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INVITED REVIEW

The significance of the Transbrasiliano-Kandi tectonic corridor for the amalgamation of West Gondwana

A significação do corredor tectônico Transbrasiliano-Kandi para a amalgamação do Gondwana Ocidental

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ABSTRACT: The assembly of West Gondwana was completed by the end of the Precambrian, when the Amazonian, West African, São Francisco-Congo, Kalahari and Rio de la Plata cratons, as well as the Saharan metacraton and the Parnaíba, Paranapanema and Luiz Alves cratonic fragments were united by means of the Brasiliano-Pan African orogeny, a geotectonic process that was active from the late Neoproterozoic to the early Paleozoic, related to the closure of a large oceanic domain, the Goiás-Pharusian Ocean. Several accretionary complexes and possible microcontinents were trapped within the Brasiliano-Pan African mobile belts, and they have been accommodated within a few hundred kilometers of the Transbrasiliano-Kandi tectonic corridor. The supercontinent was already formed at about 600 Ma, as indicated by the existence of a very large Ediacaran epicontinental sea covering large areas of west-central Brazil and southern Uruguay along the margins of the Amazonian and Rio de la Plata cratons, demonstrating the connection of both cratonic units at that time and making the idea of a collisional suture closing a supposed Clymene Ocean unsustainable. In the Cambrian, a major plate reorganization occurred, being responsible for the initiation of subduction of the oceanic lithosphere along an open and unconfined Pacific Ocean. The resulting Pampean Orogeny correlates nicely in time with the Saldania, Ross, and Tasmanian belts along the southern Gondwana margin. Simultaneously, extensional-type post-tectonic episodes occurred repeatedly along the Transbrasiliano-Kandi tectonic corridor.

KEYWORDS: Gondwana; tectonic corridor; supercontinent; Goiás-Pharusian Ocean.

RESUMO: *O supercontinente Gondwana Ocidental completou-se no final do Pré-Cambriano, quando os crátons Amazônico, São Francisco-Congo, Kalahari e Rio de La Plata, o metacraton do Sahara e os fragmentos cratônicos do Paranapanema, Parnaíba e Luiz Alves foram amalgamados pelos eventos da Orogenia Brasiliana-Pan-Africana, processo geotectônico ativo entre o Neoproterozoico e o início do Paleozoico, relacionado com o fechamento de um grande domínio oceânico, o Oceano Goiás-Farusiano. Neste processo, diversos complexos acrecionários e possíveis microcontinentes foram aprisionados nos cinturões móveis brasilianos-pan-africanos e foram acomodados no interior do corredor tectônico Transbrasiliano-Kandi. O supercontinente já estava formado em ca. 600 Ma, em vista da existência de vasto mar epicontinental ediacariano entre o centro-oeste brasileiro e o sul do Uruguai ao longo das margens dos crátons Amazônico e Rio de La Plata, comprovando sua conexão e tornando insustentável a ideia de uma sutura colisional fechando um suposto Oceano Clymene. No Cambriano, ocorreu uma reorganização das placas tectônicas maiores, responsável pelo início da subducção da litosfera oceânica ao longo do Oceano Pacífico aberto. O orógeno Pampeano resultante é correlativo com os cinturões análogos Saldania, Ross e Tasmaniano ao longo da margem meridional de Gondwana. Ao mesmo tempo, episódios tectônicos do tipo extensional estavam ocorrendo, repetidamente, ao longo do corredor tectônico Transbrasiliano-Kandi.*

PALAVRAS-CHAVE: *Gondwana; corredor tectônico; supercontinente; Oceano Goiás-Farusiano.*

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INTRODUCTION

Almost all studies on the formation of Gondwana suggest that the supercontinent was formed by the amalgamation of a few building blocks of different sizes, in a series of continental collisions. Most of these blocks originated from the breakup of Rodinia, covering the entire timeframe of the Neoproterozoic (Li *et al.* 2008).

Several large-scale models were put forward for the assembly of Gondwana. The simplest one describes the final amalgamation of two large continental masses, West Gondwana (made of South America and Africa) and East Gondwana (made of Antarctica, Australia, India and Madagascar), forming the Mozambique belt (Kröner 1980, McWilliams 1981, Shackleton 1996). With the progress of geological knowledge in recent years, especially in the fields of paleomagnetism and geochronology, the mechanisms of Gondwana assembly are now more precisely constrained, especially concerning the timing of the successive collisions between continental building blocks. Different models for the assembly of Gondwana were suggested, such as those by Meert (2003), Cordani *et al.* (2003), Yoshida *et al.* (2003), Collins and Pisarevski (2005), Trindade *et al.* (2006), among others.

The schematic map of Fig. 1 shows the nomenclature used in this article for supracontinental building blocks: (1) the Amazon-West African block is formed by the Amazonian and West African cratons, as well as the small São Luis craton and a possible microcontinent covered by the Phanerozoic Parnaíba basin; (2) the Central African block includes Congo-São Francisco, Rio de la Plata and Kalahari cratons, plus the Paranapanema block concealed beneath the Paraná basin and most of northern Africa, named the Saharan metacraton; (3) the Indo-Arabian block includes the Indian shield, Madagascar, Sri Lanka, and the eastern basement of the Arabian-Nubian shield; and (4) the Australian-Antarctic block includes East Antarctica and Australia, excluding the Tasman orogen. Sizes and relative positions are only indicative, and Fig. 1 should not be considered as a palinspastic reconstruction.

The main objective of this paper was to review the process of amalgamation of West Gondwana due to the convergence of the Amazon-West African and the Central African blocks, related to the closure of a large oceanic domain, the

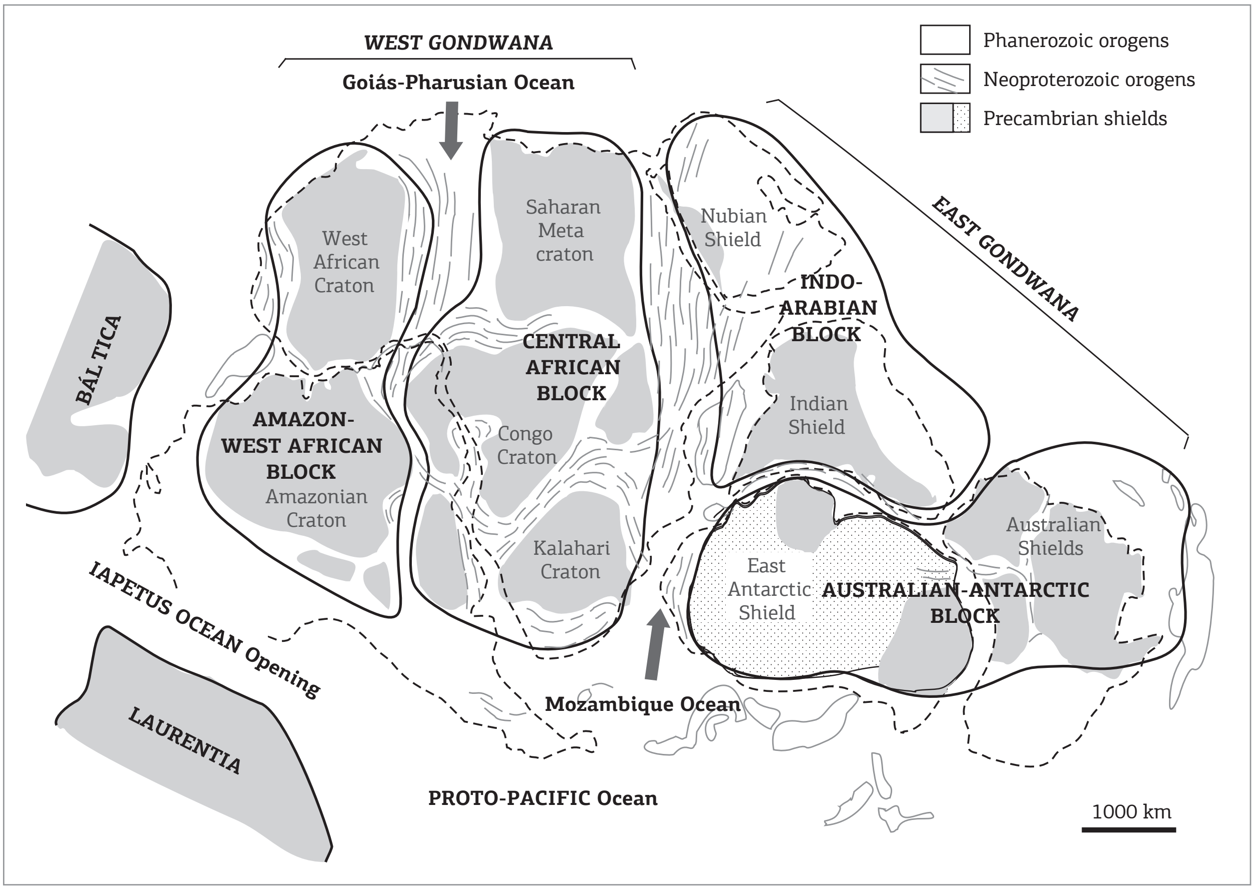


Figure 1. Crustal building blocks for the amalgamation of Gondwana, after the closing of the Goiás-Pharusian and Mozambique oceans. Location of the Iapetus Ocean between SW Gondwana, Laurentia and Baltica, and location of the Proto-Pacific Ocean before the onset of the subduction of the Pacific Plate.

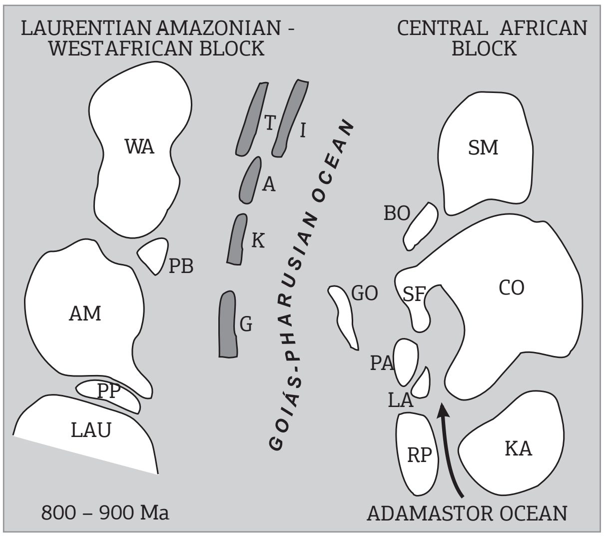
Goiás-Pharusian Ocean. From our point of view, this was responsible for the Brasiliano-Pan African orogeny, a geotectonic process that was active in the late Neoproterozoic. We will also review the alternative scenario proposed by Trindade *et al*. (2006), as well as Tohver *et al*. (2012), arguing that the final assembly of Gondwana would have occurred in the Cambrian, as a result of the closure of a different ocean, called Clymene. This topic, which is relevant to the age of amalgamation of West Gondwana, will be briefly discussed in the appropriate chapter.

GEOTECTONIC SETTING OF WEST GONDWANA

The Amazon-West African block and the Central African block (Fig. 1) are formed by several juxtaposed continental nuclei, which are residual fragments from the disruption of Rodinia, in a process that started around 900 Ma, and finished only at *ca*. 570 Ma, when Laurentia was finally separated from the Amazon-West African block, with the formation of the Iapetus Ocean (Meert 2003, Li *et al*. 2008, among others). However, the disruption of Rodinia is not free of controversy. For example, based on a great deal of geochronological and tectonic evidence, Cordani *et al*. (2003) and Kroener & Cordani (2003) suggested that the Central African block may have never been part of Rodinia. Tohver *et al*. (2006) reached a similar conclusion based on their review regarding the available paleomagnetic data from Africa and South America.

The position of the Goiás-Pharusian Ocean (Kröner & Cordani 2003), where intraoceanic island arcs were formed at about 850 – 900 Ma, is indicated in Fig. 2, adapted from Cordani *et al*. (2013). In many paleomagnetic reconstructions, such as those by Meert (2003) or Cordani *et al*. (2003), this ocean was named "Brasiliano", or sometimes "Adamastor". A more restricted Adamastor Ocean (Hartnady *et al*. 1985), located along the western-southwestern boundary of the Central African block, is illustrated in Fig. 2. Its formation and disappearance are related to initial rifting, followed by dispersion, and later the reassembly of two important cratonic nuclei, Kalahari and Rio de la Plata, and some smaller cratonic fragments, such as Paranapanema and Luís Alves, against the larger Congo-São Francisco craton. Although data from the early arc assemblages in the Adamastor Ocean yielded juvenile signatures for *ca*. 800 Ma granitoids (Tupinambá *et al*. 2012), its extension seems to be much more restricted than the ones of Goias-Pharusian Ocean due to the confined nature of the Araçuaí Orogen.

As a consequence of the subduction of oceanic lithosphere related to the closure of the Goiás-Pharusian Ocean, several accretionary complexes and possible microcontinents were trapped within mobile belts formed during the Neoproterozoic collisional events. The tectonic process was extremely complex, leading to the formation of several sutures. The mobile belts were the result of the Brasiliano-Pan African orogeny, and are now exposed in very large areas of West Africa and South America. They may be classified into two types of orogenic units, showing different ages, tectonic environments and evolution:



Cratons: AM = Amazonian; CO = Congo; KA = Kalahari; LAU – Laurentia; RP = Rio de La Plata; SF = São Francisco; SM = Sahara metacraton; WA = West African. Smaller cratonic fragments: BO = Borborema; GO = Goiás Central Massif; LA = Luiz Alves; PA = Paranapanema; PB = Parnaiba; PP = Pampia. Intra-oceanic magmatic arcs: A = Amalaoulaou; G = Goiás; I = Iskel; K = Kabyé; T = Tilemsi. Adapted from Cordani *et al.* (2013).

Figure 2. Major tectonic elements related to West Gondwana at about 800 – 900 Ma ago, prior to the final amalgamation.

1. An older component (dated at 950 – 650 Ma) made of magmatic and sedimentary assemblages, many of which have mantle-derived intraoceanic features, constituting accretionary-type orogenic belts. They essentially comprise plutonic-volcanic magmatic associations, which are exposed at upper-middle crustal levels, such as the Iskel, Tilemsi, Amalaoulaou, Kabyé and Goiás magmatic arcs, trapped between the Amazon-West African and the Central African blocks (Dostal *et al*. 1994, Caby 2003, Laux *et al*. 2005, among others). The tectonic evolution is coeval with that of the Arabian-Nubian Shield, whose intraoceanic magmatic arcs are exposed between the Central African and Indo-Arabian blocks;
2. A younger component (dated at *ca*. 700 – 520 Ma) formed by the collage of orogenic belts located along the cratonic margins, comprising reworked basement plus collisional fold-and-thrust and metamorphic belts. They consist of metasedimentary and metavolcanic rocks,

which were intruded by large amounts of granitoid rocks, exposed at deep to shallow crustal level, and were tectonically affected by a protracted Brasiliano-Pan African orogeny. These tectonic units may include oceanic assemblages, such as ophiolites, accretionary prisms and island-arc magmatic suites, and in some places HP, UHP and UHT metamorphic assemblages. Examples are the Trans-Saharan, Dahomeyan, Brasília and Paraguay belts (Fig. 3).

In addition, the Gondwana Supercontinent was subjected to widespread Ediacaran-Cambrian tectono-thermal reactivation in almost all regions that were previously affected by the Neoproterozoic accretionary, collisional or intracontinental orogenies, be it within the mobile belts of that age or at the marginal parts of cratonic areas. This tectono-thermal overprint is also detected over very large areas, such as the Saharan metacraton in Africa and its counterpart in South America, within the Borborema Province.

CLOSURE OF THE GOIÁS-PHARUSIAN OCEAN

The Goiás-Pharusian Ocean occupies a very large area and includes many intraoceanic magmatic arcs, whose tectonic evolution started as early as *ca*. 900 Ma. Approximately 300 Ma later, this ocean closed due to successive continental collisions, which sutured the West African Craton against the Saharan metacraton (Abdelsalam *et al*. 2002) in the north, and the Amazonian against the São Francisco Craton in the south.

The several Brasiliano-Pan African orogenic belts, which were created in this process, are aligned along a very long corridor in South America and Africa that is dominated by a megashear zone, which is one of the major tectonic elements in the world. Schobbenhaus (1975) coined the name "Transbrasiliano lineament" in his compilation of the tectonic map of Brazil, showing that this structure crosses a large part of the continent, from northeast Brazil down to Paraguay and Argentina. Caby (1989), Trompette (1994), Fairhead & Maus (2003), Santos *et al*. (2008), among many others, have shown that it extends to Africa, where it crosses the western part of the continent, from Togo to Algeria, along the Hoggar 4º50'-Kandi shear system (Fig. 3). The megashear is formed by a series of ductile shear zones, which occur in very large areas. It probably reaches the bottom of the lithosphere, and the shear zone motion must have started shortly after the closure of the Goiás-Pharusian Ocean, taking advantage of the several weak lithospheric zones formed during continental collisions. All collisional sutures related to the Brasiliano-Pan African belts are accommodated within a few hundred kilometers of the lineament, in a region that will be referred to as the Transbrasiliano-Kandi tectonic corridor.

The coherence of the lineament is clearly marked by the strong linear magnetic anomalies obtained from the CHAMP satellite survey and reported by Fairhead & Maus (2003). Within the Trans-Saharan and Dahomey belts of West Africa, a string of positive gravimetric anomalies, locally associated with linear magnetic anomalies, is observed near the margin of the West African craton, associated with a series of mafic and ultramafic massifs. Their tectonic significance may be attributed to the rise of mantle diapirs, which indicate the position of Neoproterozoic suture zones (Trompette 1994). In South America, the lineament is clearly visible in the aeromagnetic mosaic of central and northeast Brazil, forming a series of low amplitude magnetic anomalies, which can be traced across the country from NE to SW. Elongated gravimetric and aeromagnetic anomalies along the main trend of the lineament have also been observed in Brazil, such as a strong anomaly observed within the Parnaíba basin, associated with the main depocenter of the Paleozoic sedimentary sequences (Nunes 1993).

THE BORBOREMA PROVINCE AND THE TRANS-SAHARAN BELT

The Saharan metacraton, named by Abdelsalam *et al.* (2002), is not well defined. It is characterized as a large portion of cratonized continental crust of the pre-Neoproterozoic age dominated by medium to high-grade gneissic and migmatitic terrains, which were highly remobilized during the Pan-African orogeny. These authors interpreted the evolution of this tectonic unit as an initially coherent cratonic mass that was subjected to a widespread extensional tectonic regime, which caused, possibly during the early Neoproterozoic, pervasive rifting and the formation of narrow oceanic basins. These basins closed during the late Neoproterozoic, forming a collage of continental blocks. The aforementioned tectonic evolution seems to be similar to the one described for the basement of the central part of the Borborema Province of Brazil, where the Archean to Paleoproterozoic sialic basement (Brito Neves *et al*. 2000, Van Schmus *et al*. 2008, among others) underwent widespread Neoproterozoic rejuvenation and pervasive granite magmatism.

In Fig. 4, the dividing line between the Trans-Saharan belt and the Saharan metacraton established by Abdelsalam *et al*. (2002) is the Raghane shear zone, located in the eastern part of the Tuareg Shield (Liégeois *et al*. 1994; 2000), where the Barghot and Aouzegueur terranes

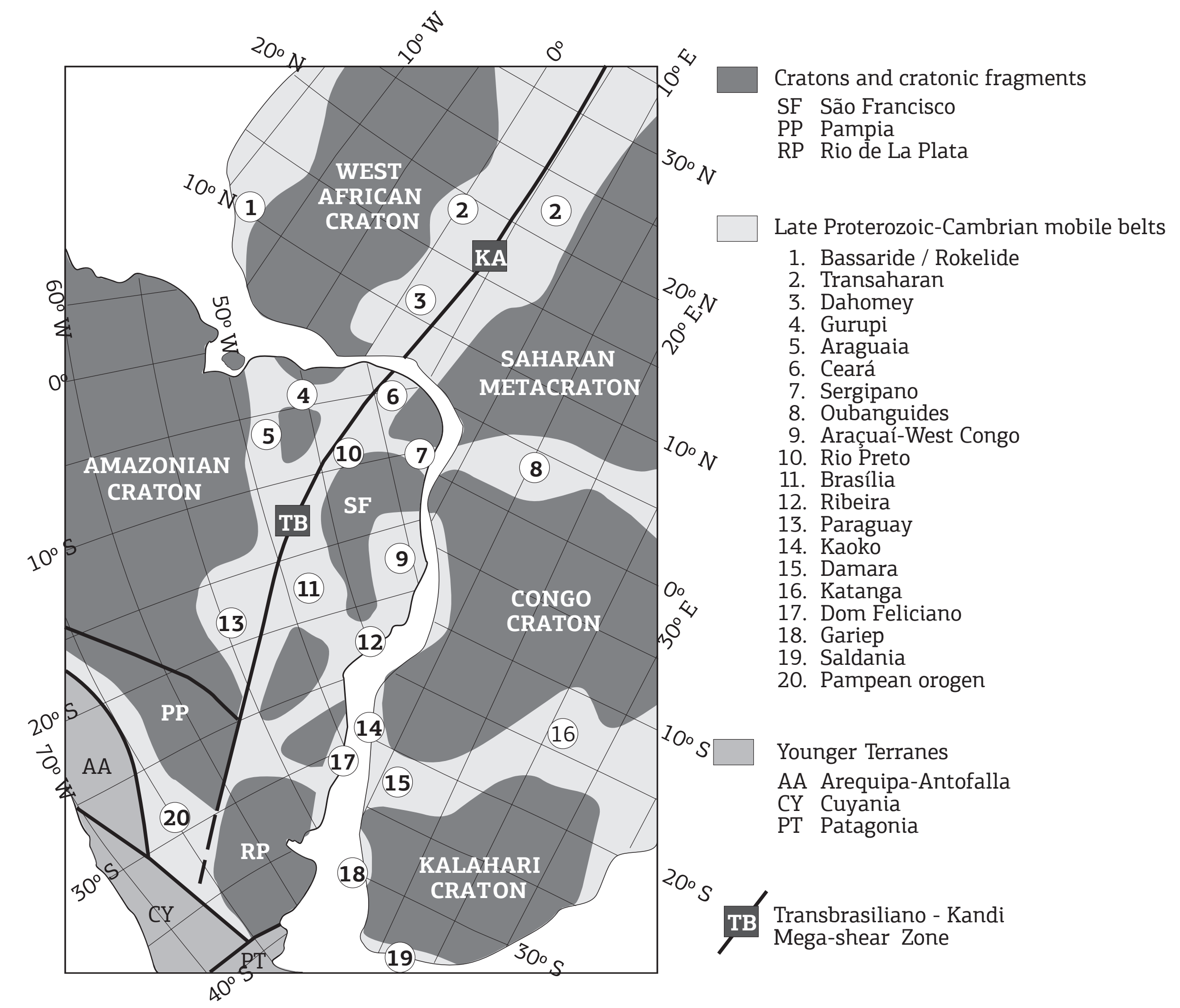


Figure 3. Outline of the Transbrasiliano-Kandi mega-shear zone in a late Paleozoic pre-drift reconstruction of South America and Africa, with the relative position of cratons, cratonic fragments and late-Proterozoic-Cambrian mobile belts. Adapted from Cordani *et al.* (2013).

have been thrust from west to east across a rigid cratonic block. The Raghane shear zone extends to the south, cutting through the Air Massif and disappearing beneath undeformed Phanerozoic rocks. Although we acknowledge the need for better control and additional evidence, we propose that the dividing line between the Dahomeyan belt and the Saharan metacraton, as a continuation of the Raghane shear zone, could be represented by the important lineament at the eastern limit of the "Nigerian schist belt", which marks the boundary between the western and eastern Nigeria terranes, as depicted by Arthaud *et al*. (2008). Also in Fig. 4, along the eastern side of the West African craton, there are two typical marginal sequences deposited at the boundary of the cratonic region and facing an eastern ocean. These are the Gourma and Volta basins, in which there are several kilometres thick sedimentary sequences accumulated. The deposits are mainly flyschoid material made up of siltstones, shales and greywackes, with some intercalation of carbonatic rocks with stromatolites, which indicate the late Neoproterozoic age (Trompette 1994).

Early Neoproterozoic (*ca*. 870 – 700 Ma) oceanic terranes have been identified in many parts of the Trans-Saharan belt (Fig. 4), from the Hoggar to the Dahomeyan segments (Caby 1989; 2003, Berger *et al.* 2011). In Hoggar, in the Silet region (Algeria), diorite-tonalite and monzogranite plutons from the Iskel island arc yielded U-Pb zircon ages of *ca*. 868 and 839 Ma. The occurrence of slices of pre Pan-African basement directly overlain by shelf sediments and capped by volcanic arc rocks in several localities suggests that the Iskel magmatic arc was built on attenuated continental crust, adjacent to possible slices of oceanic lithosphere (Lapierre *et al.* 1986, Caby 2003). Further to the south, in the Gourma

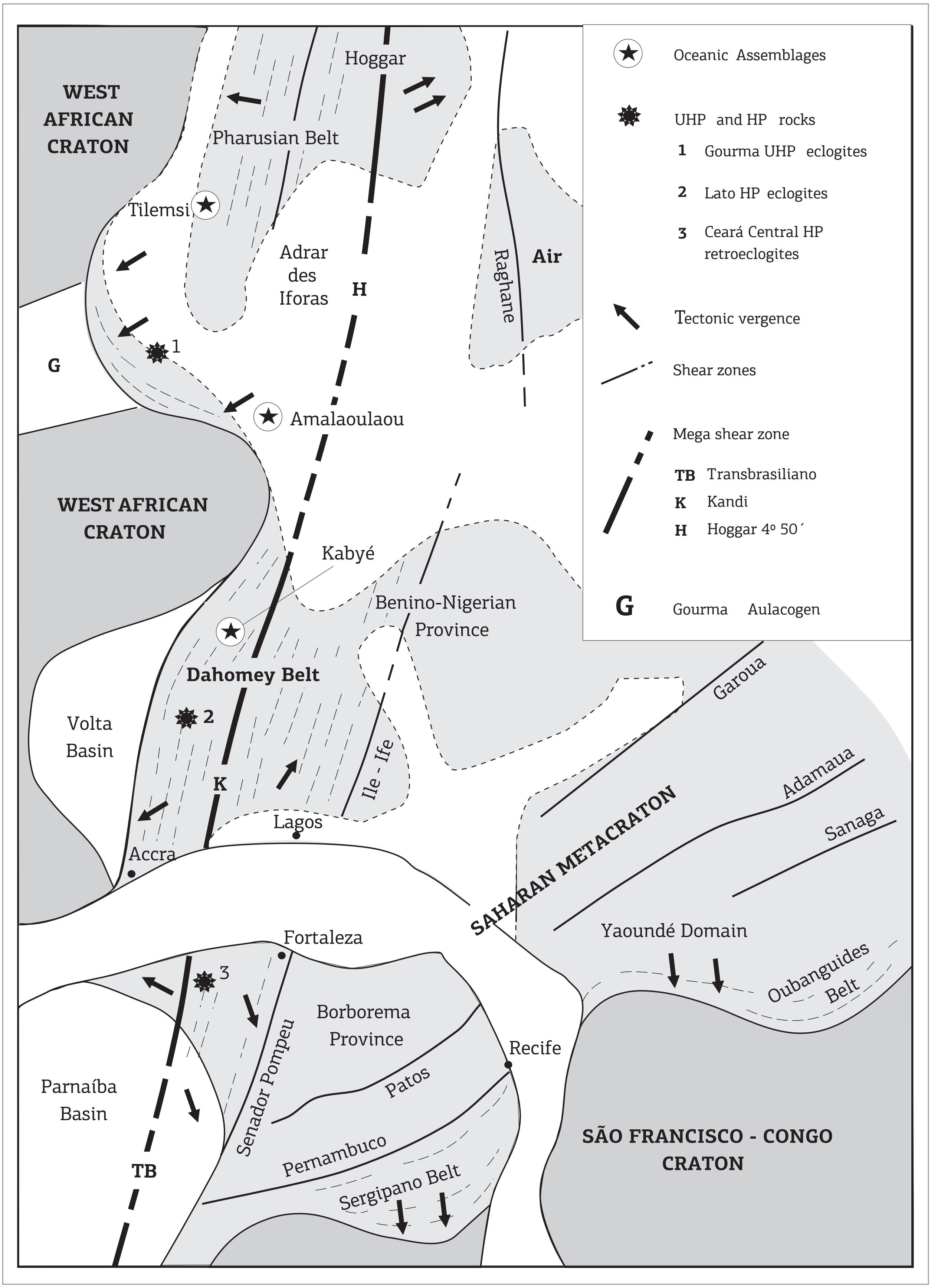


Figure 4. Geological correlations between north-eastern South America and north-western Africa, in a late Paleozoic pre-drift reconstruction.

region (Mali), the Tilemsi-Amalaoulaou intraoceanic arc assemblages (Dostal *et al*. 1994) were dated at *ca*. 790 – 710 Ma, and the Tilemsi arc is considered as the upper crust superstructure, equivalent to the Amalaoulaou complex (Berger *et al*. 2011). Although there are not enough precise geochronological data for the Kabyé massif in the Dahomeyan belt (Togo), geochemical and field characteristics suggest that this massif may be the continuation of the Iskel-Tilemsi-Amalaoulaou intraoceanic arc system (Duclaux *et al*. 2006). The late Neoproterozoic Andean-type active continental margin, which produced extensive arc plutonism, is located east of the oceanic terranes. This stage of ocean-continent subduction was dated at 696 ± 5 Ma in the Kindal terrane and 716 ± 6 Ma in the Adrar des Iforas region, in Mali (Bruguier *et al*. 2008), indicating that it was partially coeval with the ocean-ocean subduction active further west.

To the south, the Dahomey belt is characterized by a complex thrust stack and suture, representing the convergence and subsequent collision between the Benino-Nigerian province, part of the Saharan metacraton, and the West-African craton. This belt comprises a series of metasiliciclastic rocks (quartzites and schists) from the Atakora and Kante units, but it also contains high-grade metamorphic rocks (up to eclogite facies) with mafic and ultramafic protoliths (Agbossoumondé *et al*. 2001). In Benin, possible arc-type granitoids related to the consumption of the Pharusian Ocean were dated at *ca*. 660 – 650 Ma (Kalsbeek *et al*. 2013).

The subsequent closure of the Pharusian oceanic domain, by means of a continent-continent collision (Himalayan-type orogen), is constrained by the presence of UHP and HP rocks in the Trans-Saharan orogenic belt (Fig. 4). In the Gourma region, coesite-bearing eclogites (up to 25 kbar) and blueschists have been identified (Caby 1994, Jahn *et al*. 2008). Geochronological studies on these rocks indicated the age of eclogitization at *ca.* 620 Ma. Eclogites (*ca.* 19 kbar) and HP granulites have also been described in Togo (Attoh 1998, Agbossoumoundé *et al*. 2001). Geochronological ages of these rocks are scarce. However, a single Pb-Pb zircon age of 612 ± 1 Ma obtained from a HP granulite (Affaton *et al*. 2000) suggests that collision was already going on at that time in this sector of the Trans-Saharan orogenic belt.

As shown in Fig. 3, the central part of the Borborema tectonic province in Brazil is very probably the counterpart of the Saharan metacraton of northern Africa. The northwestern part of this province has been correlated with the Trans-Saharan domains of West Africa for many years (Torquato & Cordani 1981, among many others). In particular, the region close to the Transbrasiliano lineament in northeast Brazil, represented by the Médio Coreaú and Ceará Central domains (Figs. 4 and 5), is considered to be the counterpart of the Dahomeyan rocks in Togo and Benin along the area of the Kandi lineament (Caby 1989, Arthaud *et al*. 2008). In that region, evidence of pre-collisional magmatic assemblages (intraoceanic and Andean-type settings) is still scarce. However, an important period of crustal growth at 900 – 700 Ma can be inferred from the record of detrital zircon grains from the regional supracrustal rocks (Ganade de Araújo *et al*. 2012); the presence of abundant grains spanning the entire interval of about 200 Ma allows us to infer the presence of a long-lived active continental margin, where subduction-related magmatism had been ongoing since the beginning of the Neoproterozoic.

In the Ceará Central domain, east of the Transbrasiliano lineament (TB, from now on), the Tamboril-Santa Quitéria Complex, a large area formed by different types of 640 – 610 Ma old granitoid rocks and migmatites, was described as a continental magmatic arc by Fetter *et al.* (2003). Van Schmus *et al.* (2011) indicate the age of collision at *ca.* 610 – 590 Ma. However, Amaral *et al*. (2010) reported ages of *ca*. 650 – 630 Ma for some high-pressure metamorphic rocks also located east of the lineament, in the Forquilha Eclogite Zone (Fig. 5). These ages have been interpreted as being related to the eclogite formation, and suggest that the continental collision may have taken place earlier. More recently, however, Amaral *et al*. (2012) reported ages between *ca*. 613 and 590 Ma for the metamorphism of granulite facies in mafic granulites of the nearby Cariré area, and therefore the precise age of continental collision remains controversial. After isostatic uplift, cooling, and denudation, the mobility and tectonic activity along the megashear continued for a long time.

Considering the continuity of major faults, the similarity of regional lithostratigraphic trends and the westward polarity of structural features, the correlation between the Trans-Saharan belt and the northwestern part of the Borborema Province is highly probable. However, as pointed out by Santos *et al*. (2008), the eclogites and related rocks of the Hoggar, as well as the HP metamafic rocks of the Dahomeyides, were located west of the Kandi-Hoggar 4°50' lineament, but UHP or HP metamorphic rocks were not identified in the Médio Coreaú domain. On the other hand, the known high-grade metamorphic rocks occurring in the Ceará Central domain are located to the east of TB.

THE BRASÍLIA BELT, THE GOIÁS MAGMATIC ARC AND THE PARAGUAY BELT

The Brasília Belt, in central Brazil, presents unequivocal evidence indicating the closure of the long-lived

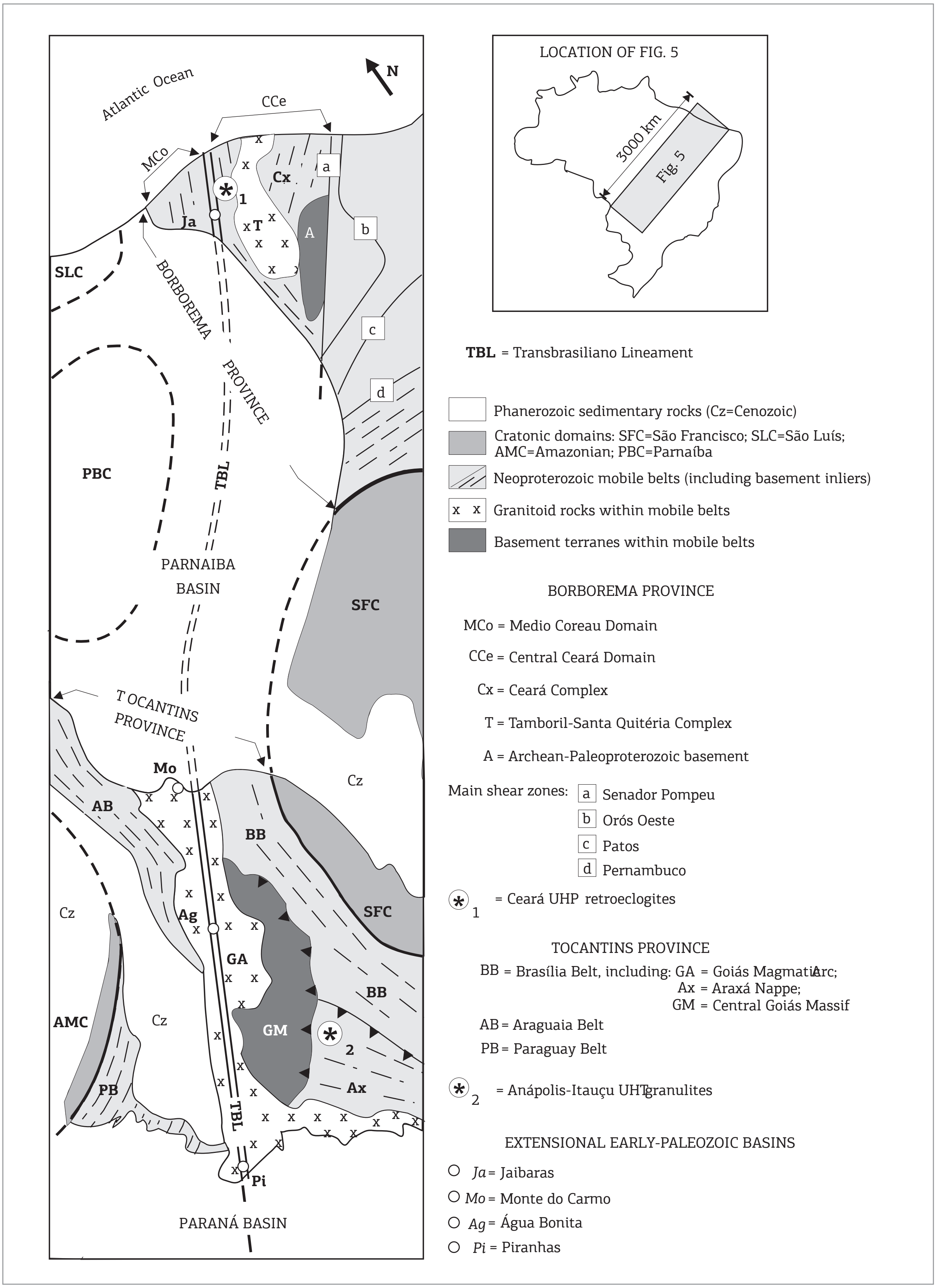


Figure 5. Main tectonic elements within the Borborema and Tocantins provinces and the Parnaíba Basin, in South America, in the vicinity of the Transbrasiliano Lineament.

(900 – 630 Ma) Goiás Ocean at *ca*. 630 Ma. The belt is one of the largest and better preserved Neoproterozoic orogenic belts in Brazil (Pimentel *et al*. 2000), comprising: (i) a thick Neoproterozoic metasedimentary pile, including the Paranoá, Canastra, Araxá, Ibiá, Vazante, and Bambuí groups, mostly overlying Paleoproterozoic and occasionally Archean basement at the western margin of the São Francisco Craton; (ii) the Goiás Massif, a microcontinent (or allochthonous sialic terrain) composed of the Archean Crixás-Goiás granite-greenstones and associated Proterozoic formations; and (iii) the large juvenile Neoproterozoic Goiás Magmatic Arc in the west (Fig. 5).

The several low to medium-grade supracrustal rock units of the Neoproterozoic metasedimentary pile show tectonic vergence to the east, towards the cratonic area (Dardenne 2000) and metamorphic grade increases westward. Recent zircon provenance data suggest that some of these units (e.g., the Ibiá, Araxá and part of the Serra da Mesa groups) were deposited and deformed within a short interval between *ca*. 650 and 630 Ma (Pimentel *et al*. 2011). Moreover, a Neoproterozoic ophiolitic mélange has been identified in the Araxá Group as a representative of the oceanic crust (Strieder & Nilson 1992).

In the western part of the Brasília belt, a large area formed of Neoproterozoic juvenile crust records the closure of a large oceanic domain between the Amazonian and São Francisco paleocontinents from at least *ca*. 900 to 600 Ma (Pimentel & Fuck 1992). This is known as the Goiás Magmatic Arc, which represents one of the most important tectonic components of the Brasília Belt (Fig. 5). It is divided into the Arenópolis arc to the south, and the Mara Rosa arc to the north, comprising: (i) juvenile island-arc (*ca.* 900 – 800 Ma; e.g., Mara Rosa and Arenópolis sequences), volcanic-sedimentary sequences associated with mantle-derived tonalite-granodiorite-granite orthogneisses; and (ii) younger (*ca.* 650 – 630 Ma) continental arc-type volcano-sedimentary sequences intruded by a series of tonalite-granodiorite plutonic complexes (Junges *et al*. 2002, and references therein). The juvenile signature of the older metavolcanic and metaplutonic rocks with tholeiitic to calc-alkaline signature is demonstrated by their low initial $^{87}Sr/^{86}Sr$ isotopic ratios, positive ε_{Nd} values and Sm-Nd T_{DM} model ages mostly between 0.8 and 1.1 Ga (Laux *et al*. 2005, and references therein). Tonalite and granodiorite of the younger arc association have older Nd T_{DM} model ages and slightly negative ε_{Nd} values, suggesting a continental arc setting for this magmatic event. For the amalgamation of Gondwana, the intraoceanic magmatic arcs were fused together by a series of soft collisions, and granitoid magmatism persisted during the tectono-magmatic episodes of the Brasiliano orogeny (Pimentel *et al.* 2000). The predominant calc-alkaline composition of these magmatic rocks indicates the action of continued subduction-related active margin processes.

It is not an easy task to identify the main sutures related to the closure of the Goiás Ocean, and the available geophysical evidence is just starting to reveal some important discontinuities. Deep crustal and lithospheric studies using seismic tomography (Assumpção *et al*. 2004, Feng *et al*. 2007), as well as deep seismic refraction and teleseismic receiver function investigations (Soares *et al*. 2006, Ventura *et al*. 2011) were conducted over the surface outcrops of the Goiás Magmatic Arc, where a large positive Bouguer anomaly occurs along the TB. The hot and dense lithospheric mantle underlying the magmatic arc, where the crust is only 36 – 38 km thick, compensates this Bouguer anomaly. To the east, crustal thickness increases to up to 43 km below the marginal Brasília belt and the western part of the São Francisco craton. Westwards, seismological data show an abrupt 16 km step in the Moho discontinuity in the passage from the Goiás arc to the Araguaia belt and the Amazonian craton. Such structure is considered as the result of the duplication of the lower mafic crust of the Amazonian paleoplate during late Neoproterozoic subduction below the Goiás magmatic arc (Ventura *et al*. 2011). In this context, the Serra Azul Archean metamorphic rocks are interpreted as an obducted sliver of the Amazonian craton basement (Soares & Fuck 2011). The geochronological evidence that is available so far indicates that the main subduction event ended at *ca*. 630 – 600 Ma, and that the main regional metamorphic peak occurred at *ca.* 650 – 630 Ma, as recorded by the granulites of the Anápolis-Itauçu Complex indicated in Fig. 5 (Della Giustina et al., 2009), as well as by several other rock units of the Brasília Belt (Baldwin & Brown 2008, and references therein). In this granulite complex, UHT sapphirine-bearing rocks yielded U-Pb metamorphic ages of *ca*. 650 Ma, which are roughly coeval with the emplacement of mafic-ultramafic complexes, thus representing the metamorphic core of the Brasília orogen (Piuzana *et al*. 2003).

The Paraguay Belt (location in Fig. 3) is a typical fold-and-thrust belt located along the southeastern margin of the Amazonian Craton (Alvarenga *et al*. 2000, Campanha *et al*. 2011). It is affected by tectonic deformation, which is almost imperceptible at the border of the craton, but increases up to tight isoclinal folds towards its inner areas. It comprises the older Cuiabá Group, including glacial sediments of the Puga Formation, and the younger Corumbá Group, comprising carbonates and pelites with Ediacaran-age fossils (Boggiani *et al*. 2010). The Cuiabá Group was affected by low-grade metamorphism, up to the biotite zone of the greenschist facies.

Within the Cuiabá Group, some "cap carbonates" of the Araras Group, directly overlying diamictites of the Puga Formation, were dated at *ca.* 630 Ma (Babinski *et al.* 2006). In addition, in Planalto da Serra, Mato Grosso, DeMin *et al.* (2013) reported $^{40}Ar/^{39}Ar$ dating on phlogopite, as well as additional Rb-Sr and Sm-Nd ages, for high-K ultramafic rocks, plugs and dykes affecting an area about 30 km long, intrusive into the low-grade metasedimentary rocks of the Cuiabá Group. Their ages, close to 600 Ma, represent the minimum age for the deposition and deformation of this unit. Later, during Cambrian, the Cuiabá Group was thrust over the Corumbá Group in a thin skin deformation, basically westerly directed. Moreover, rocks of the upper part of the Corumbá Group, located farther to the west, were virtually undeformed and unconformably deposited on the sialic basement of the Amazonian Craton. A final regional deformational phase of very low intensity, extensional in character and related to a few intrusions of granite bodies, took place during the Cambrian, or even later.

The sedimentary environment of the Corumbá Group is generally attributed to a restricted marine shelf within an epicontinental sea overlying the southeastern margin of the Amazonian Craton, and the resulting deposits correlate with the sedimentary filling of the nearby Tucavaca aulacogen, in Bolivia. Some other sedimentary sequences that are similar in age and tectonic setting to the Corumbá Group have been recently attributed to the Ediacaran and seem to represent very extensive marine transgressions, in a general context of epicontinental seas. For example, recent geochronological data by Pimentel *et al.* (2011) for the Bambuí Group in the western part of the São Francisco Craton suggest Ediacaran (*ca.* 600 Ma or younger) depositional ages for this foreland sequence. Moreover, Gaucher *et al.* (2003, 2008, 2009) and Poiré & Gaucher (2010) demonstrated the existence of a very important close correlation of the Corumbá Group with the Arroyo del Soldado Group, in Uruguay, which practically have the same stratigraphy and the same fossiliferous content of the Ediacaran age. They would therefore belong to the same continental shelf, along the margins of the Amazonian and Rio de la Plata cratons, and this reasoning is a powerful paleogeographic indicator for a connection of these two cratonic units in the Ediacaran.

The Amazonian-Rio de la Plata link in the Ediacaran is the main argument to deny the existence of oceanic lithosphere in central South America, as proposed by Trindade *et al.* (2006) and Tohver *et al.* (2012). In the latter, the suture resulting from the collision between the Amazonian and São Francisco-Congo cratons and the closure of a supposed Clymene Ocean is crossing the entire South American continent. These authors reviewed the tectonic history of the Pampean, Paraguay, and Araguaia belts along the margins of the Amazonian and Rio de la Plata cratons, and tried to demonstrate that these belts were tectonically active from the late Ediacaran to the late Cambrian, as the final stages of Gondwana formation.

In addition to the already mentioned close correlation between the Corumbá and the Arroyo del Soldado groups, located along the same Ediacaran continental shelf, which precludes the existence of a wide ocean, a few other arguments against the idea of a Clymene Ocean in central South America were presented and discussed with the pertinent details in Cordani *et al.* (2013). Some of them are briefly summarized here:

1. The most important evidence for the hypothesis of the Cambrian Clymene Ocean, the Puga paleopole, is located at low latitude, not far from the present pole, and therefore could be related to a younger remagnetization.
2. The assembly of West Gondwana was completed by *ca.* 600 Ma, After this, there is no geological evidence of an oceanic lithosphere (e.g., ophiolites, magmatic arcs etc.) in central South America.
3. The tentative correlation between the Pampean and Paraguay belts cannot be accepted, because their tectonic significance is totally different. There is no similarity in lithology, metamorphism, or structural trends.
4. The Araguaia Belt started as a Neoproterozoic intraplate aulacogenic-type basin, formed over an ancient sialic basement, which may have extended into a premature oceanic stage with limited width, with the possibility of once having been connected to the main Goiás-Pharusian Ocean.

EDIACARAN/CAMBRIAN TECTONIC EVOLUTION IN SOUTHERN WEST GONDWANA

The Goiás-Pharusian Ocean closed at the end of the Neoproterozoic, and from then on, West Gondwana became a single continental mass (Cordani *et al.* 2013). After the probable uplift following the Brasiliano-Pan African orogeny, orogenic collapse and extension took place not only within the Transbrasiliano tectonic corridor, but also in adjacent areas. Simultaneously, a major spreading center was developing between West Gondwana and Laurentia, which led to plate reorganization, responsible for the initiation of convergence along the Pacific margin of Gondwana.

Cawood (2005) suggested that the subduction of the Pacific oceanic lithosphere occurred at the Gondwana margin at *ca.* 570 Ma. The name "Terra Australis Orogen" was proposed for a very large tectonic province located along the southern margin of Gondwana, forming an open and unconfined Pacific Ocean and comprising several accretionary orogens. The Pampean orogeny (Ramos 1988, Rapela *et al*. 1998) is the South American representative in Terra Australis. According to Ramos (1988), the Eastern Pampean ranges, in which high-grade metamorphic rocks are recognized, were formed as a result of normal subduction of oceanic lithosphere, followed by continent-continent collision between the Rio de la Plata Craton and the Pampia microcontinent. Geochronological data indicate a Cambrian age for the entire tectonic development of the Pampean orogen, which correlates in time with the Saldania, Ross, and Tasmanian companion belts of Terra Australis (Cawood 2005, Schwartz *et al*. 2008).

Escayola *et al*. (2011), dealing with the study of the Pampean orogen, summarized the available lithological, stratigraphic, and structural knowledge of the Puncoviscana formation in northern Argentina and presented conclusive evidence for its syntectonic character as an accretionary complex. They showed that the orogenic process had already started in the Ediacaran, around 560 Ma, being tectonically active during most of the Cambrian, until at least 520 Ma. As already mentioned, this period was marked by the subduction of the Pacific oceanic lithosphere, which produced tectonic compression and regional metamorphism, associated with voluminous granite magmatism of orogenic and subduction-related nature (Ramos 1988, Rapela *et al*. 1998). Given the time involved, 560 – 520 Ma, the Pampean orogenic system is much younger than the Neoproterozoic collisional belts responsible for closing the Goiás-Pharusian Ocean.

While subduction was going on at the southern part of Gondwana, extensional post-tectonic episodes occurred along the Transbrasiliano-Kandi megashear, and the overall extensional tectonic scenario in central Brazil clearly contrasts with that of the coeval compressional scenario of the Pampean orogen, in Argentina. Extensional tectonic reactivation occurred repeatedly at specific intervals along the megashear. The Kandi-Hoggar 4°50 lineament in Africa cuts through the region of the Pan-African Trans-Saharan orogen and is covered, in some parts, by relatively young and shallow cratonic covers (Fig. 4). In South America, TB crosses the entire Borborema and Tocantins tectonic provinces, and it also cuts through the basement of three large and relatively thick cratonic basins, the Parnaíba, to the north, and the Paraná and Chaco-Paraná, to the south (Fig. 5). As indicated by Cordani *et al*. (2013), when TB leaves the Parnaíba Basin, immediately to the southwest of it, the linear structures of the megashear truncate the north-south structural trends of the Araguaia Belt of the Neoproterozoic age.

A series of small extensional cratonic sedimentary basins were formed along the TB in graben troughs, such as the Jaibaras, Monte do Carmo, Água Bonita, and Piranhas basins (Brito Neves *et al*. 1984). They are early Paleozoic, formed by brittle reactivation processes that affected older shear zones of the lineament. The Jaibaras rift is located at the northwestern corner of the Borborema Province (Oliveira & Mohriak 2003, Aguiar *et al*. 2011), and is described as an extensional structure forming a graben, which continues to the southwest, beneath the sedimentary rocks of the Parnaiba basin. Brito Neves *et al*. (1984) showed that it represents a precursor intracratonic rift for the thermal subsidence that started in the Silurian with the deposition of the Serra Grande formation. The main depocenters for this formation and for the younger sedimentary sequences, which continue into the Carboniferous, are located along the TB. Further south, within the Tocantins Province in central Brazil, TB maintains a northeast-southwest trend and affects parts of the Goiás Magmatic Arc. The Monte do Carmo rift, with a similar tectonic evolution to the Jaibaras rift, as well as the Água Bonita and Piranhas grabens, filled with Paleozoic sediments, are also located along the same structural trend.

Towards the southwest, TB disappears beneath the Paraná Basin. From geophysical evidence produced by Mantovani & Brito Neves (2005), and as previously suggested by Cordani *et al*. (1984), the megashear separates the supracrustal rocks of the Paraguay Belt to the west from the Paranapanema cratonic fragment to the east. Finally, continuing into Paraguay and Argentina, the TB is present within the basement of the Chaco-Paraná basin, where it has affected the tectonic evolution of sedimentary systems, as shown by the prominent depocenters of the Pilar and Las Breñas basins, where a total thickness of several kilometers is found (Wiens 1985).

Concomitantly to extensional tectonics along the Transbrasiliano tectonic corridor, mafic magma underplating and anatexis of the continental crust may have been responsible for the onset of postorogenic bimodal magmatism, active from the Ediacaran to the Ordovician (580 – 450 Ma), accompanied by the intrusion of practically undeformed K-rich, A-type granite bodies. The related rifting of the lithosphere may well have been produced by transtensional stresses, as a distant reflection of the more or less coeval compression produced at the southern border of Gondwana, during the subduction of the Pacific lithosphere.

A few examples of the Ediacaran to Cambro-Ordovician magmatism along the TB are given, as follows:

- In the state of Ceará, the emplacement of the Mucambo (530 Ma) and Meruoca (523 Ma) granites intrusive into the sedimentary rocks of the Jaibaras rift (Archanjo *et al*. 2009), as well as the Quintas Ring Complex (495 Ma), located to the east of the TB (Castro *et al*. 2012).

- In the region of the Goiás Magmatic Arc and vicinities, the emplacement of a number of intrusive complexes comprising small gabbro-diorite bodies associated with large K-rich granite plutons and A-type granitic intrusions, such as the Serra Negra (508 Ma), Iporá (490 Ma), and Serra do Impertinente (485 Ma) (Pimentel et al, 1996).
- Within the area of the Paraguay belt in Mato Grosso do Sul, in the vicinity of the TB megashear, the emplacement of the São Vicente (521 Ma), Coxim (542 Ma), Rio Negro (549 Ma), Sonora (549 Ma) and Taboco (546 Ma), intruding deformed metasedimentary rocks of the Cuiabá Group (Ferreira *et al*. 2008, McGee *et al*. 2012).

CONCLUSION

In conclusion, the collage of West Gondwana was largely completed by the end of the Precambrian, when the Amazonian, West African, São Francisco-Congo, Kalahari and Rio de la Plata cratons, the Saharan metacraton and the Parnaíba, Paranapanema and Luiz Alves cratonic fragments were united and tectonically stabilized. The geological evidence available so far indicates that the Neoproterozoic Goiás-Pharusian Ocean was already closed at about 600 Ma, and the resulting sutures are located within or close to the Transbrasiliano-Kandi tectonic corridor.

Later, in the Ediacaran and continuing at least during early Paleozoic, following the final stages of the Brasiliano orogeny, extension was predominant over West Gondwana and this structural regime may have been a result of two main factors: (1) the orogenic collapse of the folded belts produced by the Brasiliano orogeny; and (2) a distant tectonic reflection of the compressional Pampean orogeny, which was in action at the south-western margin of Gondwana. As a corollary, we argue that the idea of a collisional suture in central South America, closing a supposed Cambrian Clymene Ocean in the Cambrian, is not sustainable.

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