UNIVERSIDADE DE BRASÍLIA

INSTITUTO DE GEOCIÊNCIAS

TESE DE DOUTORADO

"EVENTOS IGNEOS E METAMÓRFICOS NEOPROTEROZOICOS/EO-PALEOZOICOS NO ARCO MAGMÁTICO DE ARENÓPOLIS, GOIÁS"

TESE n°109

João Gualberto Motta de Araújo

Orientador: Dr. Márcio Martins Pimentel

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Capítulo 1

1.1 - Apresentação da tese

A proposta da tese é investigar a importante granitogênese de alto-K que aflora na região de São Luis de Montes Belos-Moiporá-Fazenda Nova-Mossâmedes, sudoeste de Goiás, compreendendo uma área aproximada de 5 600 km2 entre as coordenadas 510 000 N/ 8235 000 E e 590 000 N/ 8150 000 E. Também investigou-se o significado geotectônico de quatro lineamentos estruturais de primeira ordem que ocorrem associados. Esses lineamentos são observados em imagem de satélite do sensor LANDSAT-5 (bandas 5 - 4 - 3) da região com destaque para o lineamento Messianópolis-Novo Brasil que possui aproximadamente 120 km de extensão e cinturão de granitóides associado. Não se sabe se este sistema de lineamentos estruturais pode representar limites de blocos crustais em contato tectônico, zona de sutura ou apenas limite entre terrenos diferentes.

Estudos geocronológicos pelos métodos U-Pb e Sm-Nd foram realizados para determinação da idade dos eventos ígneos e metamórficos e, eventualmente, do ambiente geotectônico que originou os gnaisses e granitóides da região. Investigou-se também os limites do Arco Magmático de Arenópolis e o significado das rochas com idades modelo antigas em meio a mais jovens que ocorrem nesta região.

Para atingir os objetivos propostos foram realizadas várias etapas de campo para reconhecimento desses lineamentos e coleta de amostras. Nos afloramentos foram coletadas amostras que representassem de forma mais satisfatória possível as principais unidades. Foram utilizados mapas geológicos do SIG-Goiás 2009, na escala de 1/250.000 da região estudada.

As análises U-Pb em zircão foram realizadas pelo método de diluição isotópica ID-TIMS no laboratório de geocronologia do IG-UnB e uma por SHRIMP no laboratório da Universidade Nacional da Austrália (ANU), em Canberra. O método U-Pb em zircão forneceu idades de cristalização dos granitoides, protólitos dos gnaisses e migmatitos.

A sistemática Sm-Nd é usada como traçador de processos petrogenéticos e pode ser ferramenta importante para identificação dos ambientes tectônicos de origem. Idades modelo T_{DM} em amostras de rocha total das rochas ígneas e metamórficas foram determinadas, bem como a idade do metamorfismo do ortognaisse de Sanclerlândia, a partir de uma isócrona de granada-RT. Todas estas análises foram realizadas no laboratório de geocronologia do IG-UnB.

A combinação das idades obtidas pelos dois métodos permitiu estabelecer a cronologia da evolução crustal da região com vistas a estabelecer um quadro compatível com modelos baseados na tectônica global. Essa cronologia foi correlacionada aos principais eventos tectônicos já conhecidos na Faixa Brasília e no Arco Magmático de Arenópolis. O grande número de dados isotópicos obtidos nesta investigação permitiu estabelecer uma cronologia com intervalos menores destes eventos tectônicos.

A tese foi elaborada na forma de 2 artigos, a serem submetidos à periódicos reconhecidos na área de tectônica e de circulação internacional. O primeiro artigo trata dos limites geográficos do Arco Magmático de Arenópolis e o significado de intercalações de ortognaisses e granitos deformados com idades modelo mais antigas intercaladas a mais jovens. O segundo artigo é sobre a idade dos eventos ígneos e metamórficos ocorridos no Arco Magmático de Arenópolis como a granitogenêse de alto-K pós colisional, uma das mais jovens da Faixa Brasília.

Com o estabelecimento de um quadro geológico evolutivo mais claro desta região por meio da geocronologia e da geoquímica isotópica espera-se oferecer contribuição relevante ao conhecimento da evolução da crosta continental em parte da Faixa Brasília.

1.2 - Localização da Área Investigada e Vias de Acesso

A região estudada localiza-se na porção sudoeste do Estado de Goiás, entre as cidades de São Luís de Montes Belos-Moiporá-Jussara-Mossâmedes (Fig.1.1). O acesso é feito a partir de Goiânia, pela BR-060 em direção a Trindade prosseguindo pela GO-060 até São Luís de Montes Belos.

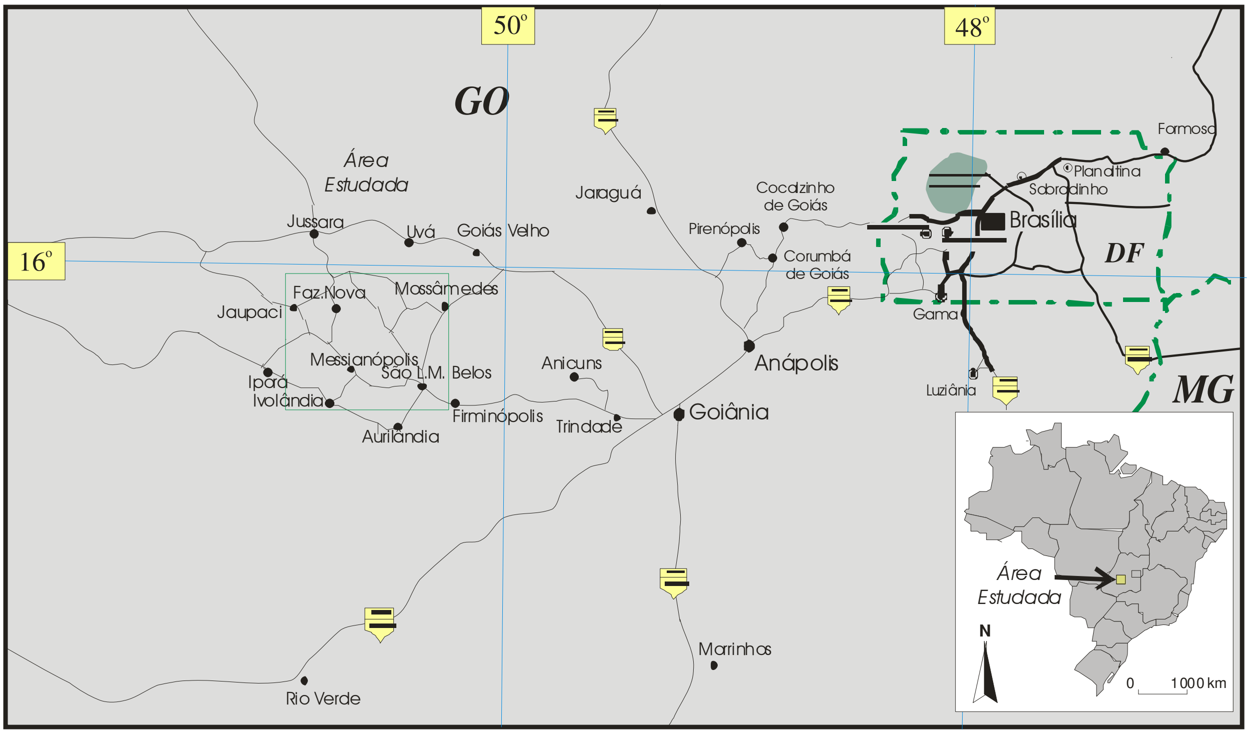

Figura 1.1: Mapa de localização geográfica e de acessos a área investigada. Fonte: guia 4 rodas.

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Este trabalho é fruto de um projeto de doutorado que teve a contribuição de dezenas de pessoas, muitos deles anônimos e que sem as suas colaraboraçõs não teríamos conseguido contribuir com o conhecimento da geologia da Faixa Brasília;

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Dedico este trabalho a meus pais *in memorian*, a Petinha e Fátima minhas irmãs por terem me incentivado ir para Ouro Preto estudar; a Dinha minha irmã mais velha *in memorian* pelo exemplo de simplicidade de vida e a Ludmila minha afilhada com sua inocência e pureza de criança que me contagia.

MUITO OBRIGADO A TODOS.

“Devem os alunos serem habituados a resolverem problemas cujas soluções dependem das teorias expostas no curso, de modo a desenvolver neles o espírito inventivo sem o qual haverá esterilidade na ciência. Não conheço melhor ginástica intelectual que esta para ensinar aos alunos a raciocinar e habituar o espírito a pesquisas. É bom, sem dúvida, conhecer-se tudo o que produziram os grandes homens dos outros povos; porém muito melhor é saber servir-se do que eles fizeram para fazer novas descobertas... Este espírito inventivo é adquirido desde a infância, nos bancos de colégios e escolas.”

Claude Henri Gorceix

Fundador da Escola de Minas de Ouro Preto

Chapter 2

Article 1

" BOUNDARY BETWEEN ARENÓPOLIS MAGMATIC ARC AND UVÁ COMPLEX BASED ON ID-TIMS U-Pb GEOCHRONOLOGICAL AND Sm-Nd DATA, BRASÍLIA BELT, CENTRAL BRAZIL"

Abstract

Data obtained in this work, combined with those available in the literature, allowed a better understanding of the crustal evolution in the southern portion of Brasilia Belt, where several rock units belonging to the Neoproterozoic Arenópolis Magmatic Arc, as well as Archean granitic-*greenstone* terrains represented by the Uvá Complex are exposed. Despite the large number of geochronological data obtained in the last two decades in rocks from this region, some questions regarding the chronology of igneous and metamorphic events and boundaries between the Neoproterozoic Arc and older units are not well established. Another aspect previously recognized in this region is the presence of gneisses with T_{DM} model age values predominantly between ca. 0.9 and 1.2 Ga, in the midst of gneisses with Archean and Paleoproterozoic model age values. Using T_{DM} Sm-Nd model ages, $\boldsymbol{\varepsilon_{Nd}}$ (T) values and U-Pb crystallization ages in zircon from gneisses and granites, it was possible to identify blocks of rock with coinciding boundaries, extensive morphostructural lineaments that stand out in Landsat satellite images: (i) Uvá Complex block with Archean model ages of about 2.9 Ga and $\boldsymbol{\varepsilon_{Nd}}$ (T) values of + 3.4 and crystallization age of 2.70 Ga; (ii) Sanclerlândia orthogneiss block has zircon U-Pb crystallization ages 828 ± 4 Ma and 822 ± 7 Ma and T_{DM} Sm-Nd model ages of 0.98 Ga and 1.44 Ga with positive $\boldsymbol{\varepsilon_{Nd}}$ (T) values. These data indicate that the protolith of this orthogneiss was formed by Neoproterozoic juvenile material; JG-22 sample represents the gneiss country-rocks of the post-collisional Córrego do Ouro granite and that pre-collisional Buriti de Goiás granite on the southern edge of Uvá Complex. U-Pb analysis in zircon of this rock revealed $^{206}Pb/^{238}U$ concordant age of ca. 614 Ma, interpreted as its crystallization age. Thus, it can be concluded that the crystallization age of the Buriti de Goiás granite cannot exceed 614 Ma crystallization age of its country rocks. Sm-Nd isotopic data of Buriti de Goiás granite revealed positive $\boldsymbol{\varepsilon_{Nd}}$ (T) values indicating that original magmas probably represent re-melts of juvenile rocks of the Arenópolis Magmatic Arc while São Matheus granite revealed negative $\boldsymbol{\varepsilon_{Nd}}$ (614Ma) values indicating that original magmas represent the participation of older recycled material; (iii) Novo Brasil wedge block has deformed gneisses and granites with zircon U-Pb crystallization ages between 532 and 570 Ma and Sm-Nd model ages between 1.28 and 1.14 Ga with $\boldsymbol{\varepsilon_{Nd}}$ (T) values between -2.2 and -1 suggesting the important presence of Neoproterozoic juvenile material in the original magma composition. Only one sample JG-31 showed a model age of 2.26 Ga and ε_{Nd} (2.1) of + 0.5; (iv) Ivolândia-Moiporá block is represented by a deformed granite represented by sample JG-138 with crystallization U-Pb age of 556 ± 5 Ma, model ages of 1.1 Ga and ε_{Nd} (T) of - 0.8 suggesting that the original magma represents partial melting of rocks from the Arenópolis Magmatic Arc. The similarity between geochronological and isotope data for the

Ivolândia-Moiporá and Novo Brasil wedge blocks, which are separated by the Moiporá-Fazenda Nova lineaments, demonstrate that this lineament does not separate rocks of different ages as it was previously believed. This lineament is probably formed by the foliation concentration and banding of deformed granites exposed in the region. The Novo Brasil wedge is limited by the Messianópolis-Novo Brasil and Moiporá-Fazenda Nova lineaments. The first represents the large discontinuity between two geological units of different ages. In its southern portion it separates the Sanclerlândia block from the Moiporá-Ivolândia block and its northern portion separates the Novo Brasil wedge from the Uvá Complex. The São Luis de Montes Belos lineament separates the Sanclerlândia block with orthogneisses crystallization age of around 825 Ma from the Turvânia-Fiminópolis-Palminópolis orthogneisses with U-Pb SHRIMP crystallization age of ca. 630 Ma. The Mossâmedes lineament has its concavity towards the southeast and separates the Uvá Complex from the Anicuns-Itaberaí volcano-sedimentary sequence. The discovery of 825 Ma crystallization ages for the Sanclerlândia orthogneiss, and between 530 and 590 Ma for gneisses and mylonitic granites of the Novo Brasil wedge are of great importance in understanding the geological evolution of the southern Brasília Belt. In special the younger, Neoproterozoic to Early Cambrian ages, which indicate, at least locally, a late event of igneous and metamorphic rocks generation, previously unknown in the region.

Keywords: U-Pb, Sm-Nd, Arenopolis Magmatic Arc, Uvá Complex, Brasilia Belt

2.1 - Introduction

The Goiás Magmatic Arc is one of the most important geotectonic units of the Neoproterozoic Brasília Belt in central Brazil. It represents a long-lived magmatic arc system attesting to the existence of a large oceanic basin between the São Francisco and Amazon cratons ca. 900 and 600 Ma (Pimentel and Fuck 1992). It is exposed along two main areas in the western portion of this orogen: (i) the Arenópolis Magmatic Arc in the southwest and (ii) the Mara Rosa Arc in the north (Fig. 2.1) (Pimentel 1992, Pimentel and Fuck 1992, Pimentel *et al*. 1997). This arc system is mostly formed by orthogneisses of various compositions from diorite to granite with ages ca. 600 and 890 Ma, as well as by volcano-sedimentary sequences (Fig.2.3). Original igneous rocks have chemical and isotopic characteristics indicative of formation in intra-oceanic and continental magmatic arcs systems. Recent data have indicated that the arc system is in first formed by two main phases of generation or arc rocks one between ca.900 and 800 Ma (Pimentel and Fuck 1992) and a younger one, between 670 and 600 Ma (Laux *et al.* 2004 b). Gneisses and associated supracrustal sequences are variably deformed and have metamorphic paragenesis indicative of metamorphism of greenschist to amphibolites facies. In the Arenópolis Magmatic Arc these rocks are intruded by a number of late to post-collisional high-K granites associated with gabbro-dioritic plutons, as well as local migmatitic injections, representing an important magmatic event at the end of the Neoproterozoic and early Cambrian (Pimentel *et al.* 1996 a, Pimentel *et al.* 1999 a, Motta-Araújo and Pimentel 2012 - in press). In southwestern Goiás orthogneisses and deformed granites with different ages and origins occur side by side. This has been repeatedly reported in the literature (e.g. Gioia *et al.* 1997, Pimentel *et al.* 1996 b) but the nature, age and significance of this juxtaposition of units gneiss and deformed granite rocks remain poorly understood, requiring additional geochronological and structural studies. The origin of the geological contacts and temporal relationships among neighbouring geotectonic units also need further clarification, since they are often marked by faults and shear zones.

In the area investigated in this study, southwestern Goiás, important lineaments and associated shear zones are exposed and separate several units of gneissic rocks from metasedimentary rocks. The most important tectonic boundary is the one that separates Neoproterozoic rocks of Arenópolis Magmatic Arc in the west, from the Uvá Archean TTG terrains of the Goiás Archean Block in the east (Fig.2.3). It is marked especially by the Messianópolis-Novo Brasil lineament (L-M-NB) extending for more than 120 km and clearly identified in Landsat-5 sensor satellite images (Fig.2.4). The lineament is connected with the Moiporá-Fazenda Nova lineament, forming a V-shaped wedge with the apex located a few miles south of Messianópolis. To the north of Jussara two lineaments are covered by the Araguaia Formation sandstones and by sedimentary rocks of the Paraná Basin to the south.

This paper presents new zircon ID-TIMS and SHRIMP U-Pb geochronological data as well as Sm-Nd isotopic data for rocks of this region and discusses their significance in the Neoproterozoic crustal evolution of that part of the Brasília Belt, with special focus on the tectonic boundary between Neoproterozoic ortogneisses of the Arenópolis Magmatic Arc and TTG terrains of the Goiás Archean block. We investigated deformed granites and orthogneisses grouped into four large blocks limited by extensive lineaments identified in Landsat-5 sensor satellite images. Sanclerlândia, Uvá Complex, Novo Brasil wedge and the region between Ivolândia and Moiporá.

2.2 - Regional Geological Context

The Tocantins Province represents an orogen formed in response to the convergence and collision between the São Francisco, Amazônico and Paranapanema (Rio de La Plata?) continents between 900 and 600 Ma (Almeida *et al.*1977; Brito Neves 1999). It is comprises the Araguaia, Paraguay and Brasilia Belts (Fig.2.1 A e B). These orogenic belts are mainly represented by thick supracrustal sequences constituting typical thrust and fold belts as well as exposures of older sialic basement rocks, especially in the Araguaia and Brasília Belts (e.g. Goiás Massif, Fig.2.1 B). In the western portion of the Brasilia Belt extensive areas of Neoproterozoic juvenile arc comprises the called soo Goiás Magmatic Arc.

The Paraguay and Araguaia belts display tectonic vergence to the west/northwest along the margin of the Amazon Craton, whereas in the Brasilia Belt tectonic vergence is towards the São Francisco Craton to the east.

The Goiás Archean Block in the Brasília Belt is interpreted as an allochthonous sialic fragment added to the west margin of the Brasília Belt (Pimentel *et al.* 2005). It consists of TTG suites associated with typical greenstone belt sequences. The Uvá Complex includes the southernmost portion of this block and is formed by a variety of tonalitic and granodioritic intrusions deformed and metamorphosed under amphibolite facies (Jost *et al.* 1998).

The Goiás Magmatic Arc occurs in large areas of western Goiás, consisting of juvenile Neoproterozoic crust formed by the accretion of island arcs systems between ca. 890 Ma and 600 Ma (Pimentel and Fuck, 1987, Pimentel 1992, Pimentel and Fuck, 1992, Fuck *et al.* 1994, Pimentel *et al.* 1997, Pimentel *et al.* 2000b). It was geographically divided into two sections, separated by the Goiás Archaean block. These are named the Mara Rosa Magmatic Arc, in the north, and the Arenópolis Magmatic Arc, in the south (Fig. 2.1B).

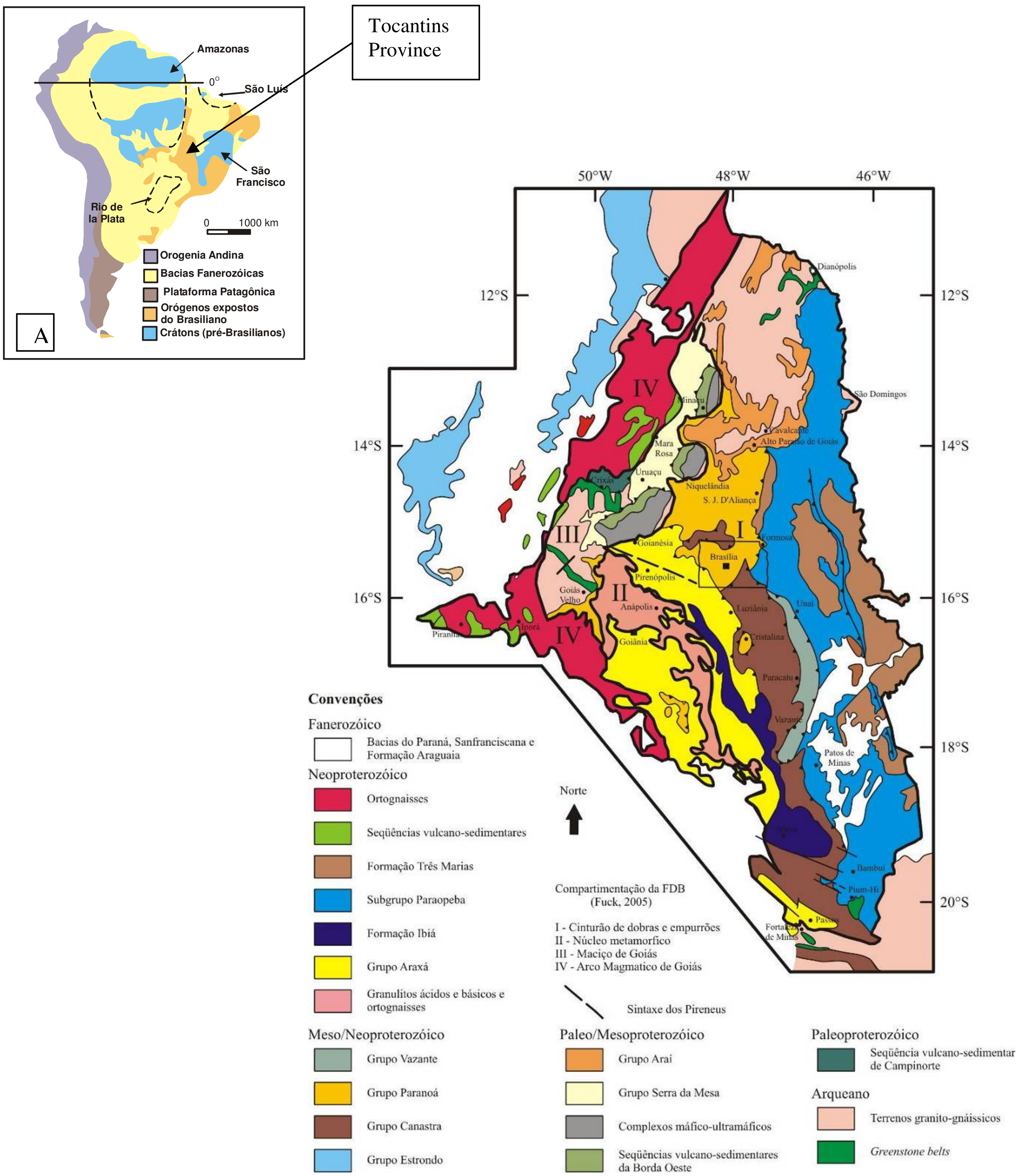

Figure 2.1 - A: Simplified geological map of South America showing the location of the Tocantins Province, B: Geological map of the Tocantins Províce (Fuck, 2005).

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This arc system consists of magmatic rocks with calcic to calk-alkaline composition, represented by: (i) dioritic, granodioritic and tonalitic orthogneisses, (ii) several volcano-sedimentary sequences formed by meta-basalts, meta-andesites and meta-rhyolites with small intrusive bodies of similar composition as well as with layers of immature detrital metasedimentary rocks (Pimentel 1992, Pimentel and Fuck 1992).

Older orthogneisses (ca. 900-850 Ma) exposed between the supracrustal rocks sequences are represented by meta-tonalites and meta-diorites with very primitive isotopic and geochemical characteristics, displaying positive ε_{Nd} (T) values (between +3.0 and +4.6) and T_{DM} Sm-Nd model ages distributed in the range between 0.9 to 1.0 Ga (Pimentel 1992, Pimentel and Fuck 1992, Viana *et al.* 1995, Laux *et al.* 2004). These rocks were metamorphosed under conditions of the greenschist to amphibolite facies and were intruded by late to post-orogenic bimodal magmatism represented by granite and gabbro/diorite plutons.

2.3 - Arenópolis Magmatic Arc

The Arenópolis Magmatic Arc is aproximately 200 km wide, extending from the vicinities of Bom Jardim de Goiás to the west, to the area around Anicuns to the east (Fig. 2.1B, 2.2 and 2.3).

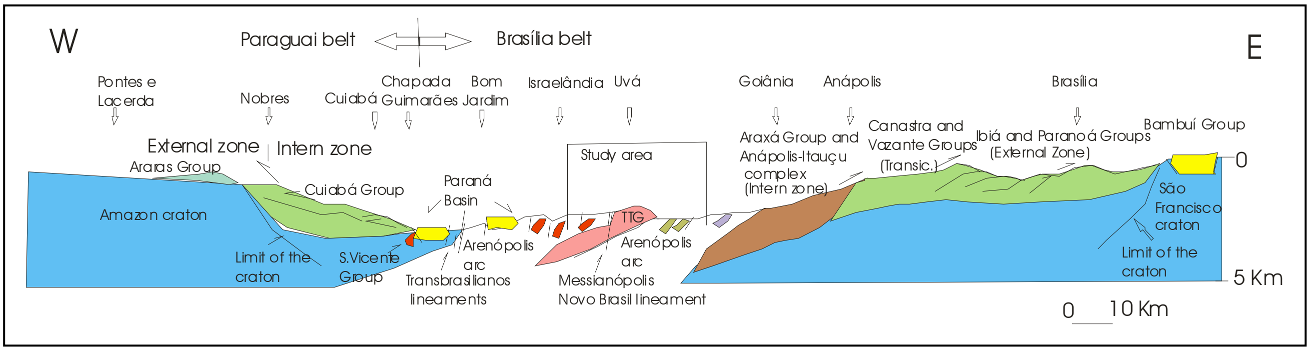
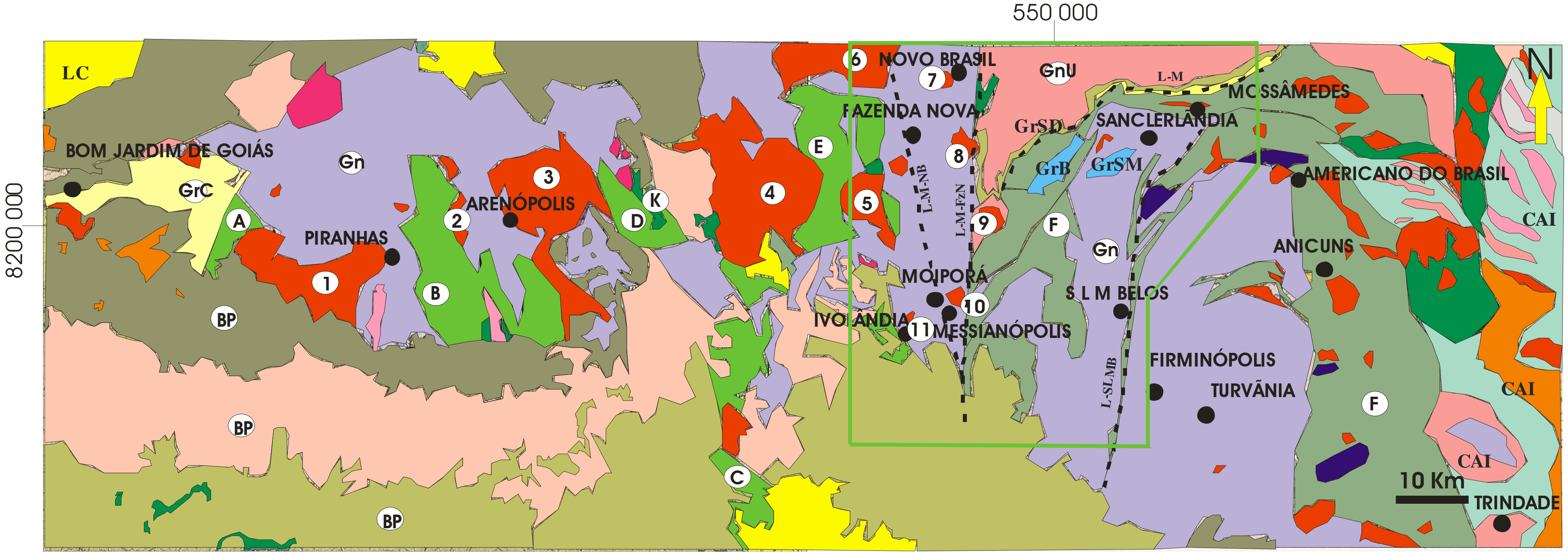


Figure 2.2 - Idealized geological section of the southern Brasília Belt structure with the main geological units between São Francisco and Amazon cratons, indicating the study area.

It consists of a mosaic of dioritic-tonalitic-granitic orthogneisses with nature calcic to calk-alkaline composition, exposed between bands of volcano-sedimentary sequences.



Legend: LC - Lateric cover; **K -**Alkaline; **Phanerozoic BP -**Paraná Basin; **Post-Collisional Granites** (1 - Serra Negra, 2 - Serra do Iran, 3 - Rio Caiapó, 4 - Iporá, 5 - Israelândia, 6 - Serra do Impertinente, 7 - Novo Brasil, 8 - Fazenda Nova, 9 - Córrego do Ouro, 10 - Messianópolis, 11 - Ivolândia); **CMU**- Mafic-ultramafic complexes; **Neoproterozoic**: **GrC -** Cuiabá Group**; Gn** - Arenópolis Magmatic Arc ortogneisses; Vulcano-sedimentary Sequences: (A - Arenópo lis, B - Iporá, C - Amorinópolis, D - Iporá, E - Jaupaci, F - Anicuns-Itaberaí); **CAI** - Anápolis Itauçu Complex ; **GrB/GrSM** - Buriti and São Mateus granites; **GrSD** - Serra Dourada Group. **Paleoproterozoic-Arquean**: **GnU** - Uvá Complex; **Lineaments**: L-M-NB: Messianópolis-Novo Brasil; L-M-FzN: Moiporá-Fazenda Nova; L-M: Mossâmed es; L-SLMB: São Luis de Montes Belos. Study Area

Figure 2.3: Schematic geological map of the Arenopolis Magmatic Arc and Goiás Archean Block (Lacerda Filho *et al.* 2000).

These gneisses have local names such as Arenópolis (899 ± 7 Ma), Iporá (804 ± 6 Ma), Matrinxã (669 ± 3 Ma), Palminópolis (637 ± 20 Ma), Firminópolis and Turvânia (630 ± 5 Ma) gneisses (Fig.2.3 and Table 2.1).

They are intensely deformed and metamorphosed in the upper greenschist to amphibolite facies. Gabbro-diorite intrusions and granite represent late-to post-collisional bimodal igneous event (Pimentel and Fuck 1992, Fuck *et al.* 1994, Pimentel *et al.* 1996b, Gióia 1997, Rodrigues *et al.* 1999).

Table 2.1: Summary of U-Pb ages and T_{DM} Sm-Nd model ages of orthogneisses of the Arenópolis Magmatic Arc.

Orthogneisses	**U-Pb in zircon ID-TIMS (Ma)**	**T_{DM} Sm-Nd model ages (Ga)**	**ε_{Nd} (*T*)**
Arenópolis	899 ± 7 (1 and 2) 637 (1 and 2)	1.0 to 1.2(1and2) 1.1 to 1.4	+ 1.9 to + 3.2 + 2.5 and + 6.9
Iporá	804 ± 6 (5)	1.18 (1and2)	+ 0.37 to + 1.85
Matrinxã	669 ± 3 (5)	0.99 (3)	+2.2 to + 6.0
Sanclerlândia	820 ± 7 (4)	0.9 to 1.0 (3and4)	+ 4.0 to + 6.0
Firminópolis	634 ± 8 (5)	1.39 (5)	- 4.6
Palminópolis	637 ± 20 Shrimp (5)	1.48 and 2.21 (5)	-6.4 and -15.1
Turvânia	630 ± 5 (5)	1.11(5)	+ 0.3

References: 1 - Pimentel *et al.* (1991), 2 - Pimentel and Fuck (1994), 3 - Gioia *et al.* (1997), 4 - Motta-Araújo and Pimentel (2003), 5 - Laux *et al.* (2004).

Laux *et al.* (2004 b) identified two episodes of crustal accretion that occurred between ca. 900 and 800 Ma and between ca.660 and 630 Ma in the Arenópolis Magmatic Arc.

The tonalitic orthogneiss of Arenópolis has an ID-TIMS zircon U-Pb age of 899 ± 7 Ma (Pimentel *et al.* 1991), T_{DM} model ages between 1.1 and 1.4 Ga and ε_{Nd} (*T*) values ranging from +2.5 to + 6.9 (Pimentel and Fuck, 1992). Metamorphic titanite from a gneiss sample revealed the age of 632 Ma (Pimentel *et al.* 1991).

The Iporá orthogneiss unit is composed of gneiss with porphyroclasts of flattened potassium feldspar, gneiss and banded gneiss. Finely banded biotite gneiss of granodioritic composition has T_{DM} values of about 1.2 Ga, ε_{Nd} (*T*) between + 0.37 e + 1.85 and 804 ± 6 Ma zircon U-Pb age, interpreted as the crystallization age of the igneous protoliths (Rodrigues *et al.* 1999).

The Sanclerlândia orthogneiss is rich in hornblende and epidote, with composition ranging from dioritic to granodioritic being petrographic and geochemical characteristics very similar to the Arenópolis gneiss (Simões 1984, Pimentel and Fuck, 1994, Pimentel *et al.* 1996b). It has a 820 ± 7 Ma U-Pb age, T_{DM} values between 0.98 and 1.1 Ma and ε_{Nd} (*T*) value of + 4 (Motta-Araújo and Pimentel 2003).

The Matrinxã orthogneiss exposed to the south of Israelândia has composition varying from tonalite to granite. It presents an U-Pb age of 669 ± 3 Ma and T_{DM} values around 1.0 Ga, ε_{Nd} (*T*) of + 2.2 (Laux 2004b).

The Turvânia, Palminópolis and Firminópolis orthogneisses exposed in the eastern portion of the Arenópolis Magmatic Arc are part of the same terrain and constitute the youngest of the orthogneisses units in this region. They are represented by gray hornblende-biotite gneisses of tonalitic to diorite composition. The Firminópolis orthogneiss protolith crystallized at 634 ± 8 Ma (U-Pb zircon age; Laux *et al.* 2003b) T_{DM} of 1.39 Ga and ε_{Nd} (*T*) of - 4.6. The Turvânia orthogneiss is a banded biotite gneiss with 630 ± 5 Ma zircon U-Pb age and 1.11 Ga T_{DM} value, and ε_{Nd} (*T*) value of + 0.3 (Laux *et al.*, 2003b). The Palminópolis orthogneisses is petrographically and compositionally very similar to the Turvânia and Firminópolis orthogneisses. Two T_{DM} ages of this rock revealed values of 1.48 and 2.27 Ga and ε_{Nd} (*T*) of - 6.4 and - 15.1. Zircon U-Pb SHRIMP age revealed the age of 637 ± 20 Ma (Laux *et al.*, 2003b). Isotope data presented by Laux *et al.* (2003b) for Palminópolis, Turvânia and Firminópolis orthogneisses show that original magmas of these units were contaminated with older crust or may have been formed in continental arc.

Five main volcano-sedimentary sequences are identified in the Arenópolis Magmatic Arc (Fig.2.3). They are separated by orthogneisses or by post-collisional granites emplaced during or after the metamorphic peak of the Brasiliano orogeny at ca. 630 Ma. They are made of metavolcanic rocks, ranging in composition from basalt to rhyolite and psammo-pelitic and chemical metasedimentary rocks. At the western part of the Arenópolis Magmatic Arc are the Bom Jardim de Goiás, Arenópolis, Iporá-Amorinópolis sequences; the Jaupaci sequence is exposed in the central part of the arc and the Anicuns-Itaberaí sequence in eastemmost part (Fig.2.3). Both orthogneisses and volcano-sedimentary sequences have mineral assemblages indicative of metamorphism in the upper greenschist to amphibolite facies superimposed by mineralogical associations indicative of a retrometamorphic phase at low greenschist facies conditions**.**

2.4 - The Arenópolis Magmatic Arc in São Luís de Montes Belos, Moiporá, Fazenda Nova and Mossâmedes region

In the vicinities Sao Luiz de Montes Belos, Moiporá and Mossâmedes, southwestern Goiás, two main geological compartments are identified: the Neoproterozoic Arenopolis Magmatic Arc and the TTG terrains of the Uvá Complex belonging to the Goiás Archean Block (Fig.2.1 and 2.3).

Important lineament systems are associated with these two geotectonic compartments: Messianópolis-Novo Brasil lineament, LM-NB, (Jost *et al.* 1986); Moiporá-Fazenda Nova lineament, LM-Fz.N (Amaro *et al.* 1989); and two other lineaments here named as Mossâmedes, L-M and São Luiz dos Montes Belos, L-SLMB (Fig. 2.3 and 2.4).

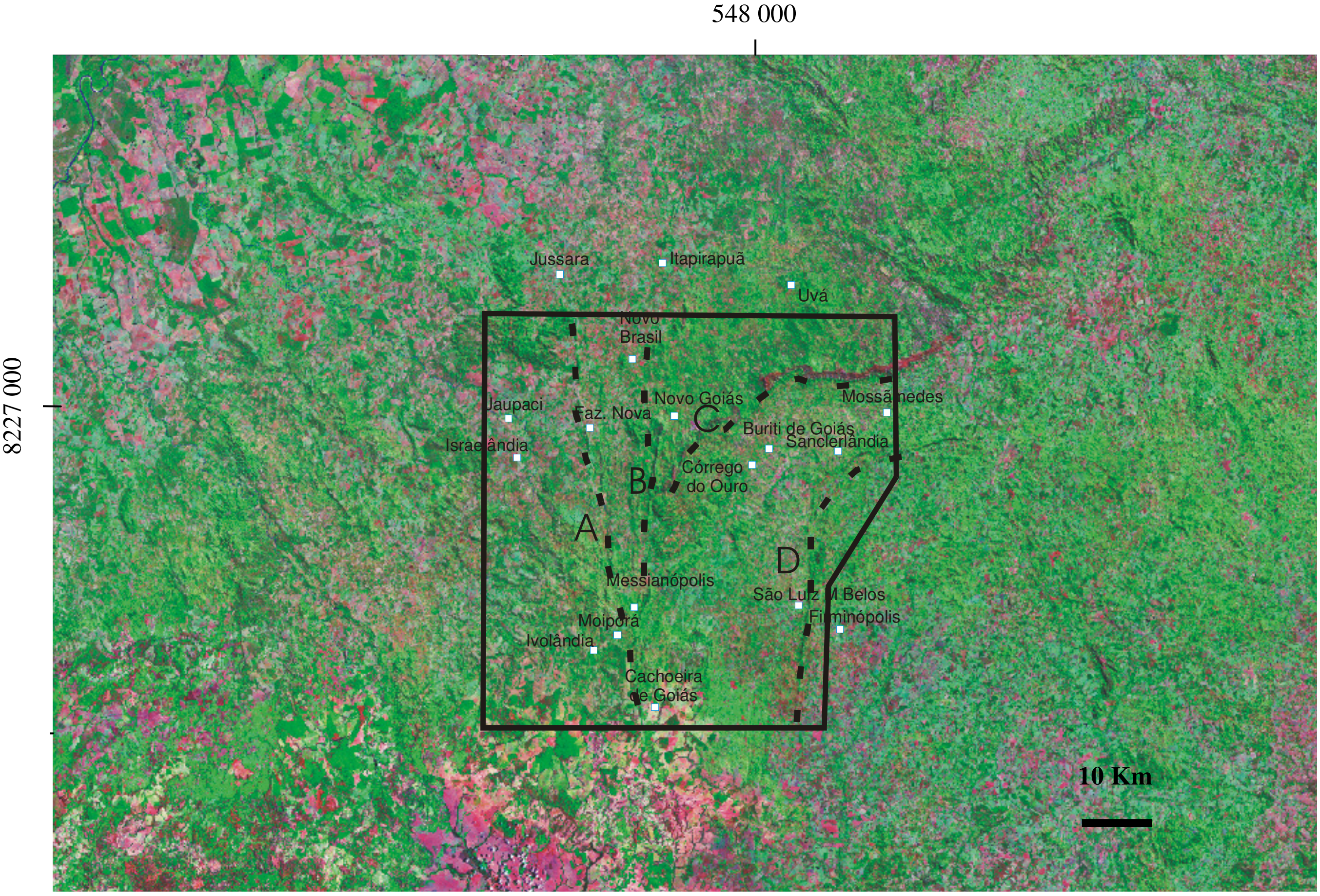


Figure 2.4 - Landsat-5 sensor satellite image, composition of 5, 4, 3 bands in the southwest region of Goiás, Brasilia Belt south with boundaries of the investigated area and the main morphostructural lineaments between São Luís de Montes Belos and Fazenda Nova. A: L-M-FzN Moiporá-Fazenda Nova lineament; B: L-M-NB Messianópolis-Novo Brasil lineament; C: LM Mossâmedes lineament; D: L-SLMB São Luis de Montes Belos lineament.

These lineaments are clearly recognized in the field as well as in Landsat-5 sensor satellite images, composition of 5, 4, 3 bands. Due to their lengths they can be classified as first-order or type 1. Two of these are straight lines that form a V-shape triangular wedge structure, which is here called the Novo-Brasil wedge, formed by the junction of the N-S Messianópolis-Novo Brasil lineament with the NN-W Moiporá-Fazenda Nova (Fig.2.4 and 2.5). Other lineaments investigated are of the Mossâmedes and São Luís de Montes Belos lineaments.

The NS Messianópolis-Novo Brasil lineament (LM-NB) marks the contact between the Archean Uvá Complex and the younger orthogneisses and granites of the Arenópolis Magmatic Arc. This system is expressed for more than 120 km in the NS direction. From Messianópolis, traces of this lineament are indicated by the Serra do Facão marking the contact with the Uvá Complex. From Novo Brasil it circumvents the oval megastructure to the east with characteristics of a pluton and extends further to the north.

The Moiporá-Fazenda Nova lineament (L-M-FZN) represents the western contact of the Novo Brasil wedge with orthogneisses and granites of Ivolândia-Moiporá and is recognized in the field by strong deformed rocks with a vertical to subvertical foliation.

Mossâmedes (L-M) and São Luís de Montes Belos (L-SLMB) lineaments are parallel and somewhat curved (Fig. 2.4 and 2.5). The trace of the Mossâmedes lineament starts east of Córrego do Ouro and extends towards the NE inflecting to EW in the vicinities of Buriti de Goiás This lineament represents the contact between the Uvá complex and the Anicuns-Itaberaí sequence.

The São Luiz de Montes Belos lineament (L-SLMB) is marked in the field by a series of aligned in the NS direction inflecting to the EW direction near Mossamedes. These ridges represent the contact between the Sanclerlândia and the Firminópolis-Turvânia-Palminópolis orthogneisses. Associated with this arc-shaped structure are a number of small mafic-ultramafic layered complexes (e.g. Mangabal I and II and, further to the east, the Americano do Brasil Complex) belonging to Americano do Brasil mafic-ultramafic suite emplaced at 630 Ma.

Gneiss Terrains

The TTG gneiss terrains of the Uvá Complex belonging to the Goiás Archean Block are mainly represented by finely banded gneisses with higher degree of deformation and metamorphism when compared to orthogneisses of the Arenópolis Magmatic Arc. They occupy the northeastern portion of the study area in tectonic contact with the other units in the region.

The Sanclerlândia orthogneiss forms a NS terrain which inflects to NE near Sanclerlândia, forming an arc-shaped structure with concavity facing SE as observed from Landsat-5 sensor satellite images (Fig.2.4). This is an orthogneiss with typical characteristics of the Arenópolis Magmatic Arc. It ranges in composition from dioritic to granodiorittic, is locally banded, and rich in hornblende and epidote. Its petrographic and geochemical features are similar to the Arenópolis gneiss (Pimentel and Fuck, 1994). In some locations there are intrafolial tight folds with axes and mineral stretching lineation with generally low angle. It is separated from Firminópolis, Turvânia, Palminópolis orthogneisses by a garnet-quartz-sericite schist band that supports the Serra de São Luís de Montes Belos.

The mylonitic orthogneisses, ultramylonitic and deformed granites from the Novo Brasil wedge, display conspicuous banding formed by bands of flattened feldspar porphyroclasts alternating with mica rich layers.

The deformed granites and orthogneisses from the Ivolândia and Moiporá region are separated from the orthogneisses and granites of the Novo Brasil wedge by the Moiporá-Fazenda Nova lineament. These orthogneisses have petrographic and structural features very similar to each other.

Metasedimentary units

Several psamitic-pelitic and chemical metasedimentary units are recognizad in the region between São Luís de Montes Belos and Fazenda Nova and are physically separated from each other, preventing any spatial or stratigraphic correlation between them. The strong deformation these rocks underwent marked their primary structures, stratigraphy and contact relationships. Some of these units were correlated to the Araxá Group by Simões (1984) and the rocks forming the Serra Dourada were compared to the Araí Group by Dardenne (2000). The Serra Dourada Group is formed by psammitic-pelitic rocks which occupy the highest altitudes in the region. It consists of sericitic quartzite intercalated with quartz-chlorite-schist. In this unit tight folds in several scales and more strongly deformed zones at low angle parallel to sedimentary layering are commonly observed. Between these strongly deformed areas primary sedimentary structures such as trough cross-bedding are preserved. Metamorphism was in conditions of the chlorite zone of the greenschist facies. Recently, the Geological Survey of Brazil included all these supracrustais units, except for the quartzites and conglomerates of the Serra Dourada ridge in the so-called Anicuns-Itaberaí volcano-sedimentary sequence dated at ca. 820-860 Ma (Laux *et al.* 2004a).

The Anicuns-Itaberaí volcano-sedimentary sequence of exposed between Messianópolis and Mossâmedes consists of garnet-quartz-sericite schists and impure quartzite. It occurs as a NE belt with foliation dipping to the southeast. The rocks are intensely deformed, showing mica-fish structures involving rotated porphyroclasts of garnet. To the north of Mossâmedes, at the foothills of the Serra Dourada, it is formed by paragneiss and muscovite-biotite-chlorite-plagioclase schist attributed to the lower unit. It presents main foliation at shallow angle and intrafolial folds.

At the southern end of the study area, between Ivolândia and Moiporá, there is a thick metapelitic sequence that probably represent the southern extension of the Jaupaci volcano-sedimentary sequence of the Arenópolis Magmatic Arc.

Syn to late-tectonic ultramafic-mafic and granitic magmatism

Syn to late-collisional magmatism in the study area occurred immediately after the thermal peak of the Brasiliano orogeny around 630 Ma that affected rocks of the Arenópolis Magmatic Arc. This magmatism is represented by mafic-ultramafic complexes of various sizes as well as granitic intrusions. The mafic-ultramafic magmatism is represented by several bodies consisting of peridotite, pyroxenite and metagabros, which in some places have preserved igneous features and are collectively callled at the Americano do Brasil type, with crystallization age of 632 ± 6 Ma (Gióia *et al.* 1999, Laux *et al.* 2004 a). These bodies are aligned in a structural arc-shaped structure faced to the southest formed by the banding inflection of the Sanclerlândia hornblende orthogneiss. The Americano do Brasil intrusion is the largest of them and most important from the economic point of view. It hosts Cu-Ni-Co massive sulphide deposits. The smaller bodies are represented by the complexes of Mangabal 1 and 2 and others emplaced into the Sanclerlândia orthogneiss between São Luiz de Montes Belos and Americano do Brasil.

Metamafic rocks are represented especially by amphibolite bodies exposed to the south of Aurilândia, interpreted as a metamorphic product of basic rocks associated with the Arenópolis Magmatic Arc.

A number of granites plutons known as Aragoiânia type (Oliveira *et al.* 2000) are represented by the Buriti de Goiás and São Mateus intrusions. These granites are deformed and have ellipsoid shape with major axis in the northeast direction. The Buriti de Goiás granite is emplaced between a strip of quartz-chlorite-sericite schist and micaceous quartzite of the Anicuns-Itaberaí sequence. The São Mateus granite is emplaced into Sanclerlândia orthogneiss, is foliated, with feldspar porphyroclasts in the form of augens reaching up to 5 mm.

Another important granite occurring is the Mossâmedes granite classified as belonging to the Piracanjuba suite (Oliveira *et al.* 2000). It is intruded into metapelitic-volcanic rocks of the Anicuns-Itaberaí sequence with EW foliation parallel to that in the enclosing rock units. Its texture in form of augens distinguishes it petrographically from Buriti of Goiás and São Mateus granites.

Post-collisional Plutonic magmatism

High-K granites with late to post-collisional in relation to the peak of Brasiliano orogeny that affected the Brasília Belt, with ca. 545 Ma U-Pb zircon ages (Pimentel and Motta-Araujo 2012, in press) are mainly represented by the Messianópolis, Córrego do Ouro, Fazenda Nova and Novo Brasil plútons (Fig.2.3 and 2.5). These granites were grouped by Oliveira *et al.* (2001) in a suite called Serra Negra. Migmatitic injections are associated with this magmatism which can be seen mainly in the banded gneisses near Messianópolis and to the east of Novo Brasil in contact of between the Arenópolis Magmatic Arc orthogneisses and the TTG gneisses of the Uvá Complex (Motta-Araújo and Pimentel 2012, in press).

2.5 - Analytical Procedures

Sm-Nd data will be used to identify crustal blocks with similar isotopic characteristics and U-Pb zircon ages for obtaining the crystallization age of granites and in the region investigated. Sm-Nd and U-Pb analyses were carried out in the geochronology laboratory of the Institute of Geosciences, University of Brasilia.

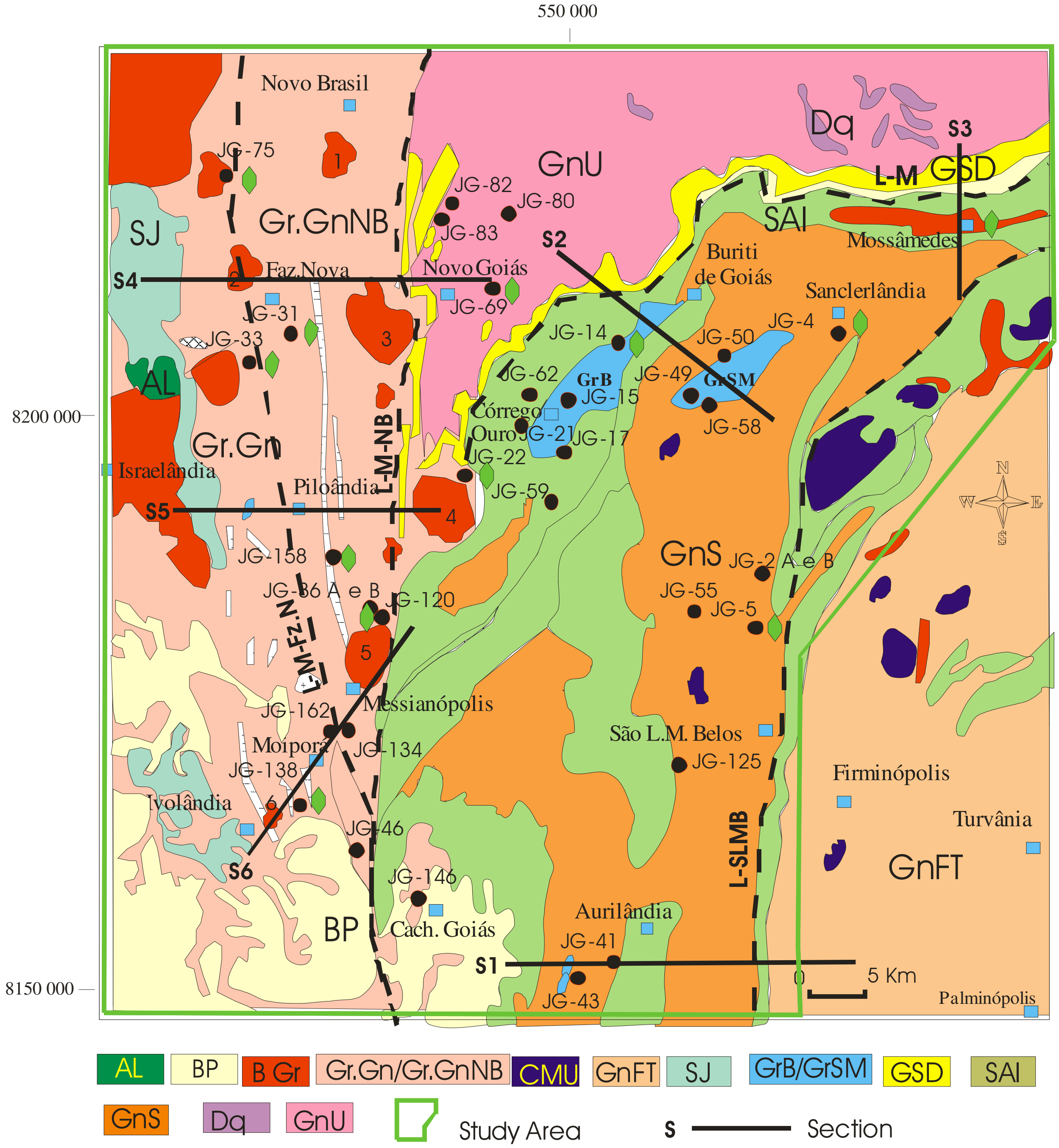
Zircon concentrates were extracted from ca. 8 Kg rock samples using conventional gravimetric (DENSITEST®) and magnetic (Frantz isodynamic separator) techniques. Final purification was achieved by hand picking using a binocular microscope. All zircon grains selected for analysis were free of inclusions and fractures and separated from the least magnetic fraction.

For the conventional U-Pb analyses, fractions were dissolved in conc. 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 with a Finnigan MAT-262 multi-collector mass spectrometer equipped with secondary electron multiplier-ion counting at the Geochronogy 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 2 σ.

Sm-Nd isotopic analyses followed the method described by Gióia and Pimentel (2000) and 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 o and 143Nd/144Nd ratios are better than ± 0,4% (1 σ) e ± 0.005 % (1 σ) respectively, based on repeated analyses of international rock standards BHVO-1 e BCR-1. 143Nd/144Nd ratios were normalized to 146Nd/144Nd de 0,7219 and the decay constant used was 6,54 x 10 -12 a-1. TDM values were calculated using the DePaolo (1981) model.

2.6 - U-Pb and Sm-Nd isotopic results

The eleven U-Pb zircon analyses by the conventional method (ID-TIMS) and thirty Sm-Nd isotope data from different rocks of the region investigated are discussed in this paper (Tables 2.1 and 2.2). For location of geological sections and samples see Fig. 2.5.



Legend: AL - Alkaline intrusions; BP - Paraná Basin; BGr - biotite granites: (1 - Novo Brasil, 2 - Serra do Impertinente type, 3 - Fazenda Nova, 4 - Córrego do Ouro, 5 - Messianópolis type biotite granite, 6 - Ivolândia granite); GrGn/GrGnNB - deformed granites of the Novo Brasil Wedge; CMU - mafic-ultramafic complexes; GnFT - Firminópolis-Turvânia orthogneisses; SJ - Jaupaci sequence; GrB/SM - Buriti and São Mateus granites; GSD - Serra Dourada group; SAI - Anicuns-Itaberaí sequence; GnS - Sanclerlândia orthogneiss; Dq - mafic-ultramafic dykes; Archean Block: GnU - Uvá Complex: TTG terrains and greenstone belt. Lineaments - L-M-NB: Messianópolis-Novo Brasil; L-M-FzN: Moiporá-Fazenda Nova; L-M: Mossâmedes; L-SLMB: São Luis de Montes Belos.

Figure 2.5 - Simplified geologic map of the region between São Luis de Montes Belos-Novo Brasil in the southwestern part of the Brasília Belt (Lacerda Filho *et al.* 2000).

2.6.1 - Uvá Complex Block (GnU)

Analytical data from five zircon grains from a banded gneiss sample, JG-69, southern part of Uvá Complex (Fig.2.6), formed a discordia (MSWD = 1.8) that revealed an upper intercept age of 2769 ± 7 Ma (Table 2.1, Fig 2.7 A). Which is interpreted as its crystallization age. The lower intercept indicates the age of 490 ± 11 Ma which is interpreted as the Pb loss age. Sm-Nd isotopic data for this sample indicates T_{DM} model ages of 2.81 Ga and ε_{Nd} (*T*) of - 0.28 (Table 2.1, Fig. 2.7 B). This isotopic composition is similar to that presented for the isotopic composition of exposed gneisses in other parts of the Goiás Archean Block, Pimentel *et al.* (1996).

Figure 2.6 - Aspects of Gneiss from the Uvá Complex, JG-69, Goiás Archean Block.

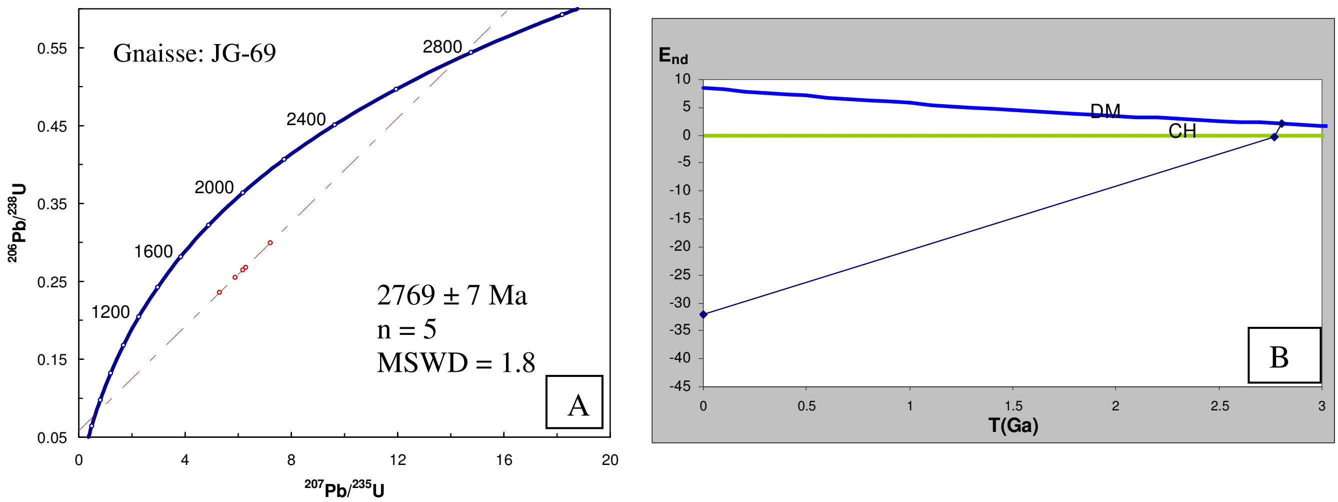


Figure 2.7 - A - Concordia diagram with for gneiss, JG-69 sample, Goiás Archean Block, B: $\boldsymbol{\varepsilon_{Nd}}$ evolution diagram showing the Nd isotopic composition of gneiss, JG-69 sample.

Sm-Nd isotopic data for two mylonitic granite samples; (JG-80 and JG-82), with flattened feldspar porphyroclasts, exposed in the westernmost part of the Uvá Complex have T_{DM} model ages with very similar values of 2.78 and 2.72 Ga and $\boldsymbol{\varepsilon_{Nd}}$ values (T=2770 Ma) between 0.1 and 0.7

(Table 2.2, Fig 2.8). If the estimated ε_{Nd} value (T = 2770 Ma) is correct the protolith of this rock may be from the Goiás Archean Block as indicated by the close ε_{Nd} *(T)* values.

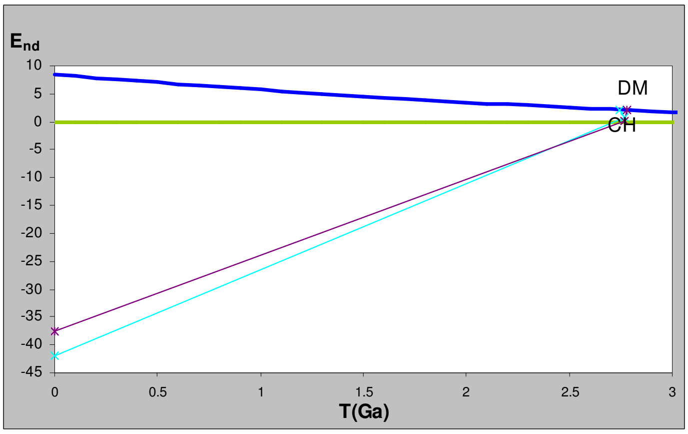


Figure 2.8 - ε_{Nd} evolution diagram of deformed granites from the east region of the Novo Brasil city, JG-80 and JG-82 samples.

Other T_{DM} model ages with values ranging between 2.85 and 3.28 Ga gneiss samples of these terrains were presented by Pimentel *et al.* (1996b).

2.6.2 - Sanclerlândia Block (GnS)

This block is represented by the Sanclerlândia orthogneiss (Fig, 2.9, 2.10 A and B). Two samples from this orthogneiss were analyzed by the U-Pb method and ten samples by the Sm-Nd method. Sample JG-4 is located in the northern part of the block and JG-5 is from the south portion separates 25 Km. Seven zircon grains from JG-04 were analyzed and showed the upper intercept age of 828 ± 4 Ma (Table 2.1 and Figure 2.10 A).

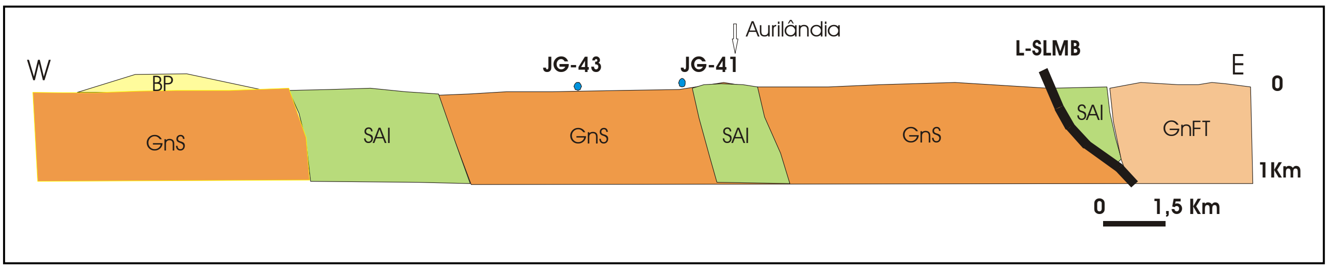


Figure 2.9: Geological section 1 located in the southern portion of the Sanclerlândia block. Caption in Figure 2.5.

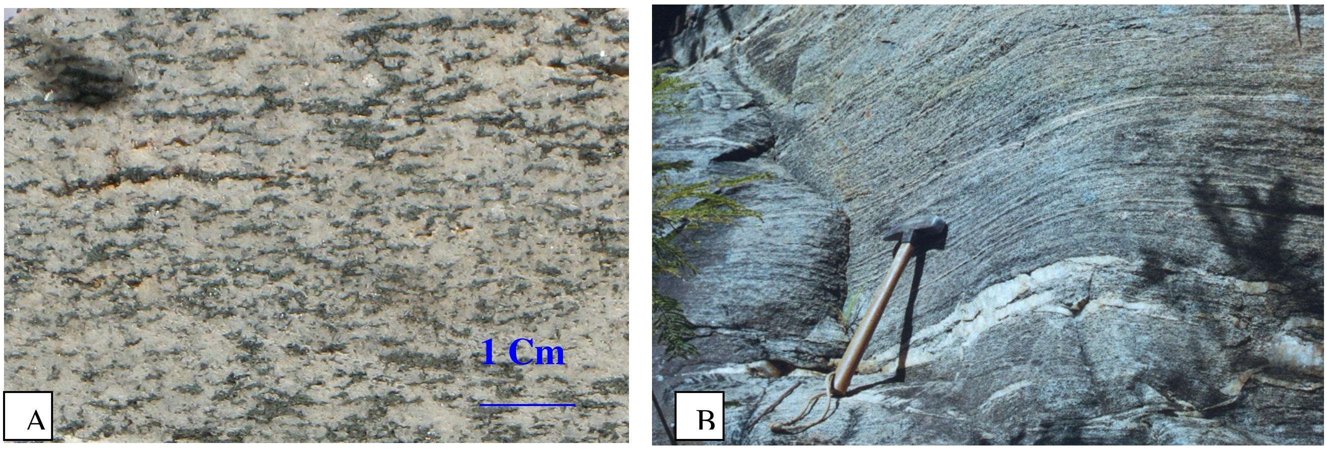


Figure 2.10 - Aspects of the banding in the Sanclerlândia tonalitic orthogneiss: A-JG-5, B - JG-59 samples.

Four zircon grains from sample JG-05 were analyzed resulting in consistent data revealing concordant age of 822 ± 7 Ma (Table 2.1, Fig.2.11 B). These ages are interpreted as indicate of the crystallization of the tonalitic protolith of the Sanclerlândia orthogneiss.

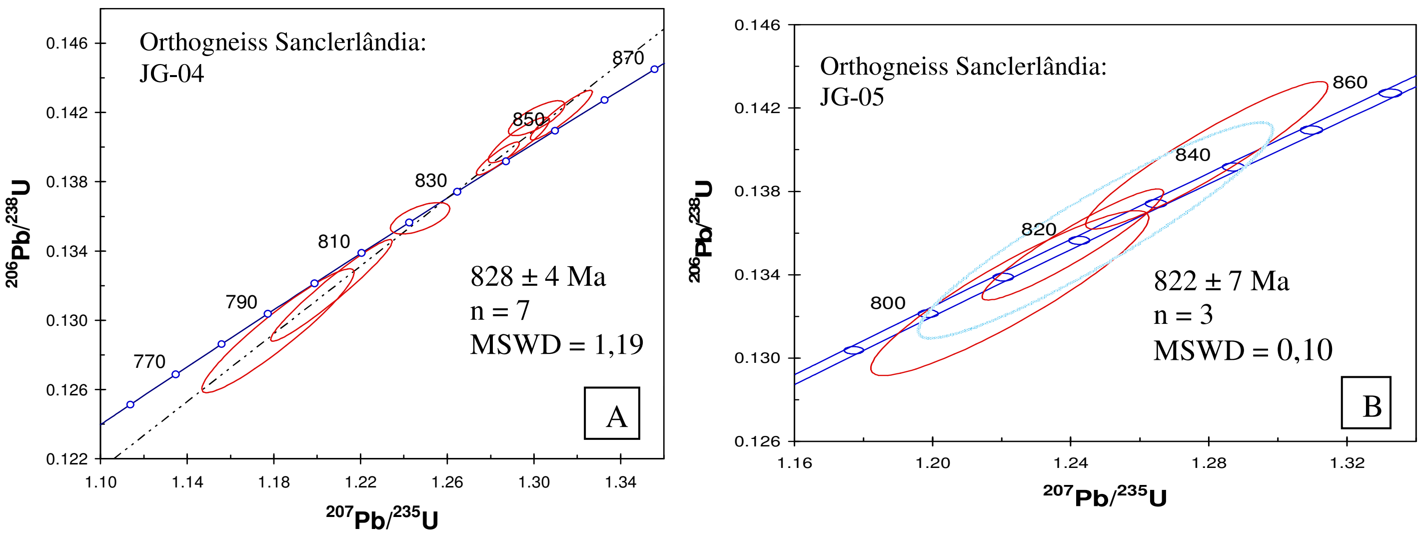


Figure 2.11 - Concordia diagram for the Sanclerlândia tonalitic orthogneiss: A: JG-4 and B: JG-5 samples.

Sm-Nd isotopic data for ten samples of these orthogneisses collected at different sites in a representative manner indicated T_{DM} model ages ranging from 0.98 to 1.44 Ga and ε_{Nd} (T) values between + 2.5 and + 4.7 (Table 2.2, Fig . 2.12 A), showing the juvenile nature of the precursor magma originating this rock.

One gneiss outcrop, sample JG-146, located in the southwestern limits of this block revealed T_{DM} model age of 1.35 Ga and ε_{Nd} values (T = 820 Ma) of - 0.3 (Table 2.2, Fig. 2.12 B).

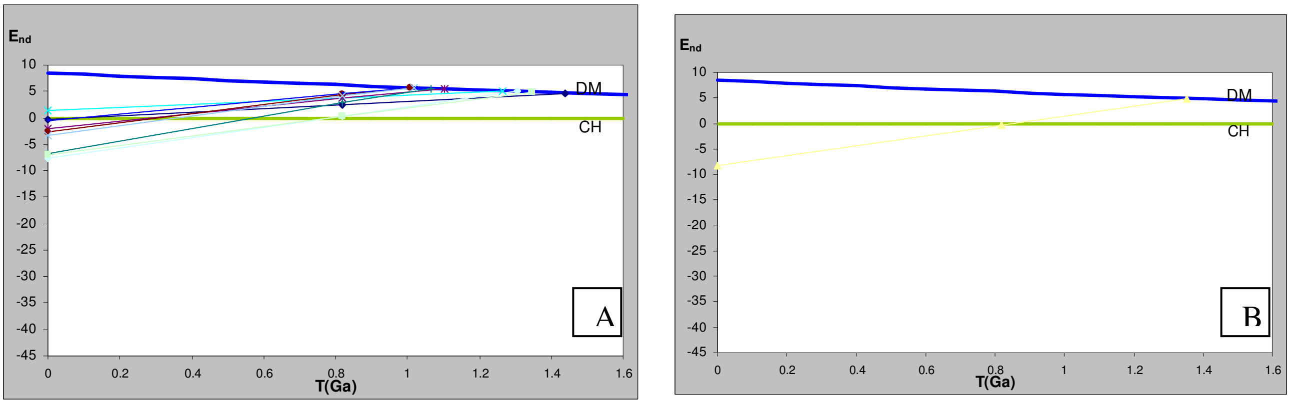


Figure 2.12 - ε_{Nd} diagram of evolution showing the Nd isotopic composition: A - Sanclerlândia orthogneiss, samples: JG - 2 A, 2B, 5, 41, 43, 55, 56, 59, 125. B: Orthogneiss, JG-146.

2.6.2.1 - Granites and Gneisses of the Anicuns-Itaberaí Sequence (SAI)

Two finely banded gneiss samples: (JG-21 and JG-22), as well as two deformed granites exposed within the supracrustal rocks of the Anicuns-Itaberaí sequence were analyzed for U-Pb and Sm-Nd.

Sample JG-22 is a finely banded garnet-bearing gneiss which represents the country-rocks for the post-collisional Córrego do Ouro granite. U-Pb analysis of eleven zircon grains from this sample did not produce a good alignment in the concordia curve and show a strong combined pattern of inheritance and lead loss. However, one of these grains is concordant with a $^{206}Pb/^{238}U$ age of ca. 614 ± 20 Ma, interpreted as its crystallization age (Table 2.1 and Fig. 2.14 A). The age indicated by the upper intercept does not seem to have geological meaning since the T_{DM} model age is lower.

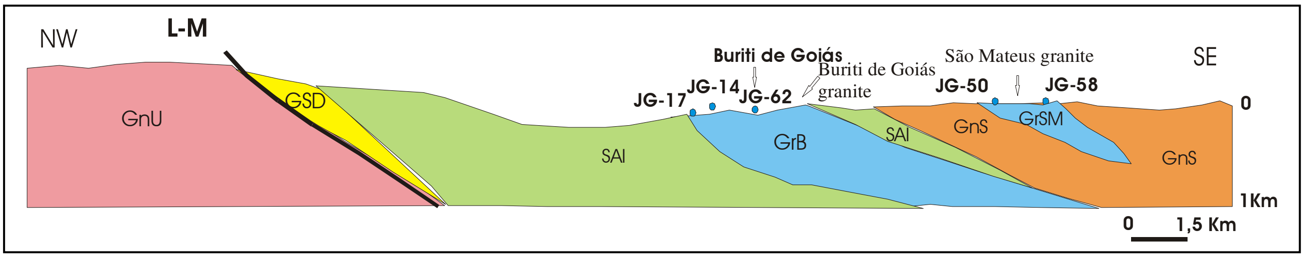


Figure 2.13 - Geological section 2 showed the contact of the Sanclerlândia block and Uvá Complex. Caption in figure 2.5.

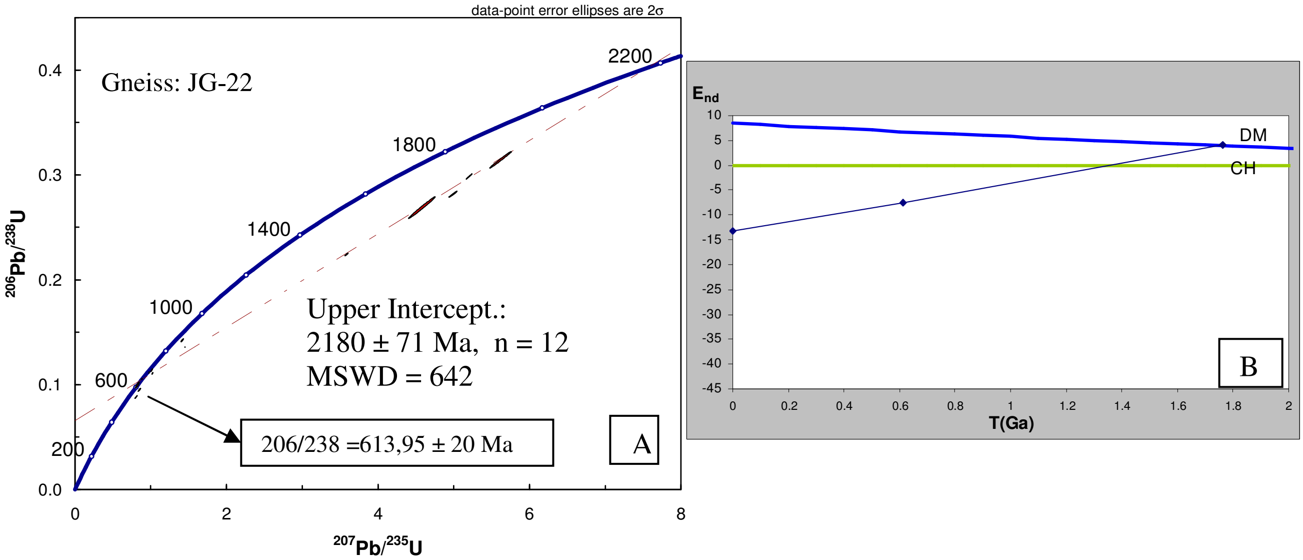


Figure 2.14 - A: Concordia diagram, sample JG-22, B: ε_{Nd} evolution diagram showing the Nd isotopic composition of samples JG-21 and JG-22.

Sm-Nd isotopic data of this gneiss, JG-22, revealed T_{DM} model age of 1.76 Ga and ε_{Nd} (614 Ma) of - 7.5 (Table 2.2, Fig. 2.14 B), suggesting recycling of older continental crust.

The two granites bodies emplaced into the Sanclerlândia orthogneiss was also investigated. This two deformed granites are here referred to as the São Mateus and Buriti de Goiás (Fig. 2.13, 2.15 A and B).

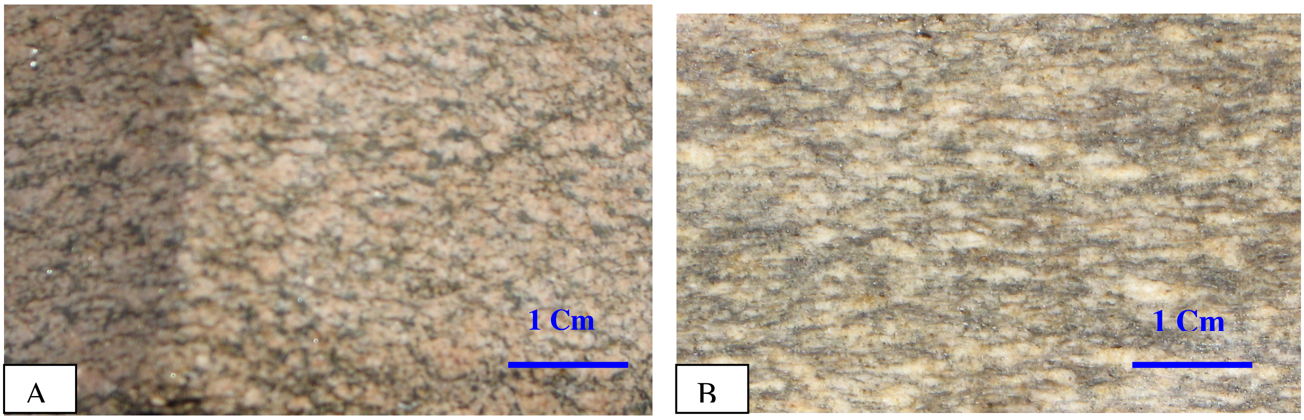


Figure 2.15 - A: São Mateus Granite, JG-50; B: Buriti de Goiás Granite, JG-14.

One sample of the Buriti de Goiás granite, (JG-14) (Fig.2.15B), was analyzed by the U-Pb in zircon method. Five zircon analysis show strong lead loss and indicated the upper intercept age 2990 ± 82 Ma (Table 2.1). However, this age does not seem to bear geological significance, since the model age value of this granite is much younger, around 1.1 Ga. Therefore the pattern shown in the U-Pb analysis must reflect strong inheritance of Archean material in a much younger (Neoproterozoic) intrusion. The lower intercept age of 906 ± 100 Ma as geologically meaningless.

Six samples from different locations of the Buriti de Goiás granite were analyzed by the Sm-Nd method; (JG-15, JG-17-1, JG-17-2, JG-17-3 and JG-62). To calculate the $\boldsymbol{\varepsilon}_{Nd}$ (*T*) values, it was admitted the crystallization age of the Buriti of Goiás granite is ca. 614 Ma.

Isotope data indicate T_{DM} model ages of 1.11, 1.20, 0.97, 1.19 and 1.04 Ga and ε_{Nd} (*T*=614 Ma) of + 2.4, + 0.4, + 1.5, + 1.2 and + 2.7, respectively (Table 2.2, Fig 2.16 B). Positive ε_{Nd} (*T*) values indicate that it is likely that the original granitic magma represent anatexis of sialic rocks of the Arenópolis Magmatic Arc.

Two samples of the São Mateus granite, (JG-50 and JG-58), were analyzed. Sample JG-50 revealed a T_{DM} model age of 1.33 Ga and ε_{Nd} (T = 614 Ma) of - 4.3. Whereas sample JG-58 has a model age of 1.28 Ga and ε_{Nd} (*T*) of -3.3 (Table 2.2, Fig 2.16 A). The data suggest that the original granitic magma of the São Mateus granite also had relatively larger participation of older crustal material in its genesis.

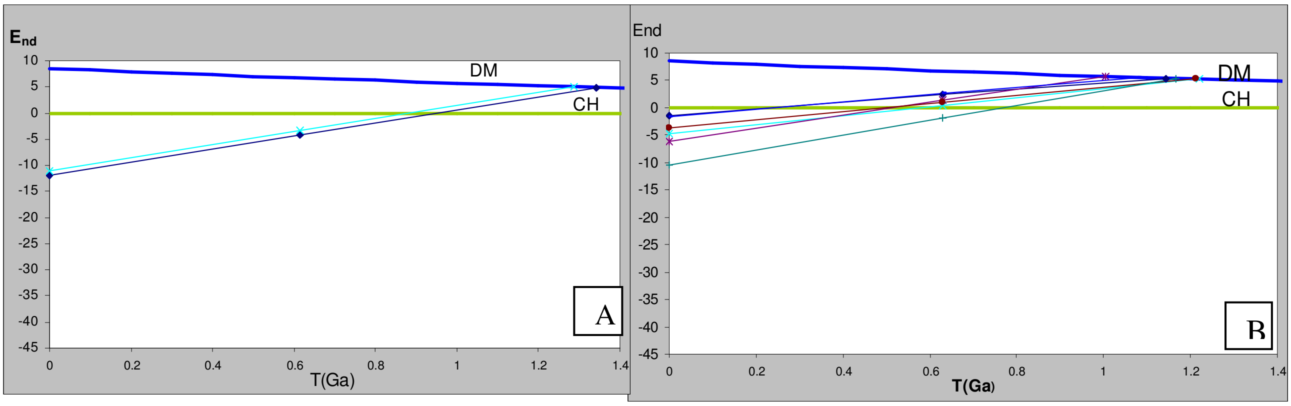


Figure 2.16 - $\boldsymbol{\varepsilon}_{Nd}$ evolution diagrams showing, A: São Mateus granite JG-50 and JG-58, B: Buriti de Goiás granite JG-15, JG-17-1, JG-17-2, JG-17-3 and JG-62. Observe the slightly more negative $\boldsymbol{\varepsilon}_{Nd}$ value of São Mateus granite.

Mossâmedes granite JG-12 - The outcrop sampled in this granite body is located in Mossâmedes (Fig. 2.17). This granite is a coarse-grained rock with porphyroclasts of flattened feldspar (0.5 cm average size) in the form of augens (Fig. 2.18). This EW foliation is subvertical, parallel to the regional structures of the country-rock.

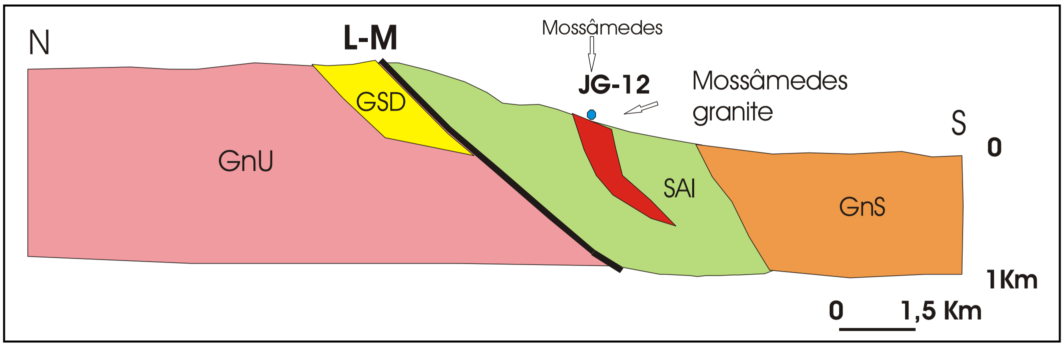


Figure 2.17 - Geological section 3 showing the Mossâmedes (L-M) lineament, Anicuns-Itaberaí (SAI) sequence, Mossâmedes granite positioned between the Sanclerlândia block (GnS) and the Uvá Complex (GnU). Caption in Figure 2.5.

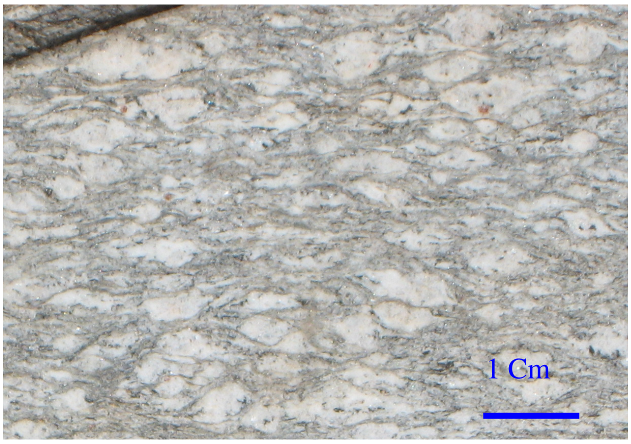


Figure 2.18 - Textural aspects of the Mossâmedes granite, JG-12 sample.

Nine zircon grains of the Mossãmedes granite were analyzed and the analytical points did not produce a good alignment in the concordia diagram, with strong lead loss possibly combined with inheritance. The upper intercept obtained all analytical points indicates the age of ca. 840 Ma. One analytical point is concordant, at the age of ca. 548 ± 11 Ma. At this stage, and until new geochronological data is available, we interpret this latter age as the best estimate for the crystallization of the original granitic magma (Table 2.1, Fig 2.19 A). The upper intercept age of 840 Ma is interpreted here as inheritance from Neoproterozoic juvenile rocks of the Arenópolis Magmatic Arc.

Sm-Nd isotopic analysis from this granite showed a T_{DM} model age of 0.93 Ga and ε_{Nd} (T=548 Ma) of + 2.57 (Table 2.2, Fig.2.19 B).

Sm-Nd isotopic data of the Buriti de Goiás and Mossâmedes granites are similar to the data for the Sanclerlândia orthogneisses, but different from data observed for the São Mateus granite which presents much older model ages and strongly negative ε_{Nd} (*T*) values.

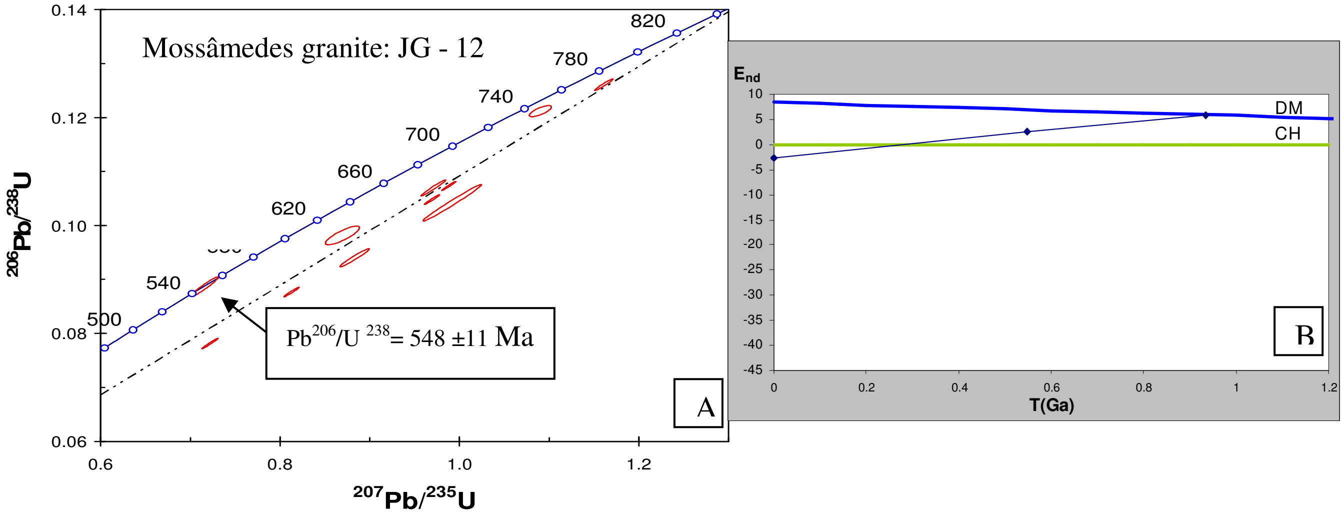


Figure 2.19 - A: Concordia diagram for the Mossâmedes granite, JG-12. B: ε_{Nd} evolution diagram for the Mossâmedes granite, JG-12.

2.6.3 - Novo Brasil Wedge Block (GrGnNB)

The rocks analyzed in this block comprise deformed granites and gneisses (Fig. 2.20 and 2.21). Five samples from within this triangular structure formed by the Moiporá-Fazenda Nova and Messianópolis-Novo Brasil lineaments were investigated by the U-Pb method and five by the Sm-Nd method (Tables 2.1 and 2.2). Deformed granites and orthogneisses analyzed here are represented by samples JG-75, JG-31, JG-33, JG-120 and JG-158 (Fig. 2.19 and 2.20). These samples are shown in geological sections 4, 5 and 6.

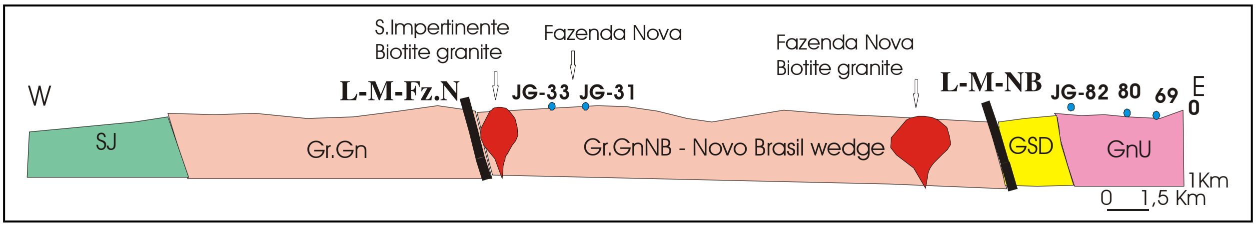


Figure 2.20 - Geological section 4 showing Novo Brasil wedge formed by Messianópolis-Novo Brasil, LM-NB and Moiporá-Fazenda Nova lineaments, LM-Fz.N. Caption in Figure 2.5.

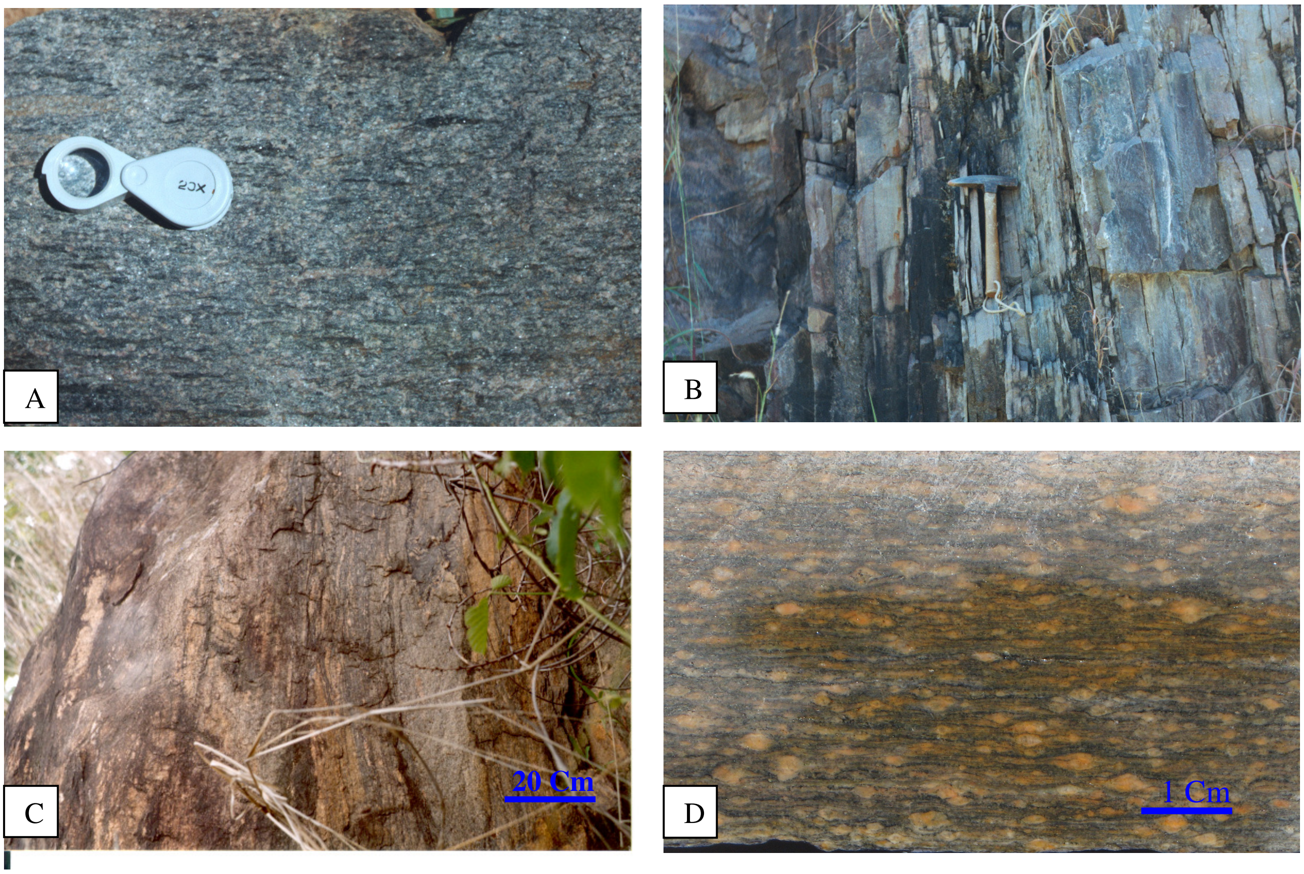


Figure 2.21 - Aspects of banded gneisses and deformed granites of the Novo Brasil wedge: (A) Orthogneiss, JG-75; (B) Mylonitic Granite, JG-33; (C) Mylonitic Granite, JG-120; (D) Mylonitic granite of the Piloândia, JG-158.

Orthogneiss - JG-75 – This rock with presents extremely flattened k-feldspar porphyroclasts forming an ultramylonitic foliation (Fig.2.21 A). Sm-Nd isotopic data of this mylonitic orthogneiss indicate a T_{DM} model age of 1.29 Ga and ε_{Nd} (545Ma) of - 2.4 (Table 2.2, Fig. 2.23 B). The data suggest that the original magma was mostly derived from re-melting of the Neoproterozoic sialic crust forming the Arenópolis Magmatic Arc.

Orthogneiss - JG-31 - This rock is also foliated with flattened K-feldspar porphyroclasts forming a mylonitic foliation. U-Pb analysis of five zircon grains showed a pattern with strong neoproterozoic Pb loss. The upper intercept age of 2137 ± 25 Ma and the lower intercept indicate the age of 589 ± 11 Ma (MSWD = 5.2) (Table 2.1, Fig 2.22 A). At this stage the correct interpretation of this data is not possible. We might be dealing with a sliever of Paleoproterozoic rocks in between younger rocks (an interpretation which we farvour here) or, alternatively, with the neoproterozoic anatectic product of Paleoproterozoic sialic crust.

Sm-Nd isotopic data indicate a T_{DM} model age of 2.26 Ga and ε_{Nd} (2,1) of + 0.5 (Table 2.2, Fig. 2.22 B).

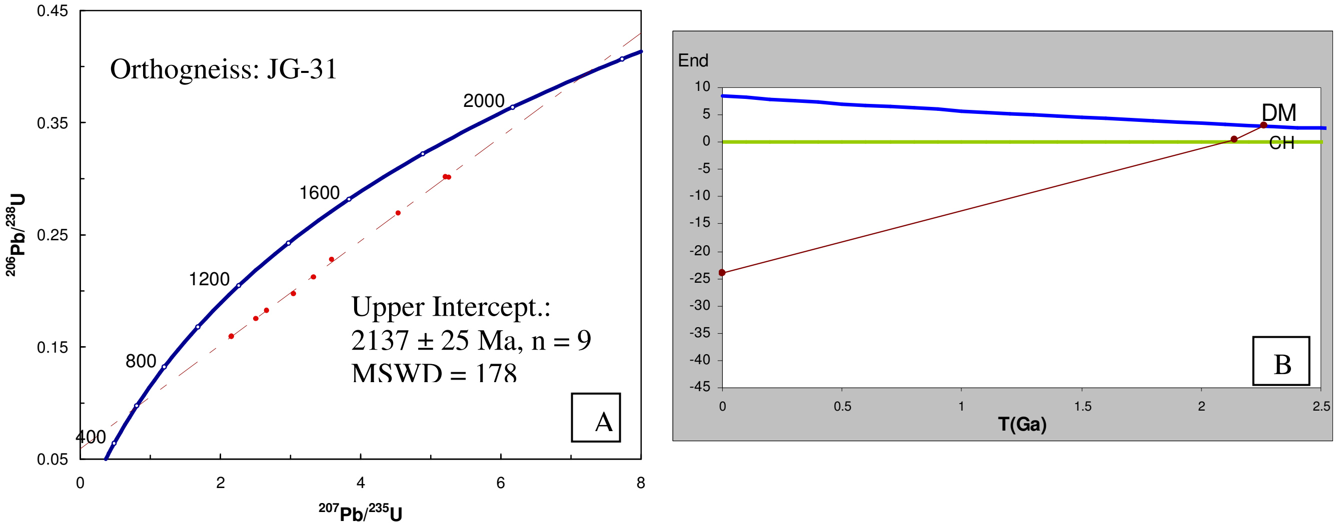


Figure 2.22 - A: Concordia diagram for orthogneiss, JG-31, B: ε_{Nd} evolution diagram showing the Nd isotopic composition of the orthogneiss, JG-31 sample.

Mylonitic granite JG-33 - This granite is very fine grained. It is pink, has rootless intrafolial tight folds and vertical mylonitic foliation in the same direction of the Moiporá-Fazenda Nova lineament (Fig.2.21 B).

Sample JG-33 has two distinct zircon populations, one formed by clean transparent light brown, long prismatic crystals and the second population consisting of pink crystals. U-Pb analysis of five zircon grains did not show a good alignment in the concordia curve. However, one of these analytical points is concordant showing $^{206}Pb/^{238}U$ age of 539 ± 6 Ma, interpreted as the crystallization age (Table 2.1 and Fig. 2.23 A).

Sm-Nd isotopic analysis of this sample indicated a T_{DM} model age of 1.12 Ga and ε_{Nd} (T=539 Ma) of - 1.0 (Table 2.2, Fig. 2.23 B). This value of the crystallization age associated with the Sm-Nd data indicates that the original magma is most likely product of anatexis of rocks of the Arenópolis Magmatic Arc.

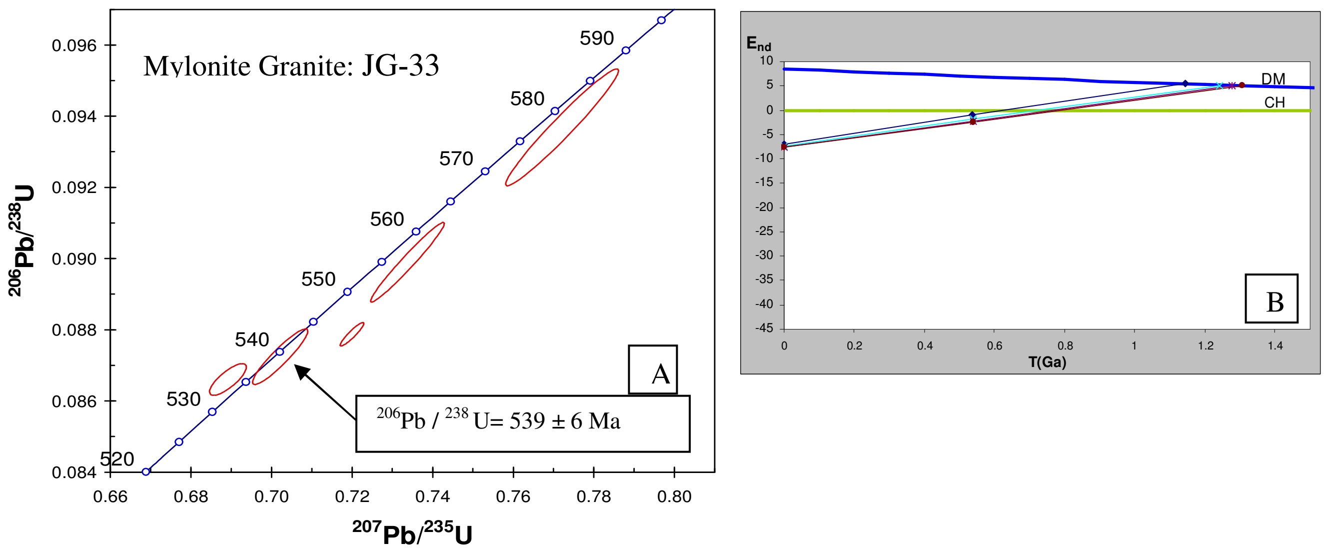


Figure 2.23 - A: Concordia diagram for mylonitic granite, JG-33, B: ε_{Nd} evolution diagram showing the Nd isotopic composition of deformed granites and gneisses exposed in the Novo Brasil wedge, JG - 33, 75, 120, 158 samples.

Granite JG-120 - This mylonitic granite is exposed between the post-collisional Messianópolis granite and quartzites of the Anicuns-Itaberaí sequence forming the hills between Messianópolis and Córrrego do Ouro. It displays mylonitic texture with strongly flattened feldspar porphyroclasts with up to one cm across (Fig.2.21 C). The foliation in this site is NS vertical, parallel to the Messianópolis-Novo Brasil lineament.

Zircon grains from this mylonitic granite form colorless prismatic crystal. Analysis of nine grains from the sample JG-120 did not show a good alignment in the concordia diagram, but concordant to semi-concordant analysis indicate ^{206}Pb / ^{238}U ages between ca. 570 Ma and 510 Ma (Table 2.1, Fig.2.24). The age between 550-570 Ma is interpreted here as the crystallization age of this rock.

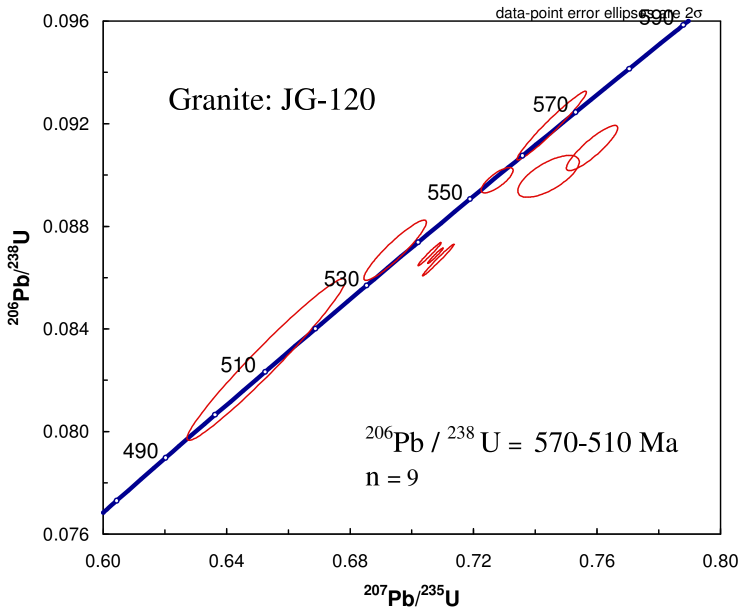


Figure 2.24 - Concordia diagram for deformed granite, JG-120.

Sm-Nd isotopic analysis of this sample revealed T_{DM} model age of 1.23 Ga and ε_{Nd} (*T*) of - 1.8 (Table 2.2, Fig. 2.23 B). The crystallization age value associated with the Sm-Nd data indicate that the original magma must be the product of re-fusion of older continental crust of the Arenópolis Magmatic Arc.

Piloândia Granite JG-158 - This mylonitic granite is finely banded with flattened porphyroclasts of K-feldspar (Fig.2.21 D). It displays NW vertical foliation parallell the Moiporá-Fazenda Nova lineament.

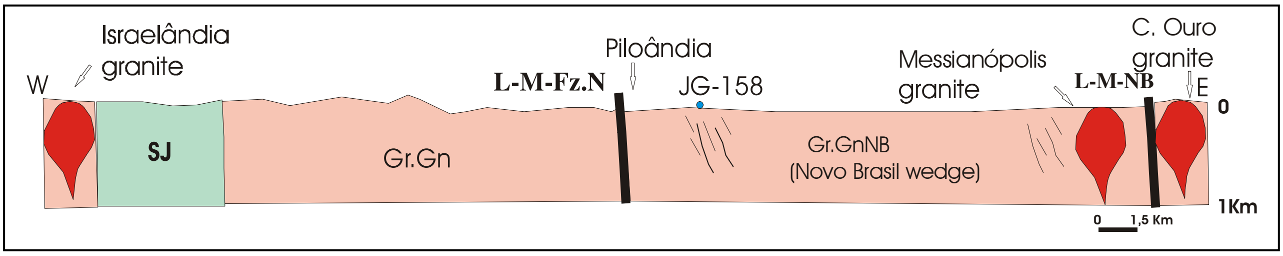


Figure 2.25 - Geological section 5 showing Novo Brasil wedge, Israelândia, Córrego do Ouro and Messianópolis granites. Caption in Figure 2.5.

Zircon grains from sample JG-158 are pink, clean and occur as long prismatic crystals. The analysis of three zircon grains from this sample showed an upper intercept age (MSWD = 0.014) of 532 ± 8 Ma (Table 2.1 and Fig. 2.26) interpreted as crystallization age of the original granite.

Sm-Nd isotopic analysis of this granite showed T_{DM} model age of 1.27 Ga and ε_{Nd} (532 Ma) of - 2.2 (Table 2.2, Fig. 2.23 B). The data suggest that it the original granitic magma was formed by anatexis of rocks of the Arenópolis Magmatic Arc.

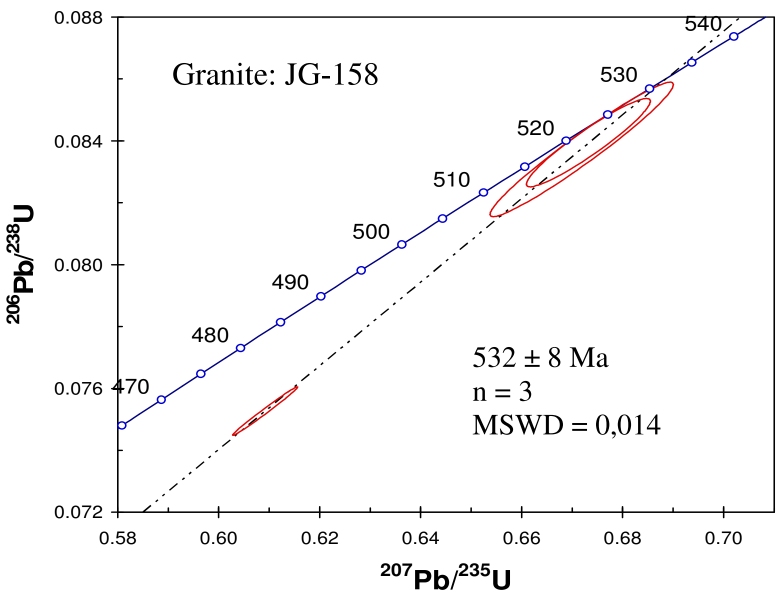


Figure 2.26 - A: Concordia Diagram of deformed granite, JG-158.

Samples from deformed granites of the Novo Brasil wedge: JG-75, JG-33, JG-120 and JG-158 have very uniform isotopic characteristics with T_{DM} model ages between 1.14 and 1.31 Ma and negative ε_{Nd} (*T*) values. The data suggest that the igneous protoliths are mostly the product of re-melting of rocks of the Arenópolis Magmatic Arc. Only one mylonitic granite represented by sample JG-31 presents much older T_{DM} model age.

2.6.4 - Ivolândia-Moiporá Block (GrGn)

This block is formed mainly by gneisses, deformed granites and post-tectonic high-K granites. Fresh rock outcrops occur in highway cuts between Ivolândia and Messianópolis (Fig.2.27, Fig.2.28 A and B).

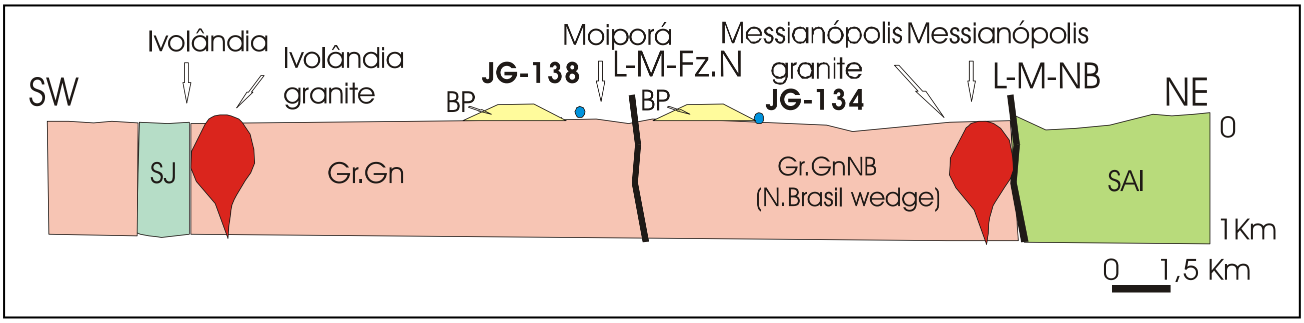


Figure 2.27 - Geologic section 6 showing the Ivolândia-Moiporá block, Novo Brasil wedge and coverage of Parana Basin. Caption in Figure 2.5.

JG-138 granite - The sampled outcrop is located along the GO-060 road between Moiporá and Ivolândia. The granite is deformed coarse-grained with flattened K-feldspar porphyroclasts surrounded by micaceous minerals (Fig.2.28 A), forming the main foliation of the rock with NS direction and subvertical dip.

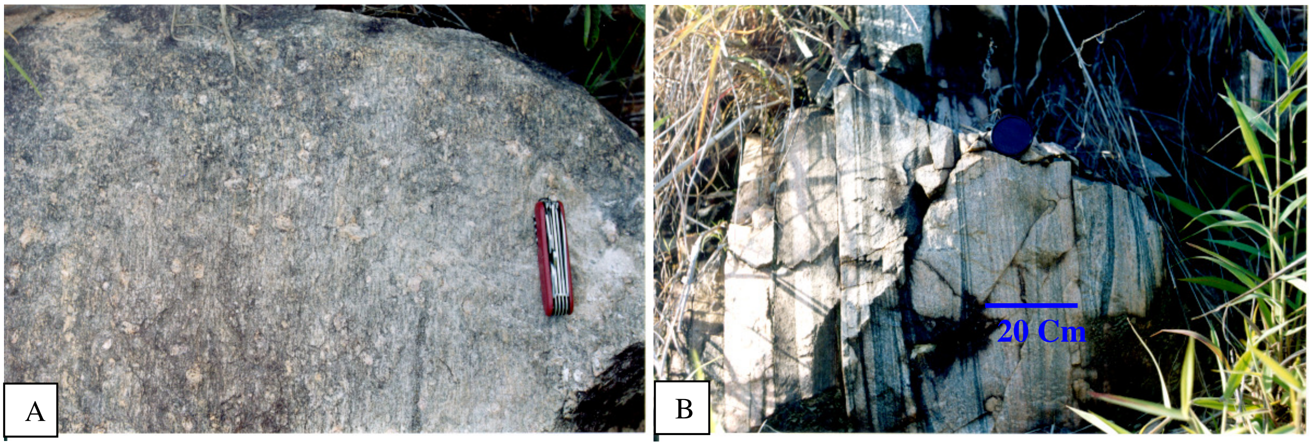


Figure 2.28 - A: Deformed granite, sample JG-138 from the Ivolândia-Moiporá block; B: orthogneiss, JG-134 from the Novo Brasil wedge.

Zircon grains from sample JG-138 are light pink, clean and form long prismatic crystals. Analysis of four zircon grains from this sample form a discordia (MSWD = 1.8) with an upper intercept age of 556 ± 4 Ma interpreted as the best estimate for the crystallization age of their protolith (Table 2.1, Fig 2.29 A).

Sm-Nd isotopic data from this granite revealed T_{DM} model age of 1.1 Ga and ε_{Nd} (T=556 Ma) of - 0.8 (Table 2.2, Fig. 2.29 B) suggesting origin of the parental magma from anatexis of the Arenópolis Magmatic Arc.

Orthogneiss sample JG-134 located in the Novo Brasil wedge is very similar petrographically to the mylonitic granite JG-33 (Fig. 2.21 B) further to the north.

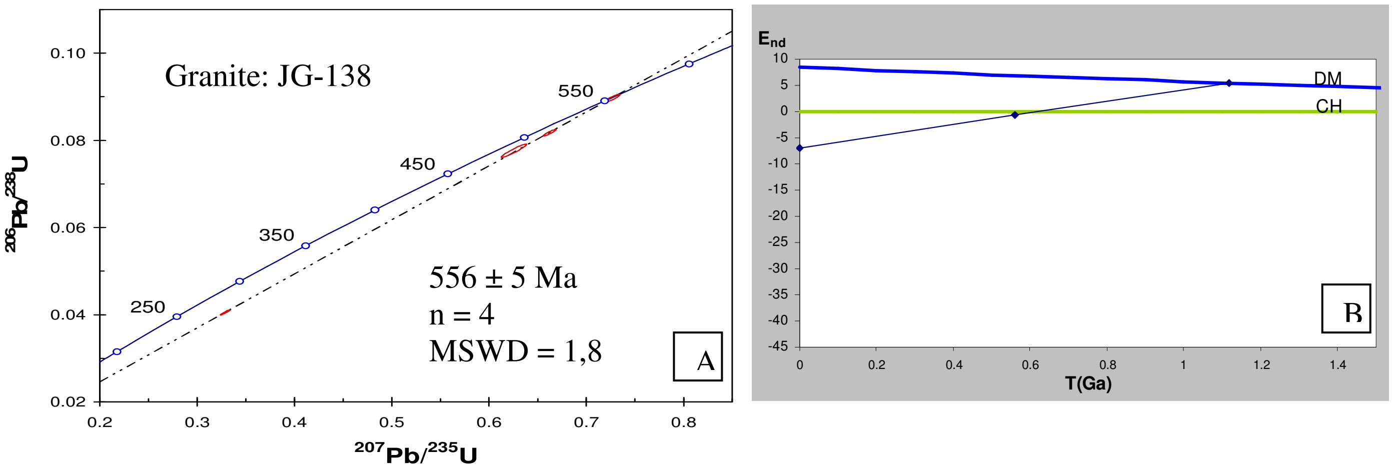


Figure 2.29 - A: Concordia diagram for granite, JG-138, B: ε_{Nd} evolution diagram showing the Nd isotopic composition.

Sm-Nd isotopic analysis of sample, JG-46, representative of a deformed granite located between the Ivolândia-Moiporá and Sanclerlândia blocks showed T_{DM} model age of 2.65 Ga and ε_{Nd} (T=560 Ma) of - 32 (Table 2.2 , Fig. 2.30). The negative ε_{Nd} (T) value indicates it has been formed by fusion of old material. The gneiss from Uvá Complex, sample JG-69 presents T_{DM} model age value similar to that of this rock.

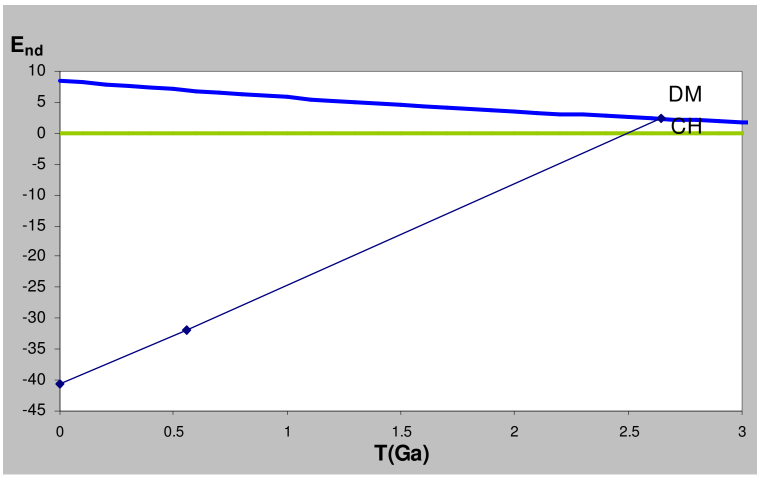


Figure 2.30 - ε_{Nd} (T) diagram evolution showing Nd isotopic composition of granite JG-46.

2.6.5 - Summary of Results

Isotope data are summarized in (Fig. 2.31).

Figure 2.31- Relationship between lineaments, U-Pb ages and Sm-Nd isotope data of the investigated region between San Luis de Montes Belos and Fazenda Nova: Moiporá-Fazenda Nova Lineament, LM-FzN; Messianópolis-Novo Brasil Lineament, L-M-NB; Mossâmedes Lineament, L-M; São Luis de Montes Belos Lineament , L-SLMB.

Table 2.1

Sample	Fraction	Size (mg)	U Ppm	Pb ppm	Pb 206 Pb204 (obs.)	Radiogenic Rations (isoplot Data) Pb207* U235	(pct)	Pb206* U238	(pct)	Correl. Coeff. (rho)	Pb207* Pb206*	(pct)	Pb206* U238 Age	Pb207* U235 Age	Pb207* Pb206* Age	(Ma)	Q
JG-69	2	0.014	343.86	111.18	383.	6.27508	0.957	0.268207	0.905	0.946609	0.169686	0.309	1531.7	2015	2554.6	5.2	6
	4	0.011	211.22	71.551	1963.	7.20323	0.339	0.299438	0.333	0.97624	0.174469	0.074	1688.5	2136.9	2601	1.2	4
	E3	0.019	371.61	92.787	1848.	5.29575	0.769	0.235874	0.727	0.957512	0.162836	0.222	1365.2	1868.2	2485.3	3.7	2
	11	0.018	232.66	93.86	2986.	6.16966	0.392	0.264522	0.386	0.983921	0.16916	0.07	1512.9	200.2	2549.4	1.2	9
	12	0.017	296.04	81.097	3288.	5.87692	0.291	0.254983	0.29	0.995775	0.167162	0.027	1464.1	1957.8	2529.4	0.45	11
JG-4	D4	0.026	65.317	10.48	749.	1.31267	0.8920	0.141847	0.825	0.929915	0.067117	0.328	855.1	851.3	841.42	6.8	1
	D3	0.023	77.201	12.018	771.	1.2930	0.89	0.140408	0.762	0.87352	0.066791	0.434	846.97	842.64	831.27	9	1
	D2	0.034	75.999	11.503	1161.	1.28333	0.63	0.139337	0.557	0.900474	0.066799	0.274	840.91	838.33	831.51	5.7	1
	H	0.027	93.012	13.476	340.	1.18191	2.43	0.129396	2.26	0.939123	0.066247	0.837	784.42	792.2	814.18	17	1
	I	0.03	101.32	15.298	329.	1.20657	1.9	0.131727	1.82	0.964591	0.066432	0.501	797.71	803.62	820.02	10	1
	O	0.019	123.45	19.096	911.	1.30126	0.816	0.141669	0.581	0.76171	0.066617	0.531	854.09	846.28	825.84	11	1
	D15	0.034	84.369	12.629	1232.	1.2475	0.897	0.135887	0.543	0.61256	0.066583	0.709	821.36	822.28	824.75	15	1
JG-5	D12	0.02	83.447	13.247	332.	1.2406	1.73	0.135452	1.61	0.936879	0.066428	0.605	818.89	819.16	757.2	13	1
	D13	0.017	134.1	19.577	396.	1.22236	2.69	0.133118	2.43	0.912123	0.665978	1.1	805.63	810.85	825.22	23	2
	D15	0.017	73.311	12.142	286.	1.27942	2.24	0.139728	2.07	0.93443	0.066409	0.8	843.12	836.59	819.3	17	1
JG-14	17	0.016	388.51	80.779	2321.	2.95727	0.7420	0.193188	0.738	0.994993	0.111022	0.741	1138.6	1396.7	1816.2	1.3	9
	18	0.024	215	115.75	2865.	9.5913	0.649	0.372483	0.644	0.991057	0.186754	0.087	2041.1	2396.3	2713.8	1.4	3
	19	0.018	242.84	102.57	466.	8.13383	0.535	0.326787	0.535	0.993921	0.180522	0.059	1822.8	2246	2657.7	0.98	3
	8	0.021	193.39	76.188	2438.	8.2858	0.311	0.329996	0.308	0.986476	0.182106	0.051	1838.4	2262.8	2672.1	0.84	2
	9	0.012	267.16	92.039	2341.	7.12252	0.56	0.299236	0.558	0.99463	0.172631	0.058	1687.5	2126.9	2583.3	0.97	4
	10	0.02	202.56	78.114	3174.	8.24287	0.604	0.329948	0.601	0.993301	0.181189	0.07	1838.1	2258.1	2663.8	1.2	3
JG-22	6	0.017	140.84	46.101	916.	5.61916	2.0800	0.315208	2.07	0.993639	0.129292	0.235	1766.3	1919	2088.4	4.1	1
	7	0.012	269.57	88.348	332.	4.99144	0.8380	0.282548	0.82	0.975273	0.128124	0.185	1604.2	1817.9	2072.4	3.3	1
	9	0.033	120.47	32.992	985.	4.5806	3.2	0.269519	3.17	0.990851	0.123263	0.432	1538.4	1745.7	2004	7.7	1
	10	0.016	178.88	18.67	574.	0.819506	2.35	0.099921	2.15	0.918928	0.059483	0.926	613.95	607.77	584.83	20	1
	11	0.025	158.56	23.221	1189.	1.41364	0.74	0.142702	0.687	0.93403	0.071847	0.264	859.92	894.69	981.61	5.4	2
	14	0.021	316.59	97.596	5455.	5.20439	0.651	0.299464	0.645	0.990841	0.126045	0.088	1688.6	1853.3	2043.5	1.6	3
	15	0.017	543.3	143.2	585.	3.58659	0.453	0.224706	0.437	0.967806	0.115762	0.114	1306.7	1546.6	1891.8	2.1	3
	11	0.016	173.01	23.834	2334.	1.44888	0.273	0.136283	0.257	0.942	0.077107	0.091	823.61	909.41	1124	1.8	3
	13	0.029	60.426	7.107	901.	1.01379	0.944	0.114357	0.922	0.978	0.064296	0.195	698	710.79	751.39	4.1	2
	14	0.02	141.86	15.301	2213.	0.982239	0.36	0.111877	0.335	0.933	0.063676	0.129	683.64	694.75	730.88	2.7	3
	15	0.014	304.94	78	2457.	0.884078	0.586	0.105934	0.248	0.483	0.060528	0.514	649.09	643.18	622.49	11	3
	11C	0.016	465.57	48.852	317.	0.802283	1.09	0.088743	1.08	0.986809	0.065568	0.177	548.01	598.12	792.61	3.7	2
	12C	0.016	406.87	47.518	268.	0.845124	1.29	0.095525	1.18	0.918999	0.064166	0.508	588.13	621.97	747.1	11	4
	15C	0.018	356.37	42.846	940.	1.01965	0.519	0.111218	0.514	0.991498	0.066493	0.068	679.82	713.74	821.93	1.4	6

JG-12	2	0.013	819.37	95.855	550.	0.992046	2.6800	0.104213	2.65	0.987963	0.069041	0.415	639.05	699.76	899.97	8.6	1
	5	0.015	431.71	46.561	353.	0.883179	1.5100	0.094029	1.46	0.971223	0.068122	0.359	579.32	642.7	872.28	7.4	1
	6	0.022	351.49	47.253	177.	0.8696	1.78	0.098146	1.44	0.82962	0.064259	0.994	603.53	635.33	750.16	21	2
	7	0.021	479.47	47.1	468.	0.812891	0.843	0.087682	0.823	0.977047	0.067239	0.18	541.81	604.07	845.18	3.7	2
	8	0.019	522.03	59.107	754.	0.969434	0.716	0.104805	0.703	0.9825	0.067087	0.133	642.5	688.17	840.47	2.8	3
	9	0.019	493.61	42.108	583.	0.721906	1.01	0.078137	0.998	0.985108	0.067008	0.175	484.99	551.79	838.02	3.6	2
	D4	0.027	97.94	8.9173	533.	0.716136	1.69	0.088678	1.62	0.958	0.058571	0.485	**547.71**	548.38	551.17	11	3
	D9	0.033	262.13	34.842	1184.	1.16089	0.713	0.126078	0.692	0.972	0.066780	0.167	765.45	782.37	830.93	3.5	3
	8	0.021	260.41	33.688	1007.	1.09016	0.926	0.121187	0.686	0.7481	0.065243	0.614	737.39	748.58	782.18	13	5
	9	0.012	261.93	29.967	602.	0.97095	1.15	0.106955	1.13	0.980157	0.065841	0.228	655.04	688.95	801.31	4.8	1
	10	0.023	245.85	28	1131.	0.98806	0.641	0.107319	0.631	0.984311	0.066774	0.113	657.16	697.73	830.72	2.4	5
JG-31	12	0.02	925.01	157.91	7207.	2.50453	0.187	0.175378	0.159	0.86182	0.103574	0.095	1041.7	1273.3	1689.1	1.7	2
	15	0.01	1106.7	172.34	2247.	2.15343	0.389	0.159341	0.316	0.82933	0.098017	0.218	953.11	1166.2	1586.8	4.1	1
	17	0.02	128.26	58.147	149.	5.20808	0.879	0.301769	0.877	0.992905	0.12517	0.105	1700.1	1853.9	2031.2	1.9	3
	18	0.022	133.3	38.784	3961	4.53387	0.177	0.269401	0.154	0.87909	0.122059	0.084	1537.8	1737.2	1986.5	1.5	1
	20	0.016	1003.4	180.45	22861.	2.65565	0.188	0.182625	0.187	0.993178	0.105466	0.022	1081.3	1316.2	1722.4	0.4	1
JG-33	12	0.019	231	21.114	993.	0.7338	1.02	0.089899	1.02	0.97466	0.059202	0.229	554.9	558.76	574.53	5	3
	D1	0.023	120.56	10.796	1557.	0.689191	0.541	0.086604	0.418	0.78333	0.057716	0.336	535.42	532.31	519.01	7.4	3
	D2	0.024	78.69	7.9086	177.	0.685664	4.35	0.090367	4.19	0.970356	0.05503	1.05	557.71	530.19	413.44	23	2
	D3	0.019	75.978	7.0769	658.	0.702159	0.796	0.087245	0.731	0.922348	0.05837	0.308	539.22	540.08	543.69	6.7	3
	D5	0.033	110.74	9.9615	2160.	0.719971	0.332	0.087873	0.306	0.925771	0.059424	0.126	542.94	550.65	582.65	2.7	2
JG-120	6	0.016	95.456	9.2678	708.	0.744275	1.09	0.089948	0.741	0.68818	0.060012	0.792	555.23	564.9	604.01	17	2
	8	0.021	123.02	11.479	1135.	0.75839	0.893	0.091049	0.79	0.88787	0.060411	0.411	561.74	573.08	618.33	8.9	2
	E6	0.016	44.688	3.8656	300.	0.652842	3.21	0.082811	3.11	0.974764	0.057177	0.717	512.88	510.23	498.36	16	3
	E7	0.013	46.072	4.565	163.	0.631668	4.05	0.082336	3.56	0.89363	0.055642	1.82	510.05	497.13	438.1	41	3
	E8	0.012	472.9	41.419	382.	0.718988	1.69	0.078768	1.62	0.966193	0.066202	0.435	488.77	550.07	812.75	9.1	3
	2	0.045	172.38	15.373	2029.	0.707628	0.288	0.086851	0.281	0.978041	0.059092	0.06	536.88	543.34	570.5	1.3	10
	13	0.052	205.87	18.508	1611.	0.705743	0.431	0.086916	0.422	0.981146	0.058891	0.083	537.27	542.22	563.05	1.8	6
	14	0.044	169.68	14.882	1507.	0.708576	0.586	0.086686	0.579	0.98869	0.059284	0.088	535.91	543.9	577.54	1.9	8
	4	0.035	115.55	10.53	670.	0.694579	1.19	0.087066	1.1	0.927714	0.057859	0.446	538.16	535.55	524.42	9.8	4
	6	0.024	142.73	13.428	774.	0.745315	1.23	0.091926	1.19	0.972166	0.058803	0.287	566.91	565.5	559.83	6.3	1
JG-158	K	0.015	861.95	64.869	880.	0.609204	0.863	0.075266	0.854	0.991747	0.058703	0.111	467.81	483.06	556.1	2.4	1
	M	0.021	149.11	13.5	473.	0.673215	1.49	0.083943	1.39	0.939634	0.058166	0.511	519.62	522.67	536.01	11	4
	E2	0.025	163.27	14.742	327.	0.671908	2.21	0.083723	2.12	0.965877	0.058205	0.572	518.31	521.87	537.49	13	2
JG-138	P	0.038	406.34	19.399	363.	0.328746	1.22	0.040505	1.17	0.964305	0.058864	0.322	255.96	288.61	562.07	7	1
	R	0.01	588.84	46.859	360.	0.625602	1.7	0.077619	1.61	0.952851	0.058456	0.515	481.89	493.35	546.9	11	1
	U	0.019	282.38	24.831	1026.	0.726422	0.897	0.089654	0.806	0.905452	0.058765	0.381	553.49	554.45	558.39	8.3	1
	1	0.02	607.67	47.823	932.	0.662419	0.806	0.081779	0.753	0.937392	0.058748	0.281	506.73	516.09	557.76	6.1	1

Table 2.2 - Sm-Nd isotopic data of rocks for the Arenópolis Magmatic Arc and Uvá Complex:

Blocks	Sample	Rock	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ (2υ)	T_{DM} (Ga)	ε_{Nd} (*T*)
Uvá Complex Block								
	JG-69	**Uvá Gneiss**	3.10	17.39	0.1077	0.510997 ± 36	2.81	- 0.3 (2770)
	JG - 80	**Biotite Deformed granite**	8.80	58.22	0.0914	0.510717 ± 8	2.78	+ 0.1 (2770)
	JG-82	**Deformed granite**	2.92	22.97	0.0768	0.510483 ± 15	2.72	+ 0.7 (2770)
Sanclerlândia Block	**JG-2A**	**Sanclerl. Orthogneiss**	1.49	5.31	0.1699	0.512621 ± 9	1.44	+2.5 (820)
	JG-2B	**Felsic aplite**	0.51	1.80	0.1731	0.512708 ± 11	1.23	+3.8 (820)
	JG-5s	**Sanclerl. Orthogneiss**	4.07	17.24	0.1427	0.512539 ± 13	1.07	+3.7 (820)
	JG-41	**Anphibolite**	3.02	14.15	0.1292	0.512499 ± 5	0.98	+4.4 (820)
	JG - 43	**Gabbro**	3.13	16.09	0.1176	0.512439 ± 7	0.95	+1.6 (820)
	JG-55	**Sanclerl. Orthogneiss**	3.04	17.74	0.1037	0.512287 ± 6	1.04	+2.9 (820)
	JG-56	**Sanclerl. Orthogneiss**	1.71	7.064	0.1466	0.512610 ± 9	0.98	+4.7 (820)
	JG-59	**Sanclerl. Orthogneiss**	2.41	11.55	0.1259	0.512471 ± 7	0.99	+4.2 (820)
	JG-125	**Sanclerl. Orthogneiss**	6.22	29.26	0.1285	0.512286 ± 21	1.34	+0.3 (820)
Deformed Granite	**JG-15**	**Buriti de Goiás Granite**	5.28	21.38	0.1493	0.512568 ± 22	1.11	+2.5 (614)
	JG-17-1	**Buriti de Goiás Granite**	19.59	89.67	0.1321	0.512393 ± 4	1.20	+0.4 (614)
	JG-17-2	**Buriti de Goiás Granite**	65.06	385.68	0.1020	0.512324 ± 6	1.00	+1.5 (614)
	JG-17-3	**Buriti de Goiás Granite**	13.88	60.73	0.1382	0.512447 ± 6	1.19	+1.0 (614)
	JG-62	**Buriti de Goiás Granite**	4.99	21.13	0.1428	0.512553 ± 11	1.10	+2.7 (614)
Anicuns-Itaberaí Sequence	**JG-21**	**Gneiss**	4.39	29.36	0.0904	0.512107 ± 8	1.17	-1.8 (614)
	JG-22	**Gneiss garnetiferous**	2.58	12.79	0.1220	0.511955 ± 9	1.76	-7.5 (614)
Deformed granite	**JG-50**	**São Mateus Granite**	11.66	71.59	0.0984	0.512024 ± 7	1.33	-4.3 (614)
	JG-58	**São Mateus Granite**	3.72	22.67	0.0991	0.512076 ± 5	1.28	-3.3 (614)
Deformed granite	**JG-12**	**Mossâmedes Granite**	3.21	15.90	0.1222	0.512502 ± 5	0.90	+2.3 (548)
Novo Brasil wedge **Block**	**JG-75**	**Deformed granite**	16.21	81.34	0.1205	0.512243 ± 7	1.29	-2.4 (545)
	JG-31	**Orthogneiss**	5.50	30.95	0.1074	0.511405 ± 6	2.26	+0.5 (2137)
	JG-33	**Mylonitic Granite**	18.06	97.96	0.1114	0.512284 ± 6	1.14	-1.0 (539)
	JG-120	**Deformed Granite**	16.7	85.63	0.1178	0.512264 ± 8	1.25	-1.9 (570)
	JG -158	**Def. Granite Piloândia**	7.39	37.46	0.1192	0.512251 ± 6	1.28	-2.2 (532)
Ivolandia-Moiporá Block	**JG-138**	**Deformed granite**	1.98	10.95	0.1090	0.512285 ± 17	1.10	-0.8 (556)
	JG-46	**Deformed granite**	5.47	43.83	0.0754	0.510555 ± 16	2.65	-32 (820)
	JG-146	**Orhtogneiss**	8.28	41.56	0.1205	0.512211 ± 5	1.35	-0.3 (820)

2.7 - Metamorphism

The garnet bearing gneisses represented by sample JG-22 and by Sanclerlândia orthogneiss, sample JG-125 (Fig.2.32), were investigated here in order to assess the age of garnet growth and associated metamorphism. Whole-rock-garnet Sm-Nd isochrones are shown in Fig.2.33A and isotopic data are in Table 2.3.

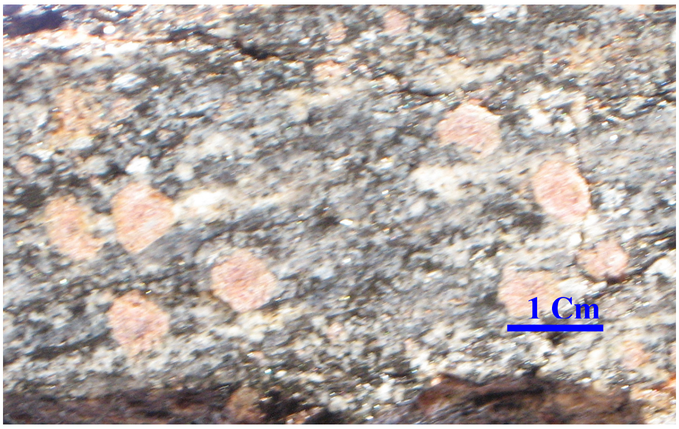


Figure 2.32 - Almandine garnet of Sanclerlândia orthogneiss JG-125.

The WR-gt isochron for gneiss, JG-22, revealed the age of 503 ± 17 Ma (Table 2.3, Fig 2.33 A). This age is slightly younger than the crystallization age of the post-collisional Córrego do Ouro granite, which is correlated to the Messianópolis granite with zircon U-Pb age of ca. 545 Ma (Motta-Araújo and Pimentel 2012, in press). Thus, it is ruled out the hypothesis that this age is interpreted as contact metamorphism imposed by the granite emplacement.

The isochron made for the Sanclerlândia orthogneiss, JG-125, revealed the age of 601 ± 31 Ma, interpreted as the age of metamorphism (Table 2.3, Fig.2.33 B). This age can be attributed to the thermal peak of metamorphism to which these rocks were subjected during Brasiliano orogeny in the region.

These ages represent different cooling ages for each block of rocks analyzed.

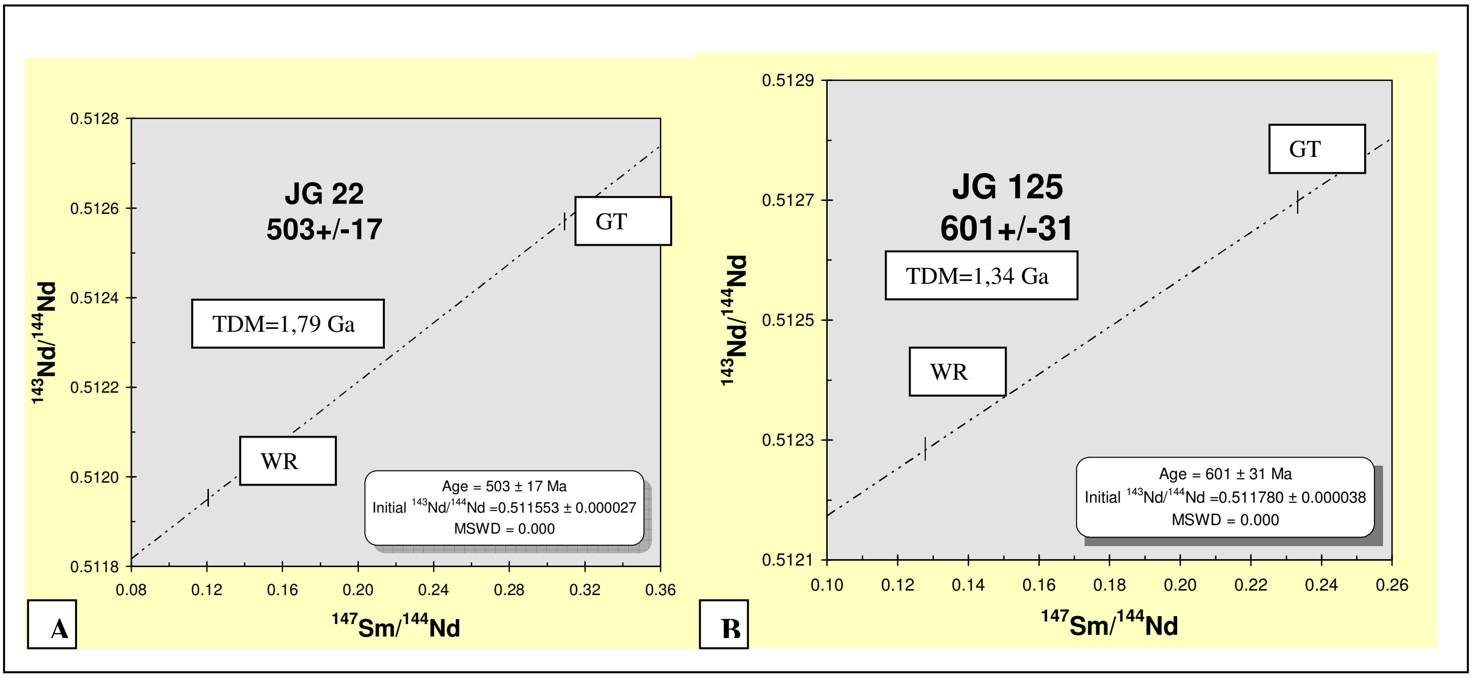


Figure 2.33 - Whole rock-garnet Sm-Nd isochrons: A - gneiss, JG-22; B: Sanclerlândia orthogneiss - JG-125.

Table 2.3 - Sm-Nd isotopic results garnet in gneiss, JG-22 and Sanclerlândia orthogneiss, JG-125**.**

Sample	Mineral	**Sm (ppm)**	**Nd (ppm)**	**^{147}Sm/^{144}Nd**	**^{143}Nd/^{144}Nd (2 SD)**
JG-22 [3]	**Garnet**	1.677	3.284	0.3087	0.512570 ± 15
JG-125 [3]	**Garnet**	1.842	4.781	0.2329	0.512697 ± 11

2.8 - Discussion

The Sm-Nd T_{DM} model ages and zircon U-Pb ages discussed in the present study help to understand the meaning of the extensive lineaments and their relationships with the main crustal blocks formed mainly by gneisses with different ages and nature in the southwestern portion of Goiás. The nature and age of the contact of Neoproterozoic orthogneisses of the Arenópolis Magmatic Arc with the Goiás Archaean block represented by TTG terrains and by the *granite-greenstone* of the Uvá complex are better understood set using these new geochronological data.
Sm-Nd and U-Pb data also allowed to clarify the real area of exposure of the juvenile Sanclerlândia orthogneiss from Sao Luis de Montes Belos to the south of Sanclerlândia. Until then this orthogneisses had poorly definide crystallization age and limits. The zircon U-Pb age revealed crystallization ages of 826 ± 4 Ma and 822 ± 7 Ma and Sm-Nd data confirmed T_{DM} model ages are

around 1.0 Ga. This is one of the oldest crystallization ages obtained from the orthogneisses of the Arenópolis Magmatic Arc. This Sanclerlândia crustal block in tectonic contact to the east with the younger (ca. 630 Ma) Turvânia-Firminópolis-Palminópolis orthogneisses. This age represents the peak of metamorphism of the Brasiliano orogeny in the Brasilia Belt. This was also accompanied by the emplacement of several small mafic-ultramafic intrusions represented in the area by the layered complex of Americano Brasil dated at 626 ± 8 Ma. This bimodal magmatism is a result of extensional events shortly following the Brasiliano orogeny verified in the southern Brasilia Belt as suggested by Pimentel *et al.* (1992). Pre to syn-collisional Buriti de Goias and Mossâmedes granites have Sm-Nd model ages which are very similar to the Sanclerlândia orthogneiss, indicating that they are the product of anatexis Sanclerlândia-type juvenile rocks whereas the São Mateus granite has Sm-Nd isotopic characteristics suggesting the limited participation of older continental crust in the origin of the parental granitic magma.

Mylonitic granites and gneisses that form the structure of the Novo Brasil wedge and of the Ivolândia-Moiporá block, have uniform isotopic Sm-Nd compositions and U-Pb ages. Deformed granites in the wedge have crystallization zircon U-Pb ages between 532 and 570 Ma, T_{DM} model ages from 1.12 to 1.29 Ga and ε_{Nd} (*T*) between -1 to - 2.2. The exception is the sample JG-75 which presents the oldest T_{DM} model age. A deformed granite in the Ivolandia-Moiporá block revealed the 556 Ma U-Pb age, T_{DM} model ages of 1.1 Ga and ε_{Nd} (*T*) of - 0.8. These data indicate that the Novo Brasil and Ivolandia blocks can be considered contemporary and belonging to a single crustal block of same age and evolution which is simply cut by the Moiporá-Fazenda Nova Lineament. This lineament should probably represent the foliation concentration at high angle in rocks and in some local contacts between metasedimentary rocks of the Jaupaci sequence and deformed granites and gneisses.

Deformed granite, JG-46, located in the Ivolândia-Moiporá block has the oldest T_{DM} model age of 2.65 Ga. This granite is located between the Ivolândia-Moiporá, Novo Brasil and Sanclerlândia blocks. This granite has isotopic characteristics very similar to those of the Uvá complex gneiss.

Orthogneiss, JG-146, located to the east of the Messianópolis-Novo Brasil lineament has the same isotopic characteristics of deformed granites and gneisses of the Novo Brasil wedge.

Table 2.4: Chronological overview of the main Precambrian geological events in SW Goiás from isotopic and geochronological data obtained in this study**.**

Period	Phase	Geological record	Geological environment
630 ± 5/-30 Ma to 542 ± 1 Ma	F 4 - Extensional 545 Ma F3- Compressive 620 Ma F 2 - Extensional 630 Ma	5 - Late to post-collisional high-K at ca. 543 Ma and migmatisation processes indicated by U-Pb dating in neossoma zircon at 537 ± 6 Ma (Motta-Araújo and Pimentel 2012,(in press) 4 - Tectonic inversion of the Brasília Belt. Regional deformation with metamorphic peak at 620 Ma 3 - Second period of crustal accretion: generation of bimodal magmatism at 630 Ma. Intrusion of layered mafic-ultramafic complexes Americano do Brasil type.	Anatexis of continental crust Collision between the São Francisco and Amazon paleocontinentes (and Paranapanema?).
1000-820 Ma-	F1- Compressive 820 Ma	2 - First period of crustal accretion: Generation of tonalite protolith of the Sanclerlândia orthogneiss. Formation of intraoceanic juvenile Island Arc of Arenópolis (Pimentel *et al.*1992).	
Archean > 2.5 Ga		1 - Generation of TTG grounds from the Uvá Complex	

2.9 - Conclusions

The new geochronological and isotopic data discussed in the present study helped to clarify details of the crustal evolution in the São Luís de Montes Belos and Novo Brasil areas in southwestern Goiás during the Neoproterozoic.

Sm-Nd T_{DM} model ages in total rock, ε_{Nd} (*T*) values, and U-Pb zircon associated with field observations and investigation of Landsat-5 sensor satellite images of the region allowed to recognize more accurately the different crustal blocks this part of the Brasília Belt. There are: (i) Uvá Complex block, (ii) Sanclerlândia block (iii) Novo Brasil wedge block and Ivolândia-Moiporá blocks.

The crystallization age of 2770 ± 6 Ma of banded gneiss, JG-69, belonging to the southern edge of the Uvá Complex confirms that its western limit is marked by the Messianópolis-Novo Brasil and New-Mossâmedes lineaments.

Sm-Nd Isotopic data and zircon U-Pb ages of 828 ± 4 Ma confirmed the extention of the area of exposure of the Sanclerlândia, metatonalite, between São Luís de Montes Belos and Mossâmedes.

The zircon U-Pb age of 614 Ma of the gneiss country-roch for the Buriti de Goiás granites indicates the maximum crystallization age for this granite.

Gneisses and mylonitic granites included in the Novo Brasil wedge have crystallization ages ranging from 530 to 590 Ma.

Deformed granite from the Ivolândia-Moiporá block presented crystallization age of 556 ± 4 Ma which is within the range of ages of deformed granites and gneisses of the Novo Brasil wedge suggesting they are part of the same crustal block.

The Messianópolis-Novo Brasil lineament represents a wide discontinuity between two geological units of different ages. Its southern portion separates the Sanclerlândia block from the Moiporá-Ivolândia block and its northern portion separates the Novo Brasil wedge from the Archean Block represented by the Uvá Complex.

The Moiporá-Fazenda Nova lineament does not separate blocks with different crystallization ages. It is believed that it represents simply the concentration of the foliation/banding at high angle of rocks and contacts between the metasedimentary rocks of the Jaupaci sequence with deformed granites and gneisses.

The São Luis de Montes Belos lineament separates the Sanclerlândia block (crystallization age around 828 ± 4 Ma) of the Turvânia-Palminópolis-Firminópolis orthogneisses of (634 ± 8 Ma).

WR-gt Isochrone for the Sanclerlândia orthogneiss showed the age of 601 ± 31 Ma. Within the range of this age is the regional record of the metamorphic peak of the Brasiliano orogeny in the region. WR-gt isochron age for gneiss, JG-22 (503 ± 17 Ma) does not seem to be related to the intrusion of granites with this age known in the region. Since there is no record of this age in rocks in the region, it is very likely that the heat that generated these garnet is related to the end of the Brasiliano orogeny. These isotopic data prove intense tectonic activity of the Brasiliano orogeny in southern Brasília Belt, which at this time was part of the western portion of the Gondwana supercontinent. This supercontinent was surrounded by various dispersions and lithospheric masses during the Neoproterozoic with several periods of crustal accretion. In the region investigated the main products of this tectonic activity are recorded throughout the Neoproterozoic with main events at 820, 630 and 545 Ma**.**

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Chapter 3

Article 2

"LATE BRASILIANO (ca 545 Ma) METAMORPHISM AND ANATEXIS IN THE WESTERN PART OF THE BRASÍLIA BELT, BRAZIL"

Abstract

In the region between Moiporá, Messianópolis, Córrego de Ouro in southwestern Goiás, there are several Neoproterozoic high-K late to post-orogenic biotite granite bodies as well as rare migmatite exposures, all associated with important N-S structural lineaments. These are I-Type granites and some bodies only present foliation along their margins.

This study investigates the relationship between granitic intrusions and the lineaments in order to understand the roles of post-collisional granitogenesis and the thermal peak of the Brasiliano Cycle in the evolution of the Brasília Belt.

SHRIMP U-Pb analysis of the Messianópolis granite and conventional TIMS zircon U-Pb data for the Ivolândia granite revealed crystallization ages of 542 ± 5 Ma and ca 550 Ma, respectively. Sm-Nd analyses revealed T_{DM} model ages that can be divided into two groups: (i) the older group, includingthe Novo Brasil, Córrego do Ouro and Messianópolis granites, have model ages between 1.49 and 2.61 Ga and ε_{Nd} (*T*) values that range, from - 4.6 to - 21.3, respectively, and (ii) the younger group, comprising the Serra do Impertinente and Ivolândia granites, have model ages between 1.15 and 1.35 Ga with less negative ε_{Nd} (*T*) values of - 1.6 and - 3.2, respectively.

The first group of granites, with older Sm-Nd T_{DM} model ages is interpreted as having been formed by magma that was generated from the re-melting of juvenile material belonging to the Arenópolis Magmatic Arc with strong contamination with ancient sialic crust material. The Córrego do Ouro granite with old Sm-Nd T_{DM} model age (ca. 2.6 Ga) and a very negative ε_{Nd} (*T*) value, can be interpreted as the product of anatexis of ancient sialic crust.

The second group of granites, which presented younger Sm-Nd T_{DM} model ages and negative ε_{Nd} (*T*) values in comparison to those of the first group, can also be interpreted as derived from re-melting of Arenópolis Magmatic Arc juvenile material in combination with some contamination with from ancient sialic crust.

U-Pb dating of the zircon from leucosome JG-36B revealed an age of 535 ± 5 Ma, which is similar to the crystallization age of the high-K granites, indicating that they are part of the same granitogenesis.

The crystallization of these granitic bodies and migmatites clearly post-dates the main phase of the regional metamorphism and deformation (ca. 630 Ma) of the Brasília Belt. Localized melting of the continental crust and the associated granitic magmatism may have been triggered by the latest movements of the lithospheric plates of the western portion of the Gondwana supercontinent in the late Neoproterozoic and early Cambrian periods at approximately 545 Ma ago.
Keywords: biotite granites, U-Pb zircon TIMS and SHRIMP, Sm-Nd, Arenópolis Magmatic Arc, Brasília Belt.

3.1 - Introduction

The tectonic evolution of the Brasília Belt has been investigated in the context of characterization the associated granitic rocks (for a review, see Pimentel *et al.* 1999a).

Four associations of granitoids with distinct crystallization ages are recognized in the Brasília Belt (Fig. 3.1B) (Pimentel *et al.* 1999a; Sial *et al.* 1999): (i) the oldest granites are of the A-type, which have zircon U-Pb ages of 1.77 to 1.58 Ga, and are related to the opening of the Araí rift and are located in the basement of the northern part of the Brasília Belt. (ii) The second group is associated with the Goiás Magmatic Arc, which was formed in an intra-oceanic island arc environment, and these granitoids which have zircon U-Pb ages between 0.89 and 0.85 Ga, younger granitoids with U-Pb zircon ages between 0.76 and 0.63 Ga, which also occur in this arc, are interpreted as having been formed in a continental arc. (iii) The third distinct group of granitoids is emplaced into metasedimentary rocks of the Araxá and Ibiá groups and is represented by granites that are located in the southern Brasília Belt with U-Pb ages of between 0.79 and 0.70 Ga (Pimentel *et al.* 1999a). (iv) The fourth group of granitoids are associated with mafic-ultramafic bodies and gabbro-dioritic stocks; they were formed after the last event of deformation that occurred in the Brasília Belt between 0.63 and 0.59 Ga (Fuck *et al.* 1987; Pimentel *et al.* 1991; Pimentel and Fuck 1987b; Pimentel *et al.* 1997; Pimentel *et al.* 1996 a e b; Pimentel *et al.* 1999a). This granitic plutonism, which is clearly post-collisional relative to the post thermal peak of the Brasiliano orogeny at ca. 630 Ma, is represented by granites of the high-K calc-alkaline series and are part of the object of investigation of this study. This granitic magmatism is represented by large volumes of acid magmas that originated by partial melting of the continental crust (Pimentel *et al.* 1999a). The main plutons include the Serra Negra, Serra do Iran, Caiapó, Iporá, Israelândia, Serra do Impertinente and Messianópolis plutons, which are emplaced into the orthogneisses and volcano-sedimentary sequences of the Arenópolis Magmatic Arc (Fig. 3.2).

The present study investigates the belt of granitic plutons that are structurally related to the Messianópolis-Novo Brasil lineament in central portion of the Arenópolis Magmatic Arc (Fig.3.2). These plutons are represented by the Novo Brasil, Córrego do Ouro, Fazenda Nova and Messianópolis granites, in addition to other, smaller bodies. They are mostly exposed to the east of the Messianópolis-Novo Brasil Lineament, except for the Córrego do Ouro granite, which is located in a region with a high concentration of lineaments. According to Pimentel *et al.* (1996), this granitic plutonic event was the most important event between the end of the Brasiliano orogeny and the beginning of the deposition of sediments of the Paraná basin during the mid-ordovician.

Despite the large number of studies that have been carried out in this region, several questions related to these plutonic rocks persist: a) the crystallization age of these high-K biotite granites, b) the nature of the source of the granitic magmas, c) the age of the migmatitic injections that is observed in some outcrops in the region and their relationships with the associated granitogenesis, d) the structures that have played significant roles in the ascent and emplacement of the granitic magma, e) the tectonic environment corresponding to the emplacement of these plutons and f) the relationship between the plutons and the Novo Brasil wedge and the Transbrasiliano Lineament (Shobbenhaus *et al.* 1984).

The Messianópolis-Novo Brasil Lineament is exposed in the southwestern portion of the state of Goiás and extends for more than 120 km in the N-S directions and may be easily observed in Landsat-5 sensor satellite images. This lineament is covered by sediments of the Araguaia Formation in the north and by Devonian sandstones of the Paraná Basin in the south. The junction of this lineament with the the Moiporá-Fazenda Nova lineament to the east, forms a triangular wedge-shaped structure, pointing to the south. This structure is commonly referred to as the Novo Brasil wedge (Fig.3.2). These morpho-structural lineaments are associated with two major geotectonic units of the Brasília Belt with different ages and evolution: the Arenópolis Magmatic Arc and the Goiás Archean block, which is represented by the TTG terrains of the Uvá Complex.

This study discusses new geochronological U-Pb zircon data (conventional ID-TIMS and SHRIMP) and Sm-Nd T_{DM} model ages with the intent to answer the aforementioned questions using base maps at the 1:250 000 scale (Lacerda Filho *et al.* 2000).

3.2 - Regional geologic context

The Tocantins Province is located in central-western Brazil and consists of a large orogenic zone that was formed in response to the convergence of the São Francisco, Amazon and Paranapamena (Rio de La Plata) continents between 900 and 600 Ma (Almeida *et al*. 1977; Pimentel and Fuck 1992; Fuck *et al.* 1993; Fuck *et al.* 1994; Brito Neves 1999). This zone is composed of three fold belts: the Araguaia, Paraguai and Brasília Belts (Fig. 3.1 A). The Brasília Belt consists of the following geotectonic units: (i) an Archean block with typical TTG gneiss and associated greenstone belts; (ii) a Paleoproterozoic basement that involves the gneissic terrains of the Almas-Dianópolis region and associated metamorphosed volcano-sedimentary sequences; (iii) the Neoproteroic Goiás Magmatic Arc; (iv) the mafic-ultramafic complexes of Barro Alto, Niquelândia and Canabrava along with their associated metamorphosed volcano-sedimentary sequences; and (v) the extensive Neoproterozoic metasedimentary sequences that are formed by the Araxá,

Ibiá, Vazante and Serra da Mesa Groups and part of the cratonic cover of the Bambuí Group (Fig. 3.1 B).

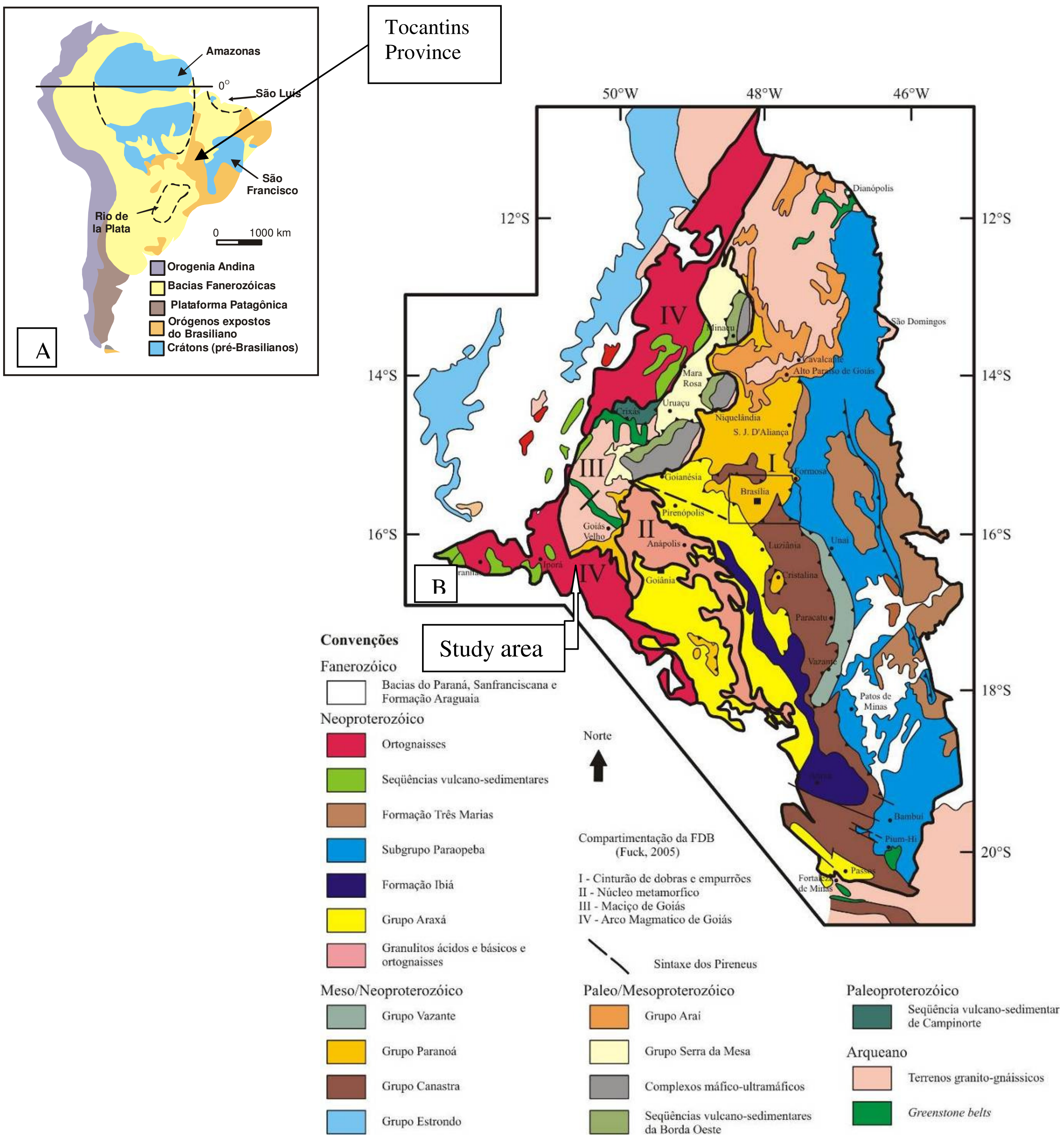


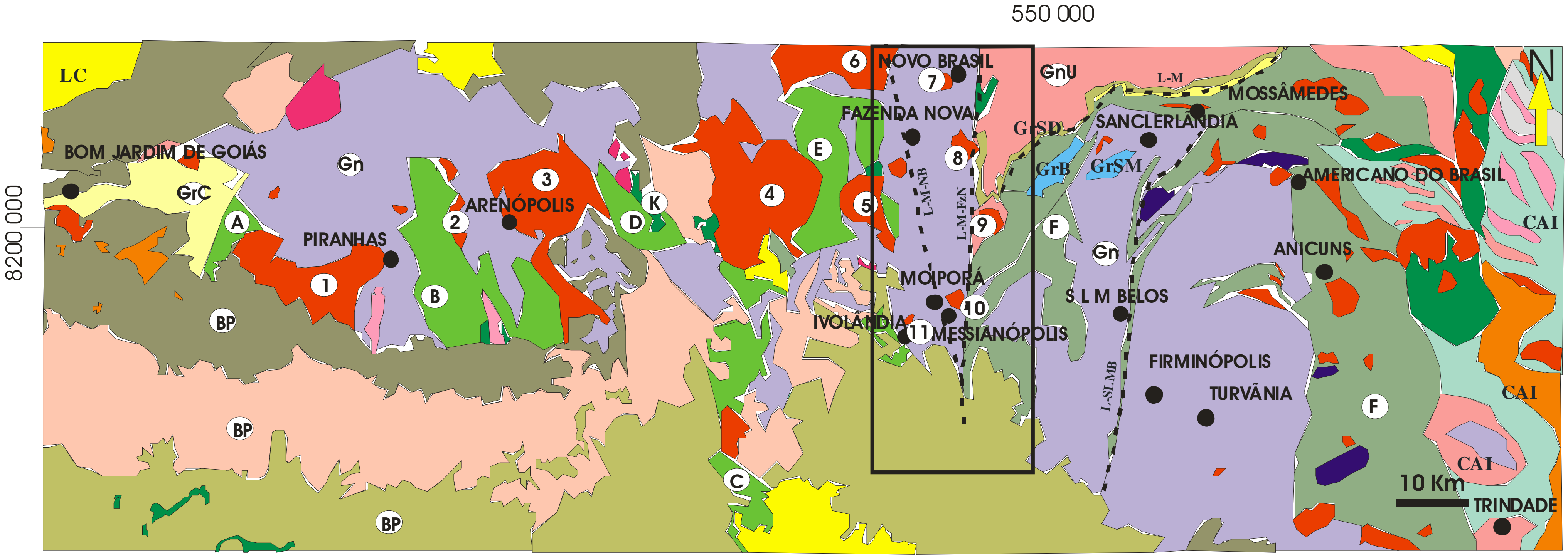
Figure 3.1 - A: Simplified geological map of South America showing the location of the Tocantins Province, B: Geological map of the Tocantins Província (Fuck, 2005).

The Goiás Magmatic Arc, consists of a segment of Neoproterozoic juvenile crust that was formed between approximately 890 Ma and 630 Ma, by the accretion of one or more island arc systems which were located to the west of the São Francisco Craton, (Pimentel and Fuck 1992; Fuck *et al.* 1994; Pimentel *et al.* 1997; Pimentel *et al.* 2000b). This arc is geographically divided into two parts separated by the Goiás Archean block: (i) the Mara Rosa Magmatic Arc to the north and (ii) the Arenópolis Magmatic Arc to the south (Fig. 3.1B). The lithological, geochemical and isotopic characteristics suggest that these rocks evolved, in their early stages, in a geotectonic environment that was similar to the currently immature intra-oceanic island arcs (Pimentel and Fuck 1986; Pimentel *et al*. 1991; Pimentel and Fuck 1992; Pimentel *et al.* 1996). The evolution of the Goiás Magmatic Arc is related to the development of an oceanic lithosphere subduction zone which originated primitive calcic to calc-alkaline magmatism with little contributions from older crustal material (Pimentel and Fuck 1986; Pimentel and Fuck 1992; Pimentel *et al*. 1997).

The Arenópolis Magmatic Arc, which is the subject of this investigation, is approximately 200 km wide, exposed from the neighborhoods of Bom Jardim in the west, to Anicuns region, in the east (Fig. 3.1 B). This arc is covered by the Aquidauana Group to the northwest, the Araguaia Formation with Tertiary sedments to the north and by the Devonian Furnas Formation of the Paraná Basin to the south.

The Arenópolis Magmatic Arc consists of a mosaic of orthogneissic terrains that originated from the metamorphism of plutonic rocks of dioritic, tonalitic and granodioritic compositions. These gneissic terrains are given local names, including the Arenópolis, Iporá, Matrinxã, Firminópolis, Turvânia, Palminópolis and Sanclerlândia gneisses (Fig.3.2, Table 3.1). These terrains experienced two episodes of crystallization: from 890 to 800 Ma and from 670 to 620 Ma (Pimentel *et al.* 1991; Laux *et al*. 2004b). The older orthogneisses have T_{DM} model ages that vary from 1100 to 800 Ma and ε_{Nd} (T) values that range from + 2.0 to + 6.5. They are intensly deformed and were metamorphosed under P-T conditions of the upper greenschist facies to amphibolite facies conditions (Pimentel and Fuck 1992; Fuck *et al.* 1994; Pimentel *et al.* 1996; Gióia 1997; Rodrigues *et al.* 1999).

The Arenópolis orthogneiss, corresponding to hornblende metatonalites, exhibits the oldest crystallization age among the Arenópolis Magmatic Arc gneisses (899 ± 7 Ma; Table 3.1). Sm-Nd data from these rocks evidence the juvenile character of the original magma, with ε_{Nd} (T) values between + 1.9 and + 6.9 (Pimentel *et al*. 1991; Pimentel and Fuck, 1992; Pimentel and Fuck 1994). The Iporá orthogneiss consists of banded porphyroclastic gneisses and finely banded, granodioritic biotite gneisses. The Sanclerlândia hornblende orthogneiss is rich in hornblende and epidote, with a composition ranging from dioritic to granodioritic, and is petrographically and geochemically very similar to the Arenópolis orthogneiss (Simões 1984; Pimentel and Fuck 1994; Pimentel *et al.* 1996). The Firminópolis orthogneiss is characterized by gray hornblende-biotite gneisses of dioritic and tonalitic composition, and it is also rich in epidote.



Legend: LC - Lateric cover; **K -** Alkaline; **Phanerozoic**: **BP -** Paraná Basin; **Post-Collisional Granites**: (1- Serra Negra, 2 - Serra do Iran, 3 - Rio Caiapó, 4 - Iporá, 5 - Israelândia, 6 - Serra do Impertinente, 7 - Novo Brasil, 8 - Fazenda Nova, 9 - Córrego do Ouro, 10 - Messianópolis, 11 - Ivolândia); **CMU** - Mafic-ultramafic complexes; **Neoproterozoic**: **GrC -** Cuiabá Group**; Gn** - Arenópolis Magmatic Arc ortogneisses; Vulcano-sedimentary Sequences: (A - Arenópolis, B - Iporá, C - Amorinópolis, D - Iporá, E - Jaupaci, F - Anicuns-Itaberaí); **CAI** - Anápolis Itauçu Complex ; **GrB/GrSM** - Buriti and São Mateus granites; **GrSD** - Serra Dourada Group. **Paleoproterozoic-Arquean**: **GnU** - Uvá Complex; **Lineaments**: L-M-NB: Messianópolis-Novo Brasil; L-M-FzN: Moiporá-Fazenda Nova; L-M: Mossâmedes; L-SLMB: São Luis de Montes Belos.

Figure 3.2 - Simplified geologic map of the Arenópolis Magmatic Arc, Goiás Arquean Block and Paraná basin Geological map of Goiás State with study area (Lacerda Filho *et al.* 2000).

Table 3.1 - Summary of isotopic and geochronological data of Arenópolis Magmatic Arc orthogneisses.

Orthogneisses	**U-Pb in zircon ID-TIMS (Ma)**	**Sm-Nd T_{DM} model age (Ga)**	**ε_{Nd} (*T*)**
Arenópolis	899 ± 7 (1 and 2)	1.0 to 1.2 (1 and 2) 1.1 to 1.4 (4)	+ 1.9 to + 3.2 + 2.5 to and + 6.9
Iporá	804 ± 6 (5)	1.18 (5)	+ 0.37 to + 1.85
Matrinxã	669 ± 3 (5)	0.99 (5)	+ 2.2 to + 6.0
Sanclerlândia	820 ± 7 (5)	0.9 to 1.0 (5)	+ 4.0 to + 6.0
Firminópolis	634 ± 8 (7)	1.39 (5)	- 4.6
Palminópolis	637±20SHRIMP (7)	1.48 and 2.21 (5)	- 6.4 and - 15.1
Turvânia	630 ± 5 (7)	1.11 (5)	+ 0.3

References: 1 - Pimentel *et al.* (1991); 2 - Pimentel and Fuck (1994); 3 - Gioia *et al.* (1997); 4 - Rodrigues *et al.1999*; 5 - Pimentel *et al.* (2000b); 6 - Motta-Araújo and Pimentel (2003); and 7 - Laux *et al.* 2004.

Younger orthogneisses with crystallization ages of approximately 630 Ma occur in the eastern portion of the Arenópolis Magmatic Arc and comprise the Turvânia, Palminópolis and Matrinxã orthogneisses (Laux 2004b).

The Matrinxã orthogneiss, exposed to the south of Israelândia, is rich in biotite and hornblende, and its composition varies from tonalite to granite. The Palminópolis orthogneiss, which is very deformed and migmatized, has petrographic aspects and tonalitic composition which is similar to that of the Turvânia and Firminópolis orthogneisses (Laux 2004).

Rare exposures of marbles and metacherts have also been also documented. Small intrusions of granites and metagabbros have been identified among the supracrustal rocks, as well as mafic-ultramafic bodies which have been interpreted as ophiolite fragments (Pimentel 1992; Pimentel and Fuck 1992).

Five volcano-sedimentary sequences comprising calc-alkaline metavolcanic rocks, with compositions that range from basalt to rhyolite, and metasedimentary rocks are recognized (Fig. 3.2). The metasedimentary rocks include psammo-pelitic rocks, greywackes, mica schists and locally marble, chert and calc-silicate rocks (Pimentel and Fuck 1992). The Bom Jardim de Goiás and Arenópolis sequences occur in the western portion of the Arenópolis Arc, the Iporá-Amorinópolis and Jaupaci sequences are in the central part, and the Anicuns-Itaberaí sequence is the easternmost supracrustal unit of the arc (Fig. 3.2). All of the orthogneisses and volcano-sedimentary sequences present mineral paragenesis that indicate metamorphism from the greenschist to amphibolite facies, followed by a retrometamorphic phase of low greenschist facies in the chlorite zone (Rodrigues 1996).

3.2.1 - The post-collisional, high-k granitoids of the Arenópolis Magmatic Arc

Several high-K granitic plutons of the calc-alkaline or alkaline series occur and are emplaced into the orthogneisses and volcano-sedimentary sequences of the Arenópolis Magmatic Arc (Pimentel and Fuck 1987b; Lacerda Filho *et al.* 1999). These plutons outcrop from the surroundings of Bom Jardim de Goiás to the proximities of Córrego do Ouro to the east (Fig. 3.1B). They are mostly metaluminous and calc-alkaline biotite granites and, to a lesser extent, hornblende granites. Afew granites have alkaline affinities, such as the Iporá intrusion, which is younger and prossesses geochemical characteristics that are similar to those of intraplate granites (Pimentel and Fuck 1987b). According to these authors, the observed granitic magmatism was caused by the re-melting of the primitive continental crust and possibly by the underplating of basaltic magmas that followed the last phase of the Brasiliano orogeny, which affected the region.

The granites that occur in the southern part of the Brasília Belt have been divided into four groups, with three of them being classified as syn- to post-collisional and one as post-collisional to the thermal peak of the Brasiliano orogeny (Lacerda Filho *et al.* 1999). Granites of the third and fourth groups occur in the region.

The fourth group of granites, which are the subject of this investigation, are post-collisional and belong to the Serra Negra suite (Pena and Figueiredo 1972). These granites are hosted by the orthogneisses, deformed granites, and Anicuns-Itaberaí sequence rocks of the Arenópolis Magmatic Arc. The Alkali feldspar granites are porphyritic biotite hornblende monzogranite, syenogranites, quartz monzodiorites, granodiorites and quartz diorites. The high-K granitic bodies of this suite include the Serra Negra, Iporá, Serra do Iran, Serra do Impertinente, Córrego do Ouro, Fazenda Nova, Novo Brasil plutons and other smaller bodies (Pimentel *et al.* 1996a).

The main geologic characteristics of these plutons are discussed below, including the country-rocks, dimensions, shape, texture, mineralogical composition, petrographic and isotopic characteristics (Table 3.2) and the presence of ductile structures, which are considered to be critical to the studies of this granitic magmatism. The main characteristics of the post-collisional plutons of the Arenópolis Magmatic Arc are summarized below (Fig. 3.2).

Serra Negra granite - This granite is emplaced between the volcano-sedimentary sequence of Bom Jardim de Goiás and orthogneisses of the Arenópolis Magmatic Arc. It is covered in the south by the Paraná basin. The Serra Negra is a biotite granite that consists of k feldspar, quartz, plagioclase and biotite (Faria *et al.* 1975; Pimentel and Fuck 1987a), and it has a pinkish to red color and isotropic equigranular texture and is not deformed. According to Pimentel *et al.* (1996a), xenoliths of foliated granodioritic rocks are recognized in this granite, in addition to crystallization features that indicate it was formed at shallow crustal levels.

T_{DM} model ages range from 1.3 to 1.5 Ga and ε_{Nd} (T) values of - 3.0 and - 4.0, indicating that the precursor magma possibly had a juvenile component which was contaminated with older crustal material during its ascent (Pimentel *et al.* 1996a).

Serra do Iran granite - This granite is emplaced at the interface between the Ribeirão gneiss and the Arenópolis volcano-sedimentary sequence. This granite has an early gabbro-dioritic facies and another late biotite granite facies which is rich in k feldspar, and it exhibits an equigranular texture (Pimentel and Fuck 1987a). The presence of xenoliths of the volcano-sedimentary sequence is common in this granite.

T_{DM} model ages vary from 0.9 to 1.4 Ga with ε_{Nd} (T) values between - 2.7 and + 2.0, which were interpreted by Pimentel *et al.* (1996a) to be indicative of juvenile precursor magma, although a part of this granite was contaminated with older crustal material .

Iporá granite - This granite forms an intrusion of batholitic dimensions with varied facies (Pimentel *et al.* 1996a). It is intrusive into the Jaupaci volcano-sedimentary sequence, to the east and into orthogneisses of Arenópolis Magmatic Arc to the north. According to Rodrigues (1996) this pluton is metaluminous to slightly peraluminous and exhibits geochemical characteristics that are similar to those of calc-alkaline high-K granites. The Iporá granite comprises alkaligranite, granite or quartz monzonite facies. This type of granite has a reddish-pink color, is isotropic, equigranular and locally porphyritic (Pimentel and Fuck 1987a; Amaro 1989). They also contain mafic enclaves and locally presents fluorite in its modal composition. There is a late phase that is porphyritic, leucocratic and alkali-rich, which has been interpreted to be a shallow crustal-level crystallization feature (Pimentel *et al.* 1996a).

Sm-Nd model ages vary between 1.0 and 1.2 Ga, with ε_{Nd} (T) values ranging from - 3.3 to + 0.7 (Pimentel *et al.* 1996a). The positive value of ε_{Nd} (T) indicates the juvenile nature of the magma that gave rise to this granite, whereas the negative value, which is close to zero, indicates contamination with older material.

Israelândia granite - This granite is exposed between the Jaupaci volcano-sedimentary sequence to the west and orthogneiss terrains to the east, north and south. The Jaupaci volcano-sedimentary sequence physically separates the Iporá and Israelândia granites. The Israelândia granite is formed by several facies with compositions that vary between granite, quartz monzonite, monzogranite and granodiorite (Amaro 1989), and the predominant facies is represented by a biotite-hornblende granite. This coarse-grained and is composed of perthitic microcline, plagioclase, quartz, biotite, amphibole, zircon, apatite, fluorite, carbonate and opaque minerals. The common presence of mafic enclavesis interpreted as the result from a mixture of felsic and mafic magmas which was generated at great depths and high temperatures (Amaro 1989; Pimentel and Fuck 1987).

Sm-Nd model ages range from 0.92 to 0.84 Ga, with ε_{Nd} (T) values ranging from + 2.0 to + 3.0 (Pimentel *et al.* 1996). These positive ε_{Nd} (T) values indicate that the original magma represents re-melting of juvenile rocks from the Arenópolis Magmatic Arc.

Serra do Impertinente granite - This granite comprises a batholitic intrusion that is located south of Jussara and emplaced into the orthogneisses of the Novo Brasil wedge. This granite is characterized by two main intrusive phases with magma sources of different characteristics: one early phase as represented by porphyritic biotite granite and a late phase formed by undeformed coarse-grained equigranular granites (Pimentel *et al.* 1999). The early porphyritic phase consists of biotite granite or biotite monzogranite with pink, fine to medium-grained macro-crystals of k feldspar, quartz, plagioclase and biotite. The late equigranular phase consists of biotite granite that is reddish, not deformed and has petrographic characteristics that are similar to those of the Serra Negra and Serra do Iran granites. Although this granite exhibits an isotropic texture, it presents some degree of recrystallization and deformation along the margins of the pluton.

According to Junqueira-Brod *et al.* (1999) this granitoid was generated by mixing processes of contrasting magmas resulting in hybrid rocks and syenogranites of the rapakivi type.

This granite has T_{DM} model ages that are relatively young, ranging from 1.0 to 1.2 Ga, and ε_{Nd} (T) values that range from - 3.3 to + 0.7, which suggests that this granite derived from a mixture of magma formed by the anatexis of Arenópolis Magmatic Arc-derived juvenile material with older material.

Fazenda Nova granite - This is a biotite granite located between the orthogneisses of the eastern margin of the Novo Brasil wedge and gneisses of the archaean Uvá Complex. This granite outcrops as an elliptical body with outcrop dimensions of 7 x 5 km, and its major axis in the NNW direction.

Table 3.2 - Summary of geochronological and isotopic data of the high-K granites in the Arenópolis Magmatic Arc, according to Pimentel *et al.* (1996).

Pluton	Sm-Nd (T_{DM}) Ga	ε_{Nd} (579±3 Ma)
Serra Negra granite	1.3 to 1.5	- 3.0 to - 4.0
Serra do Iran granite	0.93 to 1.4	- 2.7 to + 2
Rio Caiapó granite	0.93 to 1.24	- 3.3 to + 2.3
Iporá granite	1.0 to 1.2	- 3.3 to + 0.7
Israelândia granite	0.84 to 0.92	+ 3.0 to + 2.3
Serra do Impertinente granite	Early phase 2.1 to 2.7 Late phase 1.2 to 0.9	- 16 to - 19 - 4.6 to + 1.1

The model age values of the granites in Table 3.2 are similar to the model ages of the Arenópolis Magmatic Arc orthogneisses. The vast majority of these granites exhibit positive or slightly negative ε_{Nd} (*T*) values. The observed negative values that are close to zero indicate that the precursor magmas of these granitoids were derived from a juvenile source and were slightly contaminated with older crustal material. The exceptions to these observations include the early phase Serra Impertinente granite, which exhibits very negative values, and the Israelândia granite, which exhibits only positive values. The data indicate that these granites are derived from anatexis of the Arenópolis Magmatic Arc with slight contamination with older crustal material, which could possibly include rocks of the Uvá Complex.

3.3 - Analytical Procedures

Sm-Nd analyses were carried out at the geochronology Laboratory of the University of Brasília. Sm-Nd isotopic analyses followed the method described by Gióia e Pimentel (2000). The conventional U-Pb analyses followed procedures modified from Krogh (1973). One U-Pb age was obtained using SHRIMP I da Research School of Earth Sciences, University National of Australian (ANU), Canberra, Austrália.

U-Pb - SHRIMP

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 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.

U-Pb - TIMS

Zircon concentrates were extracted from ca. 8 Kg rock samples using conventional gravimetric (DENSITEST®) and magnetic (Frantz isodynamic separator) techniques. Final purification was achieved by hand picking using a binocular lupa. 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 anio 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 Geochronogy 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 2 σ.

Sm-Nd

Sm-Nd isotopic analyses followed the method described by Gióia e Pimentel (2000) and 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 o and ^{143}Nd/^{144}Nd ratios are better than ±

0,4% (1 σ) e ± 0.005 % (1 σ) respectively, based on repeated analyses of international rock standards BHVO-1 e BCR-1. $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd$ de 0,7219 and the decay constant used was 6,54 x 10 -12 a-1. T_{DM} values were calculated using the DePaolo (1981) model.

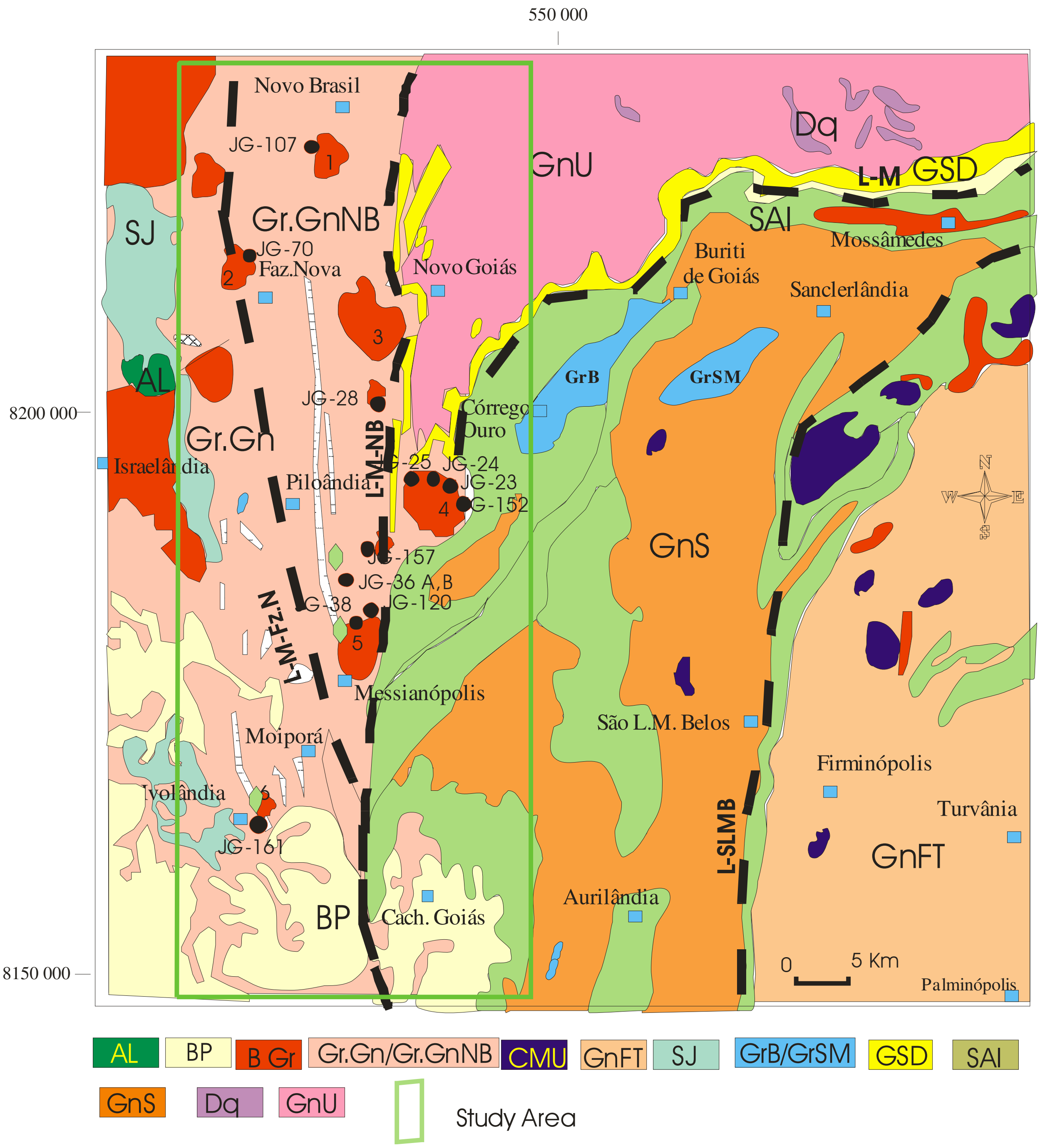
3.4 - U-Pb and Sm-Nd isotopic results

Three analyses were performed using the U-Pb zircon dating via the ID-TIMS (conventional) and SHRIMP methods (Tables 3.1 and 3.2; Figs 3.5. 3.7, 3.8 and 3.9). In addition, nine Sm-Nd isotopic analyses (Table 3.3 and Fig. 3.10), which included seven samples of granite, one sample of gneiss and one sample of quartz feldspar apophysis, were conducted. The crystallization age of the granites that were used in the calculation of the ε_{Nd} (T) values was 545 Ma, which is similar to the U-Pb SHRIMP crystallization age of Messianópolis granite. See Figure 3.3 for sample location.

3.4.1 - High-K biotite granites

In the region between Messianópolis and Novo Brasil, which corresponds to the central portion of the Arenópolis Magmatic Arc, there are several bodies of undeformed or slightly deformed, post-collisional biotite granite that are considered to be younger than the thermal peak of the Brazilian orogeny (ca. 630 Ma) and to have affected the southern Brasília Belt. The age of these bodies is still poorly constrained (e.g., Novo Brasil, Fazenda Nova, Córrego do Ouro and Messianópolis) (Fig. 3.3) These bodies comprise a series of granitic calc-alkaline intrusions, which form batholiths and smaller-dimension bodies that are primarily oval and semi-circular in shape. These plutons form hills that stand out in the landscape and are easily identified in the Landsat-5 sensor satellite images, bands 5, 4, and 3.

These granites form a 20 km wide array of plutons that stretches over 150 km in the N-S direction, from Ivolândia in the south to Novo Brasil in the north (Fig 3.3). Along this array, there are also injection migmatites that are represented by pink quartz-feldspar apophyses with no preferential directions, and these have been observed in gneiss outcrops between Novo Brasil and Buriti de Goiás.



Legend: **AL** – Alkaline intrusions; **BP** - Paraná Basin; **BGr - biotite granites**: (1 - Novo Brasil, 2 - Serra do Impertinente type, 3 - Fazenda Nova, 4 - Córrego do Ouro, 5 - Messianópolis type biotite granite, 6 - Ivolândia granite); **GrGn/GrGnNB** - mylonitic granites of the Novo Brasil Wedge; **CMU** - mafic-ultramafic complexes; **GnFT** - Firminópolis-Turvânia orthogneisses; **SJ** - Jaupaci sequence; **GrB/SM** - Buriti and São Mateus metagranites; **GSD** - Serra Dourada group; **SAI** - Anicuns-Itaberaí sequence; **GnS** - Sanclerlândia orthogneiss; **Dq** - mafic-ultramafic dykes; **Arquean Block**: **Dq**: Dique máfico; **GnU** - Uvá complex: TTG and greenstone belt. **Lineaments**: L-M-NB: Messianópolis-Novo Brasil; L-M-FzN: Moiporá-Fazenda Nova; L-M: Mossâmedes; L-SLMB: São Luis de Montes Belos.

Figure 3.3 - Simplified geologic map of the region between São Luis de Montes Belos-Novo Brasil in the southwestern part of the Brasília Belt (Lacerda Filho *et al.* 2000).

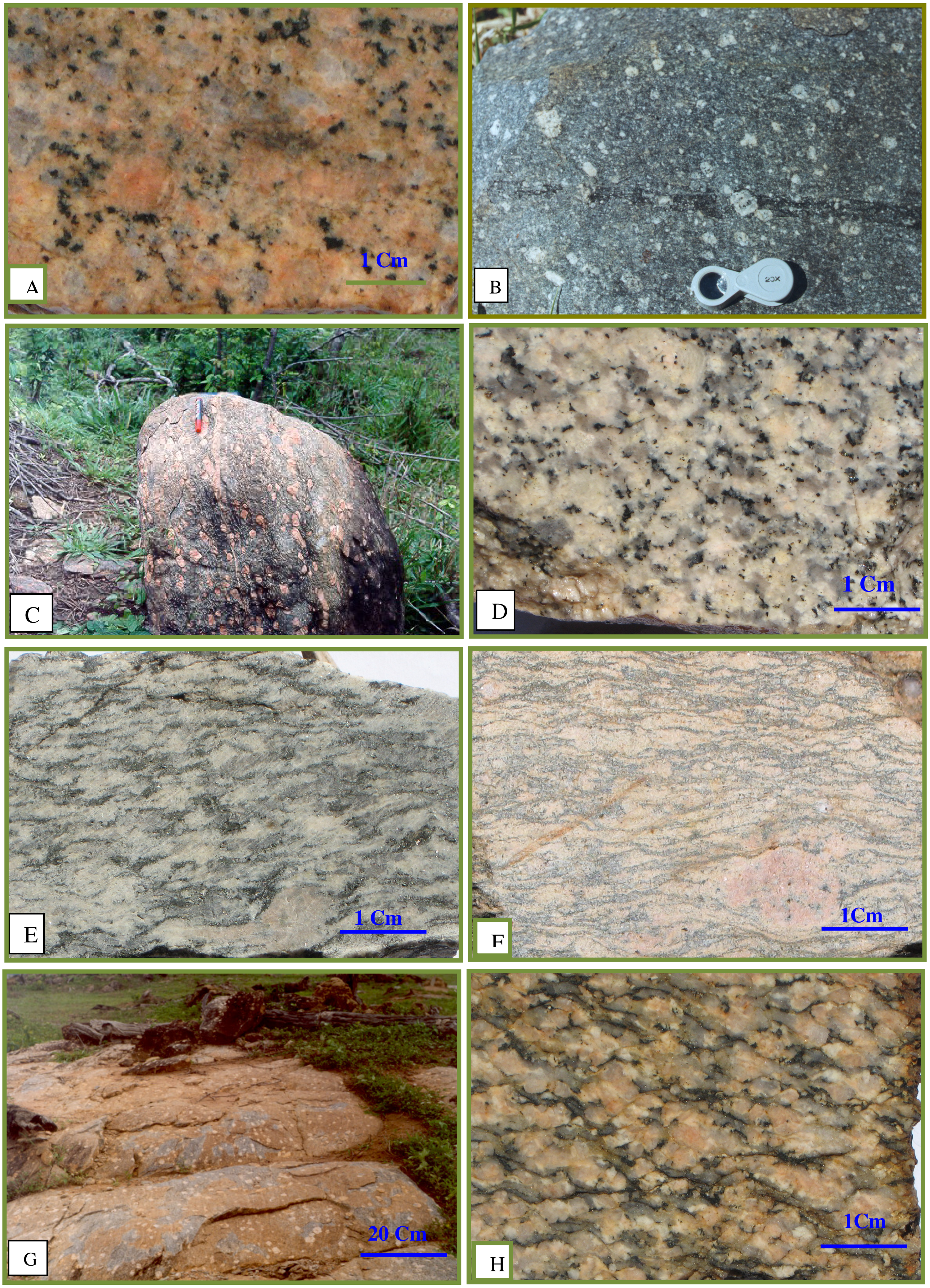


Figure 3.4 - Investigated high-K granites: (A) JG-107 - Novo Brasil biotite granite; (B) JG-70- Serra do Impertinente type granite; (C) JG-28 - Messianópolis type granite; (D) JG-25 - Córrego Ouro biotite granite; (E) JG-23 - Córrego Ouro biotite granite; (F) JG-152 - Córrego Ouro biotite granite; (G) JG-157 - Messianópolis granite; (H) JG-161 - Ivolândia biotite granite.

3.4.1.1 - Novo Brasil biotite granite JG-107 - This biotite granite is located 5 km south of Novo Brasil and is typically located between deformed granites and the Novo Brasil Wedge orthogneisses (Fig. 3.4A). In addition, this granite is a 5 x 3 km subcircular pluton, with its major axis in the NNW direction, aligned with the Fazenda Nova and Córrego do Ouro biotite granites.

Sm-Nd isotopic analysis of the JG-107 sample showed T_{DM} model age of 2.35 Ga and a strongly negative ε_{Nd} (T) of - 21.3 (Table 3.3 and Fig. 3.10 A), which indicates a significantly old crustal component in the magma composition that most likely consists of reworked and recycled continental crust.

3.4.1.2 - Serra do Impertinente type granite JG-70 - This sample was taken from an outcrop at the road between Jussara and Fazenda Nova. This granite is emplaced into orthogneisses of the of the Novo Brasil Wedge and consists of medium-grained, porphyritic biotite granite (Fig. 3.4 B). Despite the physical discontinuity between this outcrop and the Serra do Impertinente granite, compositional, petrographic and textural similarities between these two granites suggest a common magma source.

Isotopic Sm-Nd analysis of this granite indicated a T_{DM} model ages of 1.15 Ga and an ε_{Nd} (T) of - 1.6 (Table 3.3, Fig. 3.10 D). The slightly negative ε_{Nd} (T) value suggests derivation from re-melting of the Arenópolis Magmatic Arc juvenile rocks.

3.4.1.3 - Messianópolis type biotite granites JG-28, JG-38 and JG-157 - In three outcrops alined up for more than 40 km between Fazenda Nova and Messianópolis, reddish-pinkish coarse- to medium-grained granite with typical k feldspar phenocrysts as large as 10 cm in size is exposed (Fig. 3.4 C and G).

Sm-Nd isotopic analysis of this granite sample, JG-28, showed a T_{DM} model ages of 2.25 Ga and ε_{Nd} (T) of - 20.0 (Table 3.3, Fig. 3.10 B). This very negative ε_{Nd} (T) value indicates that the original granitic magma derived from an older source, which is most likely a recycled continental crust.

A second sample of this granite, JG-38, was collected approximately 40 km from sample JG-28. At this location, a subcircular 5x4 km pluton of the Messianópolis type biotite granite is recognized . This granite is medium to coarse grained, reddish to pinkish in color and its primary petrographic features include k feldspar crystals that are as large as 5 cm and a slightly angled structure in some places, as was the case for samples JG-28 and JG-157 (Fig. 3.4 C and G). This granite has petrographic characteristics that differ from those of the other granites due to its mafic matrix and larger feldspar crystals.

The zircon grains in this granite are light coloured and occur as long prisms (Fig. 3.5). U-Pb SHRIMP analysis of this granite showed an age of 542 ± 4 Ma, which can be interpreted as its crystallization age (Table 3.1 and Fig. 3.5).

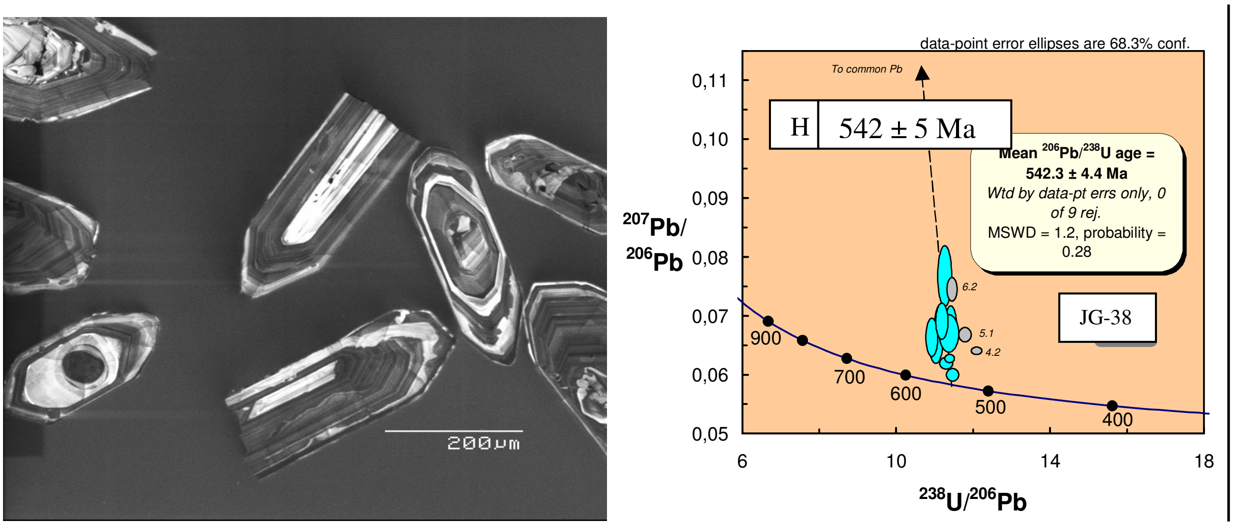


Figura 3.5: Grains of the zircon and Tera-Wasserburg concordia diagram showed U-Pb SHRIMP age of the cristalization the Messianópolis granite, JG-38.

3.4.1.4 - Córrego do Ouro biotite granite JG-23, JG-24 and JG-25 - This granite is located approximately 10 km southwest of Córrego do Ouro. According to Landsat-5 sensor satellite images, this biotite granite outcrops with an elliptical, with dimensions of 8 x 5 km and its major radius is aligned in the NW direction, which is the same direction as the biotite granite Fazenda Nova and Novo Brasil lineament (Fig. 3.4 D and E). This granite is located near the southern edge of the Uvá Complex within supracrustal rocks of the Anicuns-Itaberaí sequence (Fig. 3.3).

Sm-Nd analysis of three samples of different portions of this granite showed T_{DM} model ages of 1.49, 1.91 and 2.61 Ga and ε_{Nd} (*T*) of - 4.6, - 14.8 and - 20.7 (Table 3.3, Fig. 3.10 C). The smaller negative ε_{Nd} (*T*) values indicate that the precursor magma of this granite originates from the re-melting of the younger Arenópolis Magmatic Arc mixed with an older continental crust. The very negative ε_{Nd} (*T*) value from sample JG-25 of the same granite can be explained by the melting of older rocks or by contamination of the host rocks during the ascent of the magmatic material, as this sample was collected from the edge of a body that was in contact with the enclosing calc-silicate rocks.

3.4.1.5 - Banded gneiss JG-36A and quartz-feldspar apophyses 36 B - This outcrop is located along road GO-060, north of Messianópolis. This gneiss is finely banded, discordantly cut by quartz-feldspar apophyses (Fig. 3.6)

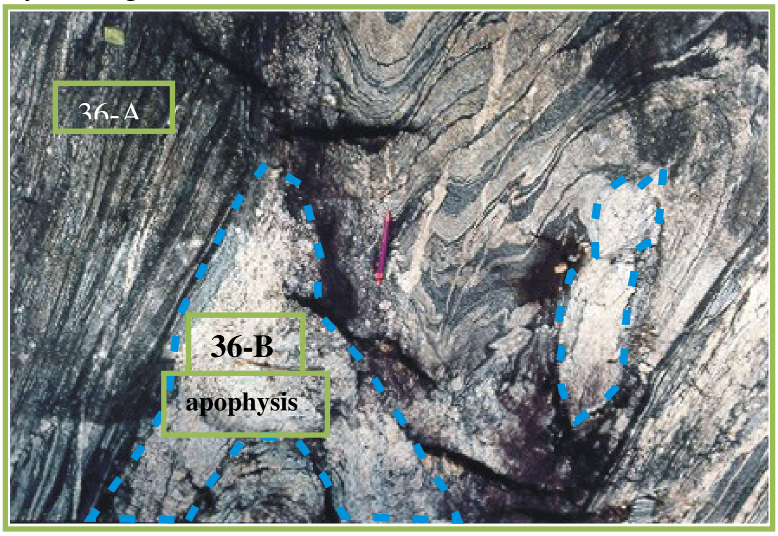


Figure 3.6 - Quartz-feldspar apophyses in a finely banded gneiss.

The zircon grains of this gneiss, JG-36 A, are light, long and prismatic. Six analyses of this gneiss were performed with the U-Pb method in zircon. The upper intercept of the Concordia diagram in Figure 3.7 corresponds to the age of 2.99 ± 31 Ga (MSWD = 286), which can be interpreted as its crystallization age (Table 3.2; Fig. 3.7). The lower intercept age of 614 ± 80 Ma can be interpreted as a result lead loss due to heating associated with the thermal peak of the Brasiliano orogeny.

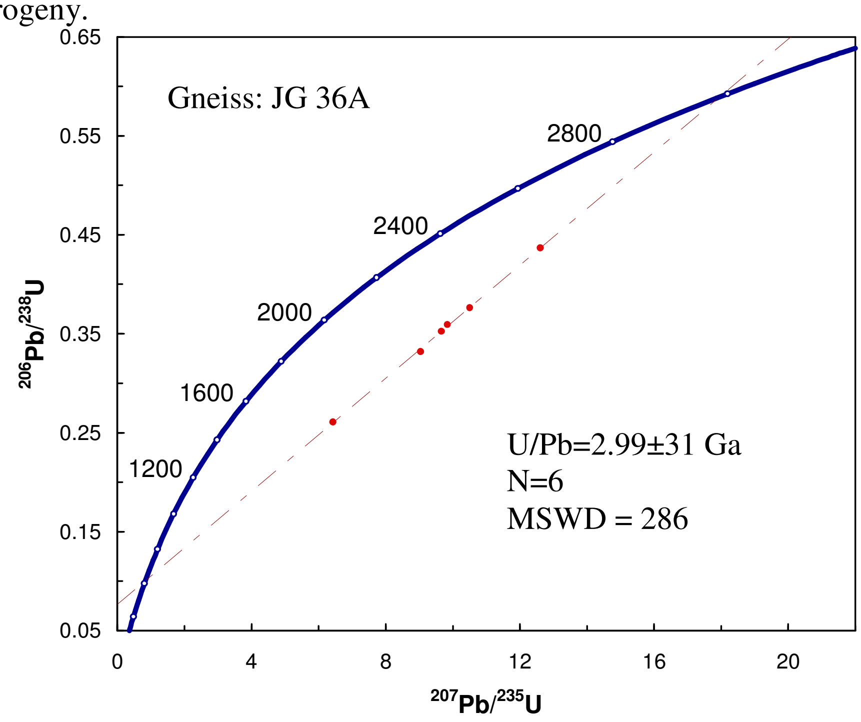


Figure 3.7 - Concordia diagram of gneiss JG-36 A from the Messianópolis region.

This gneiss has a T_{DM} model age of 3.10 Ga and an ε_{Nd} (T=2.99) of - 2.2 which indicates an older crustal material source-based protolith (Table 3.3, Fig. 3.10 E).

This gneiss exhibits textural, petrographic and isotopic characteristics that are very similar to the gneisses of the Uvá Complex.

The six zircon grains of the quartz-feldspar apophysis sample, JG-36 B, that discordantly cut gneiss JG-36A appear as elongated, prism-shaped, light, clean and pinkish, which showed a crystallization age of 535 ± 5 Ma (MSWD = 0,25) (Table 3.2, Fig. 3.8). The T_{DM} Sm-Nd model age of this sample showed an age of 2.43 Ga and an ε_{Nd} (T) = - 26.3 (Table 3.3, Fig. 3.10 E). These apophyses are associated with the emplacement of high-K granites with crystallization ages of approximately 545 Ma that occur in the same region, however, the very negative of ε_{Nd} (T) value indicates that material that originated from the banded gneiss host contaminated these apophyses.

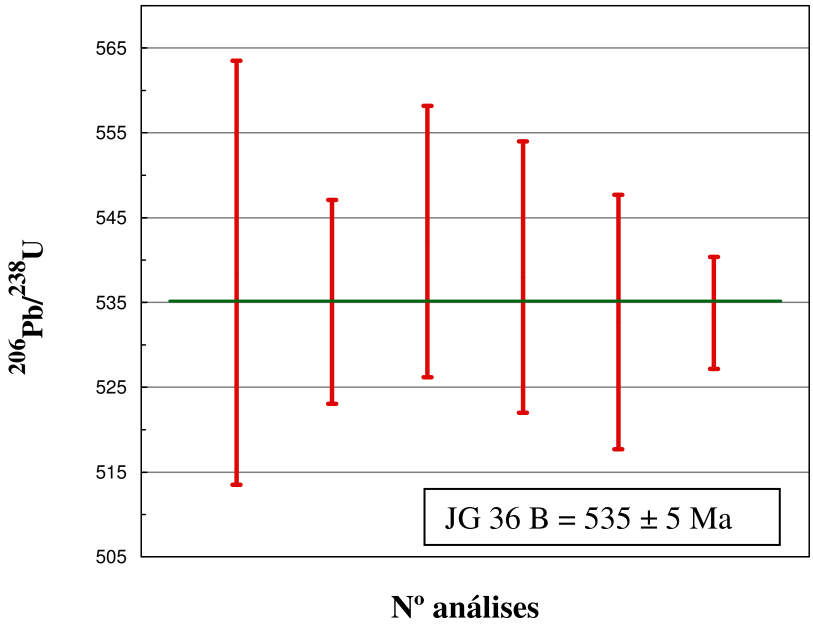


Figure 3.8 - Grafic with the U-Pb ages of the quartz feldspar aphophyses, JG-36 B, of the Messianópolis region.

3.4.1.6 - Ivolândia granite JG-161 - This is a biotite granite (Fig.3.4 H) that is emplaced into the metasedimentary rocks of the southern portion of the volcano-sedimentary Jaupaci sequence. This granite is petrographically similar to Israelândia biotite granite of, which suggests that they have the same age and magma source.

The zircon grains of this rock are short, prismatic, clean and pink. Analyses of 8 zircon grains using the U-Pb method did not yield a precise crystallization age due to inheritance combined with Pb loss (Table 3.2, Fig. 3.9). However, one of these grains has an almost concordant age of 550 ± 11 Ma, and several analyses of these zircon grains plot near that age, suggests that this is the best estimate for the crystallization age of the original magma.

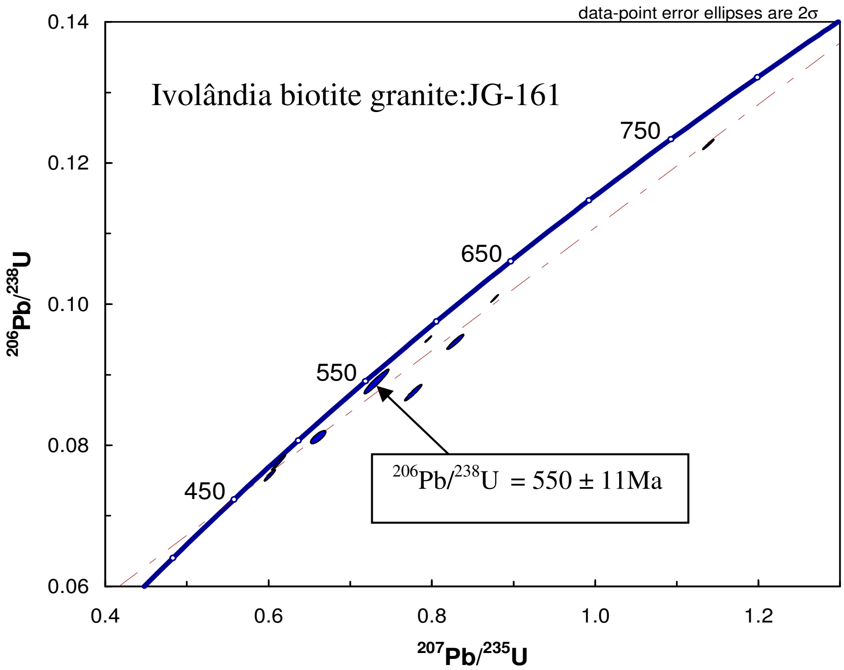


Figure 3.9 - Concordia diagram of biotite granite from Ivolândia, JG-161.

Sm-Nd analysis of this granite showed a T_{DM} model age of 1.35 Ga and an ε_{Nd} (T=550 Ma) of - 3.2 (Table 3.3, Fig. 3.10 F). The negative ε_{Nd} (T) value indicates that the composition of the granitic magma that generated this rock most likely represents the mixture of re-melted Arenópolis Magmatic Arc material with older crustal material.

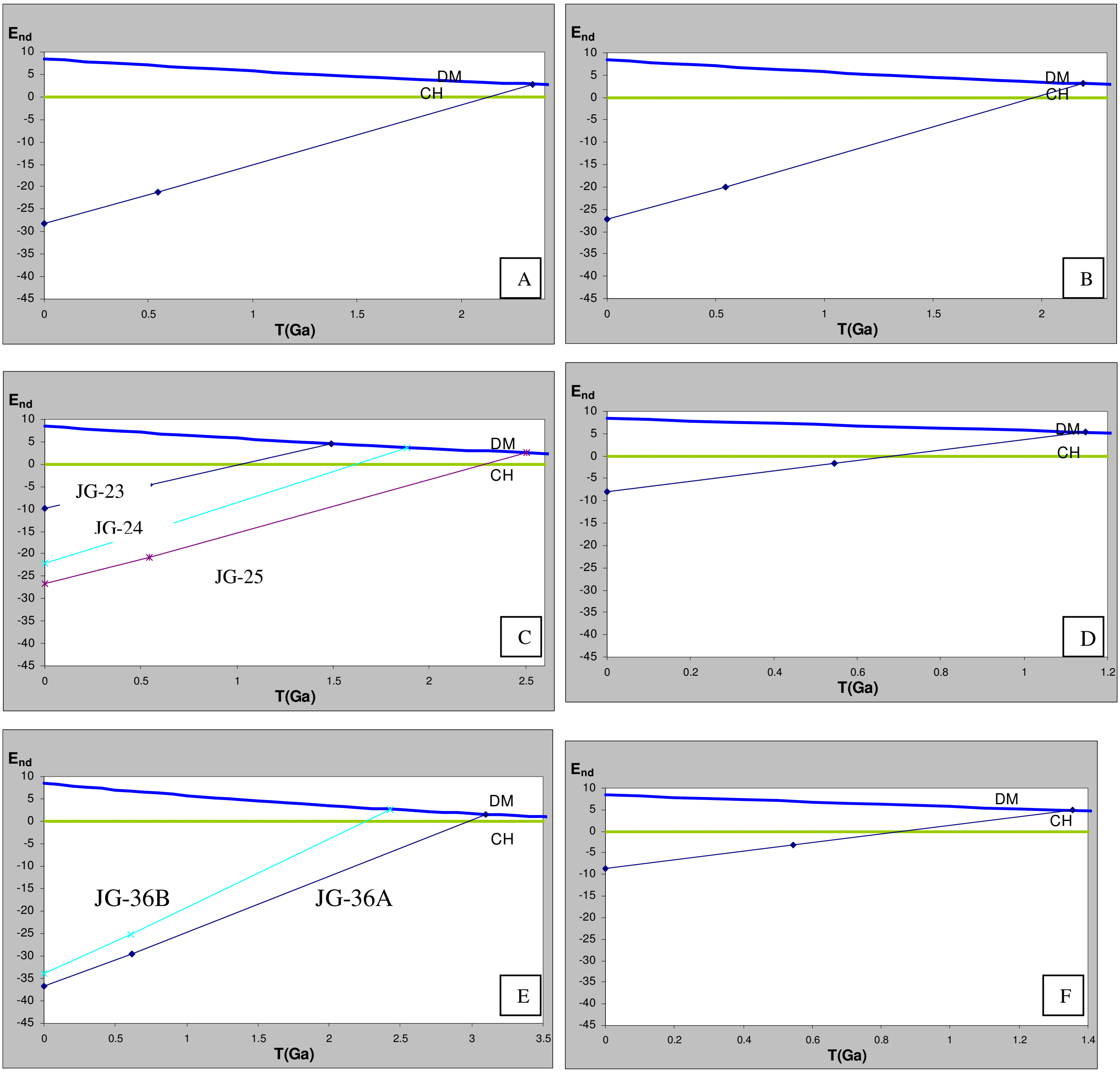


Figure 3.10 - E_{Nd} evolution diagram of granites in the region between Ivolândia and Córrego do Ouro: A - Novo Brasil biotite granite: JG-107; B - Messianópolis type biotita granite: JG-28; C - Córrego do Ouro biotite granite: JG-23, 24 and 25; D - Serra do Impertinente biotite granite: JG-70; E - Gneiss, JG36A, quartz-feldspar apophysis, JG-36B; F - Ivolândia biotite granite: JG-161. The isotopic data are shown in Table 3.3.

Table 3.1: Summary of the SHRIMP U-Pb zircon data for sample JG-38.

Grain. Spot	% $^{206}Pb_c$	ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	(2) $^{206}Pb/^{238}U$ Age		(1) $^{207}Pb/^{206}Pb$ Age		% Dis-cor-dant	Total $^{238}U/^{206}Pb$	±%	Total $^{207}Pb/^{206}Pb$	±%	(1) $^{207}Pb^*/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%	err. corr.
1.1	1.21	294	11	0.04	22.6	547.4	± 5.0	569	±180	4	11.140	0.89	0.0689	3.5	0.0591	8.2	0.722	8.3	0.08868	1.0	0.124
1.2*	0.48	284	57	0.21	89.7	2,010	±15	1,999	± 23	-1	2.721	0.84	0.1271	0.82	0.1229	1.3	6.199	1.6	0.3658	0.85	0.547
1.3*	0.09	628	188	0.31	203	2,055	±13	2,073.9	± 5.7	1	2.662	0.72	0.12899	0.29	0.12824	0.32	6.637	0.79	0.3754	0.72	0.913
2.1	1.56	228	14	0.06	17.6	545.7	± 5.2	492	±220	-11	11.16	0.95	0.0697	2.9	0.0570	10	0.693	10	0.0882	1.2	0.114
3.1	1.29	291	15	0.05	22.9	559.5	± 5.1	469	±160	-19	10.917	0.89	0.0669	3.2	0.0564	7.4	0.703	7.5	0.09041	0.99	0.133
4.1	1.36	310	17	0.06	23.5	538.9	± 7.8	474	±170	-14	11.34	1.5	0.0676	3.1	0.0565	7.5	0.678	7.6	0.0870	1.5	0.201
4.2	0.74	906	349	0.40	64.4	508.2	± 3.7	555	± 73	8	12.084	0.74	0.06467	0.66	0.0587	3.3	0.665	3.4	0.08214	0.78	0.227
5.1	1.62	253	15	0.06	18.5	519.0	± 4.6	384	±110	-35	11.78	0.91	0.06739	1.2	0.0543	5.0	0.625	5.1	0.08348	0.96	0.190
5.2	0.27	1083	300	0.29	81.2	538.1	± 4.8	545	± 38	1	11.45	0.90	0.06058	1.2	0.0584	1.7	0.701	2.0	0.08707	0.91	0.462
6.1	2.34	153	7	0.05	11.7	536.9	± 6.0	542	±180	1	11.24	1.1	0.0774	4.4	0.0583	8.1	0.699	8.1	0.08687	1.1	0.138
6.2	1.95	780	216	0.29	58.6	529.3	± 3.9	575	±100	8	11.439	0.74	0.0752	1.8	0.0592	4.8	0.700	4.9	0.08571	0.80	0.164
7.1	1.96	265	12	0.05	20.0	535.6	± 5.1	327	±250	-63	11.39	0.92	0.0687	3.5	0.0530	11	0.629	11	0.08608	1.1	0.103
7.2	0.64	759	198	0.27	57.3	540.4	± 3.9	532	± 46	-1	11.366	0.74	0.06330	0.71	0.0581	2.1	0.700	2.2	0.08742	0.75	0.334
8.1	0.73	263	11	0.04	20.5	555.3	± 6.2	607	±120	8	11.02	1.1	0.0661	3.5	0.0601	5.5	0.747	5.6	0.0901	1.1	0.204
9.1	0.81	464	20	0.04	35.3	544.7	± 5.1	451	± 65	-20	11.28	0.96	0.06251	1.1	0.0560	2.9	0.678	3.1	0.08791	0.98	0.317

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively.

The error in the standard calibration was 0.31% (not included in the above errors but required when comparing data from different counts).

(1) Common Pb corrected using the measured ^{204}Pb. Note that the data for the analyses of cores (marked *) are corrected for common Pb using ^{204}Pb.

(2) Common Pb corrected by assuming a $^{206}Pb/^{238}U$-$^{207}Pb/^{235}U$ age-concordance.

Table 3.2: Summary of the TIMS U-Pb zircon data for samples: JG-36-A, JG-36B and JG-161

Sample	Fraction	Size (mg)	U ppm	Pb ppm	Pb 206 Pb204 (obs.)	Radiogenic Rations (isoplot data) Pb207* U235	(pct)	Pb206* U238	(pct)	Correl. Coeff. (rho)	Pb207* Pb206*	(pct)	Pb206* U238 Age	Pb207* U235 Age	Pb207* Pb206* Age	(Ma)	Q
JG-36A	X	0.018	420.57	131.83	1306.	6.42606	0.65	0.2607	0.65	0.99758	0.178744	0.045	1493.6	2035.8	2641.3	0.75	5
	Z	0.022	241.98	140.8	3003.	12.6088	0.27	0.4368	0.25	0.95763	0.209336	0.078	2336.5	2650.9	2900.4	1.3	1
	4	0.015	339.66	144.63	5497.	9.03992	0.16	0.3319	0.15	0.96105	0.197537	0.044	1847.6	2342.1	2805.9	0.71	2
	12	0.032	210.22	89.078	3568.	9.18979	0.94	0.3429	0.92	0.9838	0.194377	0.169	1900.6	2357.1	2779.6	2.8	1
	13	0.035	256.18	110.62	9664.	9.835	0.28	0.3593	0.28	0.99207	0.198551	0.035	1978.6	2419.4	2814.3	0.58	1
	14	0.01	244.95	120.21	1661.	10.504	0.49	0.3763	0.48	0.98418	0.202445	0.086	2059	2480.3	2846	1.4	1
	15	0.016	267.65	120.25	2706.	9.66189	0.32	0.3524	0.32	0.99067	0.198859	0.044	1946	2403.1	2816.9	0.72	1
JG-36B																	
	D12	0.02	255.05	25.303	378.	0.68086	2.06	0.0871	1.68	0.83725	0.056676	1.12	538.52	527.3	478.97	25	1
	D13	0.025	166.73	15.1	663.	0.683693	1.17	0.0865	1.03	0.89438	0.057294	0.525	535.08	529	502.87	12	1
	D15	0.031	234.25	23.059	496.	0.751231	2.21	0.0939	1.7	0.77542	0.058014	1.4	578.65	568.94	530.31	31	1
	4	0.01	248.72	22.751	523.	0.69588	1.85	0.0877	1.69	0.92436	0.05752	0.707	542.18	580.33	511.53	16	1
	14	0.012	320.81	32.263	395.	0.687598	2.33	0.087	2.19	0.94954	0.057295	0.731	538	531.36	502.92	16	1
	U	0.022	270.05	24.969	678.	0.68544	1.02	0.0861	0.73	0.75684	0.057709	0.668	532.7	530.06	518.71	15	2
	2	0.014	221.58	20.025	829.	0.684839	0.76	0.0863	0.69	0.91869	0.057536	0.301	533.78	529.69	512.12	6.6	1
JG-161	13	0.012	875.65	81.578	1292.646	0.795544	0.4	0.0952	0.38	0.95259	0.060620	0.122	586.1	594.31	625.79	2.6	5
	E11	0.016	1139.3	110.54	1492.621	0.876594	0.44	0.1009	0.43	0.97555	0.063	0.097	619.77	639.14	708.21	2.1	2
	E12	0.026	533.83	66.293	2104.351	1.13849	0.51	0.1228	0.49	0.97233	0.067244	0.119	746.62	771.79	845.35	2.5	1
	E13	0.029	825.17	71.319	1362.279	0.731922	1.7	0.0892	1.62	0.95563	0.059531	0.502	550.63	557.68	586.56	11	5
	E15	0.023	184.73	18.144	677.592	0.82851	1.02	0.0948	0.95	0.93663	0.063402	0.359	583.71	612.78	721.75	7.6	2
	1	0.03	428.23	38.639	419.5943	0.660223	1.2	0.0813	0.91	0.78075	0.058934	0.751	503.58	514.75	564.64	16	6
	3	0.02	394.94	36.869	490.9447	0.776686	1.14	0.0876	1.08	0.94951	0.064323	0.358	541.18	583.59	752.28	7.6	5
	E8	0.018	614.31	53.805	402.2869	0.600826	0.94	0.0758	0.88	0.94878	0.057476	0.296	471.1	477.76	509.83	6.5	1
	E9	0.011	373.32	31.586	502.9831	0.611435	1.18	0.0777	1.15	0.97497	0.0571	0.262	482.16	484.46	495.4	5.8	3

Table 3.3 - T_{DM} Sm-Nd model ages results of exposed biotite granites between São Luís de Montes Belos, Mossâmedes, Fazenda Nova and Ivolândia.

Sample	Rock	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ (2 SD)	T_{DM} (Ga)	ε_{Nd} (T=545 Ma)
JG - 107	Novo Brasil biotite granite	9.62	59.43	0.0979	0.511196 ± 5	2.35	-21.3
JG-23	Córrego Ouro biotite granite	3.38	16.71	0.1221	0.512136 ± 17	1.49	-4.6
JG-24	Córrego Ouro biotite granite	13.90	90.68	0.0927	0.511509 ± 6	1.91	-14.8
JG-25	Córrego Ouro biotite granite	6.22	34.13	0.1102	0.511267 ± 12	2.61	-20.7
JG-28	Messianópolis biotite granite	5.78	37.96	0.0921	0.511239 ± 5	2.19	-20
JG -70	Serra Impertinente type biotite granite	3.32	19.15	0.1048	0.512230 ± 7	1.15	-1.6
JG-36A	Banded gneiss	6.86	38.71	0.1071	0.510760 ± 7	3.10	-2.2(T2990)
JG-36B	Quartz-feldspar apophysis	3.63	0.501	0.0834	0.510896 ± 7	2.43	-26.3
JG-161	Ivolândia biotite granite	1.42	7.24	0.1185	0.512193 ± 13	1.35	-3.2

3.5 - Discussion

Granitoids that are generated during the several stages of an orogenic cycle have particular characteristics which may provide important informations of the geodynamic evolution of the orogen. This analysis is based on several criteria, such as mineral assemblages, petrographic and textural aspects, chemical, isotopic and structural characteristics and crystallization ages.

In the present study, we characterized the source and extent of the magmatism granitic pulse in the southern part of the Neoproterozoic Goiás Magmatic Arc and identified relevant information regarding the nature of the pluton magma sources based on isotopic characteristics and crystallization ages. The emplacement mechanisms and relationchips with large-scale regional lineaments were also investigated. The petrographic characteristics of these granites were compared with the isotopic and geochronological data of high-K granites that occur in the western portion of the Arenópolis Magmatic Arc.

3.5.1 - The sources of the precursor magmas of the high-k granites based on their geochronological and isotopic characteristics

The U-Pb in zircon ages and Sm-Nd model ages of the granites can be used as parameters for assenssing the nature of the magma sources that generated these granites.

The high-K biotite granites have crystallization ages that can be represented by the U-Pb SHRIMP age of 542 ± 5 Ma of the Messianópolis granite (sample JG-38). All of the ε_{Nd} (*T*) values are negative. Samples JG-23, JG-24 and JG-25 of the Córrego do Ouro granite in this same suite displayed T_{DM} Sm-Nd model ages of 1.49, 1.91 and 2.61 Ga and ε_{Nd} (*T*) values of - 4.6, - 14.8 and - 20.7, respectively. The very negative ε_{Nd} (*T*) values that are close to zero indicate that this granite's precursor magma originated from the re-melting of a younger source in combination with older crustal material.

The Ivolândia biotite granite, which is represented by sample JG-161, belongs to the Ivolândia-Moiporá block, which is outside of the Novo Brasil Wedge, and also presents a $^{206}Pb/^{238}U$ age of 550 Ma, a model age value of 1.35 Ga and a ε_{Nd} (*T*) of - 3.2.

The isotopic Sm-Nd data in these granites are very similar to the deformed granites of the Novo Brasil Wedge and do not present the positive or negative ε_{Nd} (*T*) values that are characteristic of the western portion of the Arenópolis Magmatic Arc. The very negative ε_{Nd} (*T*) values of some of the granitoids in the investigated region indicate anatexis of older crustal material for the origem of the precursor magma; however, the negative and nearly zero ε_{Nd} (*T*) values in some of the granite samples also indicate the re-melting of Arenópolis Magmatic Arc juvenile orthogneisses in combination with contamination with older material.

The crystallization age of these post-collisional high-K granitic bodies is represented by a U-Pb SHRIMP age of 542 ± 5 Ma.

3.5.2 - The tectonic regime, magma transport and emplacement of the high-K biotite granites

The emplacement models of the granitic plutons that have been described in the literature show that they can accommodate themselves in discontinuities that are generated by extensional or compressional movements. The final structure of the granitic pluton emplacement is controlled by tectonic movements that generate necessary space for the emplacement (Tikoff and Teyssier 1992). Pre-existing structures are easily reactivated during subsequent tectonic movements, opening the way for the movement of magmatic material through the crust. Another important discontinuity is the contact between two geologic units, which is an ideal location for the emplacement of magma generated during an orogeny.

The emplacement of the 542 ± 5 Ma biotite granites in the investigated region may be attributed to the tectonic uplift of crustal blocks that created openings due to the decompression of transtractional sites, which were generated during the directional movements that affected the region at this time. These locations served as conduits for the migration of granitic magmas through the upper crust in a possible strike slip tectonic regime, taking advantage of pre-existing structures, such as the main foliation and discontinuities.

Transpression is a possible tectonic model that explains the emplacement of these bodies, Transtractional zones are generated from directional movements in the transpressional regime. The transpression zone is considered to be a directional displacement zone that is accompanied by a shortening of components and extensions along the shear plane (Harland 1971; Sanderson and Marchini 1984).

It is believed that the magma source that produced these melts took place at a depths of 10 km at the transition from the brittle-ductile areas of the continental crust, which is the place where the Arenópolis Magmatic Arc and Uvá Complex re-melted.

The Novo Brasil, Fazenda Nova and Córrego do Ouro plutons are aligned for up to 50 km along the N15W direction and correspond to the positions of potential fracturas in an “echelon” formation, which were possibly generated by the movement of the Messianópolis-Novo Brasil Lineament and the tensioning of the Transbrasiliano Lineament. Movement along the fault plane of directional movements opened dilation sites, which were filled with granitic magma that originated in magma chambers in the middle portion of the continental crust because granitic magmas do not migrate over long distances.

According to Barbarin (1999), several types of granitoids have strong relationships with the geotectonic environments and successive stages of the Wilson Cycle (Wilson 1966). Barbarin has also reported that high-K granitoids can be formed during three stages of this cycle (Fig. 3.11): (i) in the stage A environment, there is an active continental margin in the convergence of two lithospheres, one being a continental lithosphere and the other oceanic; (ii) in the stage B the environmental conditions result from the convergence of two continental lithospheres; (iii) in stage C, these granitoids are formed during the formation of collisional belts following the relaxation of the continental lithosphere and uplift.

All of the exposed rock characteristics allude to stages B and C of the Wilson Cycle in terms of formation environment for the aforementioned 542 ± 5 Ma, high-K granites in southwestern Goiás.

In stage B, which involves an active continental margin, magmas are formed during tectonic compression and are emplaced when there is tension along the shear zones (transtension) or during local relaxation. During a collision, crustal thickening increases the temperature and pressure in the middle crust in collisional orogenies, forming magmatic chambers and extensive conduits. This collision with subsequent continental crust thickening could have been induced by the interaction of the lithospheres of the Amazon, Paranapanema and São Francisco cratons against the southern Brasília Belt at the end of the Neoproterozoic and early Cambrian periods, which formed the precursor magmas of these granites in the final stages of collision.

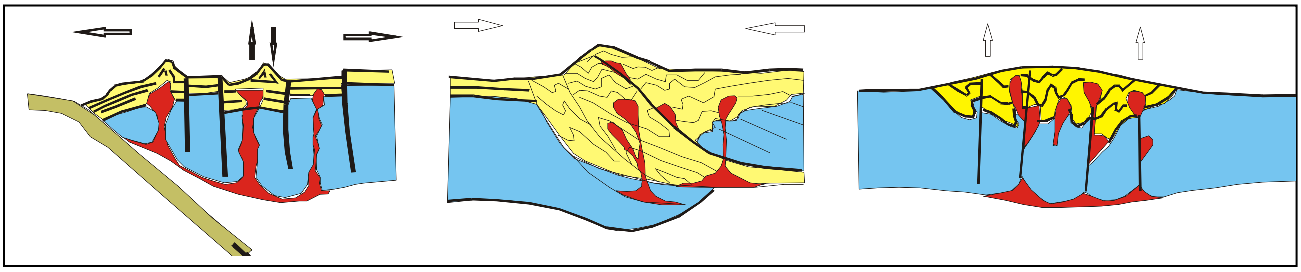


Figure 3.11 - Possible environments for the generation of calc-alkaline high-K magmas according to the successive stages of the Wilson Cycle (Barbarin 1999). For each stage, the nature of the involved lithosphere, tectonic regime and plate movement are shown. A - Subduction: oceanic and continental lithosphere convergence; B - collision: the convergence of two continental lithospheres; C - post-collisional uplift resulting from continental lithosphere relaxation. The blue area is the crust or continental lithosphere, the yellow area represents metasedimentary rocks and the red area represents post-collisional granites.

In stage C, post-collision uplifts are associated with the cooling of open transcrustal fractures, which serve as conduits for the ascent of magmatic material from magma chambers and also provide space for the lodging of magma in shallower levels of the crust.

It is believed that the transport or migration of the 542 ± 5 Ma granitic magma in the investigated region was controlled by the movements of crustal blocks, which were induced by the movement of the Transbrasiliano Lineament (Shobbenhaus *et al.* 1984). This could have stretched the main lineaments in the region, which, when interconnected, would open extensional sites for the accommodation of the magmatic material, generating several of the biotite granite bodies in the region such as the Fazenda Nova, Messianópolis, Novo Brasil and Córrego do Ouro intrusions. One of these lineaments, probably the Messianópolis-Novo Brasil Lineament, was responsible for opening sufficient space and hosting the magmatic material.

During the region's tectonic movement in the late Neoproterozoic period, it is believed that the granitic magma that was generated by partial melting of the magmatic arc rocks and Archean block spread through fractures that were controlled by the regional tension field and emplaceded along the Messianópolis-Novo Brasil Lineament, which represents the contact between these two units. Pre-existing structures, such as the mylonitic foliation of the hosts, are also ideal locations for the opening of space for the lodging of magmatic material.

The collisions that occurred between 740 and 500 Ma west of the Gondwana supercontinent are attributed to the Pan-African/Brasiliano orogenic cycle. Around 545 Ma, part of the supercontinent of Laurentia was separated into the Amazon craton, Baltica and Siberia (Fig. 3.12). At this time and under this scenario, in the final stages of the Brasiliano orogeny, the high-K granitogenesis of the Arenópolis Magmatic Arc occurred.

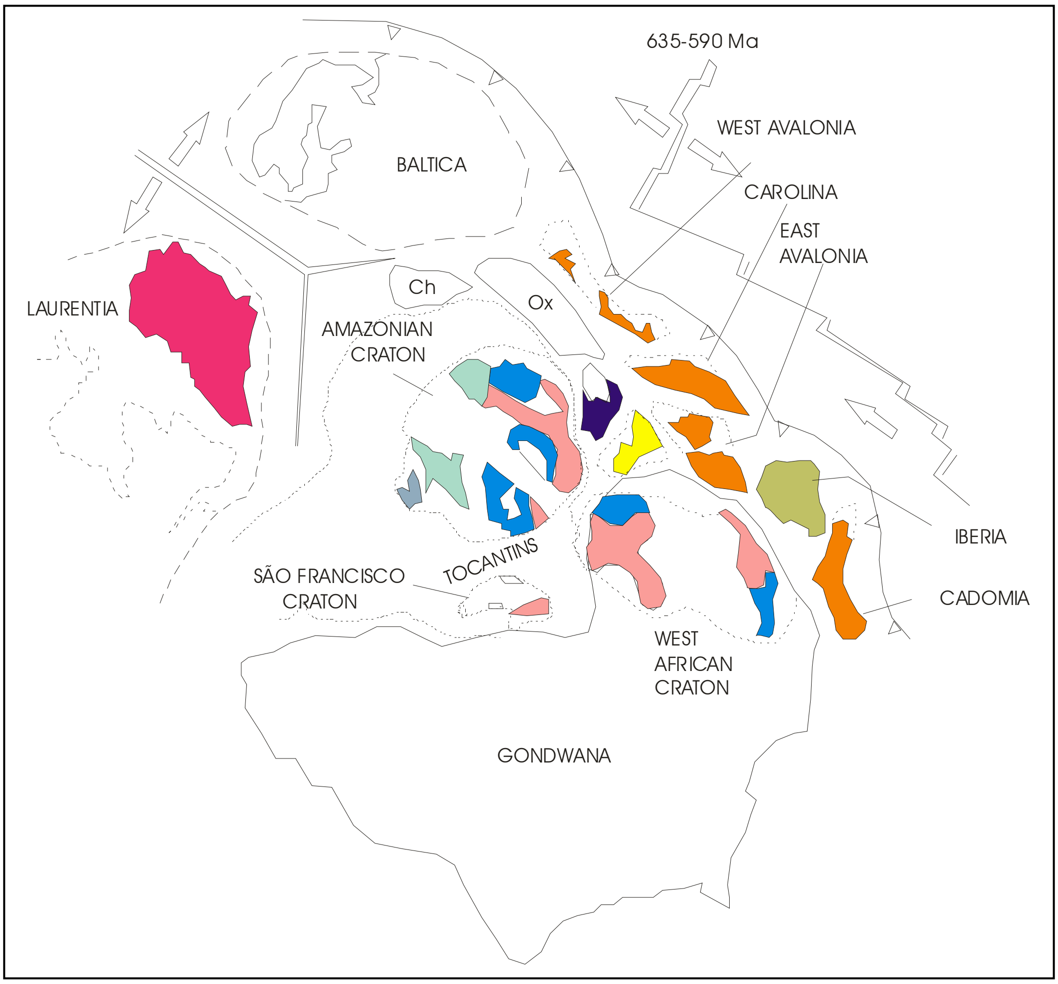


Figure 3.12 - The geotectonic position of the Tocantins Province NW of the Gondwana Supercontinent at the end of the Neoproterozoic between 635-590 Ma (Nuncy *et al.* 2002).

3.6 - Conclusions

The Messianópolis granite has a SHRIMP U-Pb crystallization age of 542 ± 5 Ma. This granite belongs to the Serra Negra suite, which was formed by late to post-collisional high-K biotite granites that were emplaced into Arenópolis Magmatic Arc in the São Luís de Montes Belos-Fazenda Nova region. These are the youngest granites known in the Brasília Belt. After determining the U-Pb age, it can be established that the Serra Negra suite belongs to a fifth group of granitoids in the Brasília Belt, adding to the four groups that were previously identified.

In the investigated region, the granites of this suite have two Sm-Nd model age groups. The first granite group (Messianópolis, Novo Brasil and Córrego do Ouro biotite granites) has values that range from 1.49 to 2.61 Ga and very negative ε_{Nd} (T) values that range from - 4.6 to - 21.3. These data indicate that the magma that formed these structures derived from the re-melting of older crustal material from a recycled continental crust, which, perhaps, could have come from the

TTG gneisses of the Uvá Complex. The granites of the second group (Serra do Impertinente biotite granite and Ivolândia biotite granite) have model ages that range from 1.15 to 1.35 Ga and comparatively lower ε_{Nd} (*T*) values that range from - 0.8 to - 2.96, which are close to those values, suggesting that they were generated from the re-melting Arenópolis Magmatic Arc juvenile rocks.

The banded gneiss outcropping that occurs among the rocks of the Novo Brasil wedge and close to the Uvá Complex has a model age of 3.10 Ma and an ε_{Nd} (*T*) of - 30.4. The feldspar apophyses that discordantly cut this gneiss banding have a model age of 2.43 Ga and ε_{Nd} (*T*) of - 26.1.

It is believed that the Messianópolis-Novo Brasil lineament represents an important crustal discontinuity that extends to great depths and has served as an important granitic magma conduit for the alignement of several granite bodies that runs for over 150 km with clear structural control provides evidence of the extension and importance of the geographic distribution of this granitic magmatism. This lineament, which is possibly connected to the Transbrasiliano Lineament can be interpreted as a linear suture zone, which is configured as an extensive fault that separates the Archean Block of rocks from the Neoproterozoic Arenópolis Magmatic Arc. The movement of this block, followed by uplift, deformation and reactivations, and the subsequent opening of spaces, created the conditions for the emplacement of granitic magmas at the end of the Neoproterozoic and and early Cambrian.

The heat source for the melting metatonalites and gneisses of the Archean block may have originated during the uplift of the asthenosphere, which generated a plume of heat that melted the continental crust in this region. It is suggested that the post-Brasiliano anatexis that generated this granitic magmatism in southwestern Goiás is part of global-scale tectonic phenomena that are related to the significant dispersion of various-sized continental blocks at the western edge of the Western Gondwana supercontinent that occurred in the Ediacaran period.

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