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WAS THERE AN EDIACARAN CLYMENE OCEAN IN CENTRAL SOUTH AMERICA?

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ABSTRACT. **Previous studies have proposed that a major suture resulted from the collision between the Amazonian and São Francisco-Congo cratons during the Cambrian, following the closure of a supposed Clymene Ocean. The proposal tentatively located this ocean along the Araguaia and Paraguay belts at the eastern margin of the Amazonian Craton, and its southern extension reached the Pampean belt in Argentina. In the present study we will argue that the existence of Ediacaran-Cambrian oceanic lithosphere in central South America is highly unlikely.**

West Gondwana was assembled during the convergence between the Amazonian, West African, São Francisco-Congo and Rio de La Plata cratons as well as the Saharan Metacraton, leading to the closure of the Goiás-Pharusian Ocean during the Neoproterozoic. Final closure and continental collision resulted in the development of the Transbrasiliano-Kandi mega-shear zone that cuts through several mobile belts, but leaves the cratonic areas totally untouched. Consistent results of radiometric dating along the Transbrasiliano (TB) mega-shear in South America and of metamorphic rocks of the Brasília Belt have indicated that the Neoproterozoic collision finished at *ca.* 620 Ma. After isostatic uplift, cooling, and denudation, between 590 and 500 Ma, emplacement of undeformed K-rich postorogenic granites represented the main tectonic event. At this time or afterwards, a series of small extensional sedimentary basins formed in graben troughs, most of which are within the TB tectonic corridor. They all were of extensional character, contrasting clearly with the convergent tectonics occurring within the coeval Pampean Orogen in Argentina.

The main arguments showing that an Ediacaran to Cambrian oceanic closure in central Brazil is untenable include: (i) the assembly of West Gondwana was completed by *ca.* 600 Ma, when the convergence between the Amazonian, São Francisco and Rio de La Plata cratons had already ended. After this, there is no geological evidence of an oceanic lithosphere (for example, ophiolites, magmatic arcs, *et cetera*), ruling out the possible existence of an Ediacaran or Cambrian Clymene Ocean in Central Brazil; (ii) the Gurupi and Araguaia belts in Brazil, as well as the Bassaride and Rokelide belts in West Africa, are regarded as aulacogenic-type systems formed within an intraplate tectonic setting. Their tectonic history precedes the collision between the Amazonian and São Francisco-Congo cratons, as demonstrated by the linear structures of the Transbrasiliano megashear which truncate the N-S structural trends of the Araguaia Belt; (iii) there is a close correlation between the Corumbá Group of the Paraguay Belt in Brazil and the Arroyo del Soldado Group in Uruguay. These sedimentary sequences belonged to the same Ediacaran continental shelf and this is a powerful indicator for an Ediacaran connection between the Amazonian and Rio de La Plata cratons, which precludes the existence of a wide ocean (for example, the Clymene) between them. On

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the other hand, the tentative correlation between the Sierras de Cordoba and the Paraguay Belt cannot be accepted, because these are far apart and there is no similarity in lithology, metamorphism, or structural trends; (iv) the Puga paleopole is the most important evidence for the hypothesis of the Cambrian Clymene Ocean, however the age of about 600 Ma for this paleopole, taken on the basis of Sr and C isotopes, is loosely constrained. In addition this is located at low latitude, not far from the present pole, and therefore could be related to a younger remagnetization; (v) the Pampean Orogen is made up of medium- to high-grade metamorphic rocks constrained between 560 Ma and 520 Ma and therefore was tectonically active during most of the Cambrian. However, at this time, an oceanic lithosphere is not evident in the vicinity of the Paraguay belt, and in central Brazil extensional rather than convergent tectonic processes have been observed.

Key words: South America, West Gondwana, tectonic evolution, Goiás-Pharusian Ocean, Transbrasiliano mega-shear, Pan African orogeny

INTRODUCTION

Almost all publications regarding the formation of Gondwana stress that it was formed by the amalgamation of several building blocks of different sizes, most of them originating from the breakup of Rodinia. They assembled through a series of continental collisions that covered the entire Neoproterozoic (see, for example, Li and others, 2008, and references therein). West Gondwana, the largest building block of the supercontinent, included the Amazonian and West African cratons, the Congo-São Francisco, Rio de La Plata, and Kalahari cratons, as well as a few smaller continental fragments, such as the Paranapanema, the Goiás Massif, and the Luiz Alves (see fig. 1). It also included a large region of northern Africa, named the Saharan Metacraton.

West Gondwana was assembled during the convergence between the Saharan Metacraton and the Amazonian, West African, and Congo-São Francisco cratons. This event led to the closure of the Goiás-Pharusian Ocean and to the development of several orogens during the Neoproterozoic Era. In central Brazil the Brasilia Belt occurs along the western margin of the São Francisco Craton. Further to the west, along the eastern/southeastern margins of the Amazonian Craton, they are known as the Paraguay and Araguaia belts. According to most existing tectonic, stratigraphic, and geochronological evidences, West Gondwana was already assembled by *ca.* 650 Ma to 600 Ma.

As an alternative scenario, Trindade and others (2006) postulated that the final assembly of Gondwana occurred in the Cambrian, after the closure of a large oceanic basin, named the Clymene Ocean. This event was a result of the convergence and collision between the Amazonian and Congo-São Francisco continents. Their rationale for this model was based on paleomagnetic data for sedimentary rocks of the Araras Formation, which were obtained by Trindade and others (2003) from the Paraguay Belt of Central Brazil. These rocks were believed to have been deposited at *ca.* 600 Ma. However, its paleopole plotted quite far from the other Gondwana poles for that time. This observation was understood to imply that the Amazonian Craton and the rest of Gondwana were far apart during Ediacaran to Cambrian times. Although the Clymene Ocean was not properly described in their work, the concept was readily accepted by researchers working in southern South America, such as Li and others (2008), Pisarevski and others (2008), Cordani and others (2009), Tohver and others (2010), and Ramos and others (2010).

The hypothesis of a Cambrian ocean seems appealing in terms of its elegance and simplicity, and has been seriously considered. For instance, Cordani and others (2009) indicated two alternative timeframes for the assembly of West Gondwana. In the first timeframe, the Amazonian and West African cratons joined the São Francisco-Congo Craton before the Ediacaran. In the second timeframe, the model put forward by

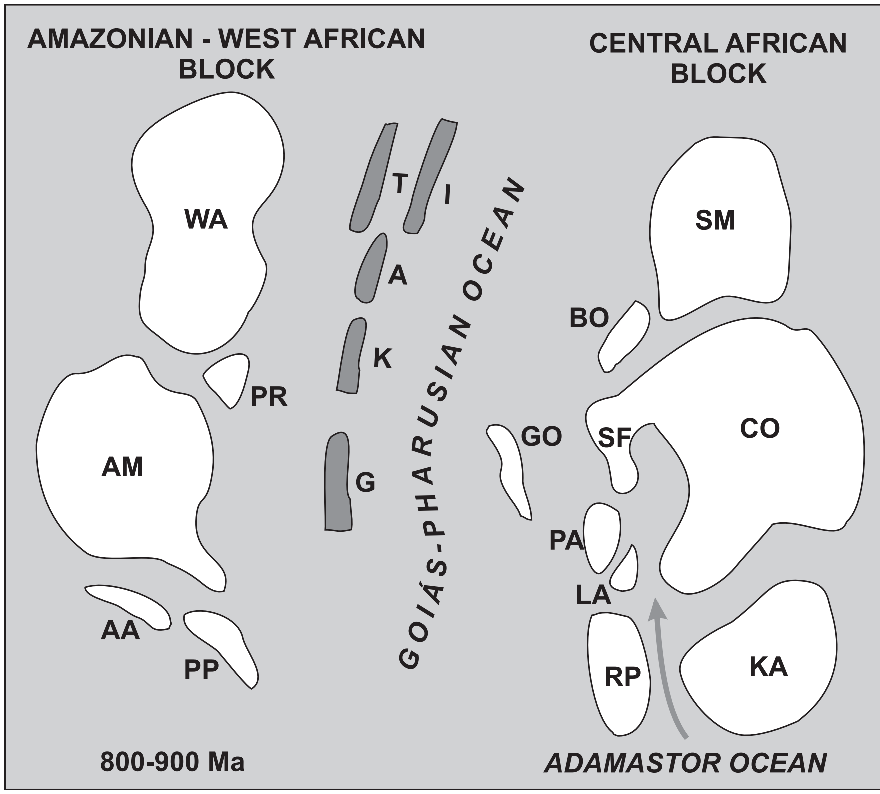

Fig. 1. Major tectonic elements related to West Gondwana, prior to the final amalgamation. Major cratons: AM = Amazonian; CO = Congo; KA = Kalahari; RP = Rio de La Plata; SF = São Francisco; SM = Sahara Metacraton; WA = West African. Smaller cratonic fragments: AA = Arequipa-Antofalla; BO = Borborema; 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.

Trindade and others (2006) was followed, and the assembly of West Gondwana was completed only after the Ediacaran.

Supporting the idea of the Cambrian Clymene Ocean and looking for a suitable location for the suture resulting from its closure, Tohver and others (2012) proposed that the suture zone crossed the entire South American continent (as shown in fig. 2). They presented new geochronological data indicating Ediacaran to Cambrian magmatism at the Sierras de la Ventana of Argentina. They also suggested a correlation with the Pampean belt, although the shallow level of magma emplacement in the Sierra de la Ventana contrasted with the deeply exhumed high-grade rocks of the Pampean Orogen. Moreover, they reviewed the tectonic history of the Pampean, Paraguay, and Araguaia belts along the margins of the Amazonian and Rio de La Plata cratons. They tried to demonstrate that these three belts were tectonically active from the late Ediacaran to the late Cambrian times along the Clymene suture zone, marking the closure of the ocean and the final stages of formation of Gondwana.

In this paper, we will present the available evidence indicating that the South American Platform was already in place in the Neoproterozoic. We will argue that the existence of an area with an oceanic lithosphere in its central region during the period from Ediacaran to early Cambrian is highly unlikely. As a corollary, we will suggest that the Clymene Ocean and its Cambrian closure, as put forward by Trindade and others

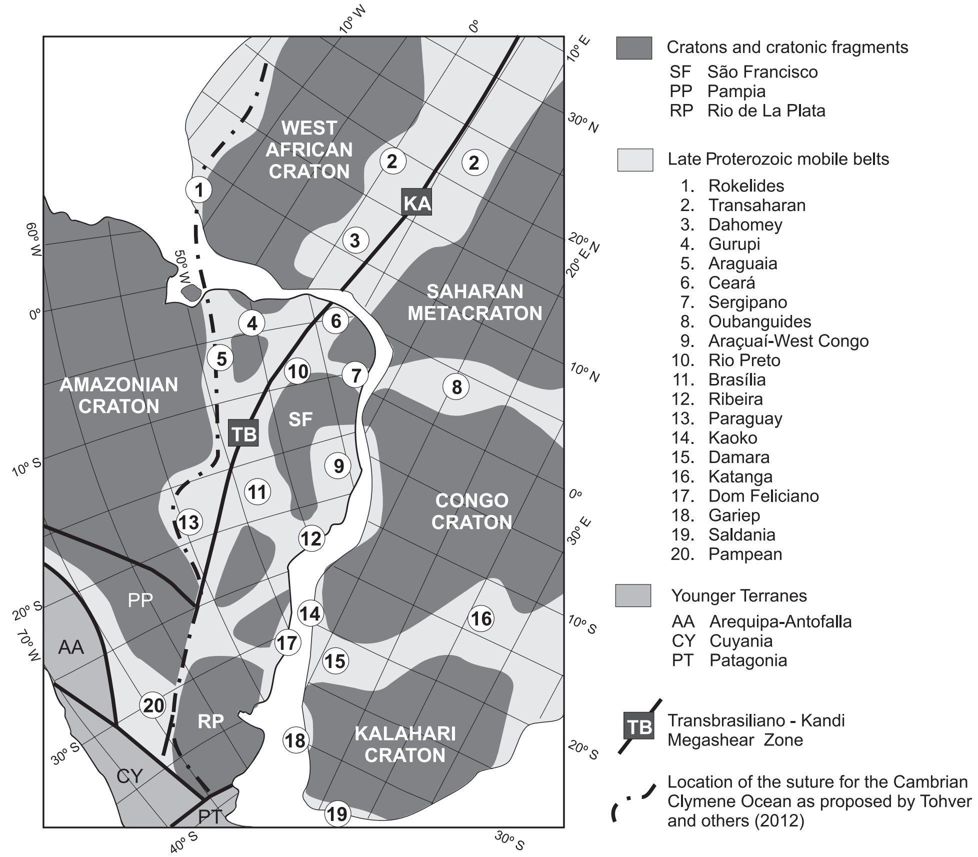

Fig. 2. Outline of the Transbrasiliano-Kandi mega-shear zone in a pre-drift reconstruction of South America and Africa. The suggested position of the Cambrian suture proposed by Tohver and others (2012) is indicated. Phanerozoic covers are omitted.

(2006) and Tohver and others (2012), are untenable on the grounds of the available evidence.

CLOSURE OF THE GOIÁS-PHARUSIAN OCEAN

Figure 1 presents a likely model for the relative positions of the main cratonic elements around 800 Ma, prior to closure of the Goiás-Pharusian Ocean and the final collisions that led to West Gondwana. This figure shows the approximate location of the oceanic realms, where the intraoceanic island arcs were already in place; outlines of the cratonic masses and fragments, together with their marginal basins that would become Neoproterozoic mobile belts; some of the accretionary units within the intervening oceans; smaller microcontinents (for example, Arequipa-Antofalla and Pampia); and smaller ancient blocks located in the Borborema and Tocantins provinces. Figure 1 also illustrates the position of the confined Adamastor Ocean, located in Central Gondwana, whose tectonic history ended only in the Cambrian.

The name “Goiás-Pharusian Ocean” was suggested by Kröner and Cordani (2003), although many paleomagnetic reconstructions, such as those by Meert (2003) and Cordani and others (2003), have named this ocean “Brasiliano” or “Adamastor.” This ocean occupied a very large area and included intraoceanic magmatic arcs, whose

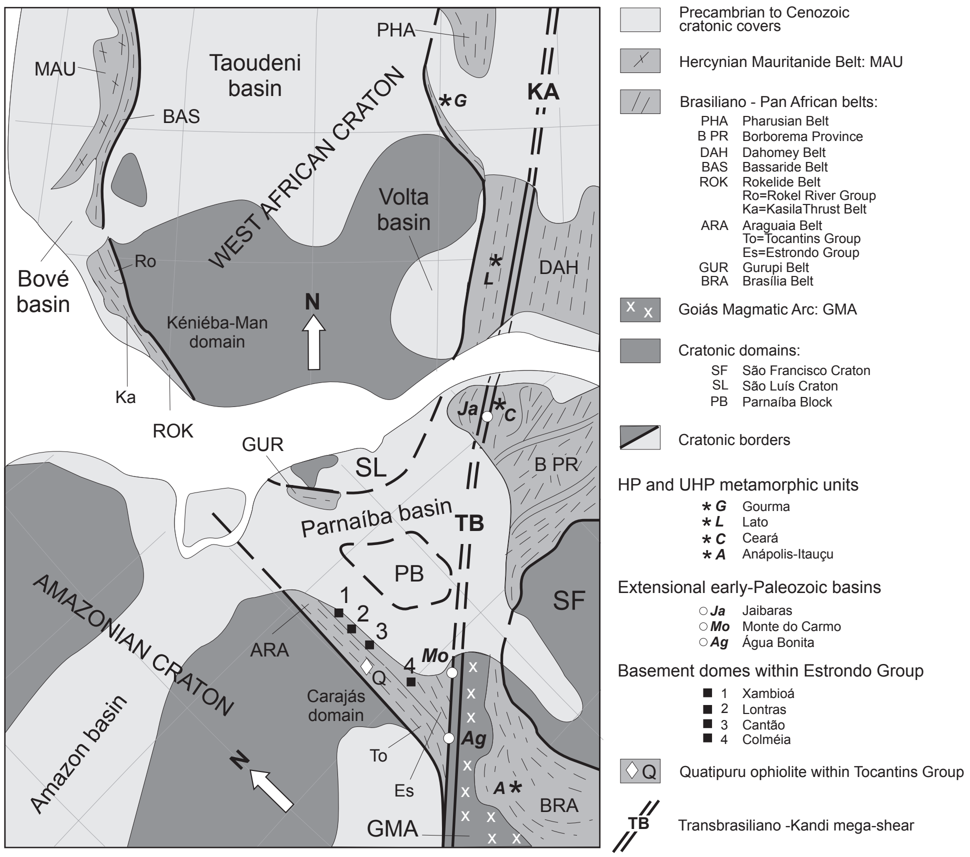

Fig. 3. Geological correlations between northeastern South America and northwestern Africa, in a pre-drift reconstruction. The location of specific tectonic features mentioned in the text are indicated: HP and UHP metamorphic units of Neoproterozoic age; extensional early Paleozoic basins; and basement mantled domes within the Araguaia Belt.

tectonic evolution started as early as *ca.* 900 Ma and covered the entire Neoproterozoic. As mentioned above, this ocean closed *ca.* 650 Ma to 600 Ma, after a series of successive continental collisions that gave rise to the many mobile belts of the Brasiliano-Pan African orogenic cycle. In most recent paleomagnetic reconstructions, such as those by Rapalini (2006) or Tohver and others (2010), all workers agree on a consolidated West Gondwana by Middle Cambrian.

The closure of the Pharusian Ocean, in consequence of the convergence between the West African Craton and the Saharan Metacraton, was characterized by Himalayan-type continental collisions, with the development of UHP and HP rock associations in the Trans-Saharan orogenic belt (see fig. 3). Blue-schists and eclogites have been identified in the Gourma region and in Togo, and geochronological studies have estimated the age of metamorphism at *ca.* 620 Ma (Caby, 1994; Trompette, 1994; Attoh, 1998; Affaton and others, 2000; Agbossoumoundé and others, 2001; Jahn and others, 2008). Oceanic terranes, relicts of the Pharusian Ocean, have been identified in many regions, from the Hoggar to the Dahomeyan segments (Caby, 1989 and 2003; Dostal and others, 1994; Duclaux and others, 2006; Berger and others, 2011). These terranes, which have been dated within the 900 Ma to 700 Ma timeframe, correspond to the Iskel island arc in the Hoggar, the Tilemsi-Amalaoulaou intraoceanic arc assemblages in the Gourma region, and the Kabyé massif in the Dahomeyan Belt of Togo.

Abdelsalam and others (2002) set the boundary between the Trans-Saharan Belt and the Saharan Metacraton along the eastern margin of the Tuareg Shield (Liégois and others, 2000). However, their Saharan Metacraton was not well-defined. It was characterized as a large portion of pre-Neoproterozoic cratonized continental crust dominated by medium- to high-grade gneissic and migmatitic terrains, which were highly remobilized during the Neoproterozoic. The NE portion of the Borborema Province of Brazil—where large areas with Paleoproterozoic or older crust have been found, may correlate with the Saharan Metacraton. Moreover, a correlation between the northwest part of the Borborema Province and the Trans-Saharan belt is highly likely, given the similarity of the regional lithostratigraphic trends (Caby, 1989; Arthaud and others, 2008), the continuity of the major faults, and the correlation between the granitoid rocks of Dassa and Savé in Benin (Cordani and others, 1993) with rocks of the Tamboril-Santa Quitéria Complex in the Ceará State of Brazil, a large area formed by different types of granitic rocks and migmatites (Fetter and others, 2003). Ceará HP retroeclogites that are located close to the western side of this complex (see fig. 3), dated at *ca.* 650 Ma by Amaral and others (2010), are considered to be representative of the Neoproterozoic suture.

Similar to the Pharusian Ocean, the Goiás Ocean was consumed as a consequence of the convergence between the Amazonian and São Francisco cratons. As one of the largest, most complete, and most preserved Neoproterozoic orogenic belts in Brazil (Pimentel and others, 2000), the Brasília Belt presents compelling evidence for closure of the Goiás Ocean at *ca.* 650 Ma to 630 Ma, as recorded by granulitic rocks of the Anápolis-Itauçu Complex (A in fig. 3) and several other rock units (Baldwin and Brown, 2008). This belt comprises a thick Meso-Neoproterozoic sedimentary pile in the east, a microcontinent composed of Archean rock units and associated Paleoproterozoic formations (the Goiás Massif), and a large magmatic arc in the west, the so-called Goiás Magmatic Arc (GMA in fig. 3). Due to its tectonic significance and areal magnitude, the GMA represents the most important tectonic element of the Brasília Belt, and is formed by Neoproterozoic juvenile crust that records the closure of the Goiás Ocean from *ca.* 900 Ma to 600 Ma (Pimentel and Fuck, 1992).

The GMA is divided into the Arenópolis arc to the south and the Mara Rosa arc to the north, which are separated from each other by the Goiás Massif. The arc includes: (i) juvenile island arcs (*ca.* 900-800 Ma) with volcanic-sedimentary sequences that are spatially associated with tonalitic-granodioritic-granitic orthogneisses with a mantle signature; (ii) younger (*ca.* 650-630 Ma), island arc-type volcano-sedimentary sequences and associated tonalite-granodiorite plutonic complexes; and (iii) late- to post-orogenic (<600 Ma) granites that are associated with gabbro-diorite bodies (Junges and others, 2002, and references therein).

The Brasiliano-Pan-African belts with Neoproterozoic sutures are aligned along a very long area (>6000 Km) of South America and Africa that is dominated by one of the most important tectonic elements of the world. This megashear zone is called the Transbrasiliano Lineament in Brazil, continues as the Kandi-Hoggar 4°50 Lineament into Africa (Caby, 1989), and will be referred to in this work as the "Transbrasiliano-Kandi." As shown in figures 2, 3, 4, and 5, the megashear zone cuts through many of the Brasiliano-Pan African belts, but leaves the cratonic areas untouched. It may be the largest coherent shear zone on Earth (Attoh and Brown, 2008). Its coherence has been well-characterized by the very long linear magnetic anomalies obtained from the CHAMP satellite survey and reported by Fairhead and Maus (2003). This lineament probably reaches the bottom of the lithosphere and is formed of a series of ductile

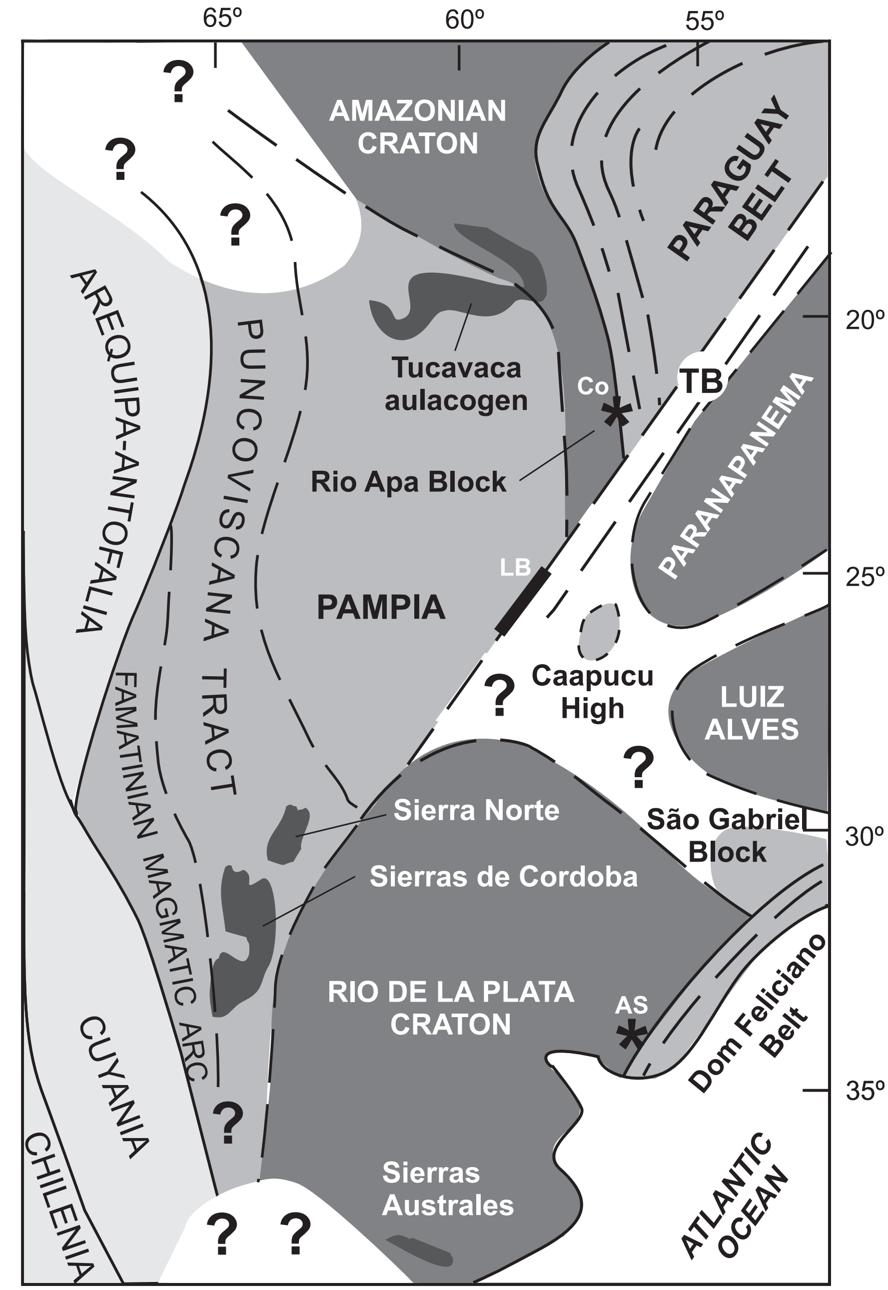

Fig. 4. Geotectonic interpretation of the south-eastern part of South America. It includes: (1), several tectonic features located close to the Transbrasiliano Lineament; (2), the Amazonian, Rio de La Plata, Paranapanema and Luiz Alves cratonic units; (3), the Arequipa-Antofalla, Famatina and Cuyania allochthonous terranes; (4), the tectonic units of the Pampean orogeny: the eastern Pampean ranges (Sierra Norte and Sierras Pampeanas) and the Puncoviscana Tract. Phanerozoic covers are omitted. LB = Las Breñas basin. Co = Corumbá Group in central Brazil. AS = Arroyo del Soldado Group in Uruguay.

shear zones, comprised of many parallel sets of faults, which may cover very broad areas. The shear zone motion must have started shortly after the closure of the

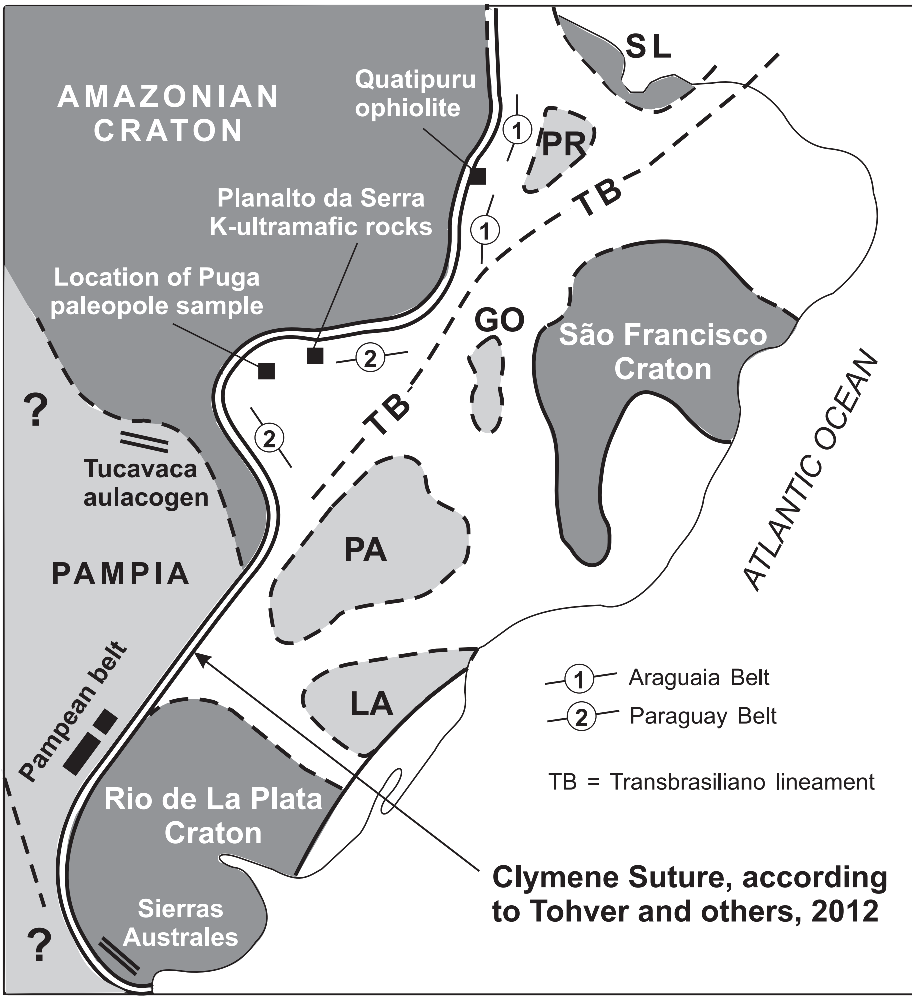

Fig. 5. Late Neoproterozoic geotectonic features of eastern South America. The location of the proposed suture resulting from the closure of a supposed Ediacaran/Cambrian Clymene Ocean is indicated.

Goiás-Pharusian Ocean. Tectonic reactivations have repeatedly occurred along the shear zone, where low-intensity seismic activity continues through the present day.

The 650 Ma to 600 Ma timeframe for the orogenic tectono-magmatic episodes in northwest Africa and central South America indicate that the convergence of the continental blocks leading to the closing of the Goiás-Pharusian Ocean was finished at that time along the corridor of the Transbrasiliano-Kandi megashear.

EDIACARAN AND CAMBRIAN SUBDUCTION OF THE OCEANIC LITHOSPHERE IN SOUTHERN AMERICA

In the previous chapter, we showed that the Goiás-Pharusian Ocean closed at the end of the Neoproterozoic, at which time West Gondwana was in place as a single continental mass. At about the same time, the Mozambique Ocean was also closing, with termination of the convergence between West Gondwana and the different components of East Gondwana. A major center was developing and spreading between

West Gondwana and Laurentia, which led to a need for major plate reorganization. This reorganization was associated with 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, more or less simultaneously with the separation of Laurentia and the opening of the Iapetus Ocean. The name "Terra Australis Orogen" was proposed for a very large tectonic province that was located at the southern Gondwana margin, along an open and unconfined Pacific Ocean and comprising a collection of accretionary orogens. These orogens were formed by the stacking of magmatic arc complexes, which were formed in successive subduction zones by the tectonic processes of "soft collision" and accretion, accompanied by the extensive production of felsic volcanic and granitoid magmas. Knowledge about such major tectonic processes is necessary for understanding the tectonic development of southern South America within the 600 Ma to 500 Ma timeframe and for assessing the possible presence of the suggested Clymene Ocean. The initiation of the Pacific subduction and the development of the Pampean Orogen are the key elements needed to analyze the plate reorganization that occurred just after the amalgamation of Gondwana.

Figure 4 shows a schematic tectonic outline for the southwestern part of South America. Describing the general tectonic setting of the Sierras Pampeanas from a mobilistic perspective, Ramos (1988) pointed to differences between the Puncoviscana Formation in the north and the Eastern Pampean ranges, including the Sierra Norte and the Sierra de Cordoba, in the southeast. Covering a very large region of northern Argentina and southern Bolivia, the Puncoviscana Formation consisted of turbidites, which have been interpreted as a deep-water "flysch-type" sequence and as part of a passive margin, whose basin was linked to a stable craton to the east but was probably open to the west to a proto-Pacific Ocean. The Eastern Pampean ranges, in which high-grade metamorphic rocks have been found, were thought to be formed as the result of normal subduction of oceanic lithosphere, followed by a continent-continent collision between the same Pampean terrane (Pampia in fig. 4) and the Rio de La Plata Craton.

Rapela and others (1998), working on the polymetamorphic basement of the Sierras de Cordoba, presented a comprehensive report on what they called the "Pampean Orogeny," in which the low-grade metasedimentary rocks of the Puncoviscana Formation and the medium- to high-grade metamorphic rocks of the Sierras Pampeanas were attributed to the same tectonic episode. Their geochronological data indicated a clear Cambrian age for the entire tectonic development. Detrital zircon grains from the low-grade sediments established a maximum age of deposition at 560 Ma to 550 Ma. An age of 530 Ma was obtained for the emplacement of the calc-alkaline granites, as a result of northeast-directed subduction. These authors followed the same interpretation offered by Ramos (1988) and proposed that the high-grade metamorphism characteristic of the Pampean Orogeny, dated shortly after emplacement of the granites at *ca.* 525 Ma, was produced by a continental collision of the western side of Gondwana (the Rio de La Plata Craton in fig. 4) with an exotic terrane, retaining for it the name of "Pampean Terrane."

Schwartz and others (2008), studying the Sierra Norte, performed an additional geochronological program and extended the time interval for the calc-alkaline magmatism from 555 Ma to 525 Ma. These authors discussed the implications of the tectono-magmatic evolution of the Pampean Orogen, correlating it with the Saldania, Ross, and Tasmanian companion belts of the Terra Australis. In particular, they noted that the plutonism in all of them was roughly coeval from Ediacaran to early Paleozoic and included very similar calc-alkaline and strongly peraluminous suites.

Escayola and others (2011), dealing mainly with the Puncoviscana Formation in the northern part of Argentina, proposed a new tectonic interpretation. They summarized the available lithological, stratigraphic, and structural knowledge on that formation and presented conclusive evidence for the syntectonic character of it as an accretionary complex. They also highlighted the almost north-south strike of the belt along the proto-Andean active margin of West Gondwana, where they located an oceanic opening called the "Puncoviscana tract" (see fig. 4). This opening is in approximately the same position as that of the oceanic basins envisioned by Ramos (1988) and Rapela and others (1998).

Recalling that Escayola and others (2007) had identified ophiolite remnants within the high-grade metamorphics of the Sierra de Cordoba, and considering the presence of some Early Cambrian felsic and mafic arc volcanic rocks in the older parts of the Puncoviscana Formation, as well as the arc-like composition of the associated turbidites, Escayola and others (2011) inferred that sedimentation occurred adjacent to an approximately coeval arc terrane. In their model, this process occurred in a basin that formed on the accretionary wedge, associated with a west-facing Pampean arc built upon the proto-Andean margin of West Gondwana. They proposed that their Puncoviscana tract was closed by a collision between Gondwana and the exotic Arequipa-Antofalla microcontinent. They indicated that this tectonic episode could be related to the separation of Laurentia and the spreading of the Iapetus Ocean.

The above discussion demonstrates the controversy surrounding the issue of the tectonic significance of the Pampean Orogeny. Regardless of whether the Puncoviscana Formation represents an active or passive margin, whether the tectonic process is collisional or non-collisional, or whether the Puncoviscana Ocean is open or restricted, the timing of the orogenic processes is clearly well-constrained between 560 Ma and 520 Ma. Therefore, the Pampean orogenic system is much younger than the Neoproterozoic belts responsible for closing the Goiás-Pharusian Ocean. The Pampean system had already started in the Ediacaran and was tectonically active during most of the Cambrian. Given that the Amazonian, São Francisco-Congo, and Rio de La Plata cratons were already together after the Brasiliano Orogeny, it can be concluded that instead of representing the final amalgamation of Gondwana, the Pampean Orogeny marks the oldest evidence of subduction of the Pacific oceanic plate under the southwestern margin of Gondwana.

EXTENSIONAL-TYPE POST-TECTONIC EPISODES ALONG THE TRANSBRASILIANO LINEAMENT IN SOUTH AMERICA

The Kandi-Hoggar 4°50 Lineament in Africa cuts through the mobile belts of the Trans-Saharan orogen and is covered, in some parts, by relatively young and shallow cratonic covers. Its South American counterpart, the Transbrasiliano lineament (hereafter, TB), cuts through parts of the Borborema and Tocantins tectonic provinces, as well as the basement of three large and relatively thick cratonic basins, the Parnaiba basin (fig. 3) and the Paraná and Chaco-Paraná basins to the south. The TB is clearly visible in the aeromagnetic mosaic of the central and eastern parts of the Brazilian territory, crossing the country from northeast to southwest. Comprised of a series of low-amplitude magnetic anomalies, it starts at the northwestern tip of the Borborema Province, continues through the eastern part of the Parnaíba Basin to the central part of Goiás, travels to the northern part of the Paraná basin, and goes to the southwest, to Paraguay and Argentina, where it seems to end near the city of Cordoba.

Consistent results of radiometric dating along the TB have indicated that the Neoproterozoic collisional tectono-magmatic events finished at *ca.* 620 Ma. However, after isostatic uplift, cooling, and denudation, the mobility and tectonic activity along the megashear continued for a long time. Within the period between 590 and 500 Ma, emplacement of virtually undeformed K-rich post-orogenic granites represented the main geological/tectonic event, which was sometimes associated with gabbros and diorites. This fact can be verified all along the TB. At the north, in Ceará State, a few granitic plutons emplaced at 530 Ma to 500 Ma have been identified that are representative of late to postcollisional processes in the Ceará Central Domain (Fetter and others, 2003; Castro and others, 2012). In Mato Grosso do Sul State, several undeformed granitic plutons with ages between 550 Ma and 520 Ma (Ferreira and others, 2008, and references therein) have been encountered along the TB, which cut through the supracrustal rocks of the Paraguay Belt, as will be described later.

In Goiás State, deep crustal and lithospheric seismic tomography (Assumpção and others, 2004; Feng and others, 2007) and deep seismic refraction and teleseismic receiver function investigations (Soares and others, 2006; Ventura and others, 2011) have been conducted at the location of a large positive Bouguer anomaly, corresponding to the surface exposure of the GMA. In this region, using group-velocity tomography and lithospheric s-velocity studies, Feng and others (2007) demonstrated that there was a region of thinner lithosphere along the shear system. This finding may suggest a process of delamination of the crustal root of the collisional orogen, which gave way to an asthenospheric uplift, with the heating and formation of post-tectonic high-K and A-type granitic intrusions. Especially within the area of the Goiás Magmatic Arc, these granitic plutons, whose radiometric ages were between 560 Ma and 520 Ma, were virtually undeformed, indicating that they were related to extensional-type tectonics along the megashear (Pimentel and others, 1996). One point yet to be clarified is the presence of small exposures of medium- to high-grade rocks (migmatites, enderbites, and mafic-ultramafic bodies), dated between 560 Ma to 520 Ma, along the TB in Goiás and Tocantins (for example, Motta-Araujo and others, 2003; Lima and others, 2008). The tectonic significance of these local occurrences is poorly understood, but they might represent exposures of lower crustal sections related to the emplacement of mafic magmas and subsequent crustal melting during Late Neoproterozoic to Cambrian times.

At the time of the intrusion of these granites or afterwards, a series of small extensional intracratonic sedimentary basins formed in graben troughs, such as the Jaibaras, Monte do Carmo, Água Bonita and Piranhas basins, along the TB in Ceará, Tocantins, Goiás, and Mato Grosso states (Brito-Neves and others, 1984). Most of them were rift basins formed between the Cambrian and the Silurian by brittle reactivation processes that affected older shear zones of the TB. They were mainly formed by fault-scarp-related paraconglomerates at the base, followed laterally and vertically by fluvial-lacustrine sandstones interbedded with shales.

The Jaibaras rift, located at the northwest corner of the Borborema Province (Ja in fig. 3), is the best representative of these extensional structures (Oliveira and Mohriak, 2003; Aguiar and others, 2011). Its age is well-controlled by the Mocambo (530 Ma) and Meruoca (510 Ma) granitic plutons. The graben trough continues to the southwest, beneath the sedimentary rocks of the Parnaiba basin, where it represents a precursor intracratonic rift for the thermal subsidence of the cratonic basin, which started in the Silurian with the deposition of the Serra Grande Group. The main depocenters for this unit and younger sedimentary sequences until the Carboniferous were located along the TB (Brito-Neves and others, 1984), demonstrating that the successive extensional tectonic reactivations occurred in the Paleozoic. Brito-Neves and others (1984) suggested the presence of a cratonic nucleus, herein named as the "Parnaiba block" (see figs. 2 and 3), within the basement of the Parnaiba Basin, to the west of the TB trend.

Within the Tocantins Province in central Brazil, the TB maintains a northeast-southwest trend and is located over the Goiás Magmatic Arc. Immediately to the southwest of the Parnaiba Basin, the Monte do Carmo rift (Mo in fig. 3) seems to have had a very similar tectonic evolution to the Jaibaras rift. The Agua Bonita graben, also located along the TB (Ag in fig. 3), is filled with Paleozoic sediments (Brito Neves and others, 1984). The Piranhas basin, filled with Cambrian and Ordovician sediments, is located right next to the border of the Paraná cratonic basin.

To the southwest, the TB disappears below the northeastern corner of the Paraná Basin. As suggested by Cordani and others (1984) and as inferred by Mantovani and Brito-Neves (2005) from geophysical evidence, within the basement of this basin, the megashear separates the supracrustal rocks of the Paraguay Belt to the west from a cratonic fragment (the Paranapanema block) to the east (figs. 4 and 5). Along the western boundary of the Paraná Basin, not far from the influence of the TB megashear, Ferreira and others (2008) dated a few practically undeformed granitic plutons, which yielded ages between 550 Ma and 520 Ma and will be discussed later. These plutons are filling spaces related to extensional features. They intrude deformed metasedimentary rocks belonging to the older lithostratigraphic system of the Paraguay Belt. Continuing into Paraguay and Argentina, the TB is present within the basement of the Chaco-Paraná cratonic basin. Here, the TB has affected the tectonic evolution of the sedimentary systems, as shown by the more prominent depocenters of the linear basins of Pilar in Paraguay (Wiens, 1995) and Las Breñas in Argentina (LB in fig. 4), where a total thickness of more than 6000 meters can be found.

In summary, the Goiás-Pharusian Ocean was already closed at 600 Ma. Therefore, later events, most of which located within or near the TB, were of an extensional character. This overall extensional tectonic scenario in central Brazil clearly contrasts with that of the coeval Pampean Orogen in Argentina. In this latter area, the period between *ca.* 560 Ma and 520 Ma was marked by the subduction of the Pacific oceanic lithosphere, including tectonic compression and regional high- to medium-grade metamorphism, associated with voluminous granite magmatism of an orogenic and subduction-related nature (Ramos 1988; Rapela and others, 1998).

WAS THERE AN EDIACARAN CLYMENE OCEAN IN CENTRAL SOUTH AMERICA?

In this section, we present some arguments showing that a Cambrian oceanic closure, as suggested by Trindade and others (2006) and Tohver and others (2012) and depicted in figure 5, is untenable on the grounds of the available evidence.

Age of the Amazonian–São Francisco-Congo Collision Along the Region of the Tansbrasiliano Megashear

As we showed in the previous chapters, the amalgamation of Gondwana involved a long process of plate convergence. In South America, it started at *ca.* 900 Ma, during the earliest magmatic phases of the juvenile, intraoceanic, and accretionary Goiás Magmatic Arc. Evidence suggests that the main collisional episodes of the Brasiliano-Pan African orogens occurred at the end of the Neoproterozoic. Several recent articles with robust geochronological control (mainly by means of U-Pb zircon ages) demonstrated that the tectonic evolution of the region dominated by the TB was developed roughly between 650 Ma and 600 Ma. Considering the possible high-grade metamorphic events that could be related to Himalayan-type collisions as tracers for the main episodes related to the convergence between the Amazonian and São Francisco-Congo cratons, we find that these events are restricted to the oldest phase of the process at *ca.* 650 Ma (Baldwin and Brown, 2008; Della Giustina and others, 2009). Younger tectono-magmatic episodes have been registered until *ca.* 600 Ma. However, within the Ediacaran to Cambrian time-period, the few magmatic episodes observed in the area have been related to either post-tectonic or anorogenic granitic plutons associated with an extensional tectonic regime.

In summary, the assembly of West Gondwana was completed by 600 Ma, when the convergence between the Amazonian-West African and the Central African blocks had already been terminated. Therefore, there is no geological evidence of a possible Ediacaran Clymene Ocean in Central Brazil.

The Bassarides, Rokelides, Araguaia, and Gurupi Belts

Figure 3 shows a possible Neoproterozoic tectonic scenario related to the process of plate interaction and convergence between the Amazonian and West African Cratons. This figure shows the position of the Brasiliano-Pan African orogenic belts, such as the Bassarides, Rokelides, Gurupi, and Araguaia, formed by the interplay and consequent collisions between the mentioned cratonic elements. It also accounts for the São Luis cratonic fragment and the possible Parnaiba Block microcontinent, which is concealed below the sediments of the Parnaiba basin and was envisioned by Brito-Neves and others (1984). The shape of this cratonic fragment is based on the geophysical interpretation of Nunes (1993) and is taken from Klein and Moura (2008).

Villeneuve (2008) extensively reviewed the orogenic belts on the western side of the West African Craton. The oldest is the Bassaride belt, which is cut to the north by the Paleozoic Mauritanide belt and to the south by the Rokelide belt, although parts of it are incorporated within the two younger belts. It is comprised of three lithostratigraphic units, the oldest of which is a volcano-sedimentary sequence formed within a rift-related basin. According to Villeneuve (2008), a few rhyolites stratigraphically below the oldest sequence of the unit yielded ages between 1050 Ma and 1000 Ma. A range of ages between 700 Ma and 650 Ma were obtained for the volcanic and plutonic rocks of the Niokolo-Koba Group, affected by compression and crustal thickening around 660 Ma. These were followed by the deposition of the flyschoid sedimentation of the Mali and Batapa Groups, whose final metamorphism has been dated at *ca.* 555 Ma (Villeneuve and Dallmeyer, 1987; Dallmayer, 1989). A molassic phase consisting of reddish sandstones concluded the sedimentary history of the belt.

According to the same author (Villeneuve, 2008), the younger Rokelide Belt consists of the high-grade basement gneisses of the Kasila thrust belt in the west, extensively mobilized during the Pan-African tectonothermal event, and the Rokelide trough to the east, filled with the low-grade and weakly deformed metasedimentary rocks of the Rokel River Group and interpreted as a foreland system. Rocks of the Kasila thrust belt (Ka in fig. 3) present Archean ages, similar to those encountered in the nearby Kénéba-Man domain of the West African Craton (Hurley and others, 1971; Williams, 1988). The Rokel River Group (Ro in fig. 3) comprises glaciogenic deposits in the lower part and clastic rocks associated with different volcanic types at the top. Delor and others (2002) reported U-Pb zircon ages of *ca.* 570 Ma from the high-grade rocks, interpreted to be the timing of the granulitization. K-Ar and Ar-Ar ages on hornblendes were obtained by Dallmeyer (1989), who reported that the range (580-550 Ma) constrained the entire tectonic evolution of the belt to a pre-Ediacaran time.

Since the article by Hurley and others (1967), the São Luis Craton (figs. 3 and 5) has been considered to be a small cratonic fragment that was separated from the much larger West African Craton and remained in South America when the Atlantic Ocean was formed in Mesozoic time. The Neoproterozoic Gurupi belt, which occurs on the western side of the craton, displays structural transport and metamorphic polarity towards the cratonic area. Klein and Moura (2008) analyzed the tectonic development of the belt, suggesting a direct continuation of the Rokelide Belt. The predominant rocks exposed in the outcropping area were basement gneisses with Paleoproterozoic ages of *ca.* 2200 Ma. These rocks, affected by the Brasiliano-Pan African orogeny, included granitoids that were correlative of similar Tromaí calc-alkaline bodies belonging to the São Luis Craton. They formed the continental basement over which a Neoproterozoic belt was developed, starting with a rifting phase at *ca.* 730 Ma (Klein and others, 2005). At the southeastern part of the belt, the medium-grade metasedimentary rocks of the Marajupema Formation were found, thrust over the basement rocks.

Klein and Moura (2008) suggested that the Neoproterozoic tectonic event was due to a collision between the São Luis Craton with the concealed Parnaiba cratonic block, located below the sedimentary rocks of the Parnaiba Basin.

In pre-drift Brazil-Africa reconstructions, the Araguaia Belt in Brazil has been routinely correlated with the Rokelides; both belts exhibit similar north-northwestern trends (see fig. 3) and virtually the same age for the tectonothermal event responsible for their final tectonic configuration (Trompette, 1994; Moura and others, 2008). However, these belts have opposite structural vergence. The Araguaia Belt shows tectonic transport to the west, in the direction of the Amazonian Craton, whereas the Rokelide Belt is transported easterly, against the West African Craton. The Araguaia Belt (Alvarenga and others, 2000) comprises two main tectonic units: the low-grade metasedimentary rocks and associated mafic and ultramafic bodies of the Tocantins Group to the west (To in fig. 3), and the medium- to high-grade gneisses of the Estrondo Group to the east (Es in fig. 3), thrust over the former tectonic unit. The Tocantins Group exhibits north-south structural trends that cut through the west-northwest–east-southeast trends of the Archean and Paleoproterozoic rocks of the Carajás domain of the Amazonian Craton. Its mafic-ultramafic rocks are included within tectonic slices and are interpreted to be remnants of ophiolitic complexes. One of these, the Quatipuru ophiolite, was dated at *ca.* 750 Ma by Paixão and others (2008) with the Sm-Nd method. Moura and others (2008) reported one very precise Pb evaporation zircon age of 817 ± 5 Ma for an intrusion of metagabbro. A rather imprecise Pb-Pb evaporation age of *ca.* 1000 Ma for the Serra da Estrela alkaline syenitic gneiss has been interpreted as indicating a major event of crustal rifting and formation of the Araguaia basin (Alvarenga and others, 2000).

Within the Estrondo Group, several basement inliers occupying mantled gneissic dome-like structures have been recognized (Hasui and others, 1984; Herz and others, 1989), yielding Archean and Paleoproterozoic ages. Four of them were located in figure 3. This finding led Moura and Gaudette (1993) to suggest that they could be extensions of the Amazonian Craton. Some zircon Pb evaporation ages ranging from 650 Ma to 550 Ma were obtained for a few syntectonic granitoid rocks, constraining the timing of structural development within the belt (Alves, ms, 2006). Radiometric ages between 560 Ma and 530 Ma obtained by the K-Ar method in a few micas and amphiboles (Moura and others, 2008) indicated that the region of the Araguaia belt was already below *ca.* 300 °C in the Cambrian. Although a more robust geochronological control is needed for the Araguaia belt, from the perspective of regional cooling, these K-Ar mica ages alone preclude the onset of major regional thermo-tectonic episodes, such as a major continental collision, in Cambrian times.

The Bassarides, Rokelides, Gurupi, and Araguaia belts have been regarded as originating within an intraplate-like tectonic setting (Brito-Neves and Cordani, 1991; Villeneuve and Cornée, 1994; Alvarenga and others, 2000; Villeneuve, 2008, among many others). In this work they will be considered as members of a few activated aulacogens, located between the West African and Amazonian cratons. Although some of these Neoproterozoic belts may have given birth to a poorly evolved oceanic rift where the ocean floor was formed in restricted areas, such as the Serra do Quatipuru within the Araguaia Belt (Paixão and others, 2002; Kotschoubey and others, 2005), the lack of arc-related magmatic rocks along all of them strongly indicates the possibility of an intracontinental tectonic evolution. Finally, the close correlation in age between the basement rocks encountered in the orogenic belts and their respective cratonic areas (see fig. 3) reinforces this reasoning. For the Gurupi belt, the basement granitoid gneisses are a direct continuation of the Tromaí granites of Paleoproterozoic age of the São Luis Craton. For the Rokelides, the allochthonous Kasila high-grade gneisses show Archean ages of the same order as those encountered in the adjacent Kénéba-

Man domain of the West African Craton. For the Araguaia belt, the granitoid rocks occupying the mantled gneissic domes, basement of the medium-grade rocks of the Estrondo Group, display either Archean or Paleoproterozoic ages, similar to the ages obtained from the Carajás domain of the Amazonian Craton.

The possibility of the existence of a concealed Parnaiba Block is strengthened when several U-Pb dates from detrital zircon ages of Neoproterozoic formations of the Gurupi and Araguaia belts are considered. Based on results obtained from a quartzite belonging to the Estrondo Group in the southern part of the Araguaia belt, Moura and others (2008) demonstrated a derivation from predominant Neoproterozoic to Mesoproterozoic sources, with ages between 1200 Ma to 800 Ma. Possible source rocks were not observed within the neighboring regions of the Amazonian Craton. These authors postulated a possible eastern provenance, from sources now below the sediments of the Parnaiba basin. Similarly, the presence of detrital zircon crystals as young as 1100 Ma from the Marajupema Formation (Klein and Moura, 2008) was taken to indicate the presence of source rocks from the south because provinces from the Mesoproterozoic age were not found on the São Luis Craton, within the southern part of the West African Craton, or from the eastern part of the Amazonian Craton.

In conclusion, we consider that the Bassarides, Rokelides, Gurupi, and Araguaia are intracontinental belts formed by the tectonic evolution of aulacogenic-type systems. Consequently, their tectonic history would precede the collision between the Amazonian and São Francisco-Congo cratons along the Transbrasiliano corridor. This conclusion is supported by the evidence that the linear structures of the TB megashear truncate the north-south structural trends of the Araguaia Belt (see fig. 3). The origin of the stresses related to the basin inversion within these belts is poorly understood. As a tentative speculation, we attribute these events, at least partially, to distant plate adjustments accompanying the successive stages of the closing of the Goiás-Pharusian Ocean along the Transbrasiliano-Kandi tectonic corridor.

The Corumbá–Arroyo del Soldado Epicontinental Sea

The Paraguay belt is a typical thrust-and-fold belt located along the southeastern margin of the Amazonian Craton (Alvarenga and others, 2000; Campanha and others, 2011; see location in figs. 4 and 5). It comprises the older Cuiabá Group, which includes the glacial sediments of the Puga Formation, and the younger Corumbá Group, which comprises carbonates and pelites with Ediacaran-age fossils (Boggiani and others, 2010). According to Babinski and others (2006), some "cap carbonates" of the Araras Group, which directly overlie diamictites of the Puga Formation, were dated at *ca.* 630 Ma (by Pb-Pb whole-rock isochron method). In general, the sedimentary environment indicates a restricted marine shelf with shallow marine waters. This situation could be related to an epicontinental sea overlying a continental basement that corresponds to the extension of the Amazonian Craton. The sediments of the Corumbá Group are mainly marine and correlate with the sedimentary filling of the nearby Tucavaca aulacogen in Bolivia (see figs. 4 and 5). Moreover, Gaucher and others (2003) demonstrated the existence of a close correlation between the Corumbá Group of the Paraguay Belt and the Arroyo del Soldado Group in Uruguay (Co and AS in fig. 4). They observed that these sedimentary sequences, which belonged to the same continental shelf that comprised virtually the same succession with the same Ediacaran age, deepened to the east along the eastern edge of the Rio de La Plata and Amazonian cratons (for example, Gaucher and others, 2003, 2008, and 2009). This finding is a powerful paleogeographic indicator for the Ediacaran connection of both cratonic units, which precludes the existence of a wide ocean (for example, the Clymene) between them.

The rocks of the Paraguay belt are affected by low-grade metamorphism up to the biotite zone of the greenschist facies. They are also affected by tectonic deformation, which is almost imperceptible on the border of the craton but increases up to tight isoclinal folds towards its inner areas (Alvarenga and others, 2000). A detailed regional study by Campanha and others (2011) in the southern part of the region demonstrated the presence of different structural domains. In particular, rocks of the Cuiabá Group (named Agachi schists by these authors) were affected by deformation and low-grade metamorphism while the sedimentary rocks of the upper part of the Corumbá Group (Tamengo and Guaicurus formations of Ediacaran age) were virtually undeformed and unconformably deposited over the sialic basement of the Rio Apa Block (fig. 4). De Min and others (2013) provided an important piece of evidence regarding the tectonic evolution of the area. In the northern sector of the Paraguay belt, they studied a series of K-rich, undeformed ultramafic bodies and associated carbonatites that intruded the low-grade metamorphic rocks belonging to the Puga Formation of the Cuiabá Group. The intrusions were plugs and dikes affecting an area about 30 km long, not far from Planalto da Serra, Mato Grosso. A few of these rocks were dated by Ar-Ar, Rb-Sr, and Sm-Nd methods, which revealed high-quality radiometric ages of *ca.* 600 Ma, placing a lower limit for the deformation of the Cuiabá Group. Moreover, the extensional tectonics of Planalto da Serra could be coeval with the one that produced the Tucavaca aulacogen. We believe that such late Neoproterozoic regional tectonics may indicate the starting point for the separation of Laurentia from West Gondwana.

A final regional deformational phase of very low intensity, extensional in character and related to a few intrusions of granitic bodies, took place during the Cambrian or even later. Within the area of the Paraguay belt in the vicinity of the TB megashear, Ferreira and others (2008) and McGee and others (2012) dated some undeformed granitic bodies, such as the São Vicente (521 ± 8 Ma), Coxim (542 ± 4 Ma), Rio Negro (549 ± 4 Ma), Sonora (549 ± 5 Ma) and Taboco (546 ± 4 Ma), which intruded the deformed supracrustal rocks of the Cuiabá Group. These plutons were coeval with felsic tuffs interlayered with sedimentary rocks of the much younger Tamengo Formation, recently dated at 543 ± 4 Ma (Boggiani and others, 2010). In the Cambrian, the Pampean Orogeny was in action at the southern margin of Gondwana, but no evidence for an oceanic lithosphere has been found in the vicinity of the Paraguay belt. Moreover, the possible suture envisioned by Tohver and others (2012) along the edge of the main thrust front of the Paraguay Belt (see fig. 5) cannot be defended, because the sedimentary sequences are autochthonous marginal basins located at the border of the Amazonian Craton.

Significance of the Puga Paleomagnetic Pole

Several large-scale models based on paleomagnetic measurements have been proposed for the assembly of Gondwana. The oldest such model showed the final collision of two large continental masses, West Gondwana (formed of South America and Africa) and East Gondwana (formed of Antarctica, Australia, India and Madagascar), during the period from late Neoproterozoic to early Paleozoic along the Mozambique belt (see, for example, original works by Kroener, 1980 or McWilliams, 1981). In recent years, the mechanism for Gondwana assembly has become more precisely constrained, due to a better understanding of the tectonic evolution and timing of the successive collisions between continental building blocks. However, the Ediacarian interval is notorious for its difficulty in paleomagnetic interpretation, and different models for the assembly of Gondwana have been suggested, such as those by Meert (2003), Cordani and others (2003), Yoshida and others (2003), Collins and Pisarevski (2005), Pisarevski and others (2008), Meert and Lieberman (2008), among many others.

Paleomagnetic measurements were obtained by Trindade and others (2003) for dolomites of the Puga cap carbonate of the Araras Formation within the Paraguay Belt (location in fig. 5), whose age has been supposed to be very late Neoproterozoic or early Ediacaran. Because this apparent pole plotted quite far from the other poles of Gondwana of the same age, the authors proposed that the Amazonian Craton and the rest of Gondwana were not united, and a large ocean existed between them during the Ediacarian. In their figure 10, they named this ocean as "Clymene."

The Puga paleopole is the most important and, perhaps, the sole evidence to which the hypothesis of the Cambrian Clymene Ocean is dependent. This finding is considered to be of high quality because of internal coherence. However, Trindade and others (2006) recognized that the age of 630 to 600 Ma for this paleopole, taken on the basis of Sr and C isotopes, is loosely constrained. Moreover, as emphasized by Pisarevski and others (2008), this Puga paleopole is located at high latitude, not far from the present-day pole; thus, it could be related to a recent remagnetization.

At present, no other reliable paleomagnetic poles are available for the Amazonian Craton for the Neoproterozoic–early Paleozoic time interval. In our view, there is currently no evidence to show definitively that the Amazonian Craton was far away from the São Francisco-Congo Craton at the time when the Iapetus Ocean started to form. New paleomagnetic measurements from Neoproterozoic to Cambrian rocks, located within the Amazonian Craton, are needed. Specifically for the Paraguay belt, it will be very important to obtain significant paleomagnetic results from the undeformed magmatic rocks of Planalto da Serra, which exhibit robust radiometric ages close to 600 Ma.

The Pampean Ocean and its Northern Continuation

Figure 4 approximately follows the model of Escayola and others (2011), in which their Ediacaran oceanic opening (called the Puncoviscana tract) runs along the proto-Andean active margin of West Gondwana, with a north-south trend. The Pampean Orogen, whose medium- to high-grade metamorphic rocks would be coeval with the less metamorphic meta-sediments of the Puncoviscana Formation, is constrained in time between 560 Ma and 520 Ma. Therefore, it was tectonically active during most of the Cambrian. The Amazonian, São Francisco-Congo, and Rio de La Plata cratons were already together after the collisions related to the Brasiliano-Pan African orogeny; thus, extensional processes, instead of convergence, are observed along the possible sutures, close to the TB megashear zone. In our view, the active margin represented by the Pampean Orogen, with its northern continuation, is the first evidence of the subduction of the Pacific oceanic plate under the southwestern margin of Gondwana. The closure of the Puncoviscana tract may have been the result of an interaction between the Rio de La Plata Craton and either the Pampean terrane of Rapela and others (1998), the Pampia terrane of Ramos and others (2010), or the Arequipa-Antofalla microcontinent of Escayola and others (2011). In any case, the subducted oceanic lithosphere would have disappeared below the Rio de La Plata Craton. The Pampean Orogeny, being coeval with the comparable Phanerozoic orogenic systems of the Southern Hemisphere, would be one of the oldest evidences for the onset of the Terra Australis Orogen, as proposed by Cawood (2005). Finally, the Puncoviscana Formation is younger than 570 Ma, as demonstrated by the age of the detrital zircon grains (Escayola and others, 2011). Thus, at the time of the Pampean orogeny, the Puncoviscana Ocean could not have reached central South America because the collisional sutures related to the Brasiliano orogenic cycle were already closed by this time.

Trindade and others (2006) did not provide conclusive arguments to prove the existence of an oceanic domain north of the Pampean ranges in Ediacaran to Cambrian times. Tohver and others (2012) tried to find a possible model to justify the existence of a Clymene Ocean of that age and suggested the location of a Clymene suture as represented in figure 5. First, they envisioned an Ediacaran link between the rocks of the Sierras de Cordoba with those within the basement of the Paleozoic sedimentary rocks of the Sierras Australes (see figs. 4 and 5). Second, they suggested a correlation of these systems with the Paraguay Belt. Although we have some difficulties in correlating the collisional rocks of the Sierras de Cordoba with the granitic rocks of the Sierra de La Ventana, we could consider an Ediacaran to Cambrian link between these regions, maintaining an unconfined position for them, while surrounding the Rio de La Plata Craton. This composite belt, extending to the northern Sierras Pampeanas as in figure 4, would be typically accretionary and related to the subduction of the proto-Andean Pacific oceanic lithosphere. However, we cannot accept the tentative correlation between the Sierras de Cordoba and the Paraguay Belt, for several reasons. First, the localities are very far apart (>500 km). Second, there is not any similarity of lithology, metamorphism, or structural trends. Third, and most importantly, there was no oceanic connection in the Ediacaran between the Pampean and Paraguay belts, as was mentioned above when referring to the Corumbá-Arroyo del Soldado epicontinental shelf.

CONCLUSIONS

From the discussion presented in the previous chapters, the tectonic history of West Gondwana can be summarized as follows:

1. The orogenic belts observed along the margins of the West African, Amazonian, São Francisco-Congo, and Kalahari cratons and the Saharan Metacraton were formed during the Brasiliano-Pan African orogenic cycle through the closing of the Goiás-Pharusian Ocean, the only large domain with an oceanic lithosphere occurring among them. After a long-lived convergence, starting *ca.* 900 Ma, the main collisional episodes of Himalayan type that formed West Gondwana were dated roughly *ca.* 650 Ma and 630 Ma, when Laurentia and Baltica were still attached to the supercontinent.
2. In Ediacaran time, Gondwana was already formed as a coherent continental block with a continental crust. Laurentia and Baltica started to separate from it, as the final stage of Rodinia fragmentation, *ca.* 600 Ma or a little later, with the onset of a major spreading center and the formation of the Iapetus Ocean. This development was concomitant with the tectono-magmatic evolution in the Brasiliano-Pan African belts, especially along the region of the Transbrasiliano-Kandi megashear.
3. At the beginning of the Paleozoic when major plate reorganization was necessary, the subduction of the oceanic lithosphere started along the Pacific margin of the supercontinent. The accretionary Pampean Orogen in Argentina was developed in the Cambrian between 550 Ma and 520 Ma. It showed tectonic shortening and regional high- to medium-grade metamorphism, associated with voluminous subduction-related granite magmatism.

In conclusion, the Ediacaran to Cambrian timeframe (see items 2 and 3 above) is critical for the assessment of the possible existence of a Clymene Ocean in South America. At that time, southern Gondwana was surrounded by marginal accretionary orogens. Early Paleozoic subduction and consequent accretionary tectonics were also occurring, which provided the kinematic framework for distant plate adjustments, such as local collisions and minor tectonic adjustments in the interior of the supercontinent. Most of these changes were of an extensional character and were along the Transbrasiliano-Kandi megashear, which was established on the continental crust. Therefore, from the Ediacaran to early Cambrian time in the central region of South America, there is no geological evidence of any area with an oceanic lithosphere, ruling out the possible existence of a Clymene Ocean in that age.

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