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The tectonic evolution of the Neoproterozoic Brasília Belt, central Brazil: a geochronological and isotopic approach

A evolução tectônica da Faixa Brasília, Brasil central: uma abordagem geocronológica e isotópica

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ABSTRACT: The Brasília Belt is one of the most complete Neoproterozoic orogens in western Gondwana. Rapid progress on the understanding of the tectonic evolution of the belt was achieved due to new U-Pb data, combined with Sm-Nd and Lu-Hf analyses. The evolution of the Brasília orogen happened over a long period of time (900 – 600 Ma) involving subduction, magmatism and terrain accretion, as a result of the consumption of the Goiás oceanic lithosphere. Provenance studies, based on U-Pb zircon data, indicate that the sedimentary rock units record different tectonic settings and stages of the evolution of the orogen. The Paranoá and Canastra groups represent passive margin sequences derived from the erosion of the São Francisco Craton. The Araxá and Ibiá groups, however, have dominant Neoproterozoic detrital zircon populations, as young as 650 Ma, suggesting derivation from the Goiás Magmatic Arc. The Goiás Magmatic Arc represents a composite arc terrain, formed by the accretion of older (ca. 0.9 – 0.8 Ga) intraoceanic island arc(s), followed by more evolved continental arcs. It extends for several thousand kilometers, from SW Goiás, through NE Brazil and into Africa. Metamorphism took place between 650 – 630 Ma reflecting final closure of the Goiás Ocean and continental collision.

KEYWORDS: Brasília Belt; Neoproterozoic; U-Pb geochronology; Sediment provenance.

RESUMO: A Faixa Brasília é um dos mais completos orógenos Neoproterozoicos no Gondwana Ocidental. Durante os últimos dez anos, o rápido progresso no entendimento da evolução tectônica desse orógeno foi proporcionado pela produção de novos dados geocronológicos U-Pb SHRIMP e LA-ICPMS, combinados com análises Sm-Nd e Lu-Hf. Os dados demonstraram que a evolução da Faixa Brasília aconteceu ao longo de um prolongado intervalo de tempo (900 – 600 Ma), envolvendo subdução, atividade ígnea e acreção de terrenos, como resultado do consumo da litosfera do oceano Goiás. Estudos de proveniência de sedimentos baseados em geocronologia U-Pb de minerais detríticos indicam que as unidades sedimentares da Faixa Brasília também registram diferentes ambientes tectônicos e estágios de evolução da Faixa. Os grupos Paranoá e Canastra representam sequências de margem passiva, derivadas da erosão do Craton do São Francisco. Por outro lado, as rochas sedimentares dos grupos Araxá e Ibiá contêm uma grande quantidade de zircões detríticos neoproterozoicos, tão jovens quanto 650 Ma, sugerindo proveniência a partir do Arco Magmático de Goiás. Os dados geocronológicos disponíveis até o momento demonstram que o Arco Magmático de Goiás, na porção oeste do orógeno, representa um terreno de arco formado pela acreção de arcos de ilha intraoceânicos mais antigos (ca. 0.9 – 0.8 Ga), seguida do desenvolvimento de arcos continentais mais evoluídos. O arco magmático se estende por alguns milhares de quilômetros na direção NNE, desde o sudoeste de Goiás, através do Nordeste brasileiro, se prolongando para o continente africano. Idades de metamorfismo, muito embora não muito abundantes, indicam pico do metamorfismo entre 650 – 630 Ma, o que provavelmente corresponde à época de fechamento do oceano e colisão continental.

PALAVRAS-CHAVE: Faixa Brasília; Neoproterozoico; Geocronologia U-Pb; Proveniência de sedimentos.

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INTRODUCTION

The Brasília Belt, in central Brazil, is one of the most complete and complex Neoproterozoic orogens in western Gondwana. It formed during the convergence of the Amazonian, São Francisco–Congo, Paranapanema (Rio de La Plata), as well as smaller allochthonous blocks (Fig. 1). It is part of a wide and long orogenic system extending for thousands of kilometers in central and northern Brazil and in NW Africa, in the Hoggar-Pharusian and Dahomey belts. In Brazil, this orogenic area is known as the Tocantins Province, which includes the Brasília Belt, developed along the western margin of the São Francisco Craton, as well as the Araguaia and Paraguay belts, formed along the continental margin of the Amazonian paleocontinent. They are all part of the amalgamation of West Gondwana during the neoproterozoic and eocambrian.

Over the last ten years, a considerable amount of new U-Pb and Sm-Nd geochronological data has been instrumental to understand in greater detail the tectonic evolution of the Brasília Belt. It has been suggested in the literature that the tectonic elements and geochronological data for the Brasília Belt record a long and complex history of deformation, metamorphism and accretion of terranes, including island arc terranes, an ophiolitic mélange, high-grade terranes and a supracrustal fold-and-thrust belt, consisting of juxtaposed metasedimentary sequences of various ages and natures (for recent reviews see Pimentel *et al.* 2011, Araujo *et al.* 2014, Cordani *et al.* 2013a, 2013b, Brito Neves *et al.* 2014, Brito Neves & Fuck 2014).

In the present study, the tectonic evolution of the Brasília Belt was discussed mainly on the light of ID-TIMS, ion microprobe and LA-ICPMS U-Pb geochronological data published mostly over the last ten years. Some key tectonic units will be highlighted:

- the supracrustal sequences of the fold-and-thrust belt and cratonic cover,
- the neoproterozoic high-grade terranes (Uruaçu and Anápolis-Itaçu complexes),
- three large Neoproterozoic mafic-ultramafic complexes of Barro Alto, Niquelândia and Canabrava, and associated volcano-sedimentary sequences of uncertain age,
- the Goiás Magmatic Arc.

GEOLOGY AND GEOCHRONOLOGY OF THE BRASÍLIA BELT

Goiás Archaean Block

This is considered to be an allochthonous microplate, accreted to the western margin of the Brasília Belt during

the latest stages of evolution of the Neoproterozoic orogen (Jost *et al.* 2013). It underlies an area of about 18,000 km² (Fig. 2) and consists of typical Archean TTG granite-gneiss complexes (Queiroz *et al.* 2008, Jost *et al.* 2013), and narrow greenstone belt sequences (Fortes *et al.* 1995, Tassinari *et al.* 2006, Santos *et al.* 2008, Jost *et al.* 2010). The granite-gneiss terrains comprise orthogneisses which, in the northern portion of the terrain, comprise the Anta, Caiamar, Moquém and Hidrolina, and, in the south, the Caiçara and Uvã complexes. The metaplutonic rocks have U-Pb ages ranging between ca. 3.04 and 2.71 Ga and a few Sm-Nd isotopic data obtained by Pimentel *et al.* (2003) from samples of the southern Uvã and Caiçara complexes yielded whole-rock model ages of ca. 3.0 Ga. The U-Pb discordias presented by Queiroz *et al.* (2008) show patterns indicating strong Neoproterozoic Pb loss.

The greenstone belts successions are made of a basal ultramafic unit made of komatiites, locally presenting well-preserved spinifex textures and pillow structures, covered by a metabasalt unit with intercalations of chemical and pelitic metasediments. At the top, a detrital unit made dominantly of conglomerate, quartzite, metapelite and local marble is recognized. The ages of the komatiite-bearing lower units are still poorly constrained. One whole-rock Sm-Nd isochron for komatiitic rocks of the Crixás greenstone belt yielded the age of ca. 3.0 Ga (Fortes *et al.* 1995). However, the provenance study of the upper metasedimentary sequences of the belts revealed the presence of Paleoproterozoic detrital zircon grains, suggesting that these upper sequences and the associated gold deposits are not part of the Archaean geology of the greenstone belts (Jost *et al.* 2010).

Additionally, a few Neoproterozoic granite intrusions have been identified within the TTG terrains. One of them, in the southern part of the terrain, was dated at ca. 625 Ma, suggesting that the allochthonous Archaean block had already docked at the western margin of the Brasília Belt at that time (Pimentel *et al.* 2003).

Exposures of Paleoproterozoic sialic basement

Paleoproterozoic sialic basement of the Brasília Belt is exposed either as small exposures in between younger rock units or as the large siderian/rhyacian region in the northern part of the belt, known as the Natividade-Cavalcante crustal block (Fig. 3) (Fuck *et al.* 2014). This consists mainly of volcano-sedimentary sequences (e.g. Almas-Dianópolis) and a great diversity of orthogneisses and granitic intrusions which have been dated between 2.4 and 2.04 Ga (Cruz & Kuyumjian 1998, Botelho *et al.* 2006, Fuck *et al.* 2013). Most of these granitoid rocks are juvenile although some of them present Nd model ages which are substantially older than

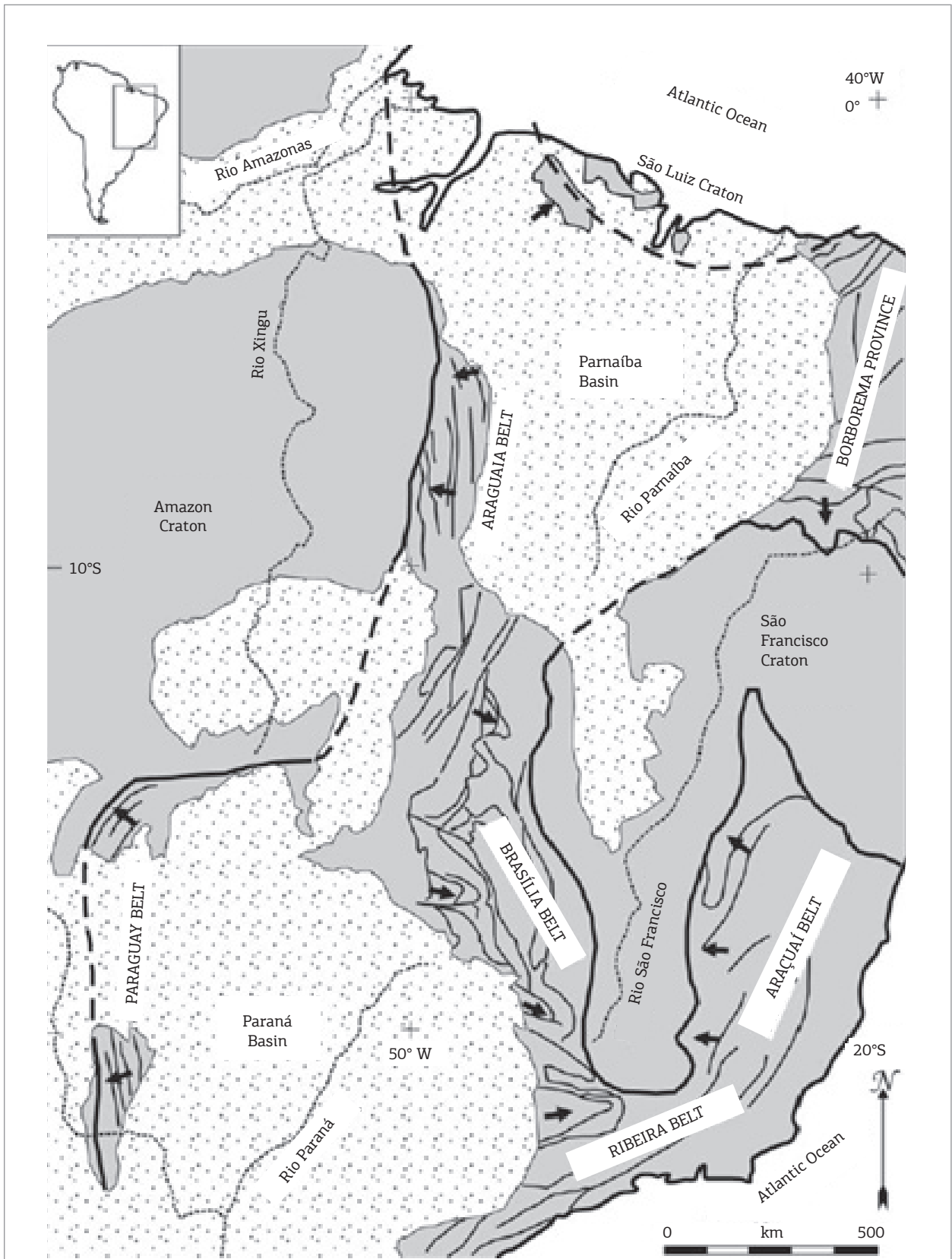


Figure 1. The tectonic elements of central Brazil, from Valeriano *et al.* (2012).

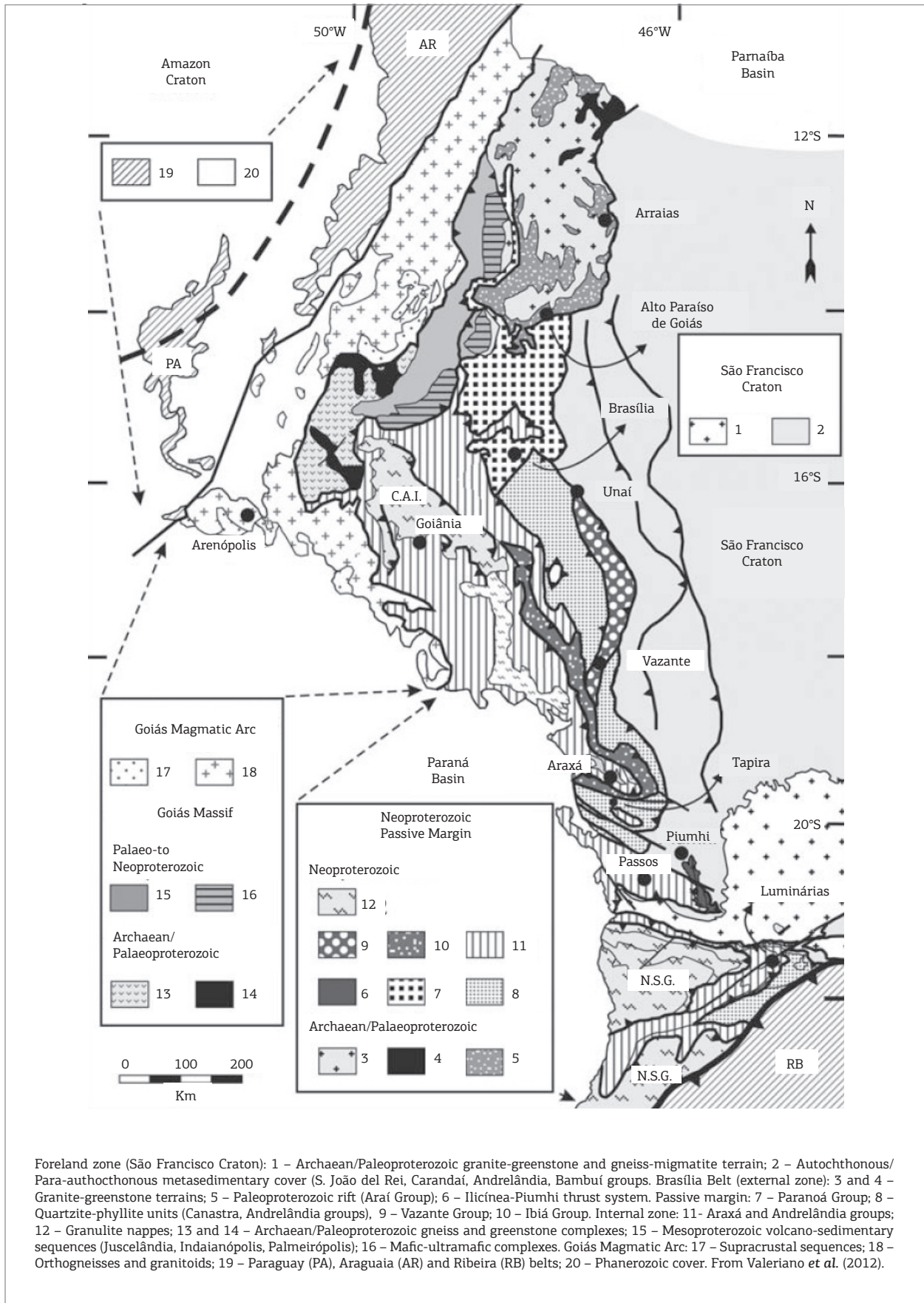


Figure 2. The Brasília Belt (from Dardenne 2000, Pimentel *et al.* 2000b, Valeriano *et al.* 2004).

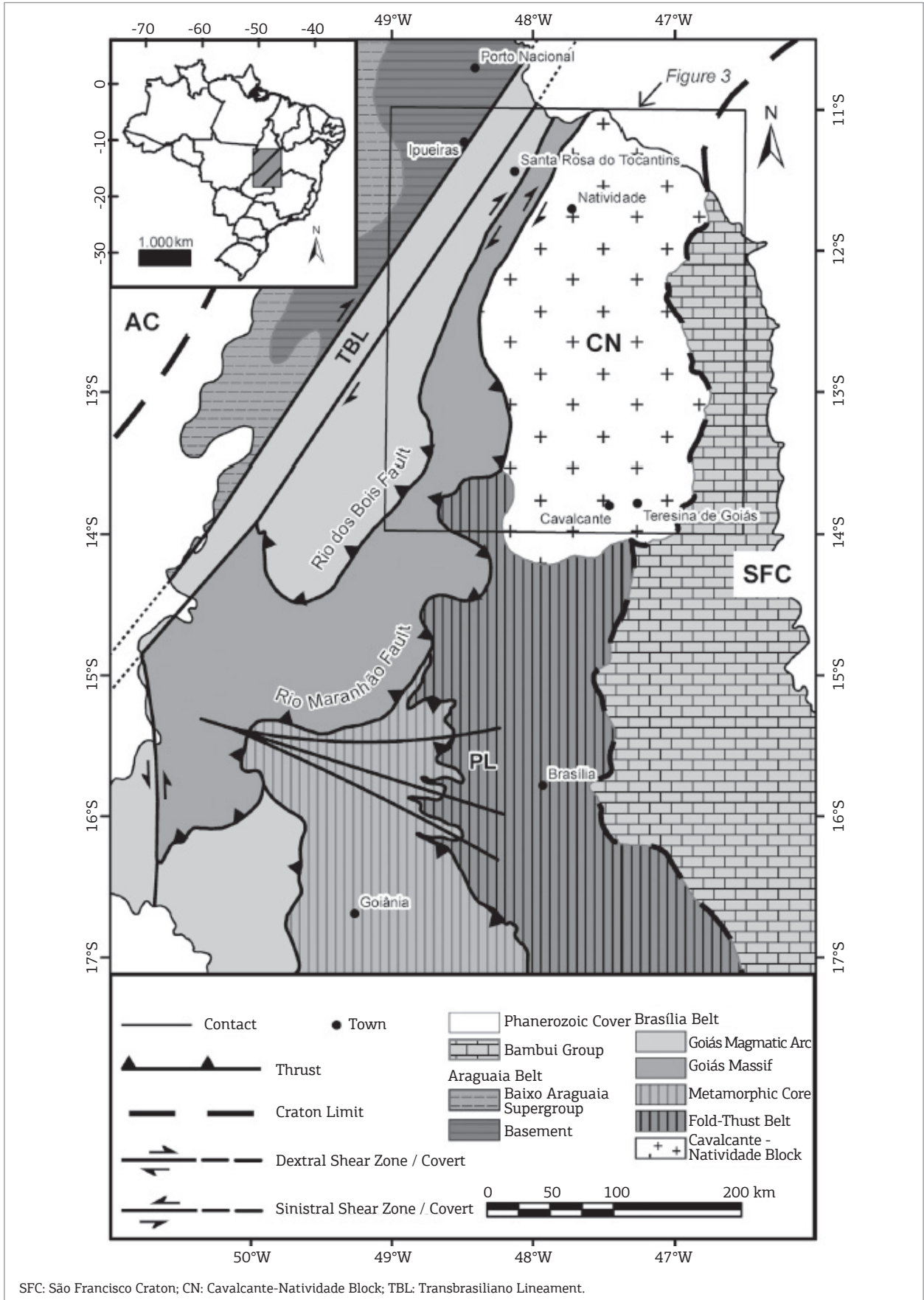


Figure 3. The northern part of the Brasília Belt.

their crystallization ages, suggesting either local reworking of Archaean sialic crust or contamination with metapelites of the Paleoproterozoic Ticunzal Formation (Fuck *et al.* 2013). In the south of the block, small Statherian A-type granite intrusions are exposed (ca. 1.77 Ga; Pimentel *et al.* 1991) coeval with the rhyolites at the base of the Araí Group rift sequence. Additionally to this large basement area in the northern part of the belt, other small Paleoproterozoic inliers are recognized in different parts of the orogen especially in its southern half. Examples are the 2.19 – 2.07 Ga old Campinorte Sequence (Della Giustina *et al.* 2009a, Cordeiro *et al.* 2014), the Silvânia Volcano-Sedimentary Sequence (2.12 Ga) and the Jurubatuba granite (2.09 Ga) (Fischel *et al.* 2001), which are pointed out in Fig. 2.

The regional geological and geochronological data available so far indicate that these exposures of Paleoproterozoic sialic rocks represent fragments of the continental basement of the supracrustal sequences of the Brasília Belt, whereas the Goiás Archaean Block consists of an allochthonous terrain accreted to the margin of the orogen at the end of the Neoproterozoic. This is supported by the gravity data provided by Marangoni *et al.* (1995), which reveals an important gravimetric discontinuity separating the supracrustal rocks of the Brasília Belt in the east from the Goiás Magmatic Arc, Goiás Archaean Block and the three large mafic-ultramafic complexes to the west (ca. 790 Ma old Barro Alto, Niquelândia and Canabrava complexes, from north to south).

The metasedimentary sequences: provenance and age of the Paranoá, Canastra, Ibiá, Araxá and Bambuí Groups

The age and significance of the different sedimentary rock units of the Brasília Belt have been a question of continuous debate. They form a thick pile of sedimentary units extending for more than 1,000 km roughly in the NS direction, along the western margin of the São Francisco Craton (Figs. 1 and 2). Regional, west-dipping thrusts, reverse faults and nappes mark the limits between the main stratigraphic units and clearly indicate tectonic transport towards the east (for a review see Valeriano *et al.* 2012). Traditional approaches have interpreted them as part of a passive margin sequence deposited on the continental shelf of the São Francisco paleocontinent (e.g. Marini *et al.* 1984). However, the strong deformation disrupted the original stratigraphic organization, and the general absence of intercalations of volcanic rocks has made difficult the exercise of reconstructing the original setting and age of the basin(s). More recently, some efforts have been carried out in order to investigate the provenance of the original sediments using mainly LA-ICPMS U-Pb analyses on detrital zircon (Pimentel *et al.* 2001,

Piuzana *et al.* 2003a, Valeriano *et al.* 2004, Pimentel *et al.* 2011, Rodrigues *et al.* 2010, 2012, Matteini *et al.* 2012). These studies have provided useful information on the maximum age of deposition and on the original tectonic setting of the different supracrustal associations, in special of the Araxá, Ibiá, Canastra and Paranoá groups (for a review see Pimentel *et al.* 2011).

The Paranoá Group comprises a mature siliciclastic sedimentary pile including thick quartzite layers, with intercalation of metasilstone and minor lenses of limestone and dolostone (for a review see Campos *et al.* 2013). It starts at the base with a paraconglomerate, followed by transgressive and regressive siliciclastic cycles, ending, at the top, with pelites and dolostones containing Conophyton metulum Kirichenko stromatolites (Cloud & Dardenne 1973). Available geochronological and microfossil data for the Paranoá Group suggest ages between ca. 1,170 and 950 Ma for source regions within the São Francisco craton (Guimarães 1997, Pimentel *et al.* 2001, Matteini *et al.* 2012). The 50 m-thick São Miguel conglomerate represents the rift phase of the Paranoá basin. It is overlain by rhythmites with mudcracks and evaporite layers, typical of tidal environments. These are followed by marine rhythmites and quartzites deposited in a platformal environment dominated by tidal currents. The sediments in the upper portion of the Paranoá Group display features indicating more varied environments, reflecting important fluctuations of the sea level. In this section, deeper water pelites alternate with tidal rhythmites and quartzites, storm rhythmites, limestones and stromatolitic dolomites. Arkoses and quartzites at the upper part of the Paranoá sequence are chemically similar to passive margin clastic sediments (Guimarães 1997).

The Canastra Group comprises a typical platformal association of psammitic and pelitic metasediments, with some carbonatic intercalations. Phyllites and quartzites are the most common rocks. The basal part of the group (Serra do Landim Formation) is made of chlorite-rich calc-phyllite or calcschist. Towards the top, the Paracatu and the Chapada dos Pilões formations are formed by carbonaceous phyllites and quartzites, representing a coarsening-upward sequence formed by a regressive megacycle. This is made of deep water sediments, grading into turbidites deposited on a continental slope by gravitational currents and to top platformal deposits with hummocky structures and cross stratification, indicating sediment transport from east to west. The Canastra Group is considered to be the lateral equivalent of the Paranoá Group (Dardenne 2000). The relationships between the Canastra, Araxá and Ibiá groups are not clear due to intense tectonic imbrication between these units.

The Ibiá Group has been divided into two formations: (i) the Cubatão Formation, at the base, lying on an erosive unconformity over the Canastra Group and consisting of a thick diamictite unit, and (ii) the Rio Verde Formation, at the top, which is made of deep water calcschists and calc-phyl-lites with fine layers of quartzite. The Cubatão diamictite has been correlated with the Jequitáí Diamictite, while the phyllites are considered to be equivalent to the metasediments of the Araxá Group. Geochemical features of the phyllites in the southern part of the belt indicate provenance from a primitive island arc source (Seer 1999).

The Araxá Group is dominantly made of micaceous quartzite and micaschists including calcschists, chlorite-muscovite schist, biotite-garnet schist, staurolite schist and feldspar schists, with a few paragneiss and marble intercalations. The internal stratigraphy of the group is poorly known due to intense deformation with development of low angle thrust sheets. Volcanic rocks associated with the Araxá micaschists are observed in many areas. These are amphibolites, meta-andesites and rhyolites (Pimentel & Fuck 1992, Valeriano & Simões 1997). In the eastern part of the Araxá Group, the ca. 0.79 Ga Maratá Sequence represents a narrow strip of rhyolitic/granitic rocks interlayered with the Araxá metasediments. This ca. 100 km long narrow unit was initially interpreted as volcanic (e.g. Pimentel & Fuck 1992) and later re-interpreted as highly deformed syn-tectonic intrusions. In the latter interpretation, therefore, the U-Pb zircon age of 0.79 Ga (Pimentel & Fuck 1992) represents a minimum age for the deposition of the Araxá sediments. Amphibolites intercalated with the Araxá schists near Goiânia have been dated at ca. 0.8 Ga (SHRIMP U-Pb zircon data of Piuzana *et al.*, 2003a). The trace element characteristics of these amphibolites are very similar to MORBs and they have been interpreted as slices of ocean floor tectonically emplaced within the Araxá metasediments. In summary, the stratigraphic relationships between these metaigneous rocks and the Araxá metasediments are still far from clear and remain controversial due to tectonic imbrications. Another important feature associated with the Araxá rocks is the presence of a large number of small lenses of serpentinite, amphibolite and talc schist, with podiform chromite deposits, representing a long, roughly NS ophiolitic mélangé (Strieder & Nilson 1992).

Provenance data based on U-Pb ages of detrital zircon grains of the four stratigraphic units above are summarized in Figs. 4 and 5 and reveal important differences between the sedimentary units.

The Bambuí Group is the most important Neoproterozoic sedimentary unit in central Brazil, forming the easternmost part of the Brasília Belt and covering large areas of the São Francisco Craton. Its basal diamictite (Jequitáí Formation) sits

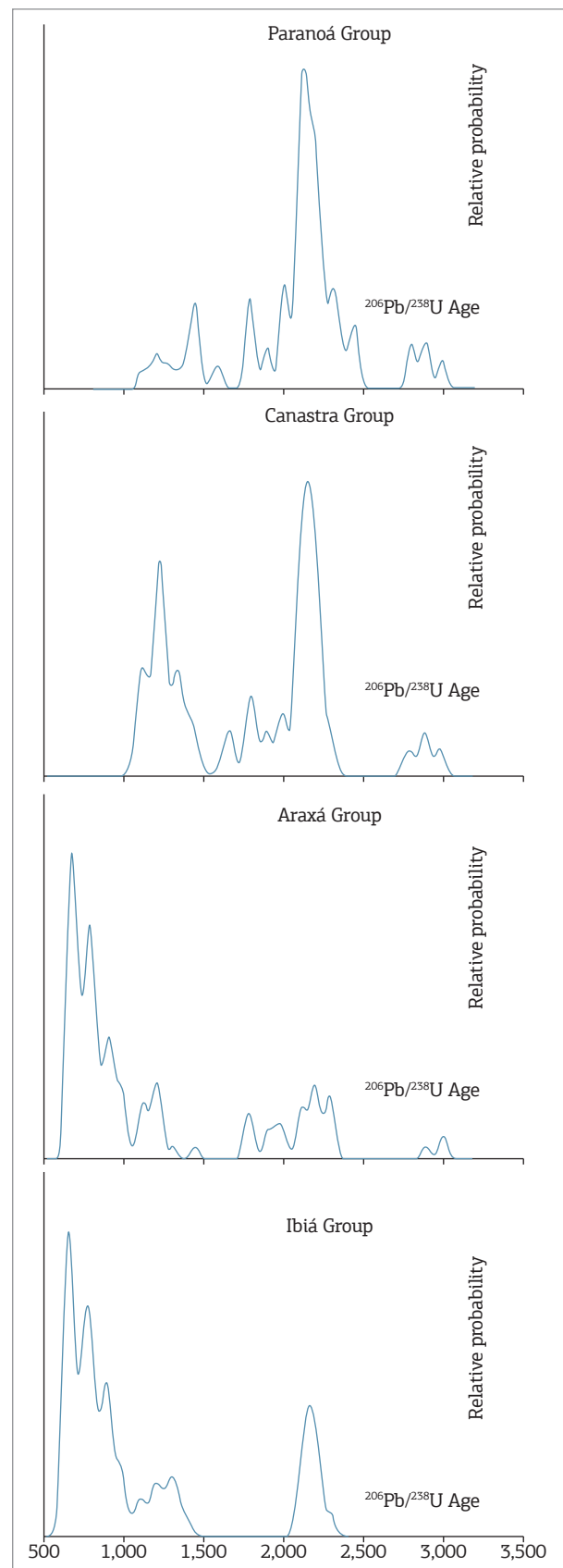


Figure 4. Provenance patterns of metasedimentary units of the Brasília Belt.

unconformably on the Paranoá Group. The age of this glacial event remains controversial. The end of this glaciation was followed by the development of a marine environment and the onset of deposition of the pelitic-carbonatic sediments of the base of the Bambuí Group. According to Santos *et al.* (2000), the sediments of the Bambuí Group were deposited in an epicontinental sea influenced by tectonic movements

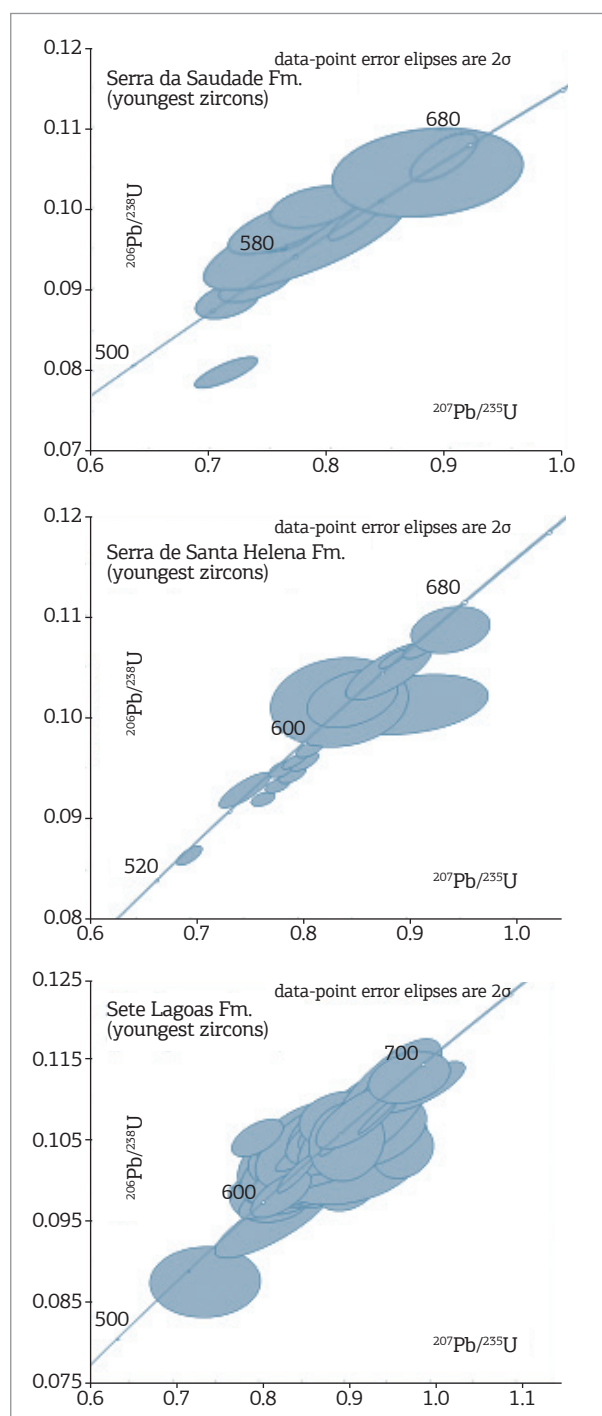


Figure 5. Concordia diagrams for detrital zircon grains of the Bambuí Group.

in the Brasília Belt (Martins, Lemos 2007). The Bambuí sedimentary rocks comprise three regressive megacycles. Each of these megacycles begins with a fast marine transgression of regional amplitude, associated with a sudden subsidence of the basin evidenced by deep pelitic marine facies, passing to shallow-platform facies and tidal to supratidal facies.

The age of deposition of the Bambuí Group has been a matter of discussion for many years. Sr and Pb isotopic data reported by Parenti-Couto *et al.* (1981) suggested depositional ages of ca. 600 Ma. Similarly, previous Rb-Sr and K-Ar data on shales reported by Thomaz Filho *et al.* (1998) have produced ages between ca. 640 Ma for the basal Sete Lagoas Formation and 540 Ma for the Três Marias Formation at the top of the succession. More recently, the cap dolostones at the base of the Sete Lagoas overlying Jequitáí diamictites have been dated at ca 740 Ma (Pb-Pb isochron; Babinski *et al.*, 2007). The data, associated with C and Sr isotopic data for the carbonates support a Sturtian age for the Jequitáí glaciation. However, the provenance age presented by Rodrigues (2008) and Pimentel *et al.* (2011), for the basal Sete Lagoas, Serra de Santa Helena, as well as for the Serra da Saudade formations, revealed the presence of a large amount of late Neoproterozoic zircons, dated at ca. 600 Ma and even a few grains being as young as 550 Ma (Fig. 5). This suggests a very late Neoproterozoic or even early Cambrian age for the deposition of the Bambuí Group as equally indicated by the data presented by Paula-Santos *et al.* (in press) for the basal Sete Lagoas Formation. This is supported by the recent discovery of Ediacara fauna in carbonates of the Sete Lagoas Formation (Warren *et al.* 2014).

According to the model by which some of these sedimentary rock units (in special the Paranoá, Canastra, Araxá and Ibiá groups) represented the passive margin of the São Francisco Craton, the original sediments should display provenance patterns dominated by Paleoproterozoic and Archaean zircons, with subordinate mesoproterozoic grains. The results demonstrated, however, that this is not the case. A compilation of the provenance data produced by the studies above is shown in Fig. 4. Siliciclastic rocks of the Paranoá and Canastra groups show provenance ages which are compatible with erosion of source regions within the São Francisco Craton, with predominance of Paleoproterozoic detrital zircons. On the other hand, the pelitic and psammitic rocks of the Araxá and Ibiá Groups display very distinct provenance patterns with a large amount of Neoproterozoic zircon grains, as young as 640 Ma. A younger source is, therefore, required.

The Goiás Magmatic Arc

The Goiás Magmatic Arc is one of the most important tectonic units of the Brasília Belt and represents one of the most expressive episodes of juvenile crustal accretion

during the assembly of Gondwana. It is exposed in two main areas, separated by Goiás Archean Block. The southern portion of the Arc is known as the Arenópolis Arc, and the northern, as the Mara Rosa Arc, extending for hundreds of kilometers in the NNE direction (Fig. 2). In both areas, the arc started its evolution at ca. 900 Ma in intraoceanic island arcs (Pimentel & Fuck 1992), and the final widespread magmatic event took place between ca. 630 – 600 Ma, during closure of the Goiás-Pharusian Ocean (Cordani *et al.* 2013a). The Goiás magmatic arc is formed by:

- supracrustal sequences comprising calc-alkaline meta-volcanic rocks, feldspar-bearing micaschist and minor quartzite and marble (e.g. the Santa Terezinha, Mara Rosa and Arenópolis sequences), and
- calc-alkaline plutonic rock units variably deformed and metamorphosed, ranging in composition from gabbro to granite, with a large volume of tonalites (Arantes *et al.* 1991). The rock units above were intruded by large, bimodal, post-tectonic granite intrusion.

The orthogneisses are mostly hornblende-bearing metadiorites, metatonalites and metagranodiorites. The rocks display positive $\epsilon_{Nd}(T)$ values and Nd model ages mostly between 0.8 and 1.1 Ga (Pimentel *et al.* 1991, 1997, 2000a, Pimentel & Fuck 1992). Geochemical and isotopic data suggest that some of the original tonalitic/andesitic magmas were similar to modern adakites (Pimentel *et al.* 1991, Pimentel *et al.* 1997). U-Pb zircon ages indicate the igneous protholites crystallized in three main events:

1. The oldest igneous events happened between ca. 900 and 804 Ma, and are represented by the juvenile Arenópolis, Sanclerlândia and Mara Rosa orthogneisses, among others (Pimentel *et al.* 1991, Pimentel & Fuck 1992), the Sanclerlândia gneiss (828 – 822 Ma) (Laux *et al.* 2005); these plutonic rocks have been compared with primitive M-type granitoids of intra-oceanic island arcs; Nd isotopic data indicate T_{DM} ages ranging from 0.89 to 1.2 Ga and $\epsilon_{Nd}(T)$ values between +0.37 and +6.0 (Pimentel & Fuck 1992, Pimentel *et al.* 1996; Laux *et al.* 2005). In the Mara Rosa Arc, the Mutunópolis gneisses, crystallized between ca. 0.81 and 0.80, represent a sub-group of this group, displaying conspicuous inheritance in the zircon pattern and considerably older T_{DM} model ages (~2.0 Ga).
2. The second event is represented by peraluminous muscovite-bearing metagranitoids (e.g. the Creoulos Granite) generated between 790 and 786 Ma and exposed in the easternmost part of the Arenópolis arc. The $\epsilon_{Nd}(T)$ values vary from -1.8 to +3.6 with T_{DM} model ages in the interval between 1.46 and 1.1 Ga (Laux *et al.* 2005).
3. The youngest event took place between 669 and 630 Ma, being represented by the metaluminous Mantrixá

gneiss (669 Ma) and by the Turvânia, Palminópolis and Firminópolis gneisses with U-Pb emplacement ages between 637 and 630 Ma (Laux *et al.* 2005). The Nd isotopic signature is varied: the Mantrixá gneiss has positive $\epsilon_{Nd}(T)$ of +2.2 and T_{DM} age of 0.99 Ga, whereas the Turvânia-Palminópolis-Firminópolis gneisses have dominantly negative $\epsilon_{Nd}(T)$ values ranging from -15.1 to +0.3 with T_{DM} ages between 1.1 and 2.2 Ga (Laux *et al.*, 2005).

Late to post-tectonic bimodal intrusions intruded the rock units above both in the Arenópolis and in the Mara Rosa arcs. They range in age between ca. 0.63 and 0.54 Ga. In the Arenópolis arc, they are mainly metaluminous, high-K calc-alkaline to alkaline (A-type) granites associated with small gabbrodioritic bodies, whereas in the Mara Rosa arc peraluminous granite intrusions are also recognized (e.g. Faina and Amador granites).

The different episodes of plutonism in the Goiás Magmatic Arc can be recognized in the Mara Rosa area, as demonstrated in Figure 6; however, the young post-tectonic A-type granitic intrusions (ca. 0.54 – 0.52 Ga) have not been identified in Mara Rosa.

The long history of arc activity suggests successive amalgamation of magmatic arcs, either island or continental arcs, forming a long and wide composite arc terrain. It is clear now that the Goiás Magmatic Arc extends in the NNE direction underlying a large area in central Brazil. In its northern end, it is covered by the Paleo-Mesozoic sedimentary rocks of the Parnaíba Basin and similar arc rocks are also present in NW Brazil, in the state of Ceará, and in Africa in the Hoggar-Pharusian area where several neoproterozoic juvenile magmatic arcs, such as the Tilemsi and Amalaoulaou, similar to the Goiás Magmatic Arc, are

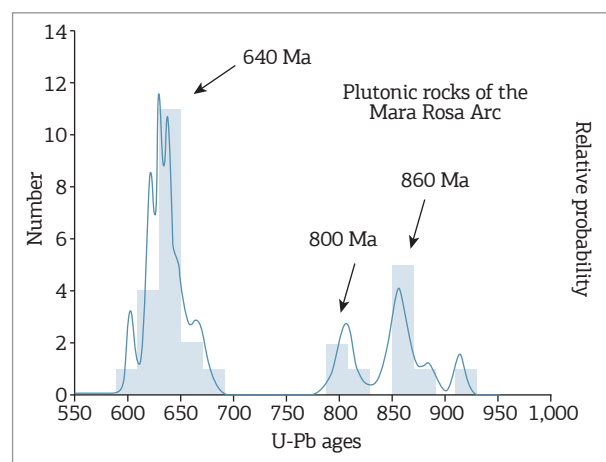


Figure 6. U-Pb ages of orthogneisses and granitoids of the Mara Rosa magmatic arc.

recognized (Caby *et al.* 1989, Dostal *et al.* 1994, Berger *et al.* 2011, Caby 2003, Cordani *et al.* 2013a, 2013b). The arc system, therefore, formed a semi-continuous belt of neoproterozoic subduction-related complexes extending for over 5,000 km, similar to the present-day arcs of the West Pacific Ocean.

Neoproterozoic high grade terrains

Uruaçu Complex

The Uruaçu high-grade Complex underlies a small area in the central part of the Goiás Massif (Fig. 7). It is a structurally complex terrain formed mainly by quartz

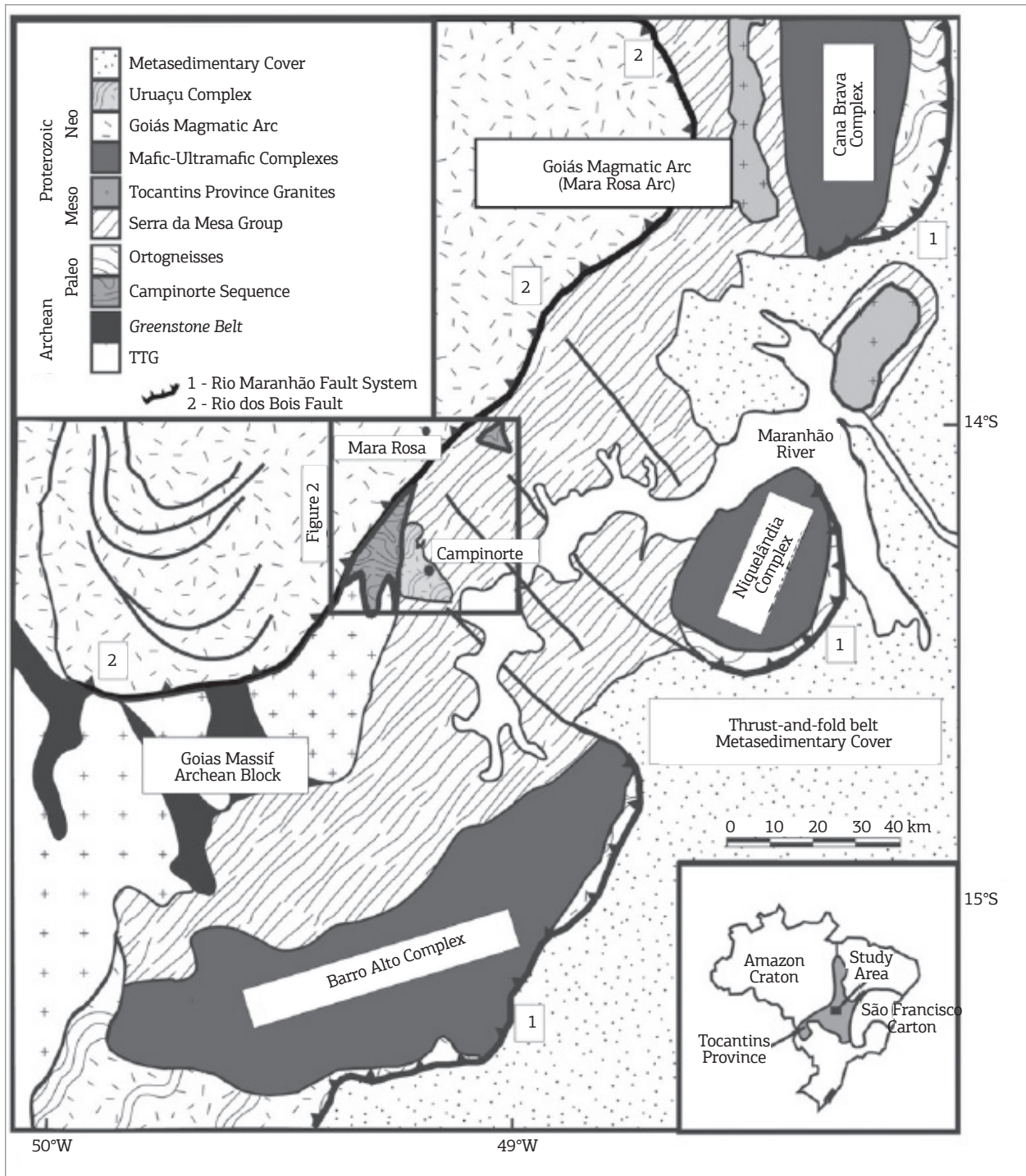


Figure 7. Location of the three large layered mafic-ultramafic complexes.

dioritic orthogneisses and sillimanite-cordierite-bearing paragneisses.

The orthogneisses are the dominant rock type in the Uruaçu Complex and are generally strongly deformed and migmatized. They are associated with mafic and ultramafic rocks consisting of garnet-amphibolite, and fine- to medium-grained schists, with cummingtonite, actinolite, talc, magnesite, garnet and clinocllore, arranged in a diablastic texture.

Paragneisses are medium- to coarse-grained banded granulites, with alternating sillimanite-cordierite rich layers and quartz-feldspar bands. They contain spinel and quartz, which is representative of ultrahigh-temperature metamorphism. Garnet-bearing quartz-feldspar-biotite-chlorite-muscovite rock is also common in the supracrustal association.

Recent U-Pb geochronological data indicated that orthogneisses, amphibolites and migmatites crystallized between ca. 690 and 651 Ma (Della Giustina *et al.* 2009b). Therefore, magmatism and high grade metamorphism took place within this 40 My time span. Detrital zircon grains for one paragneiss sample have a simple provenance pattern with ages mostly in the range between 760 and 800 Ma. This suggests that the original basin represented a syn-orogenic basin, younger than ca. 760 Ma, formed by the erosion of sources possibly within the Goiás Magmatic Arc.

Anápolis-Itaçu Complex

The Anápolis-Itaçu Complex (AIC) is exposed in the central part of the Brasília Belt. It constitutes an elongated NW-SE zone of high-grade rocks exposed between the Goiás Magmatic Arc and the lower-grade metasedimentary rocks of the Araxá Group. Geological contacts are marked by high-angle shear-zones in the northern segment of the AIC and by low-angle nappe structures in the south, thus preventing the identification of stratigraphic or cross-cutting relationships between the different rock units. Geochronological data support the interpretation that at least part of the AIC may represent high-grade equivalents of the Araxá Group (Piuzana *et al.* 2003b) and might be the exposure of the roots of the original mountain chain. The AIC includes a variety of rock types forming NW-oriented segment, in which three main rock associations may be recognized:

1. ortho- and paragneisses;
2. ortho- and paragneisses; and
3. granite intrusions.

The ortho- and paragneisses are represented by tonalitic to granodioritic gneisses, as well as by mafic rocks, exposed either as dioritic/gabbroic intrusions or as mafic-ultramafic layered

complexes made of peridotite, pyroxenite, gabbro and gabbro-anorthosite. Despite the high-grade metamorphism, relict igneous textures and compositional layering are usually observed. Geochemical data suggest a tholeiitic parental magma, with LREE enrichment and a negative Eu anomaly, and the high-Al content of relict igneous pyroxenes suggests that the intrusion took place at deep levels in the crust. Paragneisses are typically represented by aluminous granulites with variable amounts of sillimanite, garnet, spinel, cordierite and feldspar. Calc-silicate rocks and impure quartzites are also recognized. Ultrahigh temperature mineral assemblages, such as saphirine+quartz, orthopyroxene+ sillimanite+quartz, wollastonite+scapolite and hercynite+quartz, have been identified in several localities of the AIC and revealed temperatures higher than 1,100°C, at moderate pressures (~10 kbar; Baldwin *et al.* 2005; Moraes *et al.* 2002, 2006). Granite intrusions are also part of the AIC. They show variable deformational and metamorphic overprint, locally reaching granulite facies conditions (Piuzana *et al.* 2003b). Most of these granites are peraluminous, and the Nd isotopic signatures indicate that they may be represent product of anatexis of either the aluminous paragneisses of the AIC or metasedimentary rocks of the Araxá Group (Piuzana *et al.* 2003a). U-Pb zircon ages for cores and metamorphic rims are identical in some of these bodies, and, therefore, the granites are interpreted as syn-tectonic deep-crustal level intrusions (Piuzana *et al.* 2003a).

SHRIMP U-Pb ages of igneous zircon from ortho- and paragneisses including felsic and mafic rocks, as well as the intrusive granites, vary between 760 and 630 Ma, and metamorphic overgrowths are dated at ca. 650 – 640 Ma, suggesting that UHT metamorphism, emplacement of mafic magmas and anatexis were partially coeval (Piuzana *et al.* 2003b, Della Giustina *et al.* 2011). T_{DM} Sm-Nd model ages of ortho- and paragneisses fall into two age intervals, between 2.3 – 1.9 Ga and 1.7 – 1.4 Ga, and $\epsilon_{Nd}(T)$ values are negative, ranging from -9.3 to -1.4 (Piuzana *et al.* 2003a). The younger T_{DM} values are in agreement with zircon inheritance pattern observed in paragneisses (2.0 to 0.8 Ga; Piuzana *et al.* 2003a), which indicates that the Neoproterozoic Goiás Magmatic Arc, exposed to the west, might have been one of the sedimentary sources contributing to the basin (Piuzana *et al.* 2003a). The data suggest that the high-grade terrains represent the metamorphic core of the Brasília orogen.

The Barro Alto, Niquelândia and Canabrava Mafic-Ultramafic Layered Complexes

Three composite Meso-Neoproterozoic layered complexes define a 300 km long belt along the central-northern

part of the Brasília Belt (Fig. 6). Due to their geological and geochronological similarities, they have been interpreted as representative of an originally single regional-scale structure, which was disrupted during the Brasiliano event forming three individual bodies (Ferreira Filho *et al.* 1998). The three complexes consist of two magmatic systems, distinguished by their petrological and isotopic characteristics (Ferreira Filho *et al.* 1994, Ferreira Filho & Pimentel 2000, Pimentel *et al.* 2004, Ferreira Filho *et al.* 2010).

The composite intrusions are known as the Canabrava, Niquelândia and Barro Alto complexes, from north to south. In addition, previous denominations for the Mesoproterozoic layered units, exposed in the southern and central intrusions, were revisited and, accordingly, they were renamed Serra da Malacacheta and Serra dos Borges complexes, respectively (Ferreira Filho *et al.* 2010). The ages of these two magmatic systems are still controversial. Ferreira Filho *et al.* (2010), Pimentel *et al.* (2006) and Della Giustina *et al.* (2011) suggest that the western part of the complexes and the associated volcano-sedimentary sequences of Juscelândia, Indaianópolis and Palmeirópolis are mesoproterozoic in age, whereas the eastern part crystallized at ca. 780 Ma.

On the other hand, Correia *et al.* (2012) present data for the Niquelândia Complex, suggesting that both systems are neoproterozoic. According to Ferreira Filho *et al.* (1994), the Mesoproterozoic intrusions (~1.3 Ga) are composed of interlayered leucotroctolite, leucogabbro, anorthosite and occasional pyroxenite, whereas the Neoproterozoic complexes (~0.8 Ga) consist of several cyclic units of dunite, pyroxenite and gabbro, within which slices of supracrustal rocks and granite intrusions metamorphosed under high grade conditions are widespread. Trace element composition and Sm-Nd isotopic data reveal contrasting geochemical signature for both units; in the older unit, analyses attest to a depleted-mantle source for the original magmas (Ferreira Filho & Pimentel 2000, Moraes *et al.* 2003), whereas the younger association shows a large degree of crustal contamination with older sialic crust (Pimentel *et al.* 2004, 2006, Correia *et al.* 2012). To the west, the three composite bodies are in contact with Mesoproterozoic bi-modal volcano-sedimentary sequences, namely the Palmeirópolis, Indaianópolis and Juscelândia sequences, from north to south. The sequences display similar stratigraphy and consist of metapelite, calc-silicate rocks and metachert interbedded with metavolcanic rocks, consisting of fine-to-medium grained amphibolite and felsic gneiss (Brod & Jost 1991, Moraes & Fuck 1994, 1999, Ferreira Filho *et al.* 1998, Moraes *et al.* 2003). Amphibolites of the Juscelândia and Palmeirópolis sequences show positive

ϵ_{Nd} values and trace element signatures typical of MORB-like magmas, suggesting that the volcano-sedimentary sequences represent a continental rift that evolved towards an oceanic basin (Moraes *et al.* 2003, 2006). The composite mafic-ultramafic complexes, with their respective volcano-sedimentary sequences, underwent amphibolite to granulite facies metamorphism, with P and T conditions increasing progressively from west to east. Locally, ultra-high-temperature mineral assemblages are observed (Moraes & Fuck 1994, 2000, Ferreira Filho *et al.* 1998). SHRIMP U-Pb zircon analyses performed on metamorphic overgrowths constrain the age of the high-grade metamorphism in the composite layered intrusions at approximately 760 – 750 Ma (Pimentel *et al.* 2004, 2006, Moraes *et al.* 2006). Additionally, rutile U-Pb ages reveal a younger metamorphic event around 610 Ma, which is interpreted as related to the uplift of the complexes at the end of the Brasiliano orogeny (Ferreira Filho *et al.* 1994). The current structural configuration of the three composite layered complexes (Fig. 6) is ascribed to this final tectono-metamorphic episode.

DISCUSSION AND CONCLUSIONS: THE TECTONIC EVOLUTION OF THE BRASÍLIA BELT

During the last ten years, new LA-ICPMS and SHRIMP U-Pb ages, combined with Sm-Nd and, more recently, Lu-Hf isotopic data, helped to increase our understanding of the tectonic evolution of the Brasília Belt. Major breakthroughs are:

- The Goiás Magmatic Arc is a composite arc terrain made of magmatic arcs of different ages and nature; its older component, formed by calc-alkaline rocks generated in intraoceanic island arcs, was followed by two other episodes of arc activity, possibly in a active continental margin setting; the three main peaks of arc magmatism are shown in Figure 7.
- The arc system in central Brazil is more extense than what envisaged in previous models, extending for at least 4,000 km across central and northeastern Brazil and into Africa.
- The different stratigraphic units of the supracrustal sequences of the belt have distinct ages and tectonic significance:
 1. the Paranoá and Canastra groups most likely represent passive margin sequences deposited along the continental shelf of the São Francisco Craton,
 2. the Araxá and Ibiá groups are syn-orogenic deposits (back- or fore-arc deposits, younger than ca. 650 Ma), and

3. the Bambuí Group, which is as young as 550 – 540 Ma possibly, represents, at least in part, the foreland basin of the orogen.
- The three large mafic-ultramafic complexes are representative of two rift systems, one at ca. 1.25 Ga, and the younger at ca. 0.79 Ga. These ages are not common in the South America platform, and, therefore, these complexes (Barro Alto, Niquelândia and Canabrava Complexes) and associated volcano-sedimentary sequences (Juscelândia, Indaianópolis and Palmeirópolis, respectively) are interpreted as allochthonous units in the Brasília Belt evolution.
 - The high grade terrains of the Uruaçu and Anápolis-Itaçu complexes are neoproterozoic in age and represent the metamorphic cores of the orogen; the contemporaneity between the UHT metamorphism and emplacement of abundant mafic-ultramafic intrusions is noteworthy in the Anápolis-Itaçu Complex in the central part of the orogen.

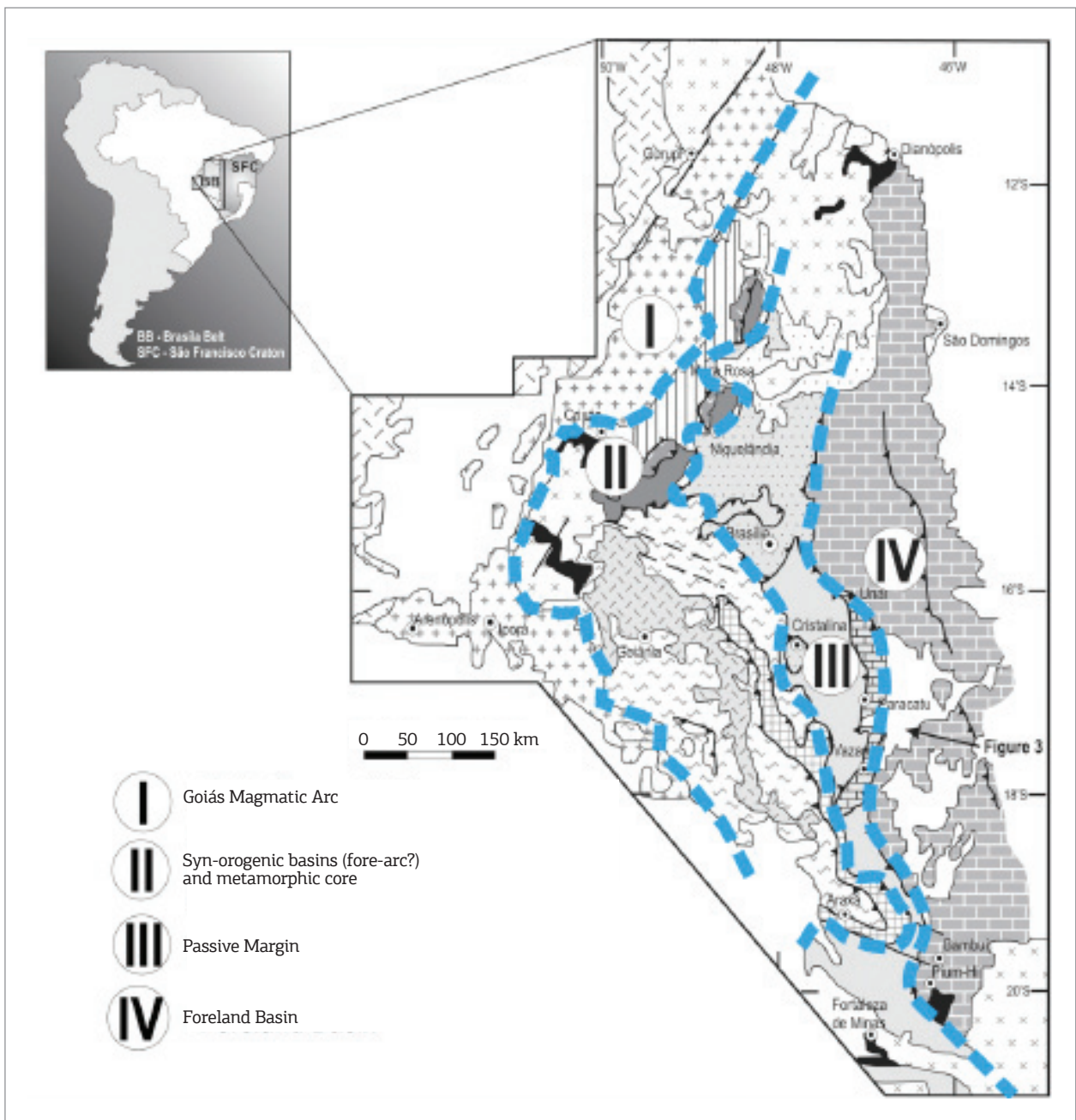


Figure 8. The different compartments of the Brasília Belt.

- The data discussed here allow, at this stage, the recognition of first order tectonic compartments of the Brasília orogen as indicated in Figure 8. The orogen records, therefore, most of the features which normally results from the closure of a wide ocean, the Goiás-Pharusian ocean, over the long period of time, between ca. 900 and 600 Ma.

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