The Anicuns-Itaberaí volcano-sedimentary sequence, Goiás Magmatic Arc: new geochemical and Nd-S isotopic data

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Resumo

A sequência vulcano-sedimentar, neoproterozóica, Anicuns-Itaberaí, exposta na vizinhança da cidade de Anicuns, oeste de Goiás, Brasil, compreende uma complexa associação de rochas ígneas e supracrustais, que têm sido divididas em: (i) Sequência Córrego da Boa Esperança, na parte oeste - incluido meta-basaltos cálcico-alcalinos, metatufos andesíticos/dacíticos, metapelitos e formação ferrífera, e (ii) Sequência Anicuns-Itaberaí, na parte leste, compreendendo rochas máfico/ultramáficas, metacherts, metaritmitos e lentes de mármores. Estas sequências são interpretadas como sendo partes das associações de rochas supracrustais do Arco Magmático de Goiás, formado entre ca. 890 e 630 Ma. Rochas graníticas, bem como pequenos corpos máficos e máfico-ultramáficos são intrusivos na sequência supracrustal. Os granitóides variam de tonali-tos, granodioritos e granitos com quartzo-sienito, monzonito e monzodiorito subordinados. Neste trabalho são apresentados e discutidos dados isotópicos e geoquímicos de rochas meta-ígneas e meta-sedimentares. Baseado no padrão de variação das rochas metabásicas, três diferentes grupos podem ser reconhecidos: 1) basaltos com assinatura primitiva tipo N-MORB; 2) rochas com enriquecimento moderado em elementos LILE e 3) rochas com pronunciado enriquecimento em elementos LILE. A maioria dos resultados isotópicos de Nd indicam valores TDM de ca. 1,0 Ga e εNd(T) positivos, padrão similar ao encontrado nas rochas meta-ígneas do Arco Magmático de Goiás. Observações de campo, juntamente com os dados geoquímicos e isotópicos, sugerem que as rochas presentes na área de Anicuns podem representar uma sequência de arc/fore-arc, representando o limite tectônico entre o Arco Magmático de Goiás, na parte oeste, e a parte oeste do continente São Francisco, no leste. Esta interpretação tem apoio em dados de geofísica regional presentes na literatura, os quais mostram que a área onde está a sequência Anicuns-Itaberaí apresenta uma queda brusca no gradiente gravimétrico regional. Os dados isotópicos e geoquímicos mostram, em geral, uma assinatura típica de associações de arco de ilha.

Palavras-chave: Sequencia Anicuns, Neoproterozóico, Arco Magmático de Goiás, rochas juvenis.

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Abstract

The Neoproterozoic Anicuns-Itaberaí volcano-sedimentary sequence exposed in the surroundings of Anicuns, western Goiás, comprises a complex association of igneous and supracrustal rocks, which has been divided into: (i) the Córrego da Boa Esperança Sequence including calc-alkaline meta-basalts, andesitic/dacitic metatuffs, metapelites, and iron formation, and (ii) the Anicuns-Itaberaí Sequence, in the east, including mafic/ultramafic rocks, metacherts, metarhytmites, and marble lenses. These sequences are interpreted to be part of the supracrustal associations of the Goiás Magmatic Arc, formed between *ca.*

890 and 630 Ma. 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, monzonite, and monzodiorite. In this work we present and discuss geochemical and isotopic data from metaigneous and metasedimentary samples. Based on the variation patterns three different groups of metabasic rocks may be recognized: 1) very primitive N-MORB-like basalts; 2) moderate LILE-enriched rocks and 3) distinctively LILE-enriched rocks. Nd isotopic results mostly indicate T_{DM} values of *ca.* 1.0 Ga and positive ε_{Nd}(T), also similar to the known primitive nature of the meta-igneous rocks of the Neoproterozoic Goiás Magmatic Arc. Field observations, together with geochemical and isotopic data from this contribution suggest that the supracrustal and associated magmatic sequences in the Anicuns area may represent an arc/fore-arc sequence, marking the tectonic boundary between the Goiás Magmatic Arc, to the west and, the westernmost exposures of the São Francisco Continental margin, to the east. This is also in agreement with regional geophysical data from the literature, which shows that the area of exposure of the Anicuns-Itaberaí sequence coincides with a steep gravimetric gradient. In general the geochemical and isotopic characteristics of the meta-igneous rocks are typical of island arc associations.

Keywords: Anicuns Sequence, Neoproterozoic, Goiás Magmatic Arc, juvenile crust

1. Introduction

The Goiás Magmatic Arc, in central Brazil (Figure 1), consists of several arc-type metavolcano-sedimentary sequences associated with voluminous tonalitic to granitic orthogneisses, forming an extensive Neoproterozoic juvenile terrain, elongated in the NNE direction, along the western part of the Brasília Belt (Pimentel & Fuck, 1992; Pimentel *et al.*, 2000a, 2003). Mafic volcanic and sub-volcanic rocks are associated with calc-alkaline andesites, dacites, and rhyolites in the supracrustal sequences (e.g. Bom Jardim de Goiás and Arenópolis; Seer, 1985; Pimentel and Fuck, 1986). In some of the sequences the basalts are associated with rhyolites forming a typical bimodal sequence (e.g. Iporá and Jaupaci sequences), in others, the complete calc-alkaline series is found (e.g. Arenópolis and Bom Jardim sequences), whereas in sequences such as the Mara Rosa and Anicuns, metabasalts are the only metavolcanic rocks. These metavolcanics typically present very primitive geochemical and isotopic characteristics, with low initial $^{87}Sr/^{86}Sr$ ratios and positive ε_{Nd}(T) values. Felsic and mafic metavolcanic rocks have U-Pb zircon ages between ca. 0.9 and 0.64 Ga (Pimentel *et al.*, 1991; Rodrigues *et al.*, 1999; Dantas *et al.*, 2002, Laux et al. 2004, 2005, Junges *et al.,* 2008). Most of the previous isotopic, geochronological and petrological studies concentrated on intermediate to felsic members of this magmatism. 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 very primitive isotopic compositions (initial $^{87}Sr/^{86}Sr$ of *ca*. 0.7026 and ε_{Nd}(T) of +6.9; Pimentel, 1991). They most likely represent 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 of them was dated at 890 ± 9 Ma (SHRIMP U-Pb zircon age; Pimentel *et al.*, 2003), from a plutonic/subvolcanic equivalent of the volcanic sequence. In the Anicuns Sequence mafic intrusive have been dated by the U-Pb method and gave crystallization ages between *ca.* 890 and 815 Ma and positive ε_{Nd}(T) values (Laux *et al.,* 2004).

The Anicuns-Itaberaí Sequence, crops out along the limits between the eastern part of the Goiás Magmatic Arc and the Anápolis-Itauçu high-grade terrain (Figure 1). It includes predominantly amphibolites (metavolcanic and metaplutonic) and metapelitic rocks, with subordinate iron formation, chert, marble, and meta-ultramafic rocks of uncertain age. This sequence has been previously correlated with: 1) the Archean Serra de Santa Rita greenstone belt, exposed to the north (Barbosa, 1987), 2) the Paleoproterozoic sequences such as the Silvânia Sequence within the Anápolis-Itauçu Complex (Lacerda Filho *et al.*, 1991) and 3) the Mossâmedes metavolcanic rocks (Nunes, 1990). Recent studies based mainly on Sm-Nd isotopic characteristics of the Anicuns-Itaberaí rocks, however, suggest that they are considerably younger and are part of the Neoproterozoic Goiás Magmatic Arc (Pimentel *et al*., 2000a, b; Laux *et al*., 2001, 2002a, b, 2004).

In this paper we present and discuss new geochemical and isotopic data for coarse-grained metamafic rocks exposed within the Anicuns-Itaberaí Sequence. Our results point towards the conclusion 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 as suggested by regional gravimetric anomalies.

2. Regional Geological Setting

The Tocantins Province represents a large Brasiliano/Pan-African orogen that developed between three major Neoproterozoic continents: the Amazon, to the west, the São Francisco, to the east, and the Paranapanema Block, concealed under the sedimentary rocks of the Paraná Basin. The province comprises three main fold belts, known as the Paraguay Belt in the southwest, the Araguaia Belt in the NW,

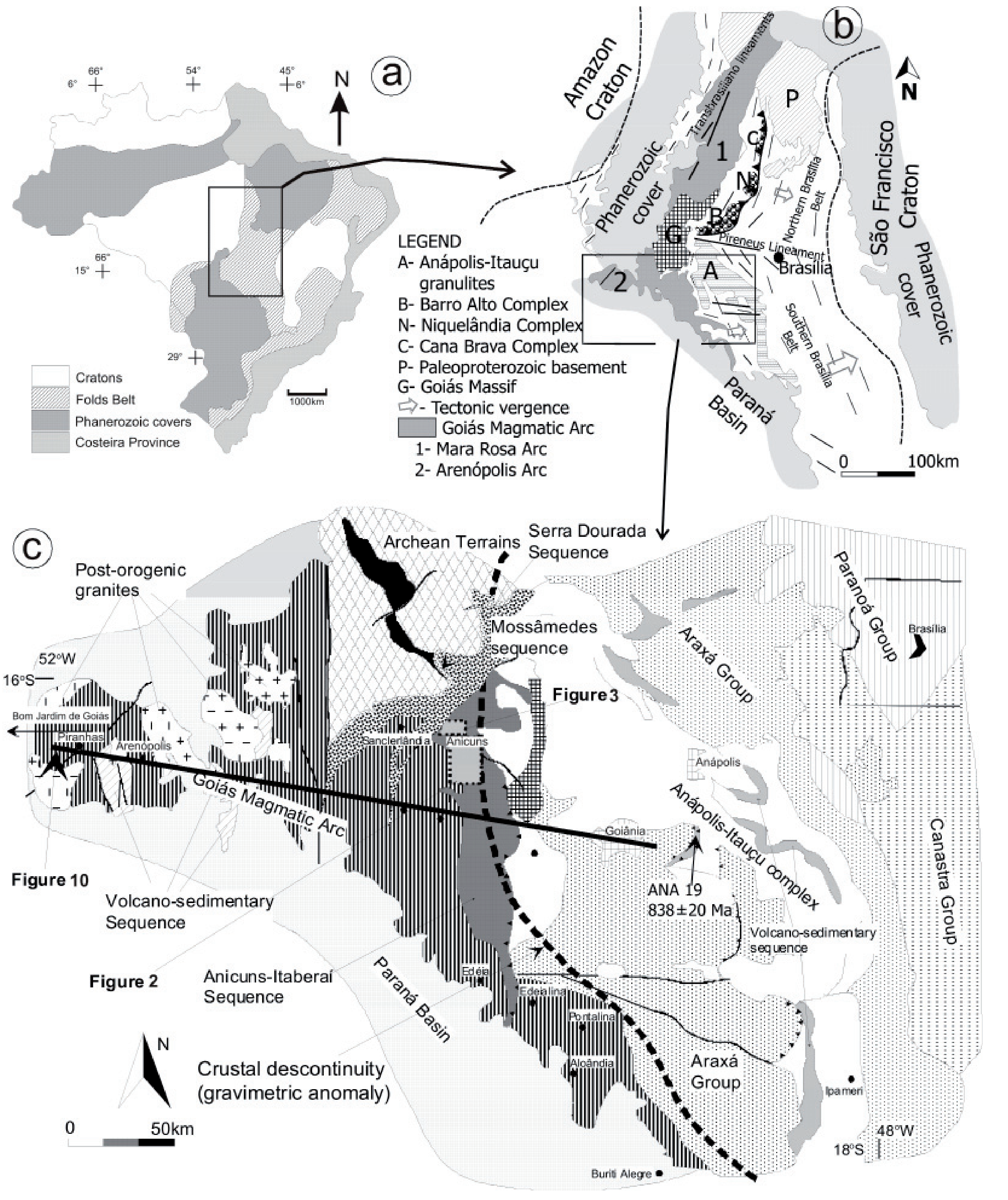

Figure 1 – a) Tectonic provinces of Brazil; b) Geological sketch map of the Brasília Belt in the eastern part of Tocantins Province, central Brazil (Pimentel et al., 2003); c) Geological sketch map of the southern part of the Goiás Magmatic Arc (Pimentel et al., 2000a), with location of the areas investigated and figures 2, 3 and 10.

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; Valeriano *et al.,* 2008).

The Brasília Belt represents one of the best preserved and possibly the most complete Neoproterozoic orogen in Brazil. It comprises: (i) a thick Meso-Neoproterozoic sedimentary pile including 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) (Figure 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. Deformation and metamorphic degree increase towards the west, reaching amphibolite facies conditions in the central part of the belt (Fuck *et al.*, 1993, 1994; Dardenne, 2000) and granulite facies conditions within the Anápolis-Itauçu high-grade complex, interpreted to be the metamorphic core of the orogen (Della Giustina *et al.,* 2011a,b).

Metasedimentary rocks belonging to the Araxá, Ibiá and Canastra groups underlie large areas in the central-southern part of the Brasília Belt (Figure 1). 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 (Figures 1). 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 metasediments, 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), suggesting 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 incorporated Neoproterozoic juvenile sequences 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 (Figures 1), 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 (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). In the southern part of the belt, this gravimetric discontinuity coincides with the area of exposure of the Anicuns-Itaberaí Sequence.

The Neoproterozoic juvenile arc (Goiás Magmatic Arc) comprise volcano-sedimentary sequences associated with calcic to calc-alkaline tonalite/granodiorite orthogneisses (Figure 1). The main arc segments are known as the Arenópolis and Mara Rosa arcs, located in western and northern Goiás/southwestern Tocantins, respectively (Pimentel and Fuck, 1992; Pimentel *et al.*, 1991, 1997) (Figure 1). In both areas, geological evolution started at *ca.* 900 - 860 Ma in intraoceanic island arcs with the crystallization of very primitive tholeiitic to calc-alkaline volcanics and associated gabbrodiorite/tonalite/granodiorite. These rocks have $\varepsilon_{Nd}(T)$ values between ca. +3.0 and +6.0 and T_{DM} values mostly between *ca.* 0.9 and 1.1 Ga (Pimentel *et al.,* 1991, 1997, 2000b; Pimentel and Fuck, 1992, Laux *et al.,* 2004, 2005). Geochemical and isotopic data (Pimentel, 1991; Pimentel *et al.,* 1997) suggest that the original tonalitic/andesitic magmas were similar to modern adakites, formed above subduction zones where young and hot oceanic lithosphere is subducted. Calc-alkaline igneous activity was recurrent during the Neoproterozoic and lasted until *ca*. 640 Ma, with younger magmas becoming progressively more evolved. In fact, recent data has demonstrated that the arc magmatism seems to have taken place in two main episodes: the older between *ca.* 900-800 Ma and the younger between *ca.* 670-630 Ma (e.g. Laux *et al.,* 2005). The main metamorphic episode occurred at *ca.* 630 Ma, as indicated by U-Pb titanite and Sm-Nd garnet ages, when final ocean closure probably took place (see Valeriano *et al.,* 2008).

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 south and to the northeast, disappearing under the Paraná and Parnaíba Phanerozoic basins, respectively (Figure 1). 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).

3. Geology of the Anicuns Region

In the Mossâmedes-Anicuns region (Figures 1, 2, and 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 archean 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, of the uncertain age.

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) to the west has been correlated with the Araxá Group and consists of metapelites, andesitic/dacitic meta-tuffs, and iron formation (Nunes, 1990) (Figure 2); (ii) the AIS to the

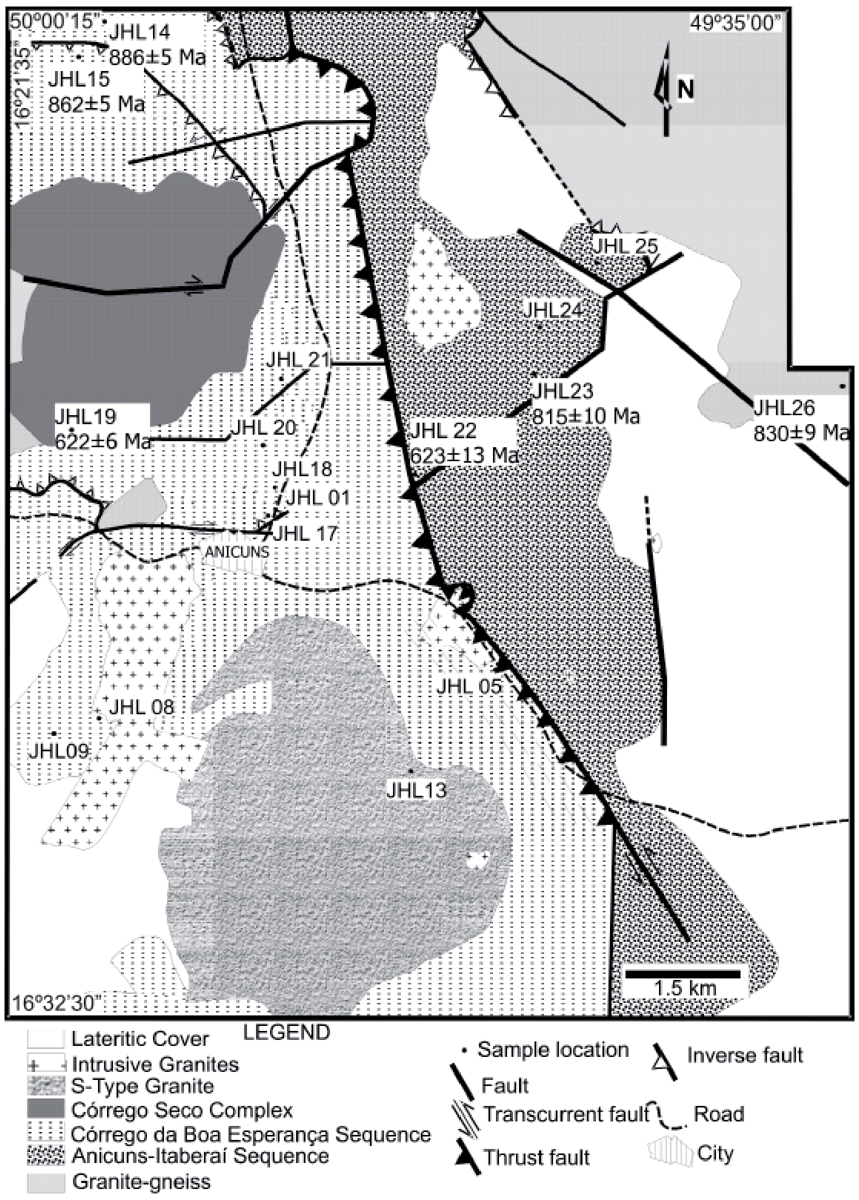

Figure 2 - Geological sketch map of the Anicuns region, with sample location (simplified from Nunes, 1990).

east, separated from the CBES by a NNW reverse fault, is composed of mafic/ultramafic rocks, metacherts, metarhytmites, and marble lenses. Laux *et al.* (2004), however, demonstrated that the Anicuns-Itaberaí and Córrego da Boa Esperança sequences are of the same age and their supracrustal rocks formed between *ca.* 890 to 830 Ma. Therefore they both 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 has already been suggested by Nilson (1981) for 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, monzonite, and monzodiorite (Barbosa, 1987; Nunes, 1990). The deformed, elongated, locally mylonitic granitic bodies represent the major part of the granite intrusive complexes in the area. They have been dated at approximately 800 Ma, whereas the late-tectonic, less voluminous granite intrusions are *ca.* 615 Ma old (Laux *et al.* 2005).

Mafic/intermediate intrusions are collectively referred to as the Anicuns-Santa Bárbara Gabbro-Diorite Suite (Lacerda Filho and Oliveira, 1995). The Córrego Seco Complex (Figure 2) comprises gabbro, diorite and amphibolite and, in some places, crosscutting relationships with the AIS are observed. This suite has been correlated to the Americano do Brasil intrusion, exposed to the north (Pfrimer *et al.,* 1981; Nunes 1990). A diorite sample from this suite yielded an age of 622 ± 6 Ma which has been interpreted as the crystallization age of the intrusion (Laux *et al.,* 2004).

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 Serra do Gongomé intrusion has an Rb-Sr isochron age of 637 ± 19 Ma and high initial Sr isotopic ratio

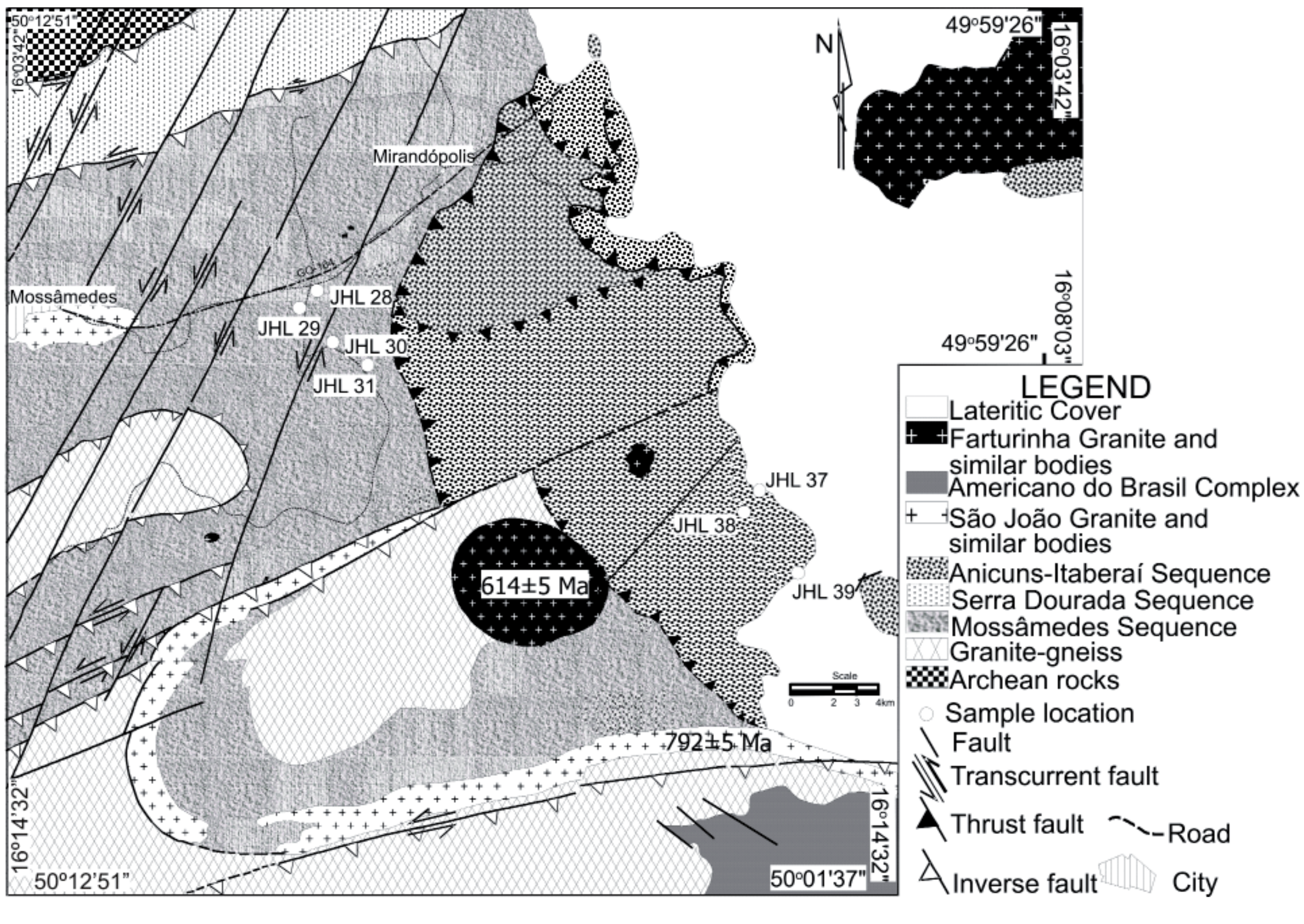

Figure 3 - Geological sketch map of the area east of Mossâmedes, Goiás (Simplified from Barbosa, 1987).

(0.7153) indicating interaction with an older continental crust (Winge, 1995). The Americano do Brasil complex crystallized at 626 ± 8 Ma (U-Pb zircon data of Laux *et al.,* 2004), and the original tholeiitic magma presents positive $\varepsilon_{Nd}(T)$ values of approximately +2.4 (Gioia, 1997) indicating little or no contamination with much older sialic crust.

4. Analytical procedures

Major element analyses were carried out by XRF at the Núcleo de Estudos de Granitos of the Universidade Federal de Pernambuco. One aliquot of each sample was placed in an oven at 1000^{0}C for two hours for the L.O.I. determination. Samples were fused into small pellets using Li tetraborate at the 1:5 proportions. 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 the Memorial University of Newfoundland, Canada. Dissolution has been carried out in an HF/HNO_3 mixture in screwd 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 a rigorous correction for matrix effects.

Sr, Nd, isotopic analyses were performed in the Geochronology Laboratory of the 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 and Sr samples were loaded on Re evaporation of double filament assemblies. The isotopic measurements were carried out on a multi-collector Finnigan MAT 262 mass spectrometer in static mode.

Sm-Nd isotopic analyses followed the procedure described by Gioia and Pimentel (2000). Powdered samples 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 performed 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 200 pg.

5. Geochemical Results

Sixteen samples of mafic rocks were analyzed for major, trace and REE (results are in Table 1). Samples ANA 19F and ANA 19A correspond to fine-grained amphibolites of the Bonfinópolis Sequence, to the east of the studied area, dated at 838 ± 20 Ma (Piuzana *et al.,* 2003a) (Figure 1) by the SHRIMP U-Pb method. Samples JHL 01, JHL 18 e JHL 09 (Figure 2) are also fine-grained amphibolite samples chemically equivalent to andesites (JHL 01 and 18) and metabasalt (JHL 09) which are most likely *ca.* 840 Ma old, based on a reference whole-rock Sm-Nd isochron (Laux *et al.* 2004). Samples JHL 13, JHL 14, JHL 15, JHL 22C, JHL 23 e JHL 24 (Figure 2) are coarse-grained amphibolites representing both metadiorites and metagabbros. U-Pb zircon ages of Laux *et al.,* (2004) are 886 ± 5 Ma and 623 ± 13 Ma respectively for samples JHL 14 and JHL 22C, indicating two different events of mafic magmatism. 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 metasediments or mixed volcanic-sedimentary supracrustal rocks. Sample JHL 29 (location in Figure 3) is a tonalite.

Major element results for 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 (Figure 4) we will concentrate the discussion on trace element results. In the AFM diagram the mafic rocks investigated seem to define a calc-alkaline trend, and in the alkalies x SiO_2 diagram they are mostly sub-alkaline.

The amphibolite samples investigated in this study show trace element variation patterns varying from very primitive compositions, similar to N-MORB basalts (Figure 5a), through a group showing moderate LILE enrichment

(Figure 5b), to a further group of samples displaying distinctive LILE enrichment (Figure 5c), more acid rocks.

Trace element characteristics of most metabasic rocks investigated are similar to oceanic island arc rocks (Figures 6a and b), ranging from the tholeiitic to the calc-alkaline series (Figures 6c and d). REE patterns for these rocks range from those of MORB-like tholeiitic basalts to LREE- enriched patterns typical of 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 include samples with flat chondrite-normalized REE patterns similar to some MORB's (Figure 7a). 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 patterns, which are similar to those of calc-alkaline arc andesites with LREE-enrichment and flat HREE pattern (Figure 7a). The third group includes samples, which display distinctive LREE fractionation and an upwards-concave HREE pattern (Figure 7b). The fourth group is formed by metasediments which form REE curves which are similar to those of group three, including the ab-

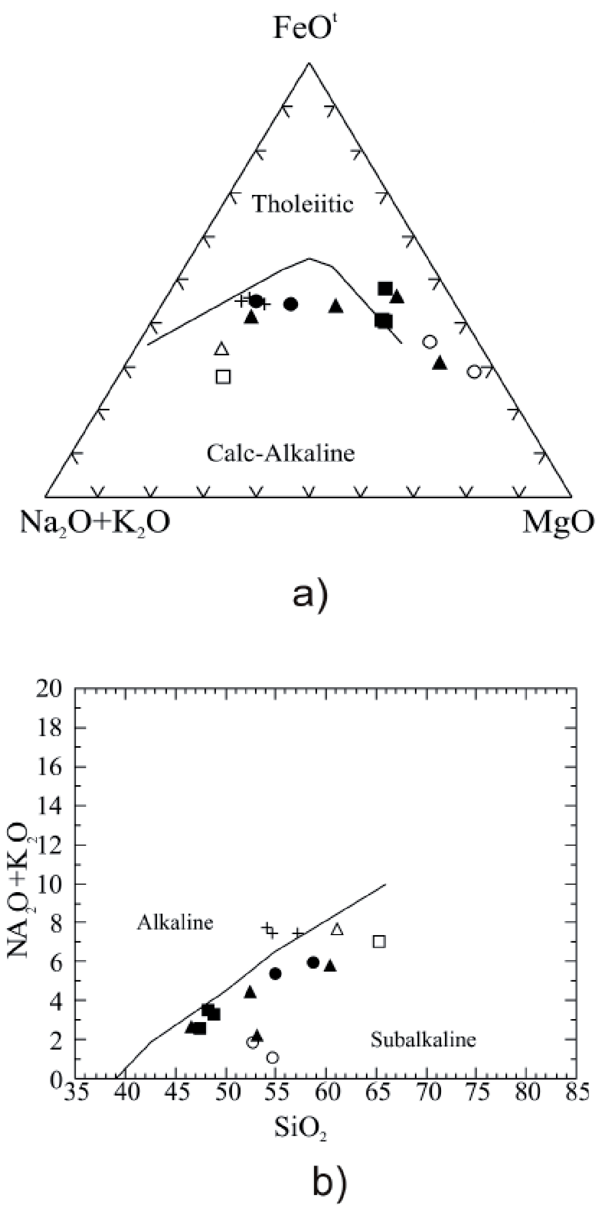

Figure 4 - Tholeiitic/Calc-Alkaline (a) and Alkaline/ Subalkaline (b) diagrams of Irvine and Baragar (1971). Symbols: cross- metandesites, full square– metabasalts, blank square– quartz-diorite, full circle– diorite (ca. 630 Ma), blank circle– metasedimentary rocks, full triangle– diorite (ca. ≈830 Ma), blank triangle- tonalite.

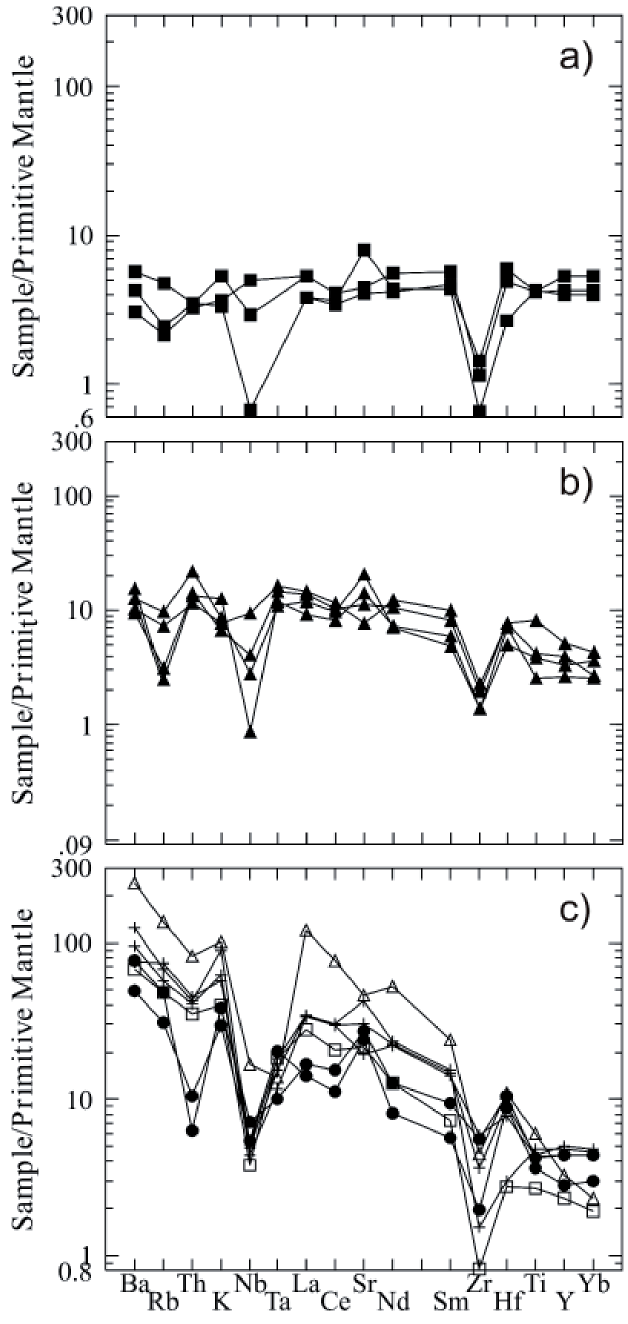

Figure 5 - Spider diagrams normalized to primitive mantle (Sun and McDonough, 1989). Symbols are the same from figure 4.

Table 1 - Geochemical results for the samples investigated.

Sample	JHL 01	JHL 09	JHL 13	JHL 14	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	Amphi.	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

Sample	JHL 01	JHL 09	JHL 13	JHL 14	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

sence of Eu negative anomaly (Figure 7c). The fifth pattern is that represented by the tonalite sample, with a very steep curve and slightly concave upward HREE pattern (Figure 7d). 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 is also characteristics shared by Archean TTG's and modern adakitic magmas, which are formed by the subduction of young hot oceanic lithosphere (Martin, 1987).

6. Nd and Sr Isotopes

6.1 Metaigneous Sequence

All rocks analysed present T_{DM} model ages of *ca.* 1.0 Ga (Table 2). This is the typical T_{DM} pattern observed in rocks from other parts of the Goiás Magmatic Arc (Pimentel and Fuck, 1992, Pimentel *et al.,* 1996, Junges *et al.,* 2002). $\varepsilon_{Nd}(T)$ values are positive, indicating the depleted nature of the mantle source. $^{147}Sm/^{144}Nd$ 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.,* 2004).

Sr isotopic results (Table 3) also point towards a primitive nature, 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 show that these rocks are not different from those studied by Pimentel and Fuck (1992) in the Arenópolis region, to the west (Figure 8).

6.2 Metasedimentary Sequence

Nd isotopic results for metasedimentary rocks in the Anicuns area are listed in table 4 and displayed in the Nd isotopic evolution diagram of figure 9. Sample locations are in figures 2 and 3.

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). On the other hand, metasediments of the Córrego da Boa Esperança Sequence display T_{DM} ages between 0.8 and 1.1 Ga (Table 4), very similar to the metaigneous rocks of the Goiás Magmatic Arc (Laux *et al.*, 2004, Pimentel & Fuck 1992). The original sediments of the latter represent, therefore, immature clastic deposits derived from the erosion of the arc itself, without any important contribution from older sources.

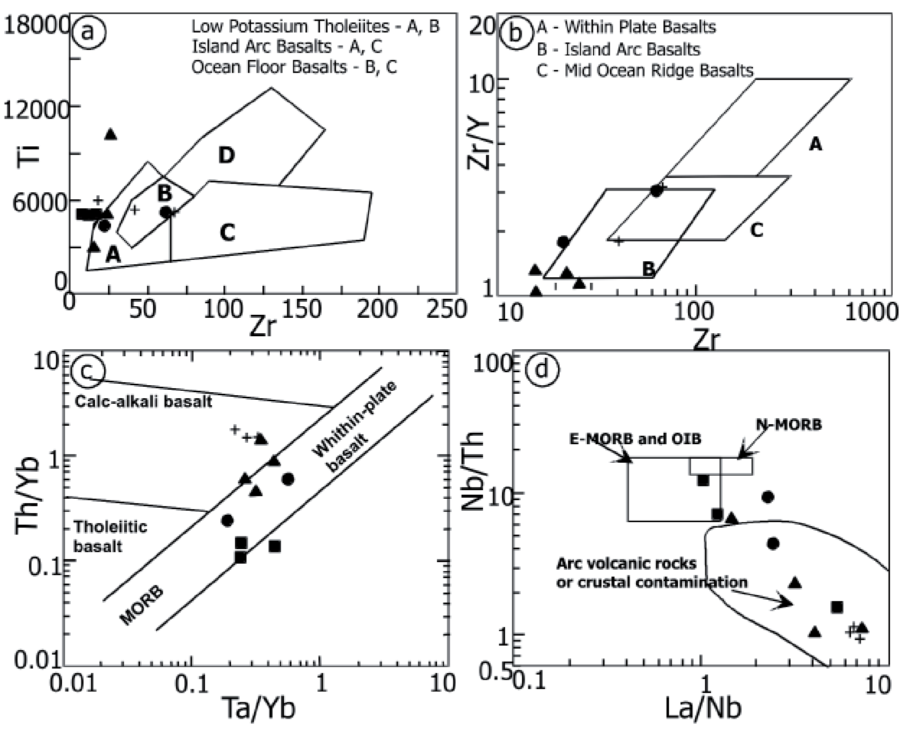

Figure 6 - Tectonic discrimination diagrams, a) Diagram Zr-Ti (Pearce and Cann, 1973); b) Diagram Zr-Zr/Y (Pearce and Cann, 1973); c) Diagram Ta/Yb-Th/Yb (Pearce, 1983); d) Diagram La/Nb-Nb/Th (Pearce, 1983). Symbols are the same from figure 4.

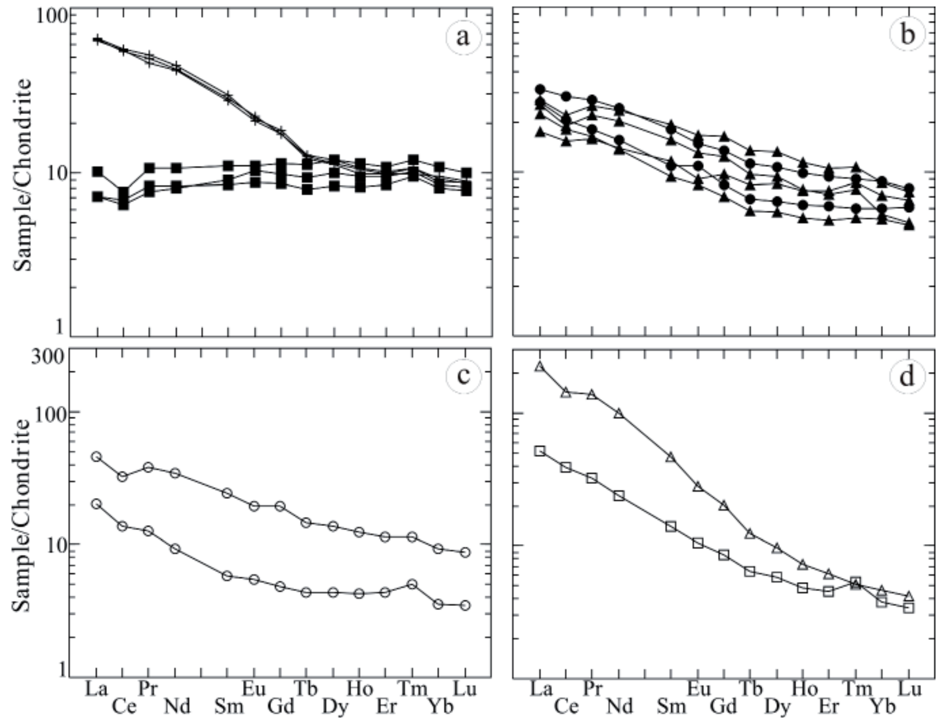

Figure 7 - REE patterns normalized to Chondrite from Taylor and McLennan, 1985. Symbols are the same from figure 4

Metasedimentary 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. These 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.

8. Discussion

The metamafic 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 (Large Ion Lithophile Element such as Ba, Rb, Cs, Pb, K, U) and HFSE (High Field Strength Element) depletion with distinctive troughs in Ti, Zr, Hf and Nb (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; Churnikova *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. In island arc 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 from 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 (Figure 1) 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 $\varepsilon_{Nd}(T)$ values, whereas 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.,* 2004), and the Goianira-Trindade layered intrusion has a Sm-Nd isochron age of *ca.* 621 Ma with an $\varepsilon_{Nd}(T)$ value of 0.

The Anicuns-Itaberaí and Córrego da Boa Esperança are roughly of the same age (*ca.* 890 – 830 Ma) (Laux *et al.,* 2004), however, the 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

Table 2 - Summary of Sm-Nd results for the mafic rocks (after Laux et al., 2004).

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

Table 3 - Sr isotopic results.

Sample	Rb(ppm)	Sr(ppm)	$^{87}Sr/^{86}Sr$(±2SE)	$^{87}Sr/^{86}Sr_{Inic.}$	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

juxtaposed against each other by an important thrust fault zone (Figure 2), suggesting that the original sequences were deposited in different settings, received clastic material from distinct sources, and were later deformed and tectonically juxtaposed. A similar bimodal behaviour of the provenance pattern of detrital sediments has also been identified for 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

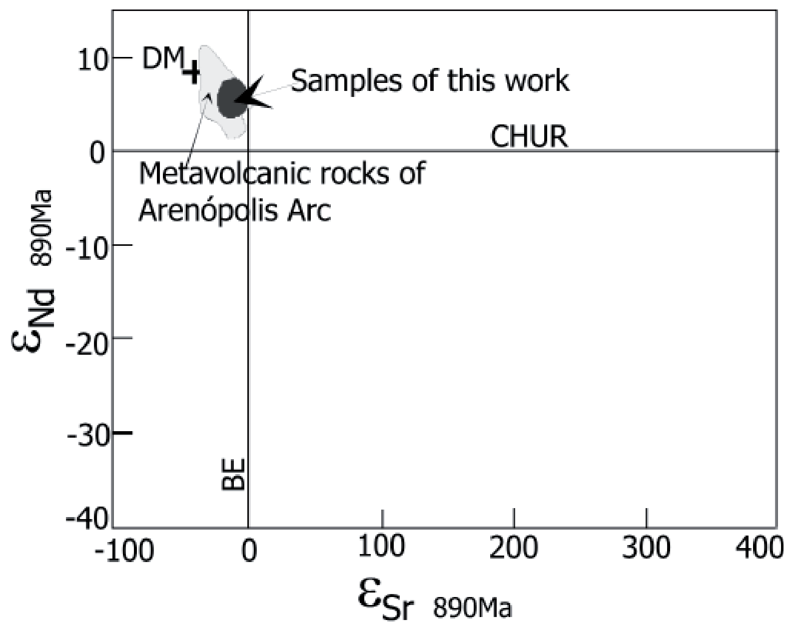

Figure 8 - Plot εSr (T=890Ma) versus εNd(T=890Ma). Field of Arenópolis metavolcanic rocks is from Pimentel (1991)

consist of a near-arc sedimentary basin (arc/fore-arc).

A likely model for the tectonic setting of this part of the Brasília Belt is illustrated in figure 10, in which the Anicuns region might represent the fore arc region of a larger island-arc system.

8. Conclusions

The samples investigated in this study correspond to tholeiitic to calc-alkaline with LILE enrichment and HFSE depletion. All rocks present T_{DM} model ages of *ca.* 1.0 Ga, typical pattern of rocks of other parts of the Goiás Magmatic Arc.

The sedimentary rocks of Anicuns-Itaberaí and Córrego da Boa Esperança are very distinct from each other. The Córrego da Boa Esperança Sequence sediments 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, geochemical and isotopic data from this work, we suggest that the supracrustal sequence exposed in the Anicuns area might represent an arc/fore-arc sequence, marking the tectonic boundary between the Goiás Magmatic Arc and the westernmost exposures of the former São Francisco continental plate.

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).

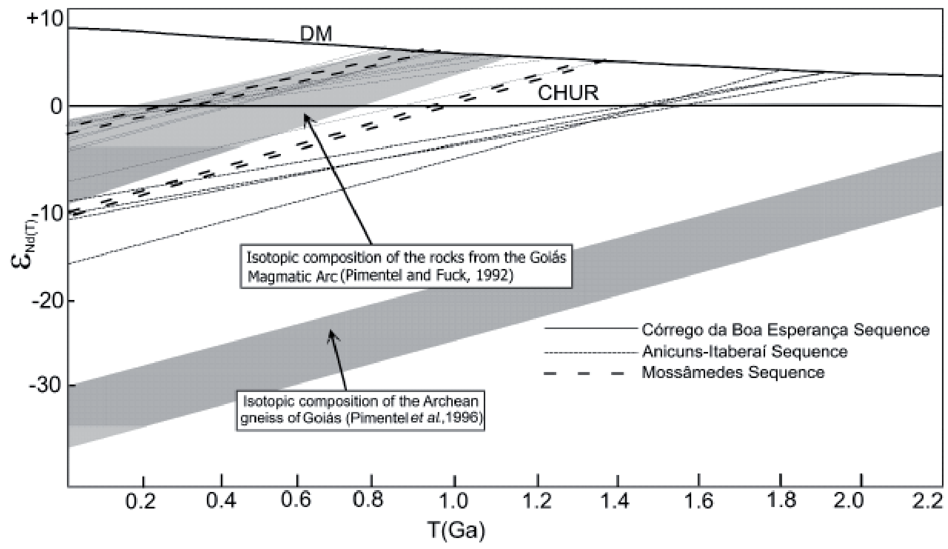

Figure 9 - Evolution εNd x Time diagram showing Nd isotopic composition of the metasedimentary rocks of the Córrego da Boa Esperança, Anicuns-Itaberaí, and Mossâmedes sequences. Nd isotopic composition of the Goiás Magmatic Arc rocks is from Pimentel and Fuck (1992) and of Archean gneisses of Goiás from Pimentel et al. (1996).

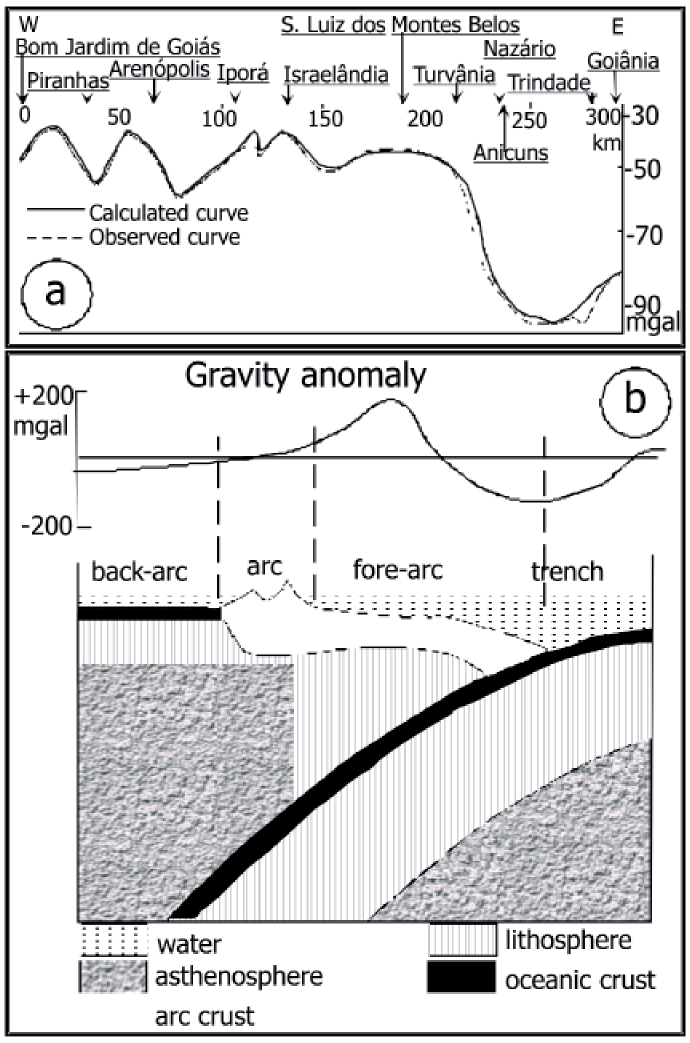

Figure 10 - Gravimetric anomaly in western Goiás (Baêta Júnior, 1994) compared with the model for island arcs from Gill (1981).

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