB-01 is a metadiorite with preserved igneous texture, representing the country rocks of the Americano do Brasil intrusion. The prismatic zircon grains analyzed result in concordant to semi-concordant analytical points indicating the crystallization age of 856 ± 15 Ma (Fig. 2.8c). The ε_{Nd}(T) value of this sample is positive (+3.0), indicating the primitive nature of the original magma.

2.6 CONCLUSIONS

The new U-Pb results demonstrate that mafic rocks associated with the Anicuns-Itaberaí and Córrego da Boa Esperança sequences are Neoproterozoic and crystallized during two main time intervals: (i) between ca. 890 and 815 Ma, and (ii) between ca. 630 and 600 Ma. The geochronological results, coupled with field data and Nd isotopic characteristics of metasedimentary rocks of the supracrustal associations (Laux et al., 2001), suggest that the Anicuns-Itaberaí and Córrego da Boa Esperança sequences are roughly of the same age. This is also demonstrated by a reference Sm-Nd isochron age for amphibolite samples of the Anicuns-Itaberaí and Córrego da Boa Esperança sequences (Fig. 2.9), showing also that the original magmas of amphibolites from both sequences have similar ε_{Nd}(T), suggesting similar petrogenetic processes and perhaps same tectonic setting of origin.

Although the Anicuns-Santa Bárbara gabbro-diorite and Americano do Brasil suites have the same age, they might not be genetically equivalent, as suggested by some authors (Nilson, 1984; Silva and Nilson, 1990).

All mafic rocks analysed present T_{DM} model ages of ca. 1.0 Ga, equivalent to model ages found for rocks of the Goiás Magmatic Arc (Fig. 2.7; Pimentel and Fuck, 1992). ε_{Nd}(T) values are strongly positive, indicative of the depleted nature of the mantle source (MORB-like). However, the lithological associations found in these supracrustal sequences are different from other island arc-like sequences of the Goiás Magmatic Arc, in which felsic and intermediate volcanic products are abundant (e.g. the Arenópolis Sequence; Pimentel and Fuck, 1986). The conspicuous presence of metachert, marble, metapelite and the dominance of mafic metaigneous rocks suggest that these supracrustal sequences in the Anicuns region are equivalent to the Córrego Santo Antônio Unit, underlying the western part of the Arenópolis Sequence, which has been interpreted as an oceanic or fore-arc sequence. $^{147}Sm/^{144}Nd$ ratios of most of the mafic rocks investigated are less than 0.19 and indicate a relative enrichment in LREE, which is not characteristic of N-MORB mafic magmas.

The area of exposure of the Anicuns-Itaberaí Sequence coincides with a regionally important gravimetric discontinuity (Fig. 2.2) indicating that it marks an important crustal boundary, possibly separating juvenile rocks of the Goiás Magmatic Arc to the west from rocks of the Anápolis-Itauçu Complex to the east, where older crustal components are registered in the Nd isotopic compositions of the igneous rocks (Piuzana et al., 2003a). This is suggested also by the initial isotopic compositions and inheritance patterns displayed by the mafic rocks around the Anicuns area. To the west of the gravimetric discontinuity, mafic rocks are pristine, and present positive ε_{Nd}(T) values, whereas mafic rock associations towards the east display evidence of contamination of the original magmas with older crust. For instance, the Gongomé intrusion has very high initial Sr isotopic ratio (0.7153) (Winge, 1995), rocks of the Santa Bárbara de Goiás Complex have inherited zircon grains of possible Mesoproterozoic age, and the Goianira-Trindade layered intrusion has a Sm-Nd isochron age of ca. 621 Ma with an ε_{Nd}(T) value of 0.0 (M.M. Pimentel, unpublished results).

Based on the field, geochronological, isotopic and regional geophysical data, we suggest that the supracrustal sequence exposed in the Anicuns area might represent a fore-arc or back-arc sequence, marking the tectonic boundary between the Goiás Magmatic Arc and the westernmost exposures of the former São Francisco continental plate.

Table 2.2 Summary of SHRIMP U-Pb data for sample JHL-14.

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	% Dis cor dant	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
JHL14-1.2	106	73	15783.1	919.9	20.5	934	43	1	6.51	2.4	0.0711	1.2	0.0702	2.1	1.48	3.2	0.1534	2.4	0.749
JHL14-2.2	78	44	697.7	924.7	21.5	1069	169	16	6.32	2.5	0.0954	4.3	0.0750	8.4	1.60	8.8	0.1542	2.5	0.285
JHL14-7.1	40	21	1687.8	907.0	21.9	616	66	-32	6.55	2.6	0.0689	2.0	0.0603	3.1	1.26	4.0	0.1511	2.6	0.644
JHL14-8.1	84	64	4273.3	894.6	20.7	824	49	-8	6.69	2.5	0.0699	1.5	0.0666	2.4	1.37	3.4	0.1489	2.5	0.724
JHL14-8.2	57	28	6831.3	900.2	21.1	886	78	-2	6.66	2.5	0.0707	1.8	0.0686	3.8	1.42	4.5	0.1499	2.5	0.554
JHL14-9.1	154	173	16895.6	887.4	19.5	862	30	-3	6.77	2.4	0.0686	1.1	0.0678	1.4	1.38	2.8	0.1476	2.4	0.853
JHL14-10.1	55	23	3675.1	921.0	21.9	825	59	-10	6.48	2.5	0.0705	1.9	0.0666	2.8	1.41	3.8	0.1536	2.5	0.669
JHL14-11.1	91	44	15761.0	900.0	23.0	838	42	-7	6.67	2.7	0.0679	1.5	0.0670	2.0	1.38	3.4	0.1498	2.7	0.802
JHL14-12.1	61	26	9215.4	881.9	20.8	887	53	1	6.81	2.5	0.0702	1.8	0.0686	2.6	1.39	3.6	0.1466	2.5	0.702
JHL14-13.1	177	107	10935.8	889.2	20.5	858	32	-3	6.75	2.5	0.0690	1.2	0.0677	1.5	1.38	2.9	0.1479	2.5	0.850
JHL14-14.1	122	74	16378.4	867.9	19.4	935	28	8	6.93	2.4	0.0711	1.3	0.0702	1.4	1. 40	2.8	0.1441	2.4	0.865
JHL14-15.1	407	184	32739.6	868.5	18.6	879	16	1	6.93	2.3	0.0688	0.7	0.0684	0.8	1.36	2.4	0.1442	2.3	0.950
JHL14-16.1	322	150	12026.6	867.6	19.3	880	18	1	6.93	2.4	0.0696	0.8	0.0684	0.9	1.36	2.5	0.1441	2.4	0.940

(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 2.3 Summary of ID-TIMS U-Pb data for the mafic 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 15 D13 [1]	0.025	46.8	66.5	43.5	380.55	1.251	2.44	0.134	2.34	0.965	0.0677	0.63	810	824	859	13	1
JHL 15 D14 [1]	0.039	64.2	9.3	27.9	798.54	1.282	1.18	0.136	1.15	0.973	0.0679	0.27	826	837	867	5.6	1
JHL 15 18 [1]	0.019	86.2	13.5	57.3	586.29	1.351	1.63	0.144	1.57	0.969	0.0677	0.39	870	868	861	8.3	2
JHL 15 19[1]	0.035	107.5	16.4	31.1	1476.53	1.336	0.59	0.143	0.53	0.921	0.0677	0.23	861	861	861	4.8	3
JHL 23 E15[2]	0.021	137.0	23.1	51.8	274.52	1.258	2.05	0.137	1.83	0.903	0.0663	0.88	831	827	816	18	1
JHL 23 D2[2]	0.034	29.7	4.3	32.0	390.89	1.137	1.55	0.124	1.45	0.944	0.0663	0.51	755	771	818	11	1
JHL 23 D3[2]	0.021	85.5	9.4	51.8	392.39	0.928	2.15	0.101	2.03	0.951	0.0668	0.66	618	667	934	14	1
JHL 26B E12[2]	0.030	89.5	15.3	36.2	271.24	1.310	1.93	0.142	1.87	0.971	0.0668	0.46	856	850	833	9.7	1
JHL 26B D2[2]	0.034	44.1	6.8	32.0	616.34	1.250	1.09	0.136	1.01	0.933	0.0666	0.39	822	823	826	8.2	1
JHL 26B D5[2]	0.041	40.7	6.3	26.5	650.57	1.250	0.95	0.135	0.85	0.910	0.0668	0.39	820	823	832	8.2	2
JHL 26B 2[2]	0.042	76.3	10.5	25.9	410.15	1.140	2.01	0.122	1.95	0.974	0.0678	0.45	742	773	864	9.5	1
JHL 26B 1[2]	0.037	85.5	11.7	29.4	267.45	1.070	2.17	0.114	2.02	0.931	0.0676	0.79	699	738	857	16	1
JHL 19 12[3]	0.022	137.8	16.9	49.4	215.02	0.847	2.73	0.101	2.30	0.867	0.0606	1.36	622	623	627	29	4
JHL 19 11[3a]	0.013	166.6	18.7	83.7	402.37	0.839	2.07	0.101	1.88	0.921	0.0603	0.80	619	618	615	17	1
JHL 19 15[3a]	0.019	106.4	11.8	57.2	453.26	0.850	1.85	0.102	1.77	0.966	0.0601	0.47	626	624	617	10	2
JHL 22C 5[3b]	0.020	78.1	9.1	54.4	448.34	0.847	1.39	0.102	1.18	0.865	0.0602	0.69	626	623	610	15	2
JHL 22C 2[3b]	0.036	87.6	9.2	30.2	621.76	0.848	1.26	0.102	1.17	0.939	0.0602	0.43	627	623	610	9.4	1
JHL 04 D10[3c]	0.017	83.8	9.4	64	332.46	0.862	2.54	0.103	2.48	0.981	0.0603	0.48	636	631	614	10	1
JHL 04 D6[3c]	0.016	99.4	11.4	68	465.10	0.856	1.72	0.103	1.15	0.714	0.0601	1.20	633	628	609	26	1
JHL 04 D9[3c]	0.029	77.0	8.5	37.5	432.70	0.842	2.11	0.101	1.66	0.819	0.0601	1.21	623	620	606	26	1
JHL 04 D9[3c]	0.144	199.8	19.2	7.5	5232.00	0.783	0.33	0.094	0.25	0.782	0.0602	0.20	581	587	610	4.4	1
SB 01 D[3c]	0.038	60.02	6.4	28.6	1468.10	0.860	0.49	0.102	0.41	0.847	0.0615	0.26	625	633	658	5.6	1
SB 01 L[3c]	0.041	120.6	13.2	26.5	689.68	0.970	1.39	0.109	1.37	0.985	0.0641	0.23	670	688	746	5	1
SB 01 19[3c]	0.072	97.7	9.5	15.1	938.38	0.790	0.83	0.096	0.69	0.853	0.0596	0.43	593	592	588	9.4	2
AMB 15 M[4a]	0.033	95.7	10.9	32.9	630.48	0.851	2.79	0.102	2.68	0.963	0.0602	0.74	629	625	612	16	1
AMB 15 O[4a]	0.031	61.3	6.7	35.1	487.56	0.858	2.07	0.102	1.93	0.941	0.0607	0.69	629	629	629	15	1
AMB 01 4[4b]	0.025	215.7	32.8	43.5	1417.10	1.290	0.71	0.138	0.62	0.869	0.0676	0.35	838	843	856	7.3	1
AMB 01 3[4b]	0.024	71.2	11.3	45.3	1281.10	1.320	0.59	0.142	0.39	0.704	0.0675	0.42	858	857	855	8.8	1
AMB 01 2[4b]	0.019	165.7	25.4	109.9	1007.80	1.300	1.39	0.140	1.32	0.951	0.0676	0.43	844	848	858	8.9	1

[1-] Córrego da Boa Esperança Sequence; [2-] Anicuns-Itaberaí Sequence; [3a]- Anicuns-Santa Bárbara Suíte - Córrego Seco Complex (intrusive in Córrego da Boa Esperança Sequence); [3b]- Anicuns-Santa Bárbara Suíte - Córrego Seco Complex (intrusive at Anicuns Itaberaí Sequence); [3c]- Anicuns-Santa Bárbara Suíte - Santa Bárbara de Goiás Complex; [4a]- Americano do Brasil Layered Complex; [4b]- Americano do Brasil Layered Complex – country rock.

Table 2.4 Sm-Nd results for the mafic rocks.

	Sm	Nd	$^{143}Nd/^{144}Nd$ (±2SE)	$^{147}Sm/^{144}Nd$	$\varepsilon_{(0)}$	$\varepsilon_{(T)}$	T_{DM}(Ga)
JHL01[1]	6.16	29.40	0.512517(±5)	0.1266	-2.3	--	0.92
JHL 09[1]	2.11	6.42	0.512876(±10)	0.1991	4.6	--	--
JHL13[1]	6.60	30.52	0.512524(±17)	0.1308	-2.2	--	0.95
JHL14[1]	2.12	9.25	0.512542(±6)	0.1387	-1.9	+4.4	1.01
JHL15[1]	2.64	9.95	0.512713(±6)	0.1603	1.5	+5.5	0.94
JHL18[1]	6.50	29.23	0.512500(±6)	0.1297	-2.7	--	0.98
JHL23[2]	3.44	13.94	0.512612(±6)	0.1493	-0.5	+4.4	1.02
JHL24[2]	4.27	15.95	0.512663(±10)	0.1620	0.5	--	0.11
JHL 26b[2]	3.21	17.01	0.512401(±6)	0.1142	-4.6	+4.4	0.98
JHL19[3a]	2.54	10.86	0.512540(±19)	0.1412	-1.9	+1.8	1.05
JHL22a[3b]	1.27	6.29	0.512374(±10)	0.1226	-5.1	--	1.11
JHL22b[3b]	5.28	22.84	0.512538(±5)	0.1398	-1.9	--	1.04
JHL22c[3b]	4.05	16.93	0.512566(±6)	0.1447	-1.4	+2.6	1.05
JHL 4a[3c]	4.83	20.14	0.512542(±7)	0.1450	-1.9	+2.2	1.10
JHL 4b[3c]	3.99	16.05	0.512587(±6)	0.1503	-1.0	--	1.09
SB 01[3c]	1.84	6.65	0.512652(±8)	0.1671	0.3	+2.6	1.26

[1-] Córrego da Boa Esperança Sequence; [2-] Anicuns Itaberaí Sequence; [3a]- Anicuns-Santa Bárbara Suíte - Córrego Seco Complex (intrusive in Córrego da Boa Esperança Sequence); [3b]- Anicuns-Santa Bárbara Suíte - Córrego Seco Complex (intrusive in Anicuns Itaberaí Sequence); [3c]- Anicuns-Santa Bárbara Suíte - Santa Bárbara de Goiás Complex.

CAPÍTULO III

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

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Richard Armstrong
Sergio Luiz Junges

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 $\varepsilon_{Nd}(T)$ values varying between +2.8 and -15.1. Rock units with negative $\varepsilon_{Nd}(T)$ 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 $\varepsilon_{Nd}(T)$ 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

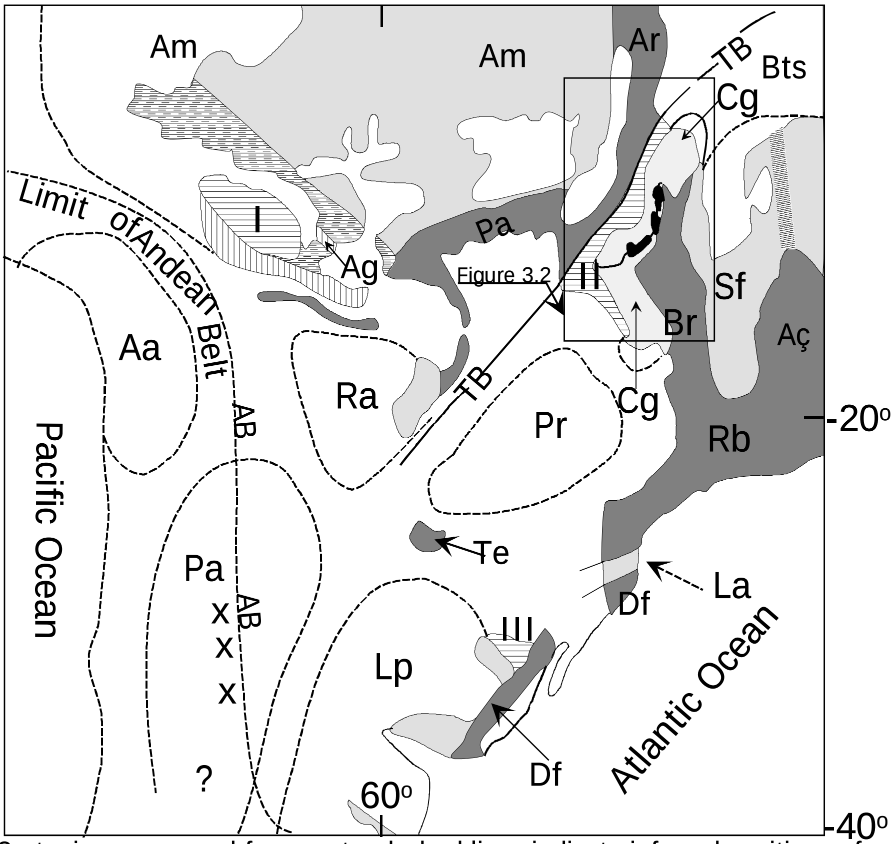
During the last decade, several studies have demonstrated that the Goiás Magmatic Arc in the western part of the Brasília Belt, in central Brazil, represents a large area of Neoproterozoic juvenile continental crust formed during plate convergence, roughly between ca. 900 and 630 Ma (Pimentel and Fuck, 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).

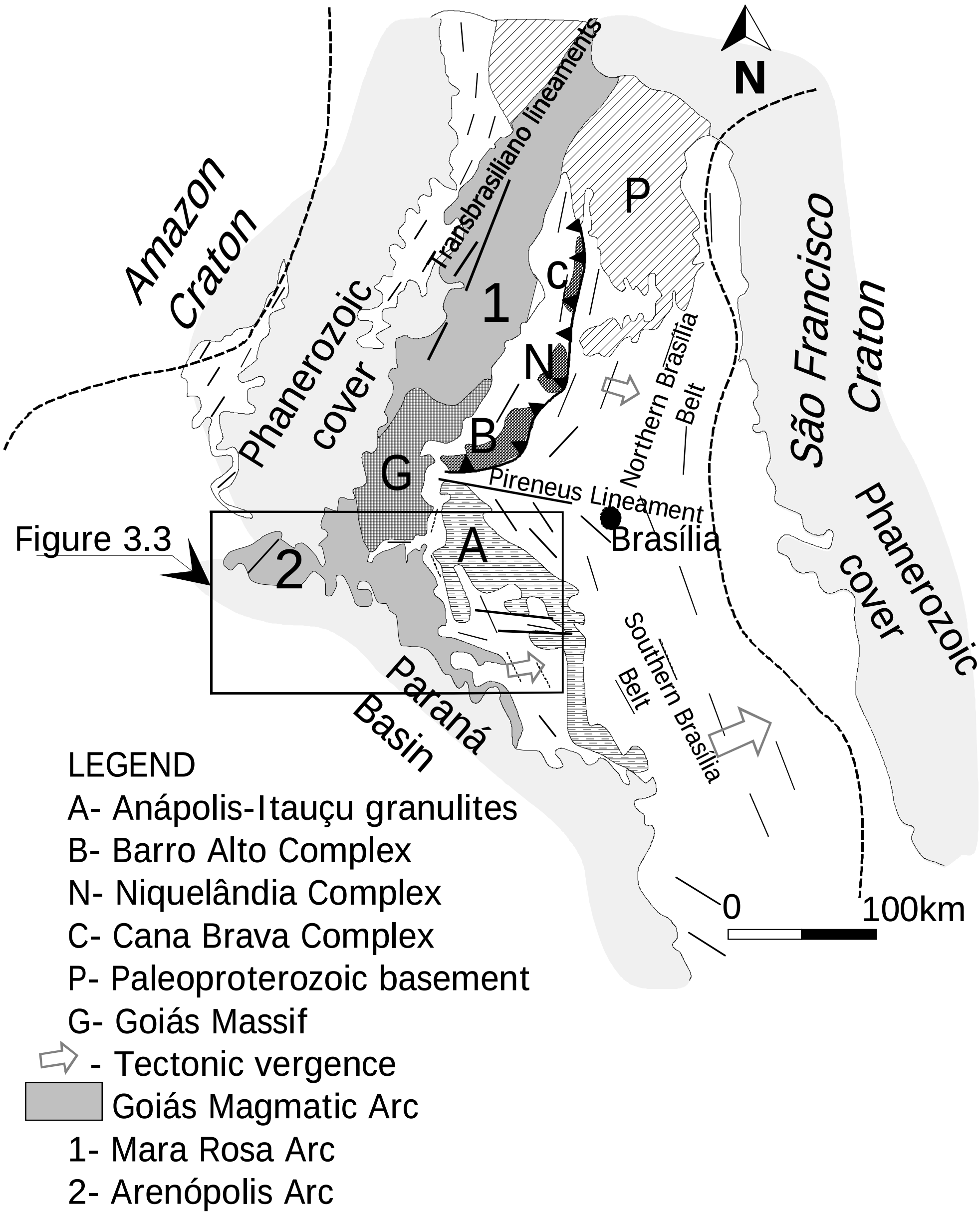


Figure 3.2 - Geological sketch map of the Brasília Belt in the eastern part of Tocantins Province, central Brazil (after Pimentel et al., 2003).

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).

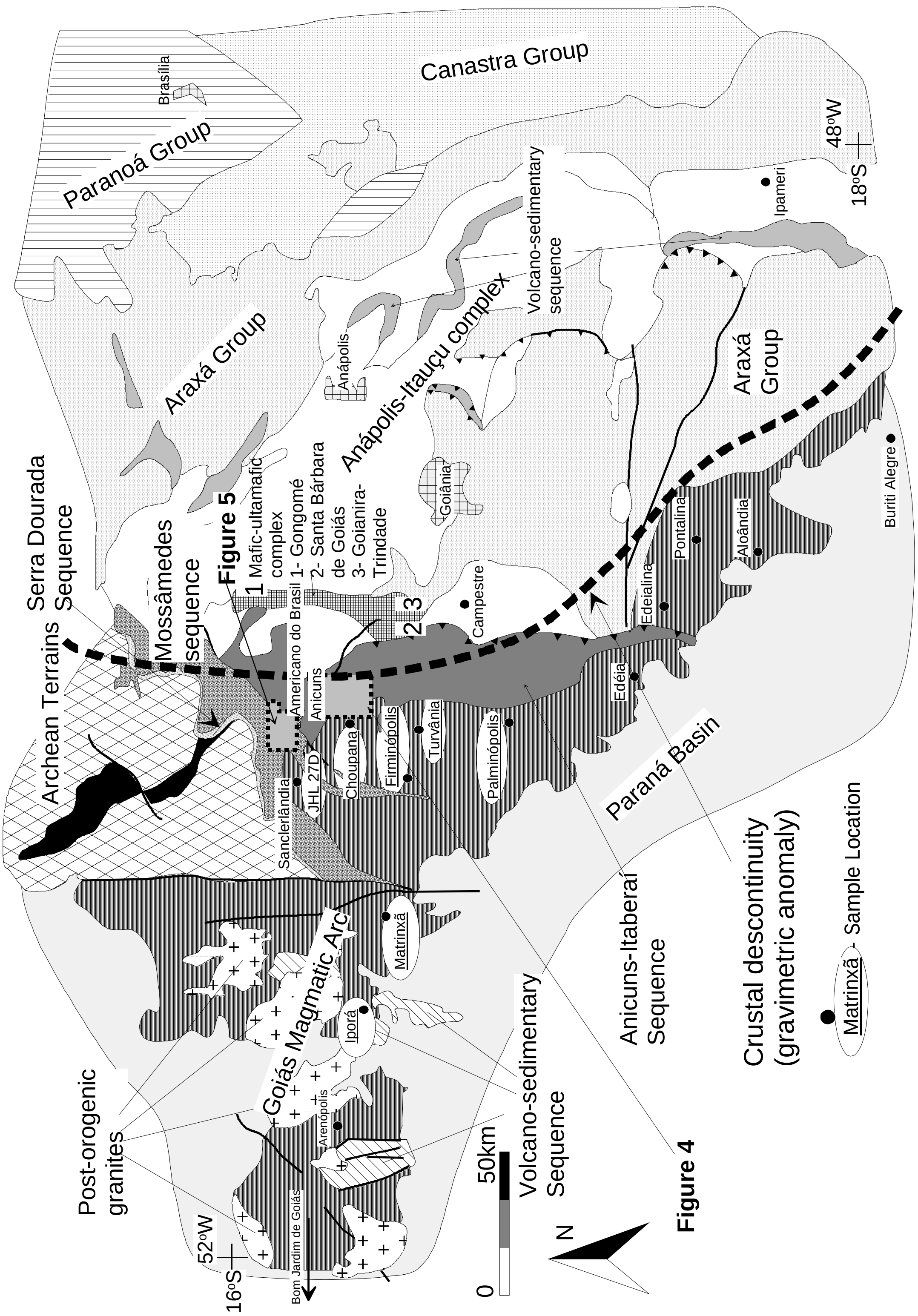


Figure 3.3 - Geological sketch map of the southern part of the Goiás Magmatic Arc, with the location of the studied areas (after Pimentel et al., 2000a).

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]	0.7025	0.9-1.0	+4.0/+6.0	2
	820±7 [a]				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.

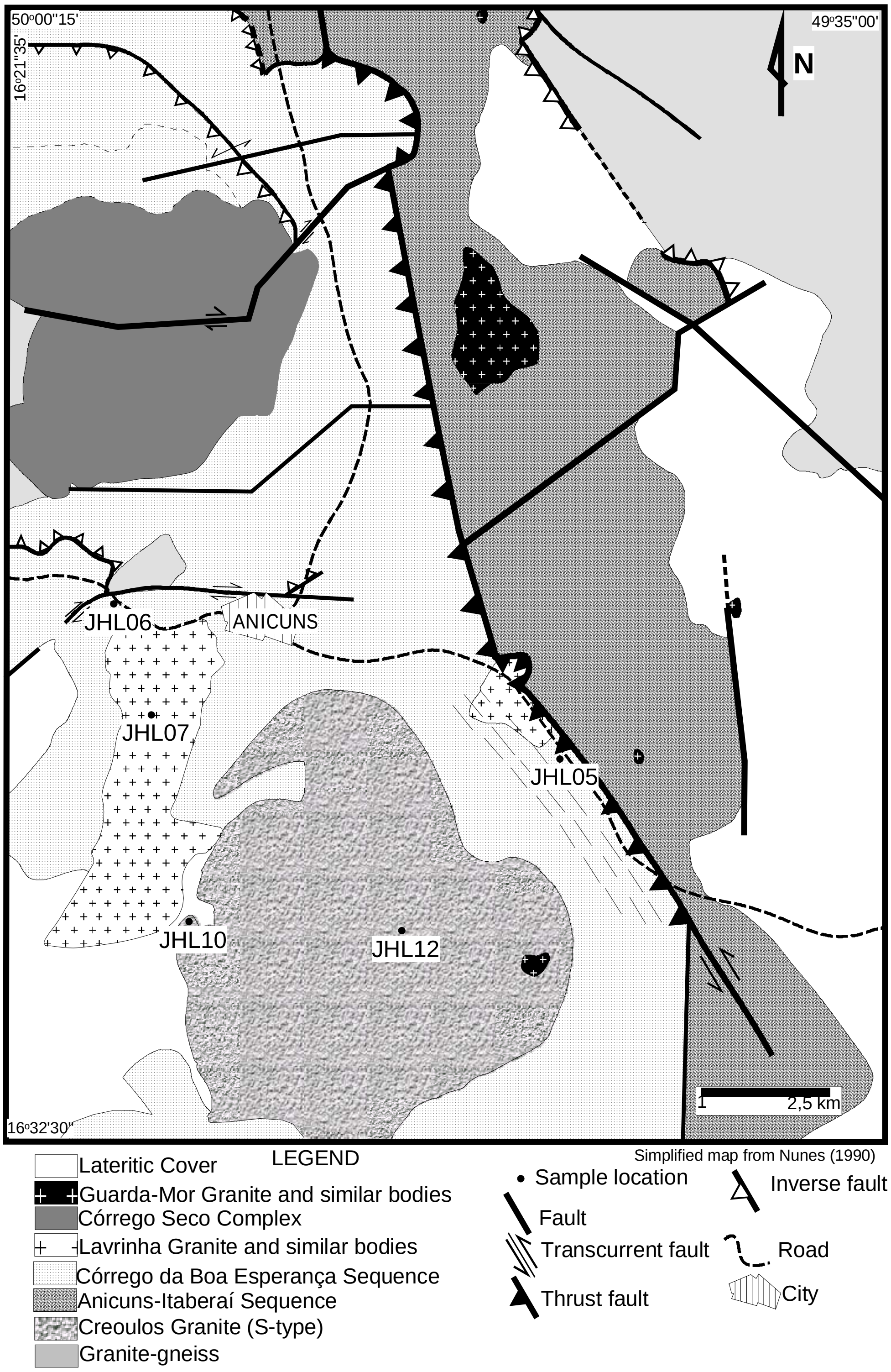


Figure 3.4 - Geological map of the Anicuns region with locations of studied samples (simplified from Nunes, 1990).

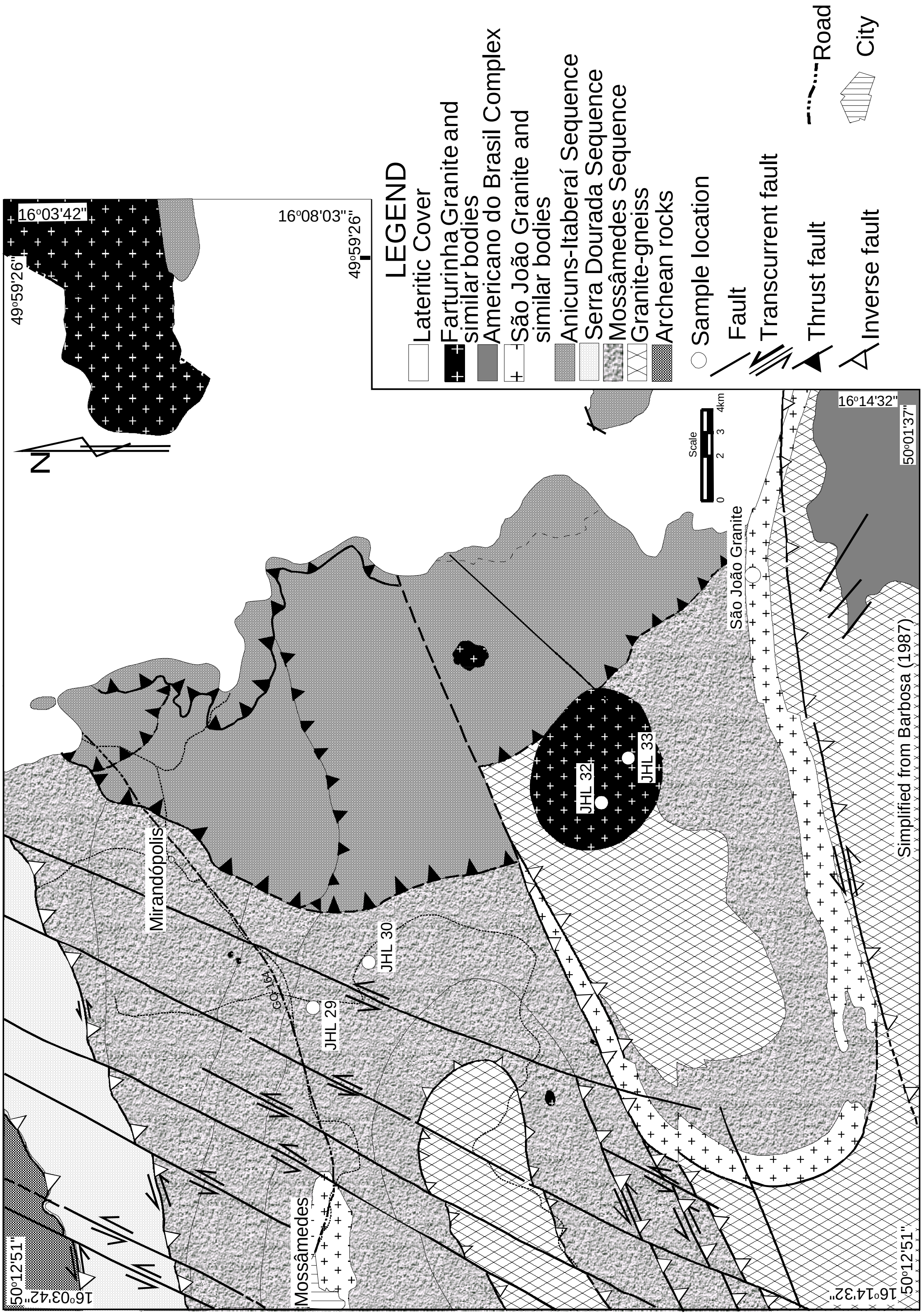


Figure 3.5 - Geological map of the area east of Mossâmedes, Goiás (after Barbosa 1987).

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).

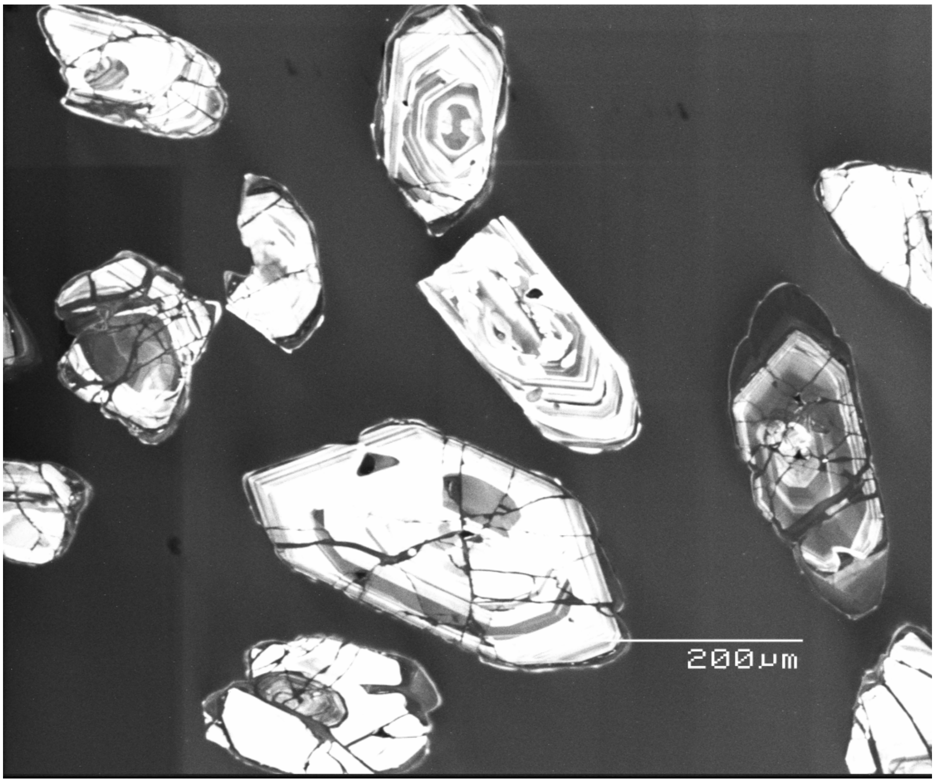


Figure 3.6 - Cathodoluminescence image of zircon grains from the Palminópolis Gneiss.

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).

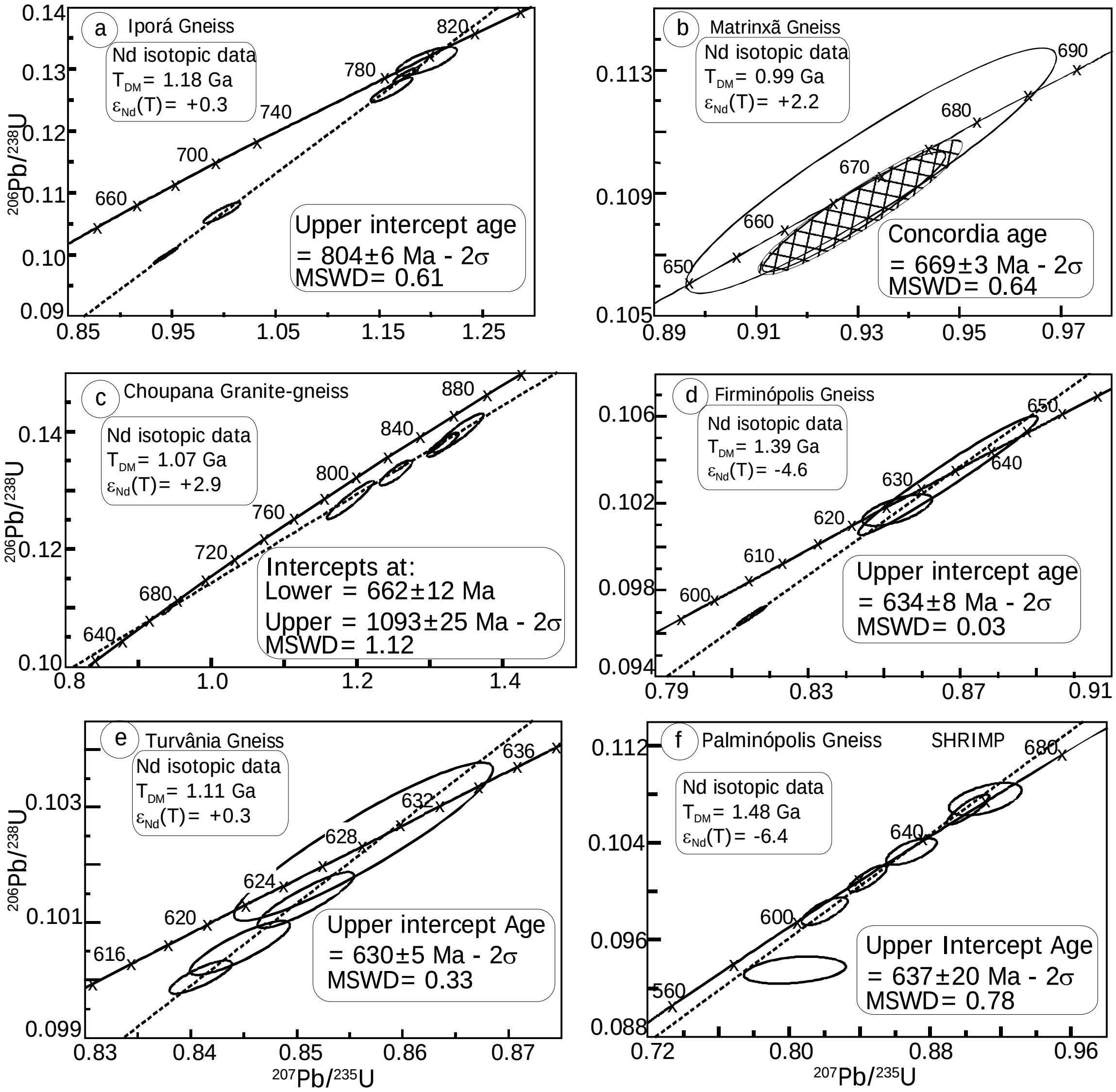


Figure 3.7 - ID-TIMS and SHRIMP U-Pb concordia diagrams for orthogneisses from the Goiás Magmatic Arc.

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).

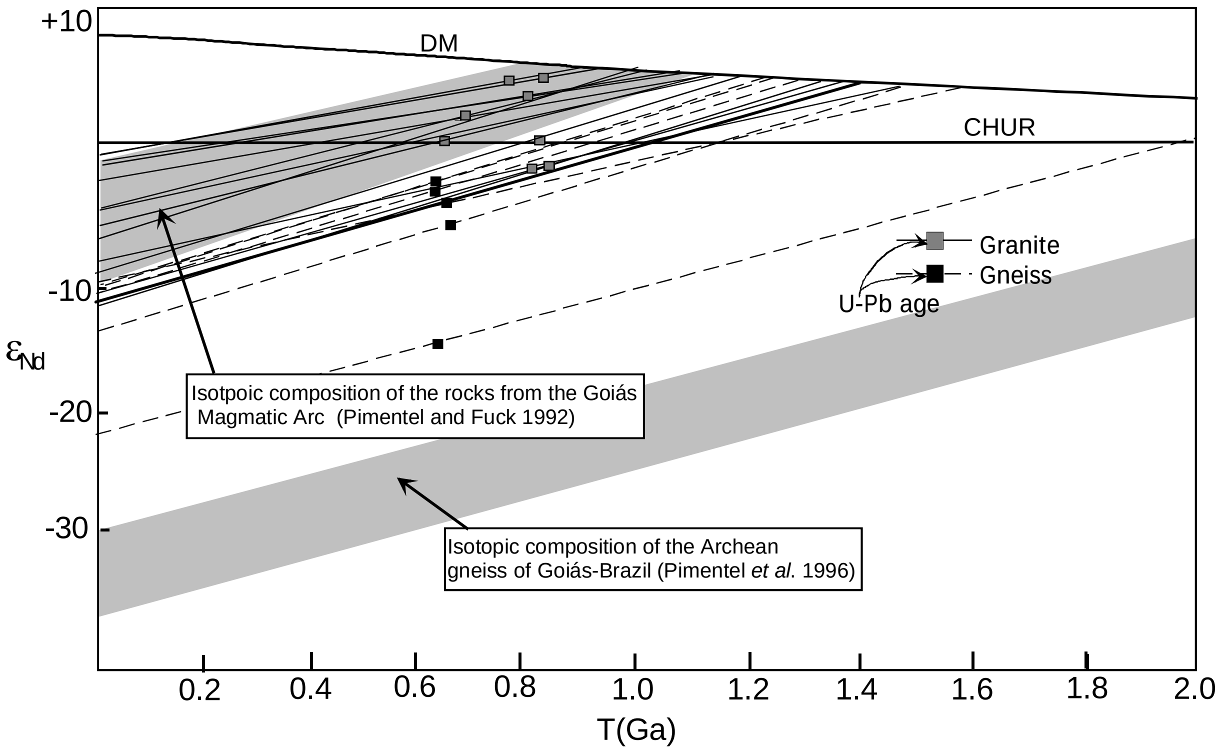


Figure 3.8 - Evolution ε_{Nd} x Time diagram showing Nd isotopic composition of the orthogneiss and granite samples studied. Nd isotopic composition of the Goiás Magmatic Arc is from Pimentel and Fuck (1992) and that of Archean gneisses of Goiás is from Pimentel et al. (1996). U-Pb ages are shown for 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.

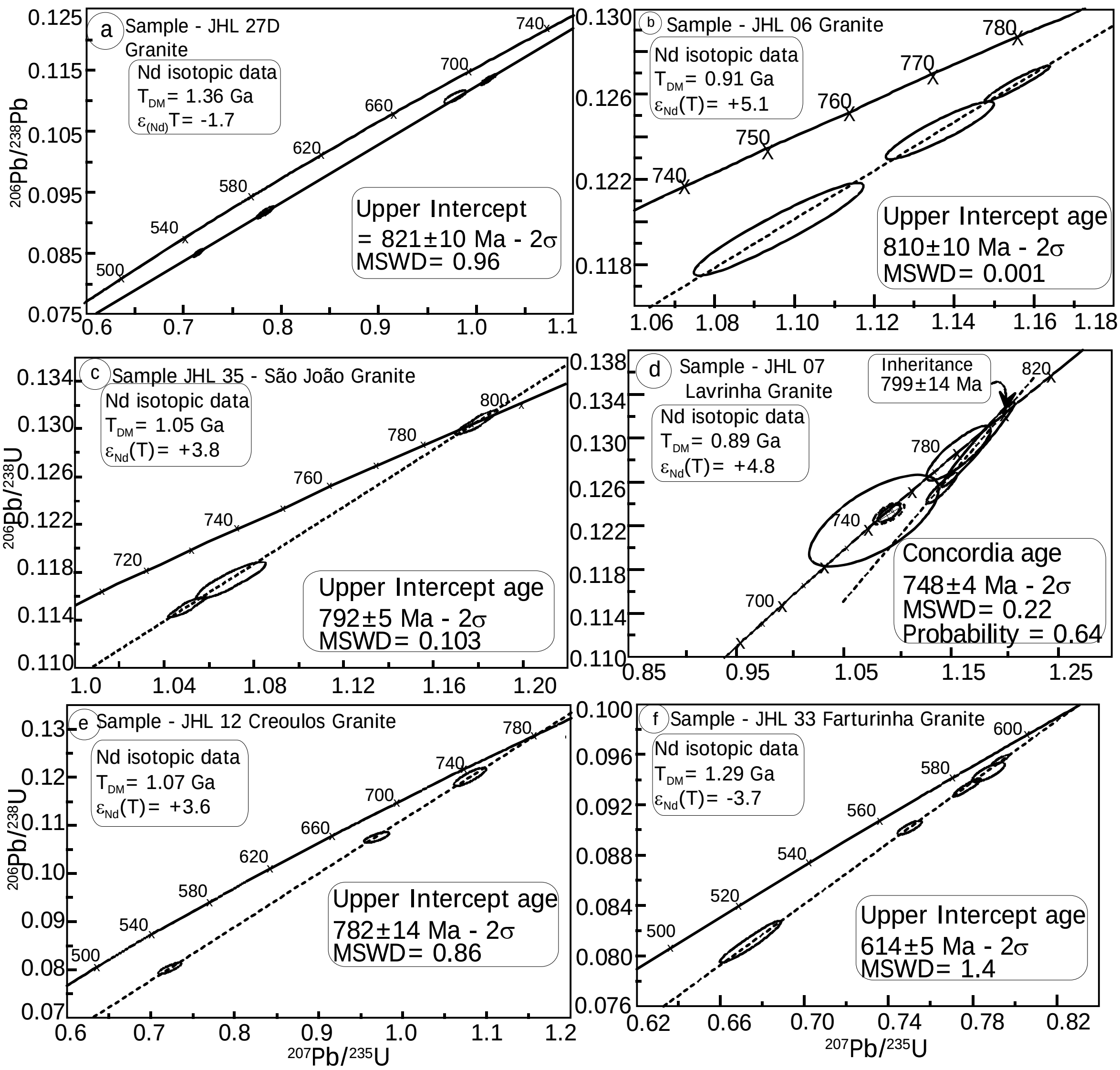


Figure 3.9 - ID-TIMS U-Pb concordia diagrams for granitic rocks of the Anicuns area.

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).

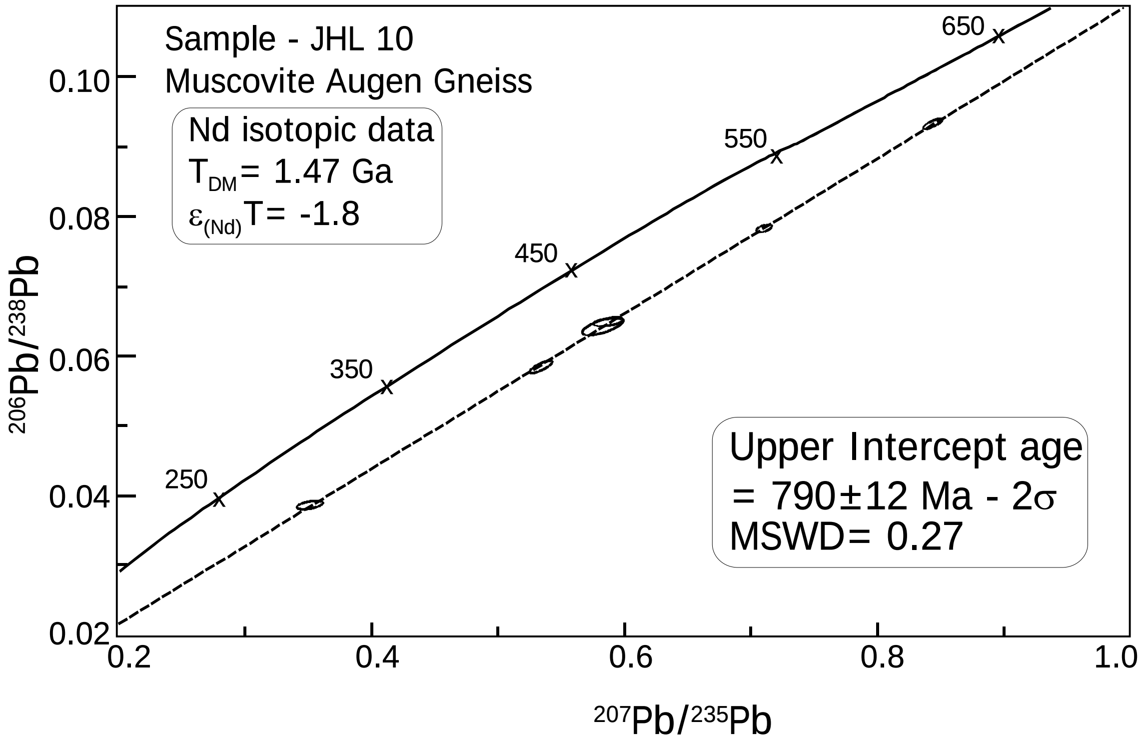


Figure 3.10 – ID-TIMS U-Pb concordia diagram for sample JHL 10.

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.

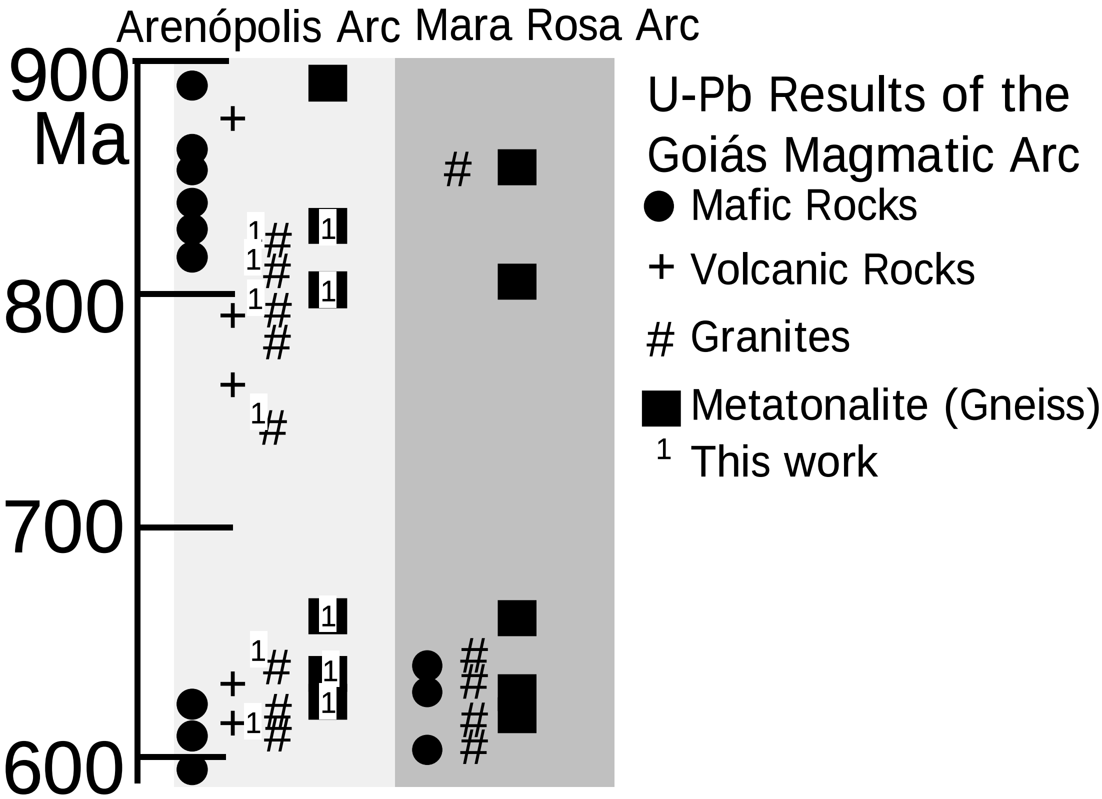


Figure 3.11 – Summary of the previous age data from the Goiás Magmatic Arc documents two distinct crustal accretion events (Data from Pimentel et al., 1991, 1997, 2003; Pimentel and Fuck, 1992; Viana et al., 1995; Rodrigues et al., 1999; Fischel et al., 2001b; Dantas et al., 2001; Piuzana et al., 2001, 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	% Dis cor dant	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.

CAPÍTULO IV

The Anicuns Volcano-Sedimentary Sequence at the limit between the juvenile Goiás Magmatic Arc and the western edge of the São Francisco Continent: new geochemical and Nd isotopic data of metabasic and metasedimentary rocks

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4.1 INTRODUCTION

The Goiás Magmatic Arc, in central Brazil, consists of several arc-type metavolcano-sedimentary sequences associated with tonalitic to granitic orthogneisses, forming an extensive Neoproterozoic juvenile terrain along the western part of the Brasília Belt (Pimentel and Fuck, 1992; Pimentel et al., 2000a). Mafic volcanic and plutonic rocks are associated with calc-alkaline andesites, dacites, and rhyolites in some of these sequences (e.g. Bom Jardim de Goiás and Arenópolis; Seer, 1985; Pimentel and Fuck, 1986), but they also form bimodal associations with rhyolites in others (e.g. Iporá and Jaupaci sequences) (Pimentel et al., 1991; Rodrigues et al., 1999). The metavolcanic rocks typically present very primitive geochemical and isotopic characteristics, with low initial $^{87}Sr/^{86}Sr$ ratios and positive $\varepsilon_{Nd}(T)$ values. Felsic metavolcanic rocks have U-Pb zircon ages between ca. 0.9 and 0.64 Ga (Pimentel et al., 1991; Rodrigues et al., 1999). Most of the previous isotopic, geochronological and petrological studies concentrated on intermediate to felsic members of this magmatism, and little is known about the associated mafic rocks. Fine-grained amphibolites of the Arenópolis volcano-sedimentary sequence are probably the best-known representatives of these Neoproterozoic mafic metavolcanic rocks. They comprise low-K tholeiites to calc-alkaline metabasalts, with primitive isotopic compositions (initial $^{87}Sr/^{86}Sr$ of ca. 0.7026 and $\varepsilon_{Nd}(T)$ of ca. +6.9; Pimentel, 1991), representing the early stages of development of an intraoceanic island arc system. Small metamorphosed gabbro-diorite intrusions are also recognized within the Arenópolis Sequence, and one has been recently dated at 890 $\pm$ 9 Ma (SHRIMP U-Pb zircon age; Pimentel et al., 2003), corresponding to plutonic/subvolcanic equivalent of the volcanic sequence.

The Anicuns-Itaberaí Sequence, exposed along the contact between the eastern part of the Goiás Magmatic Arc and the Anápolis-Itauçu high-grade terrain, is represented dominantly by amphibolites (metavolcanic and metaplutonic) and metapelitic rocks, with subordinate iron formation, chert, marble, and ultramafic rocks of uncertain age. It has been correlated, in the past, with the Archean Serra de Santa Rita greenstone belt, exposed to the north (Barbosa, 1987), or with Paleoproterozoic sequences such as the Silvânia Sequence to the west of Anápolis-Itauçu Complex (Lacerda Filho et al., 1991) and the Mossâmedes volcanics (Nunes, 1990). Recent studies based mainly on Sm-Nd isotopic characteristics of the Anicuns-Itaberaí rocks, however, suggest that they are considerably younger and might be part of the Neoproterozoic Goiás Magmatic Arc (Pimentel et al., 2000a, b; Laux et al., 2001, 2002a, b, 2004a).

In this paper we discuss new geochemical and isotopic data of coarse-grained mafic rocks exposed within the Anicuns-Itaberaí Sequence, which demonstrate that this rock assemblage belongs to the Goiás Magmatic Arc and might represent the boundary area between the juvenile arc and older sialic terrains belonging to the western edge of the Neoproterozoic São Francisco continent.

4.2 REGIONAL GEOLOGICAL SETTING

The Tocantins Province represents a large Brasiliano/Pan-African orogen that developed between three major Neoproterozoic continents: the Amazon, São Francisco, and Paranapanema/Paraná. The province comprises three main fold belts, known as the Paraguay Belt in the southwest, the Araguaia Belt in the NW, and the Brasília Belt underlying large areas of the eastern part of the Tocantins Province, along the western margin of the São Francisco Craton (for a review see Pimentel et al., 2000a).

The Brasília Belt represents one of the best preserved and the most complete Neoproterozoic orogens in Brazil, comprising: (i) a thick Meso-Neoproterozoic sedimentary pile that includes the Paranoá, Canastra, Araxá, Ibiá, Vazante, and Bambuí groups, overlying mostly 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 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) (Fig. 4.1).

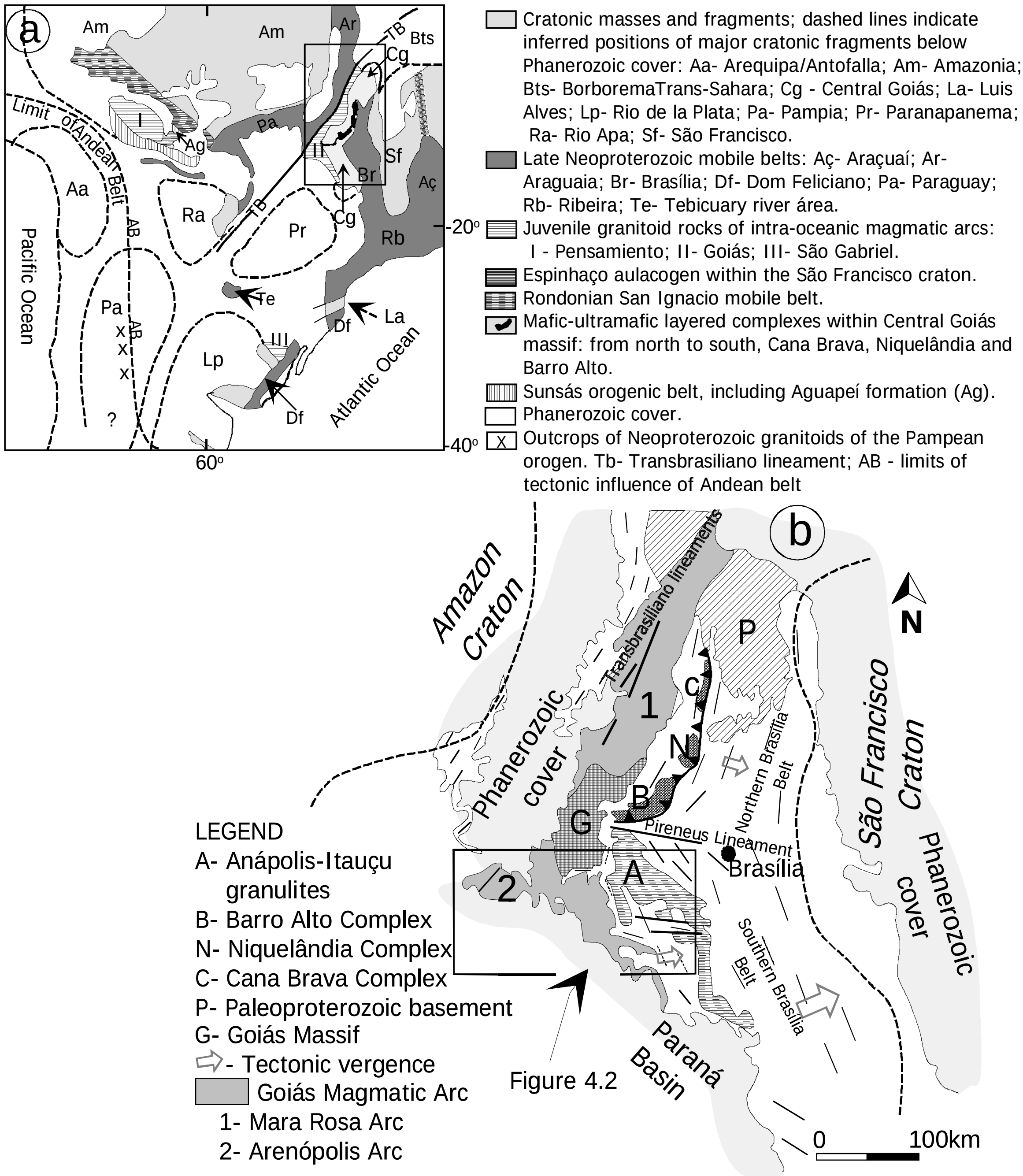

Figure 4.1 – a) Precambrian tectonic framework of Central South America (after Kröner and Cordani, 2003; Cordani et al., 2003; b) Geological sketch map of the Brasília Belt in the eastern part of Tocantins Province, central Brazil (after Pimentel et al., 2003).

The several sedimentary/metasedimentary rock 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 facies conditions in the central part of the belt (Fuck et al., 1993, 1994; Dardenne, 2000).

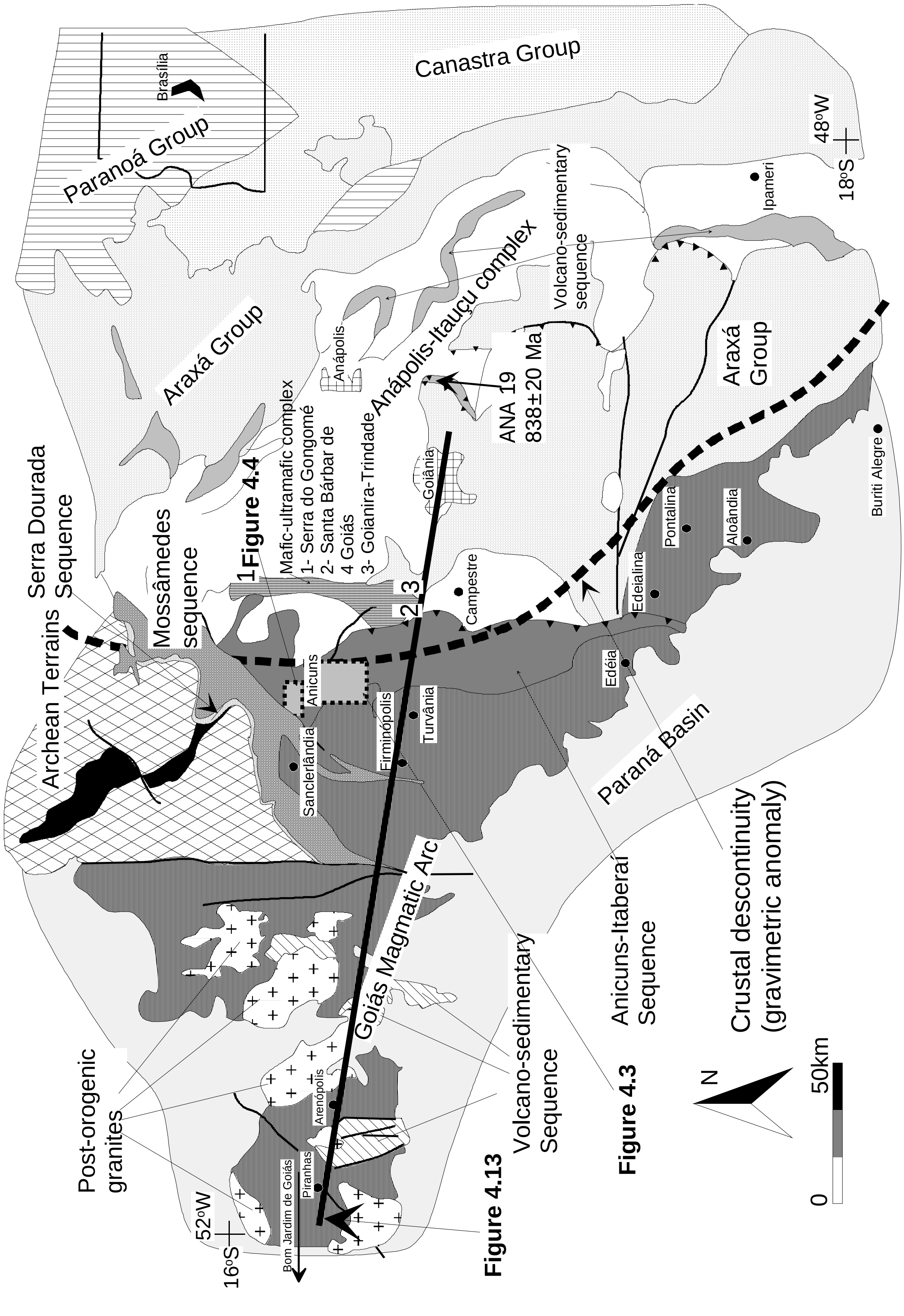

Figure 4.2 - Geological sketch map of the southern part of the Goiás Magmatic Arc, with location of the areas investigated (after Pimentel et al., 2000a).

Metasedimentary rocks belonging to the Araxá and Canastra groups underlie large areas in the central-southern part of the Brasília Belt (Figs. 4.1 and 4.2). Nappes and thrust sheets of these units overlie Paleoproterozoic basement represented by 2.1 Ga volcano-sedimentary sequences and associated granites (e.g. Silvânia and Rio do Peixe sequences and Jurubatuba granite; 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. 4.1 and 4.2). They include para- and orthogranulites, as well as strongly deformed intrusive granites. Recent data have indicated that the Nd isotopic signatures and metamorphic ages of the Araxá metasedimentary rocks, Anápolis-Itauçu felsic granulites, and intrusive granites are all very similar (Fischel et al., 1998, 1999; Pimentel et al., 1999, 2001; Seer, 1999; Piuzana et al. 2003a, b), demonstrating that at least part of the aluminous granulites of the Anápolis-Itauçu Complex may represent high-grade equivalents of the Araxá metasedimentary rocks. Therefore, source areas of the original Araxá sediments may have included Neoproterozoic juvenile areas such as the Goiás Magmatic Arc (Fischel et al., 1998, 1999; Pimentel et al., 1999, 2001; Piuzana et al., 2003a).

In the central part of the Brasília Belt is the Goiás Massif (Figs. 4.1 and 4.2), represented by: (i) Archean greenstone belts and TTG orthogneisses; (ii) Paleoproterozoic orthogneisses largely covered by younger supracrustal rocks; (iii) and mafic-ultramafic layered complexes of Barro Alto, Niquelândia, and Canabrava 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 massif is interpreted as an allochtonous block amalgamated to the Brasília Belt during the Neoproterozoic (Brito Neves and Cordani, 1991; Pimentel et al., 2000b).

The Neoproterozoic juvenile arc (Goiás Magmatic Arc) is composed of volcano-sedimentary sequences associated with calcic to calc-alkaline tonalite/granodiorite gneisses (Fig. 4.2). The main arc terrenas are known as the Arenópolis and Mara Rosa arcs, located in western and northern Goiás, respectively (Pimentel and Fuck, 1992; Pimentel et al., 1991, 1997) (Fig. 4.1). In both areas, geological evolution started at ca. 890 - 860 Ma in intraoceanic island arcs with the crystallization of very primitive tholeiitic to calc-alkaline volcanics and associated tonalites/granodiorites. These rocks have $\varepsilon_{Nd}(T)$ values between ca. +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, commonly positioned above subduction zones where young and hot oceanic lithosphere was subducted under oceanic lithosphere. 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 real area distribution of these juvenile terrains, since geochronological and isotopic data are still sparse and insufficient. Recent U-Pb and Sm-Nd data have shown that the juvenile arc extends to the southeast and northeast, disappearing under the Paraná and Parnaíba Phanerozoic basins, respectively (Figs. 4.1 and 4.2). They underlie a very large area, which constitutes a significant portion of the Brasília Belt (Pimentel et al., 2000a; Fuck et al., 2001). In this context, the Anicuns-Itaberaí sequence represents a key geological unit for the understanding of the evolution of the Goiás Magmatic Arc and adjacent terrains because: (i) it represents one of the largest supracrustal sequences within this tectonic unit, (ii) it has been traditionally considered to be an Archean or Paleoproterozoic greenstone sequence, and (iii) it coincides with a regionally important gravimetric discontinuity, separating a gravimetric high to the west and a gravimetric low to the east (Baêta Junior, 1994).

4.3 GEOLOGY OF THE ANICUNS REGION

In the Mossâmedes-Anicuns region (Figs. 4.2, 4.3, and 4.4), Barbosa (1987) recognized three distinct supracrustal sequences and assigned different ages to them based on field relationships and structural data: (i) the Anicuns-Itaberaí Sequence

(AIS) was interpreted as the southern extension of the Serra de Santa Rita (Goiás Velho) greenstone belt, (ii) the Mossâmedes Sequence (Simões, 1984), west/northwest of Anicuns, was interpreted to be of Mesoproterozoic age, equivalent to the Araxá Group, and (iii) a younger detrital sequence (conglomerates, quartzites and schists) forming the roughly E-W Serra Dourada ridge to the north. The north/south supracrustal sequence, referred to as the Anicuns-Itaberaí Sequence (AIS) by Barbosa (1987), was divided into two distinct geological units by Nunes (1990): (i) the Córrego da Boa Esperança Sequence (CBES) in the west, correlated with the Araxá Group, consists of metapelites, andesitic/dacitic meta-tuffs, and iron formation (Nunes, 1990) (Fig. 4.3); (ii) the AIS in the east, separated from the CBES by a NNW reverse fault, is composed of mafic/ultramafic metavolcanic rocks, metacherts, metarhytmites, and marble lenses. Laux et al. (2004a) have demonstrated that the Anicuns-Itaberaí and Córrego da Boa Esperança sequences are of the same age and their supracrustal rocks formed between ca. 890 and 830 Ma and, therefore, belong to the Goiás Magmatic Arc.

Both Nunes (1990) and Barbosa (1987) have suggested that the metavolcanic rocks in this region have calc-alkaline or calc-alkaline/tholeiitic nature, indicating a magmatic arc setting for their origin. This was also suggested by Nilson (1981) for the country-rocks of the Americano do Brasil mafic-ultramafic layered complex exposed to the north of Anicuns.

Granitic rocks, as well as small mafic and mafic-ultramafic bodies are intrusive into the supracrustal sequences. The granitoid intrusions are tonalites, granodiorites, and granites with subordinate quartz syenite, monzonites, and monzodiorites (Barbosa, 1987; Nunes, 1990). The deformed, elongated, locally mylonitic granitic bodies, which represent the major part of the granite intrusive complexes in the area have been dated at approximately 800 Ma, whereas the late-tectonic, less voluminous granite intrusions are ca. 615 Ma old (Laux et al., 2004b).

Mafic/intermediate intrusions are collectively referred to as the Anicuns-Santa Bárbara Gabbro-Diorite Suite (Lacerda Filho and Oliveira, 1995). The Córrego Seco Complex (Fig. 4.3) comprises gabbro, diorite, amphibolite and, in some places, crosscutting relationships with the AIS are observed. This suite has been correlated with the Americano do Brasil intrusion, exposed to the north of the AIS (Pfrimer et al., 1981; Nunes, 1990). A diorite sample from this suite was dated at 622 ± 6 Ma which has been interpreted as the crystallization age of the intrusion (Laux et al., 2004a).

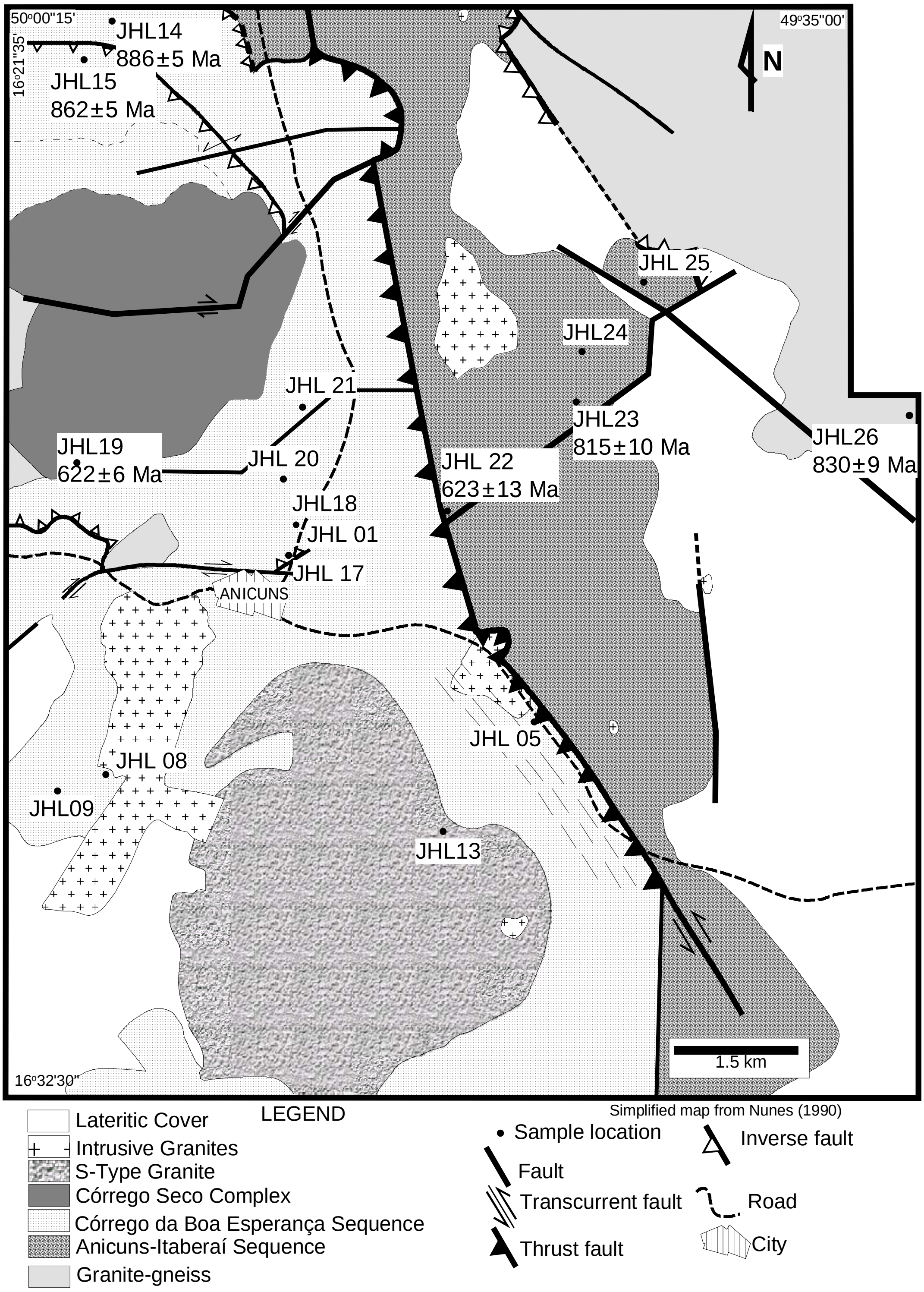

Figure 4.3 - Geological map of the Anicuns region, with sample location (simplified from Nunes, 1990).

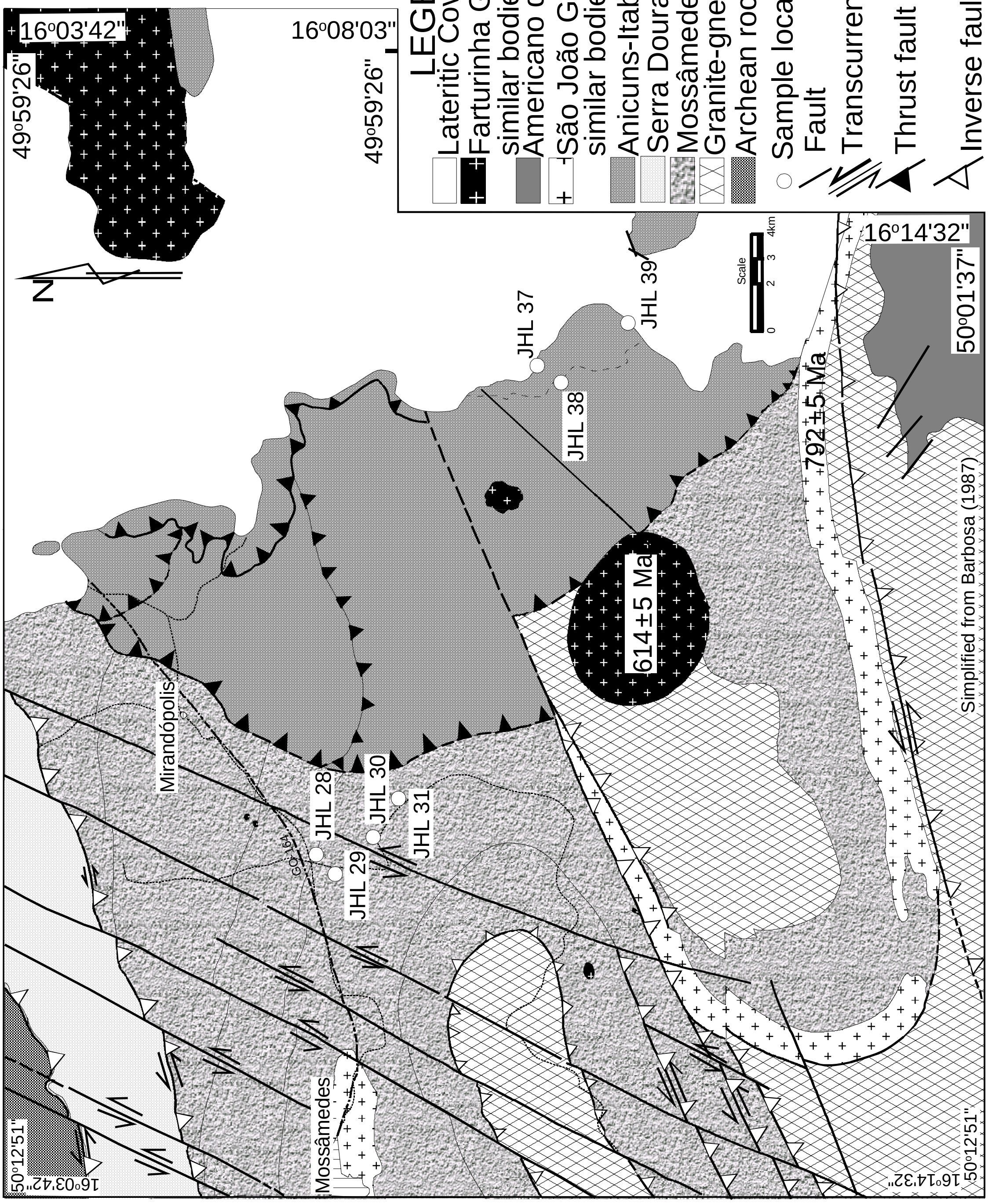

Figure 4.4 - Geological map of the area east of Mossâmedes, Goiás (Simplified from Barbosa 1987).

The Americano do Brasil Mafic-Ultramafic Suite comprises small layered bodies known as the Americano do Brasil, Mangabal I, Mangabal II, Adelândia, Fronteira do Norte, Palmeiras, and Serra do Gongomé, exposed to the north of the investigated area (Pfrimer et al., 1981; Nilson 1981, 1984; Candia and Girardi, 1985; Winge, 1995). The Americano do Brasil intrusion includes metagabbro, metagabbronorite, olivine gabbro, amphibolite, metadunite, metaperidotite, metapyroxenite, and hornblendite (Nilson, 1984). The Americano do Brasil complex was emplaced at 626 ± 8 Ma (U-Pb zircon data of Laux et al., 2004a), and the original tholeiitic magma presented positive $\varepsilon_{Nd}(T)$ value of approximately +2.4 (Gioia, 1997) indicating little or no contamination with much older sialic crust. The Serra do Gongomé intrusion has an Rb-Sr isochron age of 637 ± 19 Ma and high initial Sr isotopic ratio (0.7153) indicating interaction with older continental crust (Winge, 1995).

4.4 ANALYTICAL PROCEDURES

Major element analyses were carried out by XRF at the Núcleo de Estudos de Granitos of Universidade Federal de Pernambuco. One aliquot of each sample was placed in an oven at 1000^{0}C for two hours for L.O.I. determination. The samples were fused into small pellets using Li tetraborate at 1:5 proportion. All samples were analyzed in a Phillips XRF spectrometer using an Rh tube, and calibration curves constructed with international reference materials.

REE, Hf, Nb, Zr, Ta, Rb, Sr, Ba, Cs, Th, U, and Pb were analyzed by ICP-MS in the geochemistry laboratories of Memorial University of Newfoundland, Canada. Dissolution was carried out in an HF/HNO_3 mixture in screw top Savillex beakers on a hotplate according to the methodology described by Jenner et al. (1990). Calibration was carried out using the method of standard addition, providing rigorous correction for matrix effects.

Sr, Nd, and Pb isotopic analyses were performed in the Geochronology Laboratory of University of Brasília. Approximately 60 mg of powdered rock samples were dissolved for Sr, Sm, and Nd extraction in successive acid attacks with concentrated HF, HNO_3, and HCl. Sm, Nd, Sr, and Pb 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.

Sm-Nd isotopic analyses followed the method described by Gioia and Pimentel (2000) and 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). Uncertainties of Sm/Nd and $^{143}Nd/^{144}Nd$ ratios are better 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 the DePaolo (1981) model.

Sr was separated from the whole-rock solutions using a conventional ion exchange technique, following Pankhurst and O'Nions (1973). Mass fractionation corrections were made using a $^{88}Sr/^{86}Sr$ ratio value of 8.3752. 1σ uncertainty on the measured $^{87}Sr/^{86}Sr$ ratios was better than 0.01%. Sr procedure blanks was less than 300 pg.

For Pb, approximately 50 - 100 mg of powdered rock samples were dissolved in a mixture of 2 mL (40%) HF + 1 mL (65%) HNO_3 for two days, three days with a mixture of 2 mL (40%) HF + 1 mL (65%) HNO_3, and 24 hours in 2 mL 6N HCl. This solution was evaporated and taken in 1 mL 0.6N HBr, and Pb was extracted using columns packed with BioRad X8 anionic exchange resin in 0.6N HBr. Procedures were conducted in clean room conditions and using ultra pure reagents (sub-boiling distillation in Teflon® vials). Most of the samples were treated with the procedure described by Kuritani and Nakamura (2002), with some modifications allowing a more efficient Pb extraction (Gioia, written communication). The chemical procedure for Pb separation consists of one single step. Anionic exchange resin (100 μL) was packed into a polyethylene column (5 mm high in column with internal diameter of 4 mm). The resin bed was cleaned by flushing the column with 2 mL 6N HCl, followed by 1mL of 0.5N HNO_3 and 1mL of H_2O. The column was then conditioned with 0.4 mL of 0.6N HBr. 500uL of the sample solution was loaded onto the column and eluted with 3 mL of 0.6N HBr - 0.6N HNO_3. Particulate samples were eluted with 3.5mL of the same acid mixture. The lead fraction was extracted with 1 mL of H_2O

and dried on a hot plate. Some samples were eluted twice in the column to obtain a cleaner fraction of lead. Mass fractionation was < 0,1% for all lead ratios, corrected using NIST 981 standard.

4.5 GEOCHEMICAL RESULTS

Sixteen samples of mafic rocks were analyzed for major, trace and the RE elements (results are in Table 4.1). Samples ANA 19A and ANA 19F correspond to fine-grained amphibolites of the Bonfinópolis Sequence, dated at 838 ± 20 Ma (Piuzana et al., 2003a) (Fig. 4.2) by the SHRIMP U-Pb method. Samples JHL 01, JHL 13, JHL 18 e JHL 09 (Fig. 4.3) are also fine-grained amphibolite samples chemically equivalent to andesites (01, 13 and 18) and metabasalt (09) which are most likely ca. 830 Ma old, based on a reference whole-rock Sm-Nd isochron (Laux et al., 2004a). Samples JHL 14, JHL 15, JHL 22C, JHL 23 and JHL 24 (Fig. 4.3) are coarse-grained amphibolites representing both metadiorites and metagabbros. U-Pb zircon ages of Laux et al. (2004a) are 886 ± 5 Ma and 623 ± 13 Ma, respectively, for samples JHL 14 and JHL 22C, indicating two different events of mafic intrusion. Diorite JHL 19 and quartz diorite JHL 26B are preserved from extensive metamorphic recrystallization and present U-Pb zircon ages of 622 ± 6 Ma and 830 ± 9 Ma, respectively. Chlorite schist JHL 22A and amphibolite JHL 22B, are either metasedimentary rocks or mixed volcanic-sedimentary supracrustal rocks. Sample JHL 29 (Fig. 4.4) is a tonalite.

Major element results of these rocks are not of straightforward interpretation since they represent metavolcanic and metaplutonic rocks dominantly metamorphosed under amphibolite facies during the Neoproterozoic. Despite these limitations, previous studies using major element geochemical data have indicated tholeiitic to calc-alkaline trends and assigned island arc setting for the origin of the original magmas (Nilson, 1981; Barbosa 1987; Nunes, 1990). Although the major element data presented here corroborate this interpretation (Fig. 4.5) we will here concentrate the discussion on trace element results.

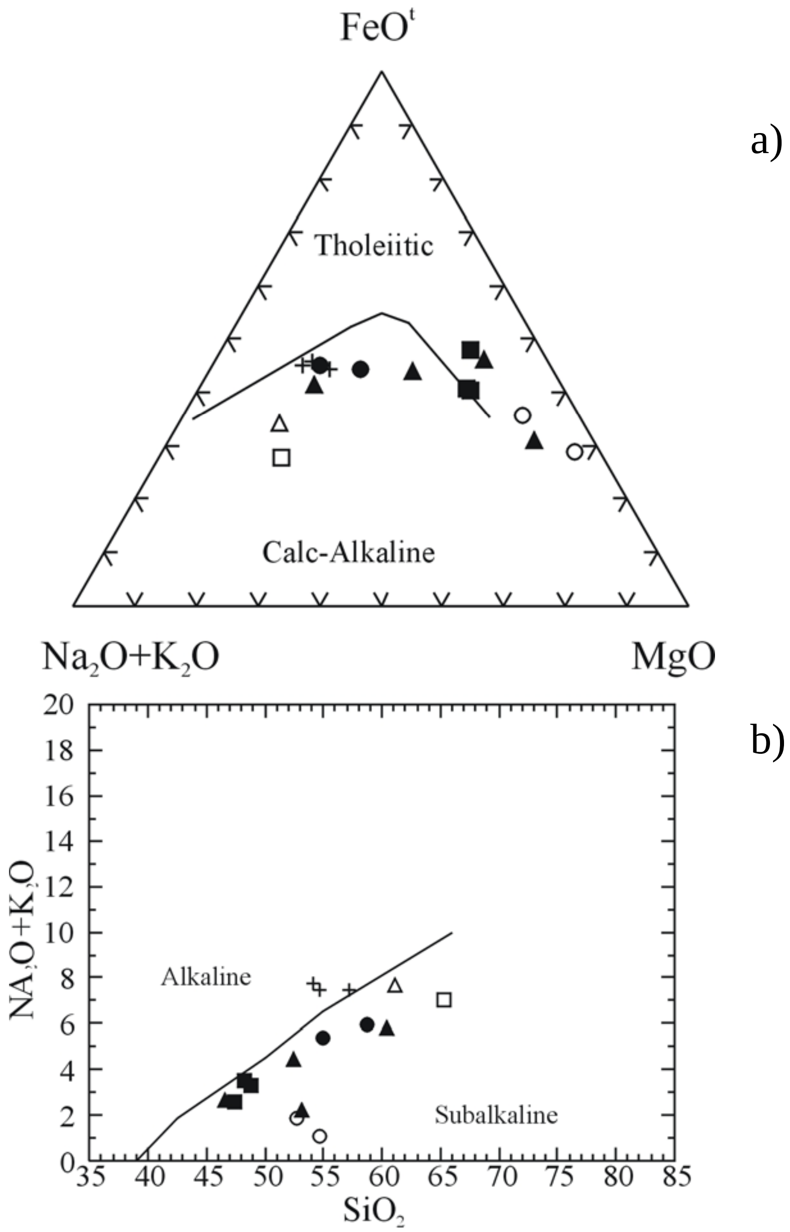

Figure 4.5 - Tholeiitic/Calc-Alkaline (a) and Alkaline/ Subalkaline (b) diagrams of Irvine and Baragar (1971). Symbols: cross- metandesites, full square– metabasalts, blank square– quartz-diorite, full circle– diorite (ca. 630 Ma), blank circle– metasedimentary rocks, full triangle– diorite (ca. ≈830 Ma), blank triangle- tonalite.

Typical trace element patterns of oceanic island arc rocks in multi-element diagrams show LILE (large ion lithophile elements such as Ba, Rb, Cs, Pb, K. U) enrichment and HFSE (High Field Strength Elements) depletion with distinctive troughs in Ti, Zr, Hf, Nb and Ta (Green and Ringwood, 1968; Pearce and Cann, 1973). Two hypotheses have been put forward to explain this pattern (Ringwood, 1990; Foley et al., 2000 and references therein; Churikova et al., 2001). One suggests that HFSE depletion is caused by rutile and/or amphibole, which incorporate

Nb and Ta in their structures and might behave as refractory phases during dehydration or partial melting of oceanic slabs in subduction zones. The second model (e.g. McCulloch and Gamble, 1991) suggests that the Nb and Ta negative anomalies are due to low solubility of these elements in fluids of subduction zones. The amphibolite samples investigated in this study show trace element variation patterns varying from very primitive compositions, similar to N-MORB basalts (Fig. 4.6a), through a group showing moderate LILE enrichment (Fig. 4.6c), to a further group of samples displaying distinctive LILE enrichment (Fig. 4.6b). The N-MORB-like samples are ANA 19A and ANA 19F, which are exposed east of the Anicuns area and are part of the Bonfinópolis Sequence, forming a thrust sheet associated with the Araxá Group metasedimentary rocks. These are most likely representative fragments of Neoproterozoic oceanic floor. All other amphibolite samples have distinctive HFSE depletion. Sample JHL 22A displays an anomalous pattern when compared to the rest, however, this is here interpreted as a metasedimentary rock (Fig 4.6c).

Trace element characteristics of most metabasic rocks investigated are similar to oceanic island arc rocks (Figs. 4.7a and 4.7b), ranging from the tholeiitic to the calc-alkaline series (Figs. 4.7c and 4.7d). REE patterns for these rocks range from those of tholeiitic basalts of MORB to LREE- enriched patterns from island arc basalts (DePaolo and Johnson 1979). A noteworthy feature of all REE patterns is the absence of negative Eu anomalies.

In terms of their REE contents, the samples analyzed may be divided into six groups. The first includes samples with flat chondrite-normalized REE patterns similar to some MORB's (Fig. 4.8a). They also present a small negative Ce anomaly, which has been assigned by some authors as product of interaction with seawater (De Baar et al., 1983; Hole et al., 1984). The second group displays patterns similar to those of calc-alkaline arc andesites with LREE-enrichment and flat HREE pattern (Fig. 4.8a). The third type of REE pattern is the most common in the group of samples investigated representing a steep pattern, with both LREE and HREE fractionation (Fig. 4.8b). The fourth group is formed by metasedimentary rocks which form REE curves which are similar to those of group three, including the absence of negative Eu anomaly (Fig. 4.8c). The fifth group includes samples that display distinctive LREE fractionation and an upwards-concave HREE pattern (Fig. 4.8d). The sixth pattern is that represented by the tonalite sample, with a very steep curve and slightly concave upward HREE pattern (Fig. 4.8d). Distinctive features of this rock sample is its low Yb content and the relatively high $(La/Yb)_n$ ratio (approximately 50). This is very similar to REE characteristics of tonalites from other parts of the Goiás Magmatic Arc (Pimentel, 1991, Pimentel et al., 1996) and are also characteristics shared by Archean TTG's and modern adakitic magmas, which are formed by the subduction of young hot oceanic lithosphere (Martin, 1987).

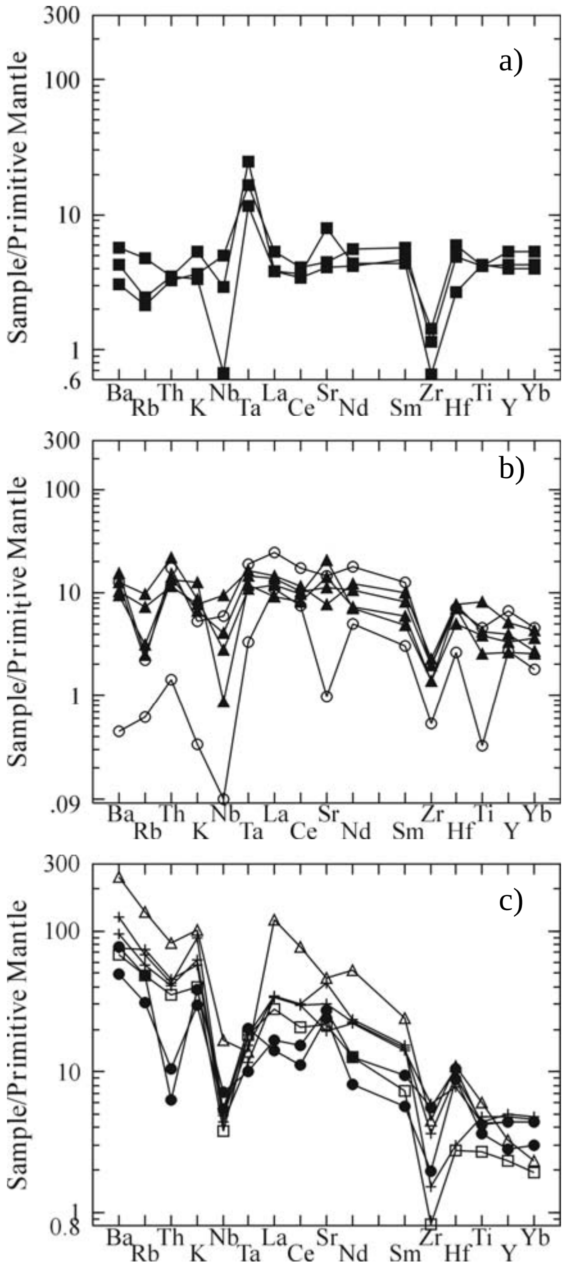

Figure 4.6 - Spider diagrams normalized to primitive mantle (Sun and McDonough 1989). Symbols are the same from figure 4.5.

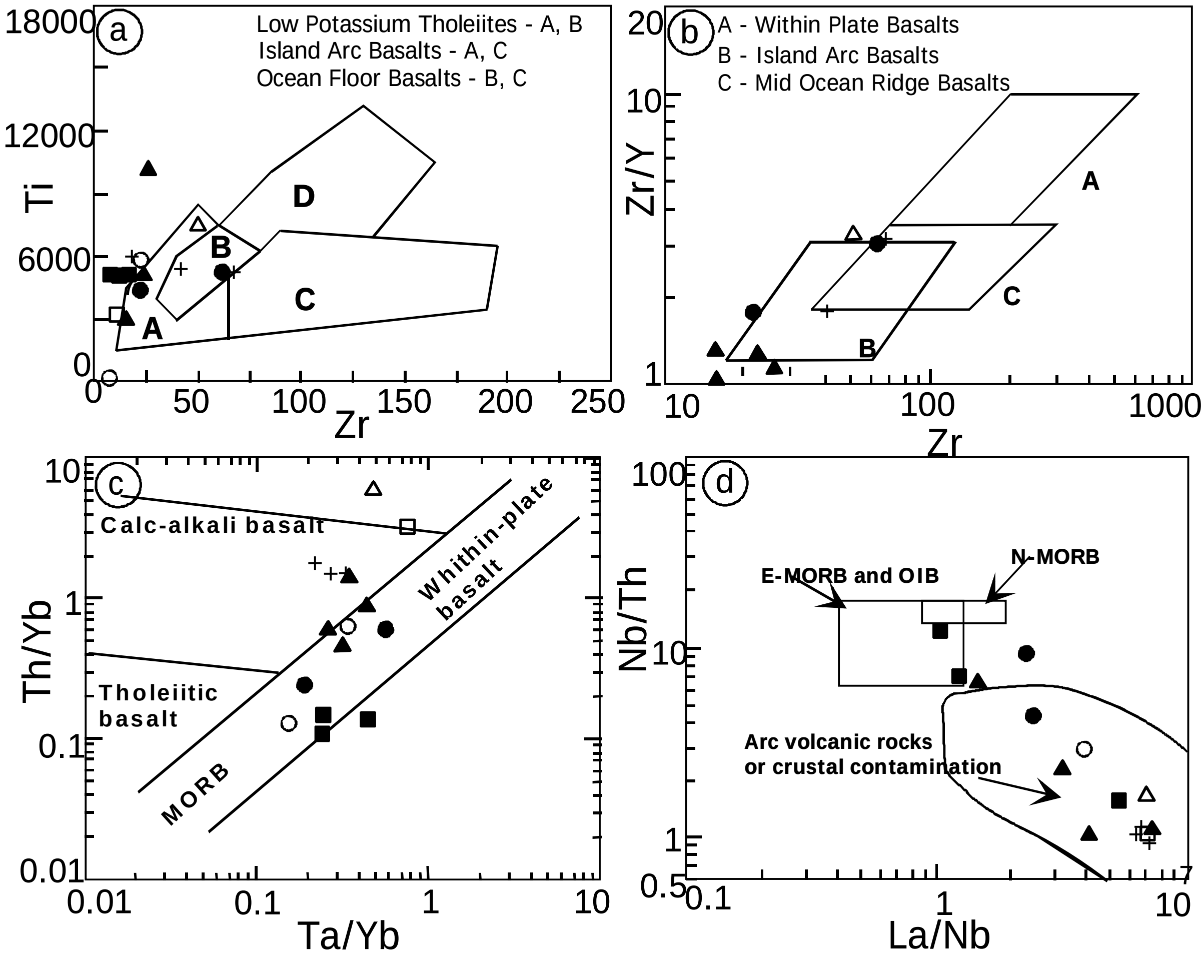

Figure 4.7 - Tectonic discriminantion diagrams, a) Diagram Zr-Ti (Pearce and Cann, 1973); b) Diagram Zr-Zr/Y (Pearce and Cann, 1973); c) Diagram Ta/Yb-Th/Yb (Pearce, 1983); d) Diagram La/Nb-Nb/Th (Pearce, 1983). Symbols are the same from figure 4.5.

4.6 Nd-Sr-Pb ISOTOPES

All rocks analysed present T_{DM} model ages of ca. 1.0 Ga (Table 4.2), except those of sedimentary origin. This is the typical T_{DM} pattern of rocks of other parts of the Goiás Magmatic Arc (Pimentel and Fuck, 1992, Pimentel et al., 1996, 1997, Junges et al., 2002). ε_{Nd}(T) values are positive, indicative of the depleted nature of the mantle source (MORB-like). $^{147}Sm/^{144}Nd$ ratios of most of the mafic rocks investigated are less than 0.19 and indicate a relative enrichment in LREE, which is characteristic of E-MORB or, alternatively, island arc mafic magmas (for more details see Laux et al., 2004a).

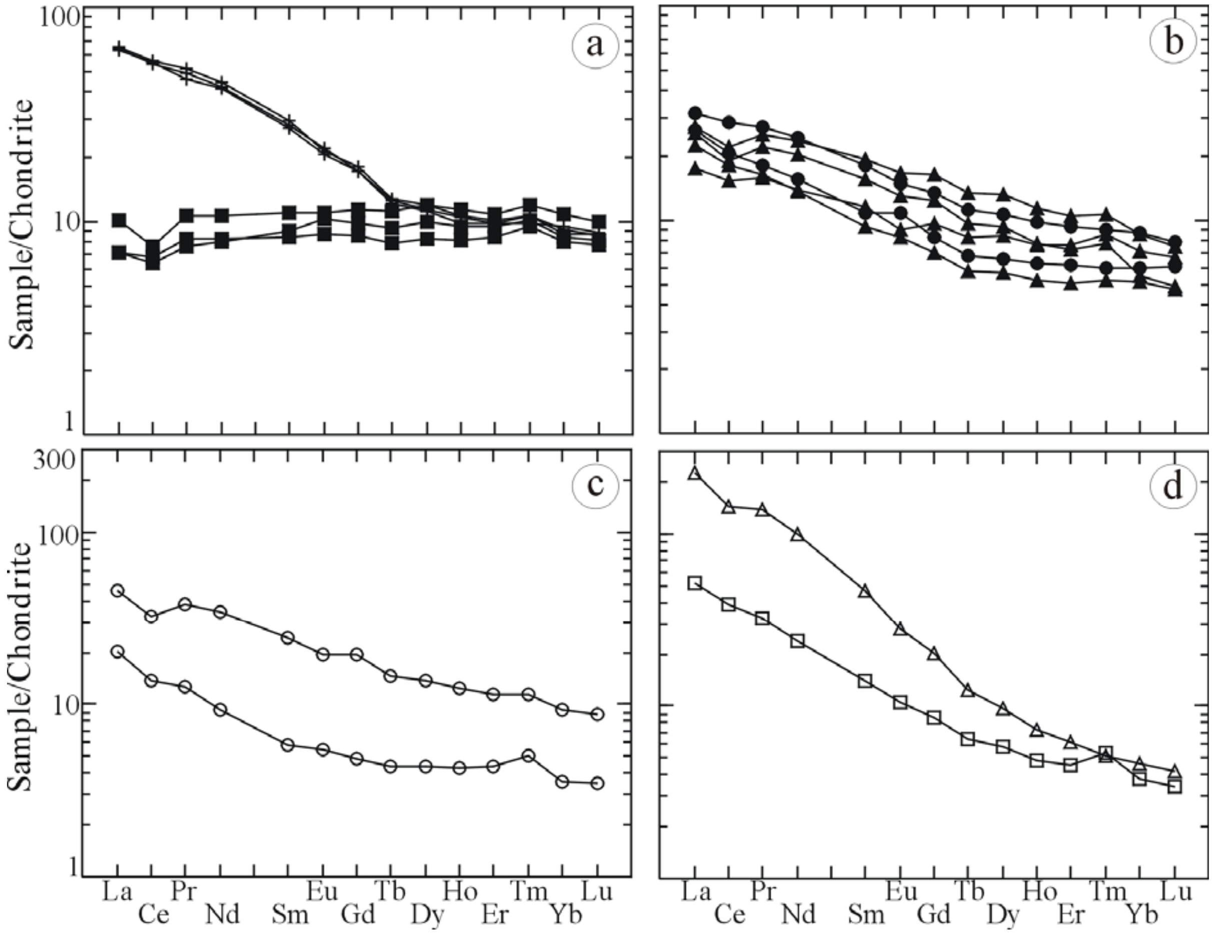

Figure 4.8 - REE patterns normalized to Chondrite from Taylor and McLennan 1985. Symbols are the same from figure 4.5.

Sr isotopic results (Table 4.3) also indicate the primitive nature of the rocks investigated, with initial $^{87}Sr/^{86}Sr$ ratios between 0.70261 and 0.70335 for the ca. 830 Ma old rocks and between 0.70313 and 0.70557 for the younger group (ca. 630 Ma). Diagram ε_{Sr} x ε_{Nd} re-calculated for 890 Ma shows that these rocks are not different from those studied by Pimentel and Fuck (1992) in the Arenópolis region, to the west (Fig.4.9).

Pb isotopes display a rather homogeneous composition for the mafic rocks analysed (Table 4.4) and their Pb isotopic ratios are compatible with either arc (orogen) or MORB (mantle) settings (Fig. 4.10).

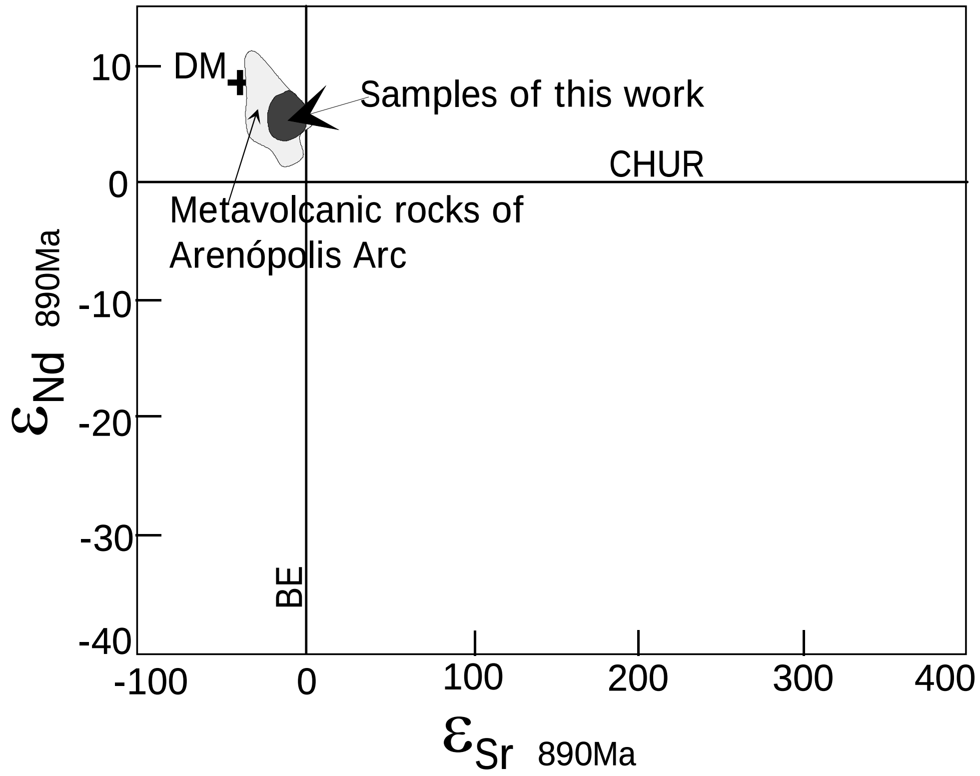

Figure 4.9 - Plot ε_{Sr} (T=890Ma) versus ε_{Nd}(T=890Ma). Field of Arenópolis metavolcanic rocks is from Pimentel (1991).

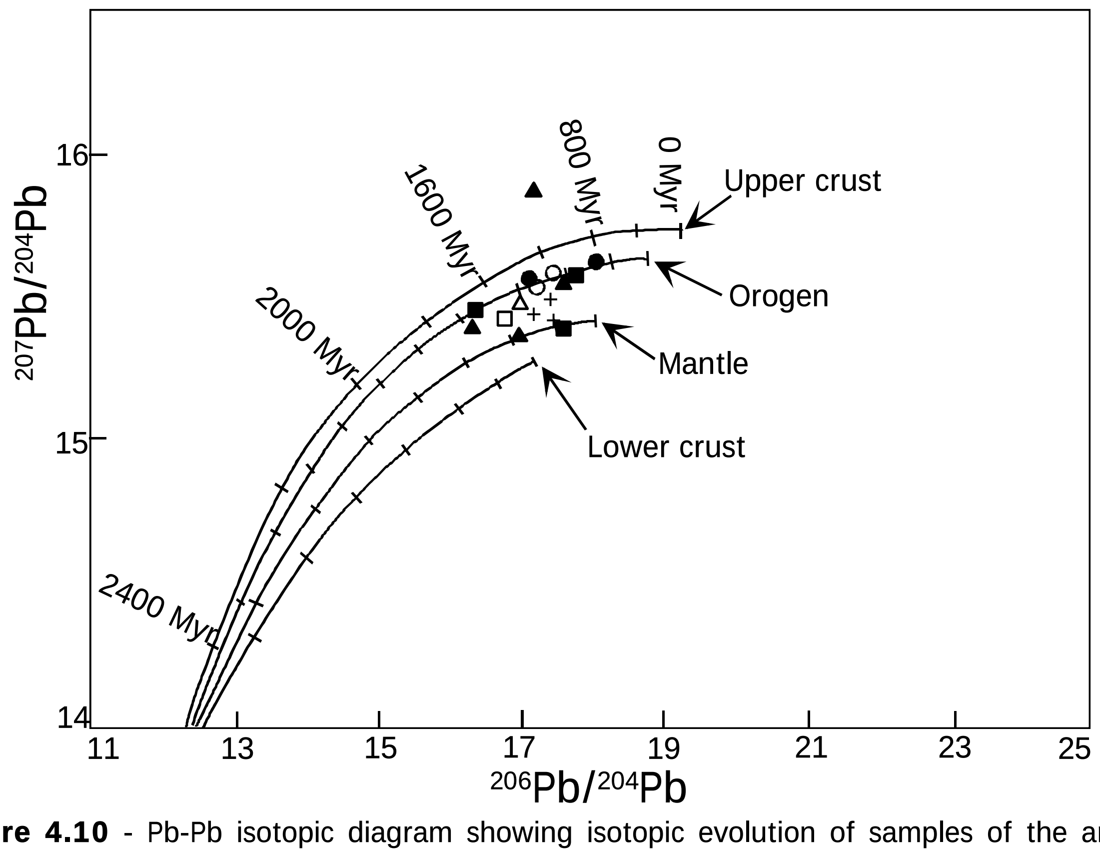

Figure 4.10 - Pb-Pb isotopic diagram showing isotopic evolution of samples of the area. Reservoirs are from Doe and Zartman (1979). Field of Arenópolis metavolcanic rocks is from Pimentel (1991).

4.7 Nd ISOTOPIC RESULTS OF METASEDIMENTARY ROCKS

Nd isotopic results of sedimentary rocks in the Anicuns area are listed in table 4.5 and displayed in the Nd isotopic evolution diagram of figure 4.11. Sample locations are in figures 4.3 and 4.4.

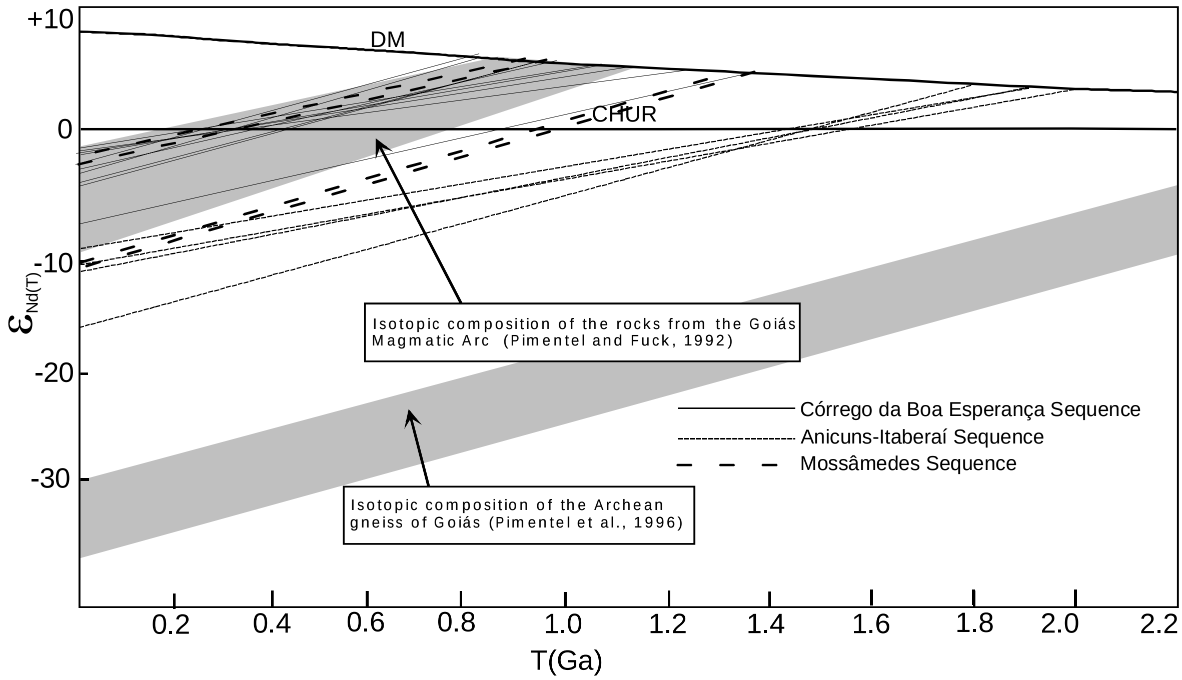

Figure 4.11 - Evolution ε_{Nd} x Time diagram showing Nd isotopic composition of the metasedimentary rocks of the Córrego da Boa Esperança, Anicuns-Itaberaí, and Mossâmedes sequences. Nd isotopic composition of the Goiás Magmatic Arc rocks is from Pimentel and Fuck (1992) and of Archean gneisses of Goiás from Pimentel et al. (1996).

Two different groups of Nd isotopic compositions for these rocks can be observed. Rocks belonging to the Anicuns-Itaberaí Sequence have T_{DM} values between 1.83 and 2.01 Ga, indicating a dominant Paleoproterozoic source region (Table 4.5). On the other hand, samples of the Córrego da Boa Esperança Sequence display T_{DM} ages between 0.8 and 1.1 Ga, very similar to metaigneous rocks of the Goiás Magmatic Arc (Laux et al., 2004a). The original sediments represent, therefore, immature clastic deposits derived from the erosion of the arc itself, without any important contribution from older sources.

Metasedimentary rock samples of the Mossâmedes Sequence are isotopically similar to those of the Córrego da Esperança, although T_{DM} model ages are slighlty older, between ca. 1.0 and 1.4 Ga. The ages show that these rocks are also derived from the erosion of the juvenile arc with a possible small contribution from an older sialic source.

4.8 CONCLUSIONS

The metamafic samples investigated in this study are tholeiitic to calc-alkaline metabasalts and display major and trace element characteristics that are compatible with an origin within an island arc setting, with LILE enrichment and HFSE depletion. In these settings, LILE enrichment is assigned to metasomatism of the mantle source due to fluids released during slab-dehydration. Amphibolite samples ANA 19A and ANA 19B, of the Bonfinópolis Sequence, associated with sedimentary rocks of the Araxá Group, are slightly different when compared to those of the Anicuns region, and most probably represent fragments of Neoproterozoic ocean floor.

The area of exposure of the Anicuns-Itaberaí Sequence coincides with a regionally important gravimetric discontinuity (Fig. 4.2) suggesting that it marks an important crustal boundary. This is suggested also by the initial isotopic compositions and inheritance patterns (and also initial Sr and Nd isotopic compositions) displayed by the mafic rocks exposed in the Anicuns area. To the west of the gravimetric discontinuity, mafic rocks are pristine, and present positive ε_{Nd}(T) values, whereas most mafic rock associations towards the east display clear evidence of contamination of the original magmas with older crust. For instance, the Gongomé intrusion has very high initial Sr isotopic ratio (0.7153) (Winge, 1995), rocks of the Santa Bárbara de Goiás Complex have inherited zircon grains of possible Mesoproterozoic age (Laux et al., 2004a), and the Goianira-Trindade layered intrusion has a Sm-Nd isochron age of ca. 621 Ma with an ε_{Nd}(T) value of 0.0 (M.M. Pimentel, unpublished results).

The Anicuns-Itaberaí and Córrego da Boa Esperança are roughly of the same age (ca. 890 – 830 Ma) (Laux et al., 2004a), however, T_{DM} values of the sedimentary rocks of these sequences are very distinct from each other. The Córrego da Boa Esperança Sequence sediments, with T_{DM} values between 0.8 and 1.2 Ga, were derived mostly from the erosion of the juvenile arc, whereas those of the Anicuns-Itaberaí Sequence indicate derivation from an older, mostly Paleoproterozoic source. In fact, these two sequences are juxtaposed against each other by an important thrust fault zone (Fig. 4.3), suggesting that the original sequences were deposited in different settings, received clastic material from distinct sources, and were later on deformed and tectonically juxtaposed. A similar bimodal behaviour of the provenance pattern of detrital sediments has also been identified in rocks belonging to the Araxá and Ibiá Groups of the Brasília Belt (Fischel et al., 2001a; Pimentel et al., 2001; Piuzana et al., 2003a). The Anicuns-Itaberaí Sequence may represent a platformal sequence similarly to the model put forward for part of the Araxá basin (for a review see Dardenne, 2000), whereas the Córrego da Boa Esperança Sequence may consist of a near-arc sedimentary basin (arc/fore-arc).

Based on the field, geochronological, isotopic and regional geophysical data, we suggest that the supracrustal sequence exposed in the Anicuns area might represent a arc/fore-arc sequence, marking the tectonic boundary between the Goiás Magmatic Arc and the westernmost exposures of the former São Francisco continental plate.

A likely model for the tectonic setting of this part of the Brasília Belt is illustrated in figure 4.12, in which the Anicuns region might represent the fore arc region of a larger island-arc system.

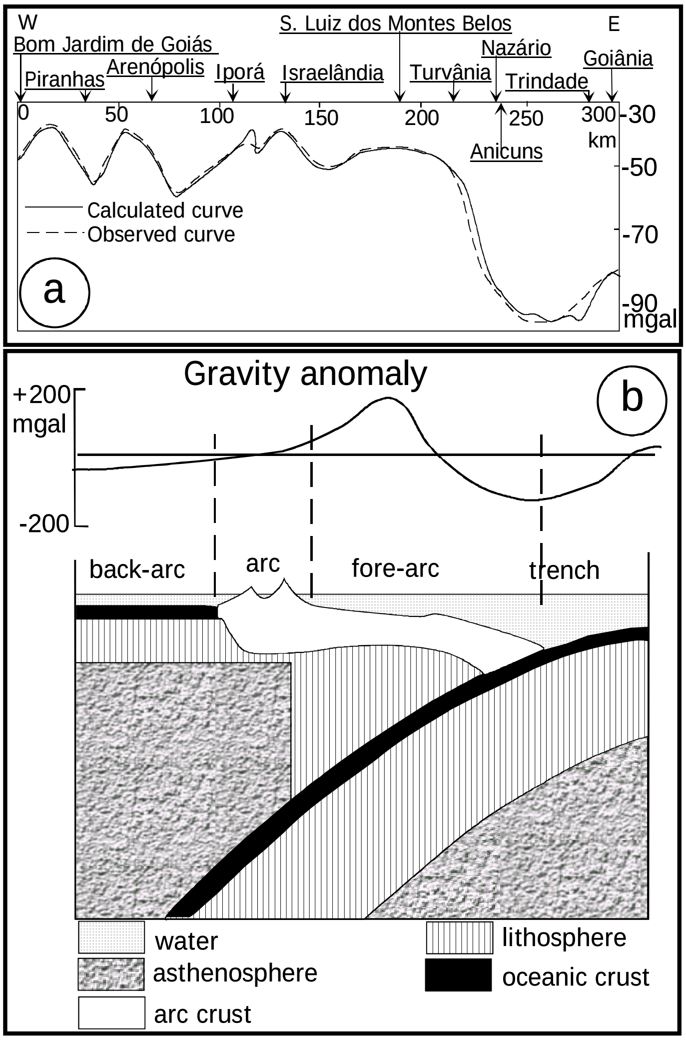

Figure 4.12 – Gravimetric anomaly in western Goiás (Baêta Júnior, 1994) compared with the model for island arcs from Gill (1981).

Table 4.1 - Geochemical results for the samples investigated.

Sample	JHL 01	JHL 09	JHL 13	JHL14	JHL 15	JHL 18	JHL 19	JHL 22A	JHL 22B	JHL 22C	JHL 23	JHL 24	JHL 26B	JHL 29	ANA 19A	ANA 19F
Rock	Amphib.	Diorite	Amphib.	Amphib.	Amphib.	Amphib.	Diorite	Amphib.	Amphib.	schist	Amphib.	Amphib.	Quartz -Diorite	Tonalite	Amphib.	Amphib.
Major Elements - X-Ray Fluorecence																
SiO_2(%)	54.6	47.4	54.1	60.4	52.5	57.2	55.0	54.6	52.1	58.6	53.2	46.6	65.3	61.1	48.8	48.3
Al_2O_3	15.0	17.8	15.7	18.2	16.5	14.7	17.7	2.8	9.5	17.9	7.9	10.4	16.2	16.2	15.0	14.5
MgO	3.1	9.1	4.2	2.6	6.5	2.7	4.3	18.9	11.3	2.8	13.9	11.4	2.6	2.6	9.7	9.7
MnO	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	<0.1	0.1	0.1	0.1
Cão	5.1	9.0	4.4	5.6	8.6	4.9	7.5	11.8	13.5	5.9	13.0	10.9	4.6	3.5	10.4	11.4
Na_2O	5.6	2.4	5.0	5.6	4.1	5.7	4.5	1.1	1.7	4.8	2.0	2.4	5.8	4.6	3.1	3.4
K_2O	1.8	0.1	2.7	0.2	0.4	1.7	0.9	<0.1	0.1	1.1	0.2	0.2	1.2	3.1	0.1	0.1
TiO_2	0.9	0.9	1.0	0.5	0.8	0.9	0.8	<0.1	1.0	0.9	0.9	1.7	0.5	1.3	0.9	0.9
P_2O_5	0.8	0.1	0.9	0.1	0.1	0.8	0.2	<0.1	0.2	0.2	0.1	0.1	0.2	0.6	<0.1	0.1
Fe_2O_3	9.9	12.1	10.5	6.7	9.6	9.3	8.6	9.1	8.1	8.0	8.0	13.4	4.1	5.9	9.8	10.0
Total	97.3	99.2	99.0	100.2	99.3	98.3	99.7	98.8	98.4	100.6	99.4	97.6	100.7	98.9	98.3	98.6
Trace Elements – ICP-MS																
Li(ppm)	18.1	28.2	27.8	17.3	2.9	22.3	14.8	16.7	10.6	7.8	9.5	10.6	12.6	41.2	12.7	8.7
Rb	36.1	3.1	42.9	6.1	1.6	47.2	19.6	0.4	1.4	30.8	1.9	4.6	30.4	87.0	1.5	1.3
Sr	634.1	166.3	887.9	441.5	296.2	406.1	508.9	20.8	309.6	569.2	239.6	161.5	453.2	968.7	86.5	93.2
Y	22.5	18.0	21.7	11.9	14.9	20.0	12.7	12.2	30.6	20.0	17.8	23.4	10.5	14.6	19.3	24.4
Zr	40.7	7.3	17.1	15.4	15.3	66.0	21.7	5.9	22.3	61.7	22.1	25.4	9.1	50.2	15.9	12.8
Nb	3.5	0.4	3.6	1.9	0.6	3.1	3.9	<0.1	4.2	5.0	2.9	6.8	2.7	11.8	2.0	3.6
Mo	0.3	0.2	0.3	0.1	0.2	0.2	0.3	0.2	0.7	0.4	0.3	0.4	0.2	0.9	0.3	0.2
Cs	1.3	1.1	1.3	0.1	<0.1	1.1	0.7	<0.1	0.1	0.3	0.1	0.2	0.5	3.5	0.1	<0.1
Ba	669.0	40.0	874.0	89.0	106.6	530.3	344.4	3.1	88.7	535.2	66.1	72.7	472.1	1690.6	30.1	21.5
Hf	2.8	0.8	0.9	2.2	1.5	2.4	2.7	0.8	2.2	3.2	2.3	2.3	0.8	3.3	1.8	1.5
Ta	0.6	0.4	0.7	0.4	0.5	0.4	0.8	0.1	0.7	0.4	0.6	0.7	0.7	0.5	1.0	0.6
Pb	9.0	2.3	6.6	9.7	2.9	8.0	4.6	2.2	4.5	4.6	4.8	1.9	4.9	19.7	0.8	0.4
Th	3.5	0.3	3.6	1.8	1.1	3.8	0.9	0.1	1.4	0.5	1.2	0.9	3.0	6.9	0.3	0.3
U	0.9	0.1	0.9	0.4	0.2	0.9	0.3	<0.1	0.7	0.2	0.4	0.2	0.4	1.4	<0.1	<0.1

Table 4.1 - Geochemical results for the samples investigated (Cont.).

Sample	JHL 01	JHL 09	JHL 13	JHL14	JHL 15	JHL 18	JHL 19	JHL 22A	JHL 22B	JHL 22C	JHL 23	JHL 24	JHL 26B	JHL 29	ANA 19A	ANA 19F
Rock	Amphib.	Diorite	Amphib.	Amphib.	Amphib.	Amphib.	Diorite	Amphib.	Amphib.	schist	Amphib.	Amphib.	Quartz -Diorite	Tonalite	Amphib.	Amphib.
Rare Earth Elements - ICP-MS																
La(ppm)	23.38	2.63	23.78	8.17	6.35	23.27	9.63	7.47	16.82	11.55	9.33	9.96	19.01	81.85	2.60	3.70
Ce	52.30	6.51	53.834	17.22	14.47	52.60	19.77	3.17	31.16	27.33	18.10	20.79	36.88	137.62	6.03	7.24
Pr	6.70	1.14	7.016	2.22	2.14	6.52	2.47	1.71	5.25	3.70	3.02	3.45	4.42	18.85	1.04	1.44
Nd	30.35	5.89	31.442	9.64	9.82	29.58	11.09	6.67	24.48	17.24	14.37	16.66	17.05	70.93	5.71	7.54
Sm	6.53	1.95	6.772	2.14	2.65	6.27	2.50	1.35	5.60	4.14	3.57	4.46	3.21	10.68	2.09	2.51
Eu	1.91	0.75	1.843	0.72	0.78	1.78	0.93	0.48	1.67	1.28	1.11	1.44	0.92	2.43	0.89	0.95
Gd	5.27	2.60	5.513	2.14	2.95	5.22	2.54	1.46	5.89	4.07	3.78	4.96	2.63	6.24	2.99	3.45
Tb	0.72	0.45	0.742	0.33	0.48	0.70	0.39	0.25	0.85	0.64	0.55	0.77	0.37	0.72	0.53	0.64
Dy	4.30	3.14	4.548	2.16	3.21	4.25	2.51	1.67	5.20	4.06	3.51	4.98	2.23	3.72	3.77	4.49
Ho	0.88	0.69	0.907	0.44	0.65	0.82	0.53	0.36	1.04	0.82	0.65	0.95	0.41	0.62	0.80	0.95
Er	2.42	2.08	2.512	1.25	1.91	2.42	1.54	1.09	2.85	2.32	1.79	2.58	1.12	1.54	2.36	2.69
Tm	0.34	0.33	0.379	0.18	0.30	0.37	0.21	0.18	0.40	0.32	0.27	0.37	0.19	0.18	0.36	0.42
Yb	2.34	1.98	2.272	1.26	1.78	2.16	1.47	0.89	2.28	2.14	1.35	2.10	0.94	1.15	2.08	2.65
Lu	0.33	0.29	0.325	0.18	0.25	0.33	0.23	0.13	0.32	0.29	0.18	0.28	0.12	0.16	0.31	0.37

Table 4.2 Summary of Sm-Nd results for the mafic rocks (after Laux et al., 2004a).

Sample	Sm	Nd	$^{143}Nd/^{144}Nd$ (±2SE)	$^{147}Sm/^{144}Nd$	$\varepsilon_{(0)}$	$\varepsilon_{(T)}$	T_{DM}(Ga)	$^{143}Nd/^{144}Nd_{(T=890)}$
JHL01[1]	6.16	29.40	0.512517 (±05)	0.1266	-2.3	--	0.92	0.511778
JHL 09[1]	2.11	6.42	0.512876 (±10)	0.1991	4.6	--	--	0.511714
JHL13[1]	6.60	30.52	0.512524 (±17)	0.1308	-2.2	--	0.95	0.511760
JHL14[1]	2.12	9.25	0.512542 (±06)	0.1387	-1.9	+4.4	1.01	0.511732
JHL15[1]	2.64	9.95	0.512713 (±06)	0.1603	1.5	+5.5	0.94	0.511777
JHL18[1]	6.50	29.23	0.512500 (±06)	0.1297	-2.7	--	0.98	0.511743
JHL23[2]	3.44	13.94	0.512612 (±06)	0.1493	-0.5	+4.4	1.02	0.511740
JHL24[2]	4.27	15.95	0.512663 (±10)	0.1620	0.5	--	1.11	0.511717
JHL 26b[2]	3.21	17.01	0.512401 (±06)	0.1142	-4.6	+4.4	0.98	0.511734
JHL19[3a]	2.54	10.86	0.512540 (±19)	0.1412	-1.9	+1.8	1.05	
JHL22a[3b]	1.27	6.29	0.512374 (±10)	0.1226	-5.1	--	1.11	
JHL22b[3b]	5.28	22.84	0.512538 (±05)	0.1398	-1.9	--	1.04	
JHL22c[3b]	4.05	16.93	0.512566 (±06)	0.1447	-1.4	+2.6	1.05	
JHL 29	10.9	72.01	0.512059 (±06)	0.0915	-11.3		1.22	
ANA 19A	2.02	5.30	0.513103 (±04)	0.2207	9.1	+6.5	---	0.511815
ANA 19F	2.33	6.78	0.513023 (±04)	0.2081	7.5	+6.3	--	0.511808

[1-] Córrego da Boa Esperança Sequence; [2-] Anicuns Itaberaí Sequence; [3a]- Anicuns-Santa Bárbara Suíte - Córrego Seco Complex (intrusive in Córrego da Boa Esperança Sequence); [3b]- Anicuns-Santa Bárbara Suíte - Córrego Seco Complex (intrusive in Anicuns Itaberaí Sequence).

Table 4.3 Sr isotopic results.

Sample	Rb(ppm)	Sr(ppm)	$^{87}Sr/^{86}Sr(\pm2SE)$	$^{87}Sr/^{86}Sr_{Inic.}$	ε(T)	Age(Ga)	$^{87}Sr/^{86}Sr_{(T=0.89)}$
JHL 01	36.13	634.13	0.70496 (±2)	0.70296	-7.6	0.85	0.70286
JHL 09	3.058	166.29	0.70326 (±2)	0.70261	-12.5	0.85	0.70258
JHL 13	42.96	887.95	0.70461 (±2)	0.70291	-8.3	0.85	0.70283
JHL 14	6.10	441.55	0.70397 (±2)	0.70346	0.1	0.88	0.70346
JHL 15	1.58	296.22	0.70307 (±2)	0.70288	-8.5	0.86	0.70287
JHL 18	47.24	406.08	0.70648 (±2)	0.70239	-15.7	0.85	0.70220
JHL 19	19.66	508.91	0.70417 (±1)	0.70318	-8.3	0.62	----
JHL 22A	0.38	20.88	0.70605 (±2)	0.70557	25.72	0.63	----
JHL 22B	1.40	309.61	0.70343 (±2)	0.70331	-6.3	0.63	----
JHL 22C	30.85	569.18	0.70452 (±2)	0.70313	-9.1	0.62	----
JHL 23	1.96	239.66	0.70363 (±2)	0.70335	-2.6	0.81	0.70333
JHL 24	4.62	161.52	0.70393 (±2)	0.70292	-8.1	0.85	0.70288
JHL 26B	30.44	453.21	0.70514 (±2)	0.70284	-9.7	0.83	0.70267
JHL 29A	87.03	968.74	0.70745 (±2)	0.70511	19.3	0.63	----
ANA 19A	1.54	86.58	0.70322 (±2)	0.70261	-12.9	0.84	0.70256
ANA 19F	1.37	93.22	0.70314 (±2)	0.70263	-12.5	0.84	0.70260

Table 4.4 Pb isotopic results.

Sample	U (ppm)	Pb (ppm)	Th (ppm)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$*	$^{207}Pb/^{204}Pb$*	$^{208}Pb/^{204}Pb$*	T(Ga)
JHL 01	0.91	9.03	3.48	18.306	15.572	37.988	16.990	15.484	36.936	0.83
JHL 09	0.10	2.30	0.29	18.110	15.520	37.460	16.818	15.434	37.115	0.83
JHL 13	0.93	6.63	3.61	18.533	15.510	38.102	17.255	15.425	36.611	0.83
JHL 14	0.42	9.74	1.84	17.607	15.475	37.229	16.329	15.390	36.723	0.83
JHL 15	0.23	2.93	1.12	18.174	15.460	37.648	16.921	15.376	36.612	0.83
JHL 18	0.99	8.05	3.85	18.594	15.564	38.564	17.290	15.477	37.242	0.83
JHL 19	0.33	4.65	0.89	18.234	15.572	37.730	17.248	15.512	37.335	0.63
JHL 22A	0.06	2.20	0.12	18.061	15.620	37.737	17.049	15.559	37.625	0.63
JHL 22B	0.70	4.53	1.45	18.472	15.638	37.951	17.463	15.577	37.287	0.63
JHL 22C	0.17	4.62	0.53	18.963	15.702	39.042	17.936	15.640	38.797	0.63
JHL 23	0.39	4.87	1.22	18.668	15.984	38.878	17.108	15.880	38.179	0.83
JHL 24	0.21	1.88	0.99	18.944	15.653	38.462	17.597	15.563	36.996	0.83
JHL 26B	0.45	4.96	3.00	18.003	15.492	38.489	16.725	15.407	36.838	0.83
JHL 29A	1.42	19.76	6.92	18.114	15.488	37.930	17.163	15.430	37.212	0.63
ANA 19A	0.07	0.83	0.29	18.697	15.640	38.731	17.357	15.551	37.751	0.83
ANA 19F	0.07	0.47	0.28	18.795	15.487	38.607	17.538	15.403	36.979	0.83

* Calculate after a curve of evolution of Pb from Stancey and Kramers (1975) using ISOPLOT version 2.11(Ludwig 2001).

Table 4.5 Sm-Nd results for the metasedimentary rocks.

Sample	Sm	Nd	$^{143}Nd/^{144}Nd$ (±2SE)	$^{147}Sm/^{144}Nd$	$\varepsilon_{(0)}$	T_{DM}(Ga)
JHL08[1]	2.79	11.69	0.512557 (±18)	0.1444	-1.5	1.06
JHL 17[1]	2.53	10.49	0.512541 (±06)	0.1461	-1.9	1.12
JHL20[1]	5.44	21.41	0.512546 (±05)	0.1535	-1.8	1.24
JHL21[1]	16.75	98.99	0.512447 (±06)	0.1023	-3.7	0.82
JHL36A[1]	4.32	14.05	0.512624 (±19)	0.1857	-0.3	---
JHL36B[1]	6.38	29.69	0.512532 (±18)	0.1299	-2.1	0.93
JHL37[1]	9.11	50.14	0.512491 (±06)	0.1098	-2.8	0.81
JHL38A[1]	3.41	18.02	0.512418 (±10)	0.1114	-4.3	0.96
JHL38B[1]	4.31	23.72	0.512405 (±06)	0.1097	-4.5	0.93
JHL 39[1]	7.01	33.95	0.512491 (±07)	0.1248	-2.8	0.94
JHL22D[2]	0.45	2.04	0.512027 (±24)	0.1346	-11.9	1.94
JHL22E[2]	3.38	14.67	0.512054 (±11)	0.1393	-11.4	2.01
JHL22F[2]	10.42	43.88	0.512133 (±04)	0.1436	-9.8	1.96
JHL25[2]	3.61	19.90	0.512789 (±06)	0.1099	-16.5	1.83
JHL 27A[3]	11.24	66.46	0.512066 (±06)	0.1022	-11.1	1.32
JHL 28[3]	2.84	13.87	0.512469 (±04)	0.1238	-3.3	0.97
JHL 30B[3]	2.54	14.81	0.512043 (±06)	0.1237	-11.6	1.37
JHL 30D[3]	6.00	25.52	0.512535 (±06)	0.1420	-2.0	1.07

[1-] Córrego da Boa Esperança Sequence; [2-] Anicuns Itaberaí Sequence; [3]- Mossamedes Sequence).

CAPÍTULO V

5.1 CONCLUSÕES

Os novos dados isotópicos U-Pb e Sm-Nd, combinados com resultados geoquímicos e integrados com os da literatura, confirmam que o Arco de Arenópolis se estende por mais de 200 km, desde Bom Jardim de Goiás, no oeste, até as vizinhanças de Anicuns, no leste, com contínua exposição de rochas juvenis neoproterozóicas.

Os dados apresentados também identificam dois períodos principais de acresção crustal no Arco de Arenópolis. Um antigo, de idade entre ca. 0,89 e 0,78 Ga, e um mais novo entre 0,66 e 0,60 Ga. O evento mais antigo foi dominado por magmatismo primitivo em ambiente de arco de ilhas, com idade modelo T_{DM} ao redor de 1 Ga e valores de ε_{Nd} positivos.

Rochas do evento mais novo apresentam um grau variado de contaminação crustal, como indica a herança meso- a neoproterozóica observada nos dados U-Pb em zircão, eg. granito-gnaisse Choupana e granito Lavrinha, e valores elevados de idades modelo T_{DM} (e.g. gnaisses Palminópolis e Firminópolis).

A Seqüência Anicuns-Itaberaí coincide com importante descontinuidade gravimétrica que marca um limite crustal, e que, possivelmente, separa as rochas juvenis do Arco Magmático de Goiás, a oeste, das do Complexo Anápolis-Itauçu e do embasamento da Faixa Brasília, a leste. As rochas próximas deste limite registram herança isotópica, marcada nas características isotópicas de Nd das rochas ígneas. Isto é também mostrado no padrão de herança de rochas máficas da região de Anicuns. A oeste da descontinuidade gravimétrica, as rochas máficas são primitivas e possuem valores positivos de $\varepsilon_{Nd}(T)$, enquanto que as de leste contém evidências de contaminação do magma original com crosta antiga.

Os dados U-Pb das rochas máficas demonstram que as seqüências Anicuns-Itaberaí e Córrego da Boa Esperança são neoproterozóicas e cronocorrelatas. As rochas máficas investigadas neste estudo são toleíticas a cálcio-alcalinas e mostram conteúdos de elementos maiores e traços característicos de rochas de ambientes de arco de ilha, com enriquecimento em LILE e empobrecimento em HFSE. Contudo, os valores de T_{DM} das rochas metassedimentares de ambas as seqüências são distintos. As da Seqüência do Córrego da Boa Esperança, com valores de T_{DM} entre 0,8 e 1,2 Ga, foram derivadas da erosão das rochas juvenis do arco, enquanto que as rochas da Seqüência Anicuns-Itaberaí indicam fonte mais antiga, principalmente de crosta paleoproterozóica. Estas duas seqüências estão justapostas por importante zona de falha de empurrão, o que sugere que foram originalmente depositadas em diferentes ambientes e posteriormente justapostas. A Seqüência Anicuns-Itaberaí pode representar uma seqüência plataformal que recebeu sedimentos de um continente mais antigo, enquanto a Seqüência Córrego da Boa Esperança foi depositada em bacia próxima ao arco, principal fonte de seus sedimentos.

Os dados de campo, geocronológicos, isotópicos e de geofísica regional sugerem que as rochas da região de Anicuns representam uma seqüência de arco/*fore-arc*, que coincide com o limite tectônico o Arco Magmático de Goiás e a borda oeste do continente São Francisco.

CAPÍTULO VI

6.1 REFERÊNCIAS BIBLIOGRÁFICAS

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