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Article

Linking the Neoproterozoic to Early Paleozoic Belts Bordering the West African and Amazonian Cratons

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Abstract: Correlations between the Neoproterozoic belts surrounding the West African Craton and northern Brazilian cratons have long been a subject of interest and controversies. Due to the splitting of African and South American continents by the Atlantic oceanic domains, no direct links are preserved, requiring relying on various geological or geophysical characteristics to propose such correlations. In addition to the opening of the Atlantic oceanic domains, another difficulty arises from the covering of northern Brazilian belts by upper Paleozoic and Mesozoic basins, making these correlations speculative. Recently, four orogens have been evidenced in the Neoproterozoic belts of the western margin of the West Africa Craton, while the belts on the eastern side underwent only one orogeny. Similarities with the Pan-African I (900-650 Ma) and with the Pan-African II (650-480 Ma) orogenic events have been evidence in the western Brazilian belts (Araguay and Paraguay). The two first orogens on the western margin (Pan-African I and Pan-African II) can thus be extended to the western Brazilian belts and can be considered as parts of a single geodynamic system running from the Mauritania to the Paraguay including the "Gurupi rift" as an aulacogen connected to the NNW-SSE Panafrican I and II oceanic domains. Consequently, the eastern Brazilian belt should rather be linked the Eastern Trans-Saharan belts.

Keywords: West African fold belts; Brazilian belts; Neoproterozoic orogens; Early Paleozoic; Gondwana; Correlations

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1. Introduction

Several cratons that formed the Rodinia supercontinent around 1 Ga [1] were separated during its early Neoproterozoic break up and were reunited again during the late Neoproterozoic, forming a series of orogenic belts [2]. For instance, the West African, Guaporé-Amazonian, São Francisco, Central African and Saharan cratons were reunited during Neoproterozoic to early Palaeozoic tectonic events that lead to the formation of various orogenic belts. Reconstructing the geometries of these belts and correlating them is challenging, because the opening of the Atlantic oceans split apart African cratons and their bordering belts from their Brazilian counterparts. In addition, the opening of the Atlantic oceanic domains was accompanied by intracontinental deformations, hampering correlations of pre-Mesozoic structures through Africa and South America [3]. Another, more important, difficulty arises from sedimentary covers younger than late Palaeozoic, because key structures are hidden beneath sedimentary basins. For instance, the Parnaíba and Paraná basins rest on potential suture zones [4]. Consequently, many attempts to correlate Neoproterozoic to Early Palaeozoic belts bordering African and South American cratons have been proposed [2,5–11] but remain speculative and sometimes conflicting due to the lack of decisive constraints.

In this work, we review new data on the western branch of the West African Craton (e.g., [12–14]) and on the eastern side of the Amazonian Craton (e.g., [15,16]). This allows proposing a new hypothesis for correlating Neoproterozoic belts on both sides of the Equatorial Atlantic Ocean.

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2. Geological setting

Three main cratons are distinguished in west and central Africa, and in South America (Figure 1): the West African Craton (WAC) in West Africa, and the Guapore - Amazonian (GAC) and the São Francisco (SFC) cratons in northern Brazil. The SFC is considered to represent the western part of the Central African Craton (CAC; e.g.,[17]). In addition, two small blocks are inferred to occur beneath the Parnaiba and Paraná basins: the Parnaiba Block (PB) and the Paranapanema Block (PnB; e.g.; [4]).

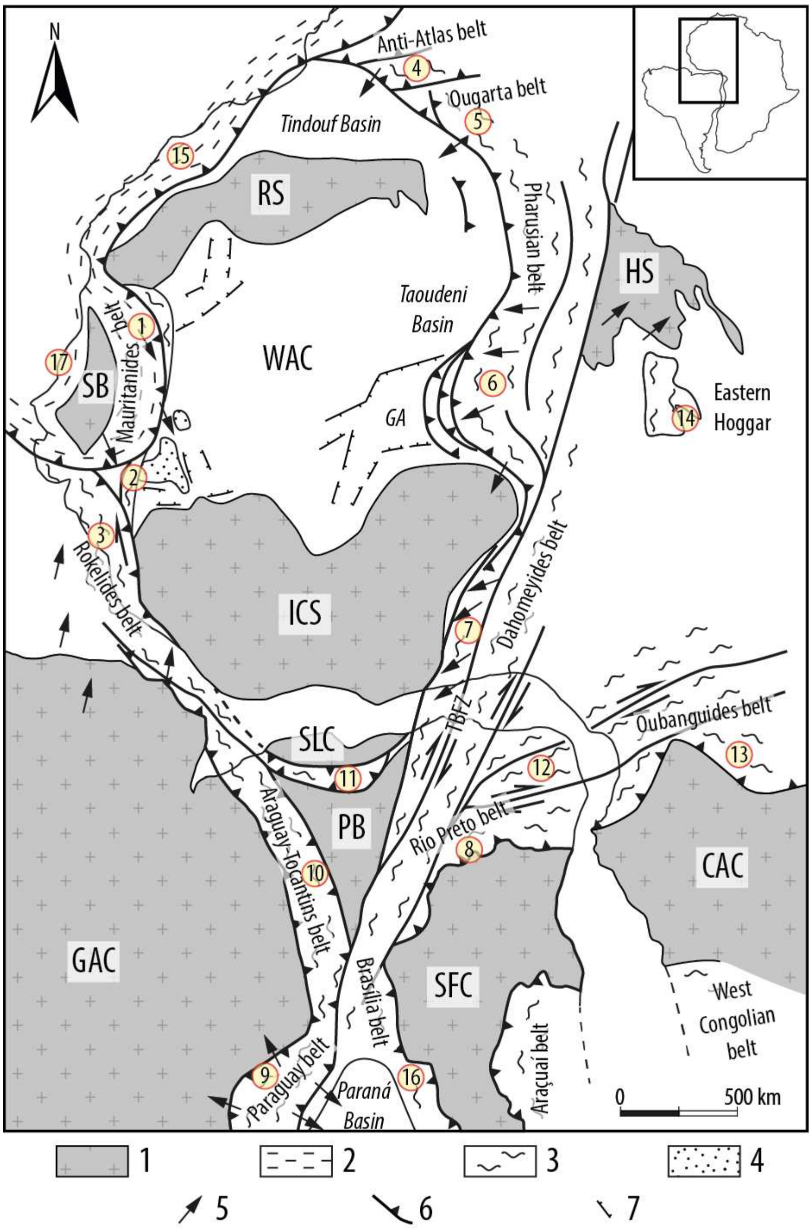

Figure 1. Cratons and belts in west Africa and northeast Brazil after Villeneuve and Cornée [11], modified. 1- Cratons, blocks, and shields, 2- Variscan belts, 3- Neoproterozoic to early Palaeozoic belts, 4- Foreland basins associated with Neoproterozoic to early Palaeozoic belts, 5-Moving directions, 6- Major thrust belts or suture zones, 7- Normal faults. **Cratons, blocks, and shields**: WAC (West African Craton), GAC (Guaporé-Amazonian Craton), SFC (São Francisco Craton), CAC (Central African Craton), SLC (São Luis Craton), PB (Parnaíba Block), RS (Reguibate Shield), ICS (Ivory Coast Shield), HS (Hoggar Shield), SB (Senegal Block). **Rift**: GA (Gourma Aulocogen). **Belts** (circled numbers): (1)- Mauritanide, (2)- Bassarides, (3)- Rokelides, (4)- Anti-Atlas, (5)- Pharusides, (6)- Adrar des Iforas, (7)- Dahomeyides, (8)- Rio Preto, (9)- Paraguay, (10)- Araguay, (11)- Gurupi, (12)- Borborema, (13)- Oubanguides, (14)- Aïr, (15)- Souttoufides, (16)- Brasília, (17)- Western Thrust Belt.

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At least 17 different belts mainly linked to the Neoproterozoic orogenetic events surround these Cratons and blocks: the WAC is bordered by ten belts in west Africa, six other belts occur in northern Brazil, and one is located to the north of the CAC, central Africa (Figure 1). Each belt has its own history and evolution resulting from different orogenetic events. In this study, we review the evolution of ten out of the 17 identified belts, selected because their geodynamic evolution allows discussing correlations of Neoproterozoic belts on both sides of the Atlantic Ocean.

From the Mesoproterozoic to the end of Palaeozoic, four orogenic events have been evidenced on the western side of the WAC [13] and are thus taken as references for assessing the geological evolution of West Africa and north Brazil and propose correlations between African and South American Neoproterozoic to Early Palaeozoic belts. Of course, each of these orogenic events is not recorded by every belt ascribed to the Brasiliano - Panafrican cycle, and some orogenic events are missing depending on the position of the belts in the Gondwana continent. These orogenic events (Figure 2) are reviewed hereafter.

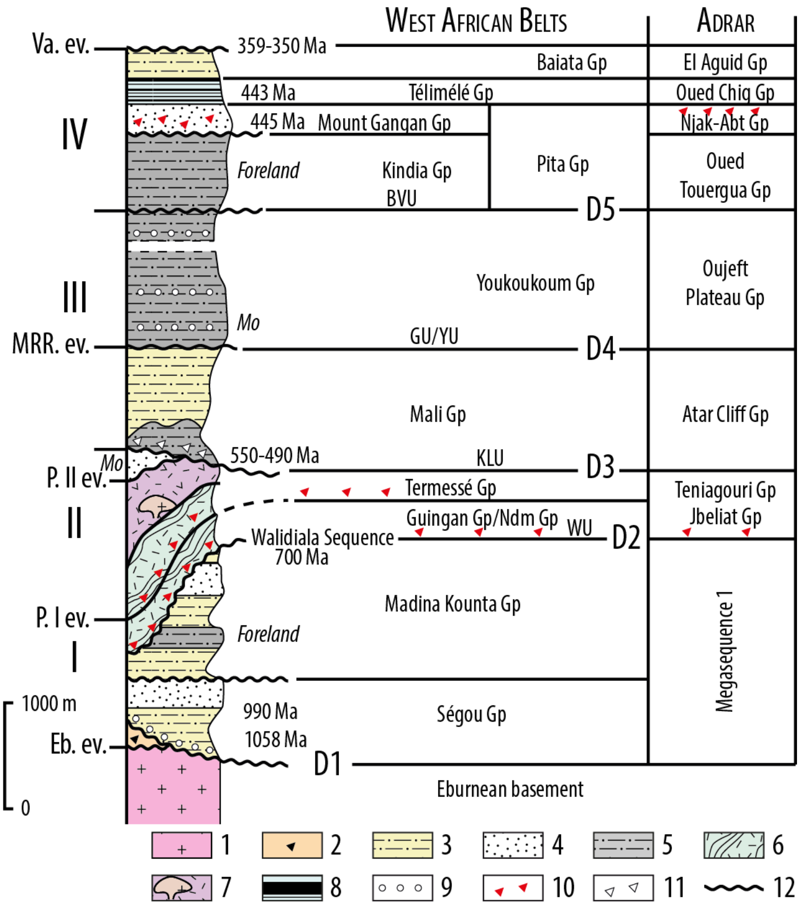

Figure 2. Orogenic events and unconformities in west Africa. 1 - West African basement, 2 - sandstones and conglomerates, 3 - shales and siltstones, 4 - sandstones, 5 - volcano-sedimentary rocks, 6 - phyllites and micaschists, 7 - andesites, jaspers, rhyolites, and related intrusive magmatic rocks, 8 - shales, 9 - conglomerates, 10 – diamictites of probable glacial origin, 11 – other diamictites, possible glacial origin, 12 - unconformities: WU - Walidiala Unconformity, KLU - Koubia-Lessere Unconformity, GU - Gaoual Unconformity or YU - Youkounkoun Unconformity, BVU – Bové Unconformity. Main orogenic phases and events: roman numbers: I - pan-African I orogenic cycle (P. I ev.), II – pan-African II orogenic cycle (P. II ev.), III - Mali–Rokel River orogenic cycle (MRR. ev.), IV - Variscan orogenic cycle (Va. ev.). Eb. ev.: Eburnean event, Mo.: Molasses.

- *The Panafrican I orogeny* (900 to 650 Ma) results from an oceanic subduction with related volcanic arc. The collision occurred around 660-640 Ma [14]. In the western side of the WAC and in the Aïr belt (Eastern Hoggar shield) this subduction is toward the west [18]. Foreland basins associated with

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this belt are the Madina Kouta and Taoudeni basins and the molassic deposits related to this orogen crop out in the Cangarafa Group, in the Mauritanian belt.

- *The Panafrican II orogeny* (650 to 480 Ma) initiated with the opening of an oceanic domain after 650 Ma called the WANO (West African Neoproterozoic Ocean) in Africa. The sedimentary succession began with a diamictite level of glacial origin (Walidiala tillite) and associated cap carbonates linked to the worldwide Cryogenian glacial events [19]. The sedimentary deposits in the foreland are the Jbeliat and Teniagouri groups (Figure 2). The closure of this ocean and the collision began about 550 Ma and post-collisional granitic intrusions occurred between 530 and 480 Ma. The molassic stage related to this orogeny has been recorded in the "Fello Bonda" Formation (Kemberra inlier) in Guinea in which the younger detrital zircon displays an age of ca. 531 Ma [20]. Late to post-orogenic magmas consist mainly of granites and micro-gabbros and display ages around 485 Ma [21] and crop out mainly in the Tominé inlier (Guinea).

- *The Mali-Rokel-River orogeny* (480 to 470 Ma?) is only evidenced in west Africa. It initiated with intercontinental troughs infilling by sediments corresponding to two different groups. The lower Mali-Rokel River Group started with a diamictite level (Koubia-Lessere diamictite) evidenced in Guinea and Sierra Leone [13]. These diamictites cover the 480 Ma micro-gabbros in the Tominé inlier. The Mali-Rokel River Group is folded in the western troughs. The upper group, referred to as the Youkounkoun Group, correspond to a molassic stage deposited in the flat lying Youkounkoun Basin (Guinea/Senegal). Age of the Mali-Rokel River tectonic event is unknown owing to the lack of dating results in the Bové Basin Unconformity (BVU). The opening and subsequent inversion of these rift basins are likely linked to the opening and closure of the "Iapetus Ocean" and consequently tied to the Taconic orogeny.

- *The Variscan orogeny* (460 to 270 Ma) is recorded by Palaeozoic sediments infilling the Bové and Taoudeni basins. This sedimentary pile was deposited from the Ordovician to the late Devonian. These sedimentary rocks are locally deformed, mainly in the Mauritanian belt by the Variscan tectonic event, which was induced by the assembly of Pangea during the Carboniferous and Permian periods.

3. Geology of the belts

In order to correlate West African fold belts with their counterparts in northeast Brazil (1 to 17; Figure 1), it is necessary to know their evolution with respect to the different orogenic events considered here above.

3.1. West African belts

3.1.1. On the western side

Excepted the Souttoufide belt (15) located in southern Morocco and northern Mauritania, there are:

- The Mauritanide belt (1) which is cropping out in Senegal and Mauritania. It underwent three orogenic events: the Panafrican I, Panafrican II and Variscan ones. Deformations associated with the Mali-Rokel-River orogeny are suspected but not yet evidenced. Owing to the double vergence of slabs evidenced by seismic investigations [22] it is difficult to ascertain the vergence of the Panafrican I or II oceanic slabs. Considering that the Variscan suture is located in the Western Thrust Belt (WTB; 17) located to the west of the Senegalese Mesozoic to Cenozoic basin, the Variscan deformations in the Mauritanide belt are linked to a continental collision between the West African Craton and the Senegalese Block.

- The Bassaride belt (2) is cropping out in eastern Senegal and northern Guinea [23]. This belt ascribed to the Panafrican I orogenic event results of the closure of an unnamed ocean subducting to the west with an island arc located to the west, in the Niokolo-Koba branch. This orogenic event is recorded by the Guinguan Group. In addition, remnants of a Mesoproterozoic belt (1300 to 1064 Ma) have been found in the Guinguan Group [21]. Remnants of the Bassaride belt matched with parts of the Mesoproterozoic relicts that have been evidenced in Sierra Leone [12].

- The Rokelide belt (3) is cropping out from the Guinea to the Liberia and results from a collision, after subduction to the east of an ocean called WANO (West African Neoproterozoic Ocean). It comprises an island arc in the western Niokolo-Koba branch and a back-arc basin in the Bassaride belt (Termesse Group). The collision occurred around 550 Ma and was followed by post-tectonic granites emplaced at about 530 Ma [24,25]. Similar ages are also recorded in the sedimentary rocks of the Fello Bonda molassic group. The last granitic intrusion has been dated at 485 Ma in the Tominé inlier [21]. The third orogenic event (Rokel-River orogeny) is recorded by some small basins (among them the Rokel River one) which are infilled by early Ordovician sediments with a diamictite level at its base.

3.1.2. On the eastern side

There are at least five Neoproterozoic belts on this margin: the Anti-Atlas (4), Pharusian (5), Aïr (15), Adrar des Iforas (6) and Dahomeyides (7) belts. In the following, only the last two ones are taken into account for correlations with Brazilian belts.

- The Adrar des Iforas belt (6) is a part of the "Trans-Saharan mega orogen" which extends on the eastern side of the WAC, from the Pharusides to the Dahomeyides [20,26]. This belt was formed by only one orogenic event that started with the closure of an oceanic domain around 800 Ma [27,28]. The formation of the orogen was accompanied by the formation of the Taoudeni foreland basin, particularly in the "Gourma Aulacogen" (GA; Figure 1). According to Liegeois et al. [29], this ocean has subducted to the east between 730 Ma and 620 Ma. Oceanic subduction was followed by continental collision with the Hoggar massif between 620 Ma and 580 Ma. The uplift after subduction occurred between 580 Ma and 570 Ma and the distention with intrusion of post-tectonic granites took place until 540 Ma together with molassic deposits in post-orogenic grabens, which also comprise a basal diamictite level. These events are linked to the Panafrican II orogeny. Deformations related to the Panafrican I event have been suspected but are not clearly demonstrated. However, a geodynamic evolution similar to that of the western side of the WAC with an oceanic subduction to the west until 670 Ma (Panafrican I orogen) followed by new subduction to the east until 580 Ma (Panafrican II orogeny), was recorded in the Aïr massif, western Hoggar [18].

- The Dahomeyides belt (7) presents an evolution similar to the "Adrar des Iforas belt" with only one orogenic event (Panafrican II). The foreland units consist of the Bombouaka and Oti groups, which crop out in the Volta basin [30,31]. The "nappes" were emplaced between 607 and 579 Ma in the Buem units [32,33], and the suture dips to the east. The post- collisional stage had begun around 575 Ma.

3.2. Brazilian belts

There are six Neoproterozoic belts in the northern part of Brazil which are connected to the WAC (West African Craton) or to the CAC (Central African Craton). For the purpose of this study, we focus on the belts cropping out between the Amazonian Craton and the São Francisco Craton, namely the Gurupi, the Araguay, the Paraguay, the Brasília and the Rio Preto belts.

- The Gurupi belt (11) crops out along the São Luis Craton (SCL; Figure 1) and is limited to the west by the Neoproterozoic Araguay belt. Ages determined with the Rb/Sr and K/Ar methods [34] were complemented by recent U/Pb ages on zircon [35,36] and indicate that the São Luis Craton comprises rocks with ages ranging from ca. 2200 to 1920 Ma, supporting a connection with the Ivory-Coast Shield. Metamorphic and sedimentary rocks in the Gurupi belt display ages ranging from ca. 1130 to 504 Ma[36]. Furthermore, gravimetric anomalies in the Gurupi belt have a NW-SE trend differing from those of the Araguay Belt which have a N-S orientation [36]. Although the geodynamic evolution of the Gurupi belt is not yet well understood and relatively complex, Klein et al. [36] proposed a polyphased geodynamic evolution starting with an intra-continental rift that transitioned to a passive margin between ca. 1130 Ma and 740 Ma, and remained a passive margin until 600 Ma [15]. Later, this passive margin was involved in a continental collision marked by the emplacement of collisional peraluminous magmatic rocks between 580 Ma and 550 Ma. The magmatism continued in a post-collisional setting between ca. 550 Ma and 517 Ma. Finally, Klein et al. [15] interpreted the

Gurupi belt as the result of an intracontinental process with opening of a rift and its inversion during the Cambrian.

- The Araguay belt (10) belongs to the Tocantins province. The Araguay belt is almost 1000 km long and 100 km wide and is located on the eastern side of the Guapore - Amazonian Craton. It is limited to the south by the Goiás massif. The Araguay belt is delimited to the east by the Transbrasiliano lineament and comprises two main units: the Tocantins unit to the west and the Estrondo unit to the east. The western vergence to the west brought the Estrondo unit over the Tocantins unit. The Estrondo unit is well characterized and contains Paleoproterozoic massifs (2.07 Ga to 1.85 Ga), Mesoproterozoic metamorphic rocks (ca. 1 Ga), Neoproterozoic granites dated at ca. 660 Ma and Cambrian (ca. 510 Ma) massifs [37]. On the contrary, the Tocantins Unit is poorly characterized and comprises Paleoproterozoic rocks together with the Neoproterozoic Quatipuru ophiolites (757 ± 49 Ma, Sm-Nd isochron; [38]). Other tectonic events are recorder in this belt and consist of a NS strike-slip faulting linked to the Transbrasiliano lineament [4], at ca. 331-345 Ma event ascribed to the Variscan orogen in northern Gondwanides and a 197 - 198 Ma event linked to the central Atlantic Ocean opening [3]. Several geodynamic models have been proposed for the Araguay belt, including the closure of the Clymene Ocean around 550 Ma [39,40].

- The Paraguay belt (9) is located along the Amazonian Craton and separated from the Aaraguay belt by sediments of the Bananal Basin [37]. This belt has been studied at least since the 90s [41], and recent investigations allow to better constrain its stratigraphic evolution [16] and propose a correlation with the Bassaride and Rokelide belts (Figure 3). The oldest stratigraphic unit consists of Neoproterozoic Cuiabá Group, which was deformed around 652 Ma. This group is capped by the Puga Formation deposited during the Marinoan glacial event around 635 Ma. Tillites of the Puga Formation are capped by the Araras Group comprising limestones and argilites. The Araras Group is overlain by the early Cambrian Alto Paraguay Group which comprises conglomerates, sandstones and shales with “skolithos” burrows. Granitic intrusions (e.g., São Vicente granite) emplaced at 518 Ma [42] provide a minimum age for this group. The last stage consists in the deposition of sediments from the Ordovician to the Devonian in the Paraná Basin [43]. In the Paraguay belt the metamorphism decreases from east to west. Structures present a double vergence: toward the Amazonian Craton in the western side and toward the east in the internal Cuiabá and Araras groups to the east. Little is known about the first orogenic event (900 to 650 Ma) and the D1 deformation ascribed to this orogeny is only recorded in the Cuiabá group. Other deformation events (D2 and D3) imprinted all groups until the Alto Paraguay Group. The geodynamic evolution of this belt is still debated between an intra continental ensialic model [44] and a classical subduction model with an island arc in the Goiás massif [45]. Another hypothesis considers the Paraguay belt as the foreland of the Brasília belt at about 600 Ma [20].

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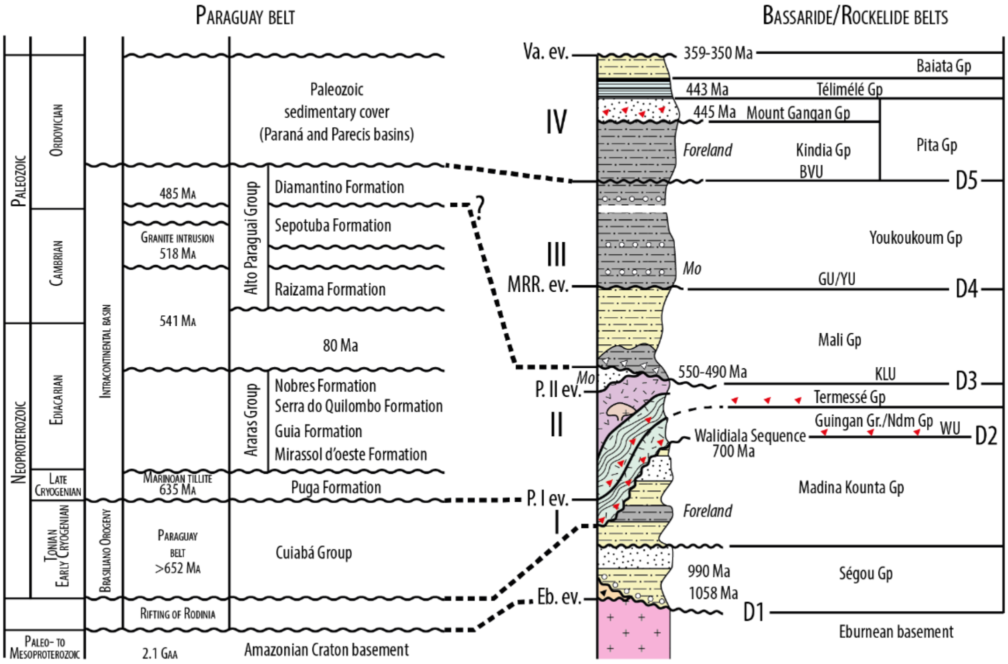

Figure 3. Stratigraphic correlations between the Bassaride/Rokelide and the Paraguay belts. See Figure 2 for legend.

- The Brasília belt (16) is separated from the Paraguay belt by the Goiás massif and the Goiás magmatic arc. According to Trompette [20] this belt can be divided in three parts which consist of the Brasiliano metasediments including the Bambuí Group with glaciogenic deposits at its base, middle Proterozoic sediments metamorphosed during the Brasiliano orogeny and the Central Goiás massif with a magmatic arc, from east to west. From the base to the top, the stratigraphic succession comprises the Araxa Group, which was deformed by the Uruaçu orogeny about 1200 - 1000 Ma, and the São Francisco Group which was affected by the Brasiliano orogeny about 600 Ma. The link between the Goiás magmatic arc and the Brasília belt is debated. According to [45] this magmatic island arc was active between 900 Ma and 600 Ma and could results from the "amalgamation of several island arcs" [46]. In the southern part of the Goiás massif [45] dated two granitic intrusions younger than the 643 Ma to 608 Ma granites related to the arc volcanic activity: the older one is dated at 588 Ma to 560 Ma and the younger one was emplaced between 508 Ma and 485 Ma. These last intrusions do not occur in others Brazilian belts except in the eastern Borborema belt. According to D'el Rey Silva et al. [7] the Brasília belt presents a complex evolution with an ocean separating the Amazonian and São Francisco cratons before 800 Ma. Then, this ocean subducted toward the east under the São Francisco Craton until its closure around 650 - 635 Ma. This closure leads to the opening of the Quatipuru-Paraguay Ocean and to the accretion of the Paranapanema Block to the Brasília belt.

- The Rio Preto belt (8) is located to the northwest of the São Francisco Craton. This belt resulted from the convergence between Borborema Province and the São Francisco Craton between ca. 640 Ma to ca. 500 Ma [17,47–49]. The Rio Preto belt initially corresponded to a rift that initiated around ca. 900 Ma [50]. The lack of oceanic rocks within the Rio Preto belt suggests an intracontinental setting, and the rift was later inverted during a convergence phase between ca. 640 Ma to ca. 500 Ma [50].

- **The Borborema belts** (12) are located in northeastern Brazil and comprise four different zones or belts including, from north to south: the "Ceará belt" (or Ceará central domain) oriented NE-SW and linked to the Hoggar belt, the "Central Fan belt" or "Rio Grande do Norte domain" with NE-SW orientation and linked to the eastern Hoggar (Aïr massif), the "Patos - Pernambuco shear zone" [51] oriented W-E and liked to the central African fault zone (Amadaoua fault zone), the "Southern frontal zone" including the "Sergipano fold belt" oriented WNW-ESE and linked to the Oubanguide belt located to the north of the CAC. Every belt has a different geodynamic evolution. For example, the northern Ceará belt is characterized by a subduction to the south and a syn-collisional stage at 640

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Ma [52], while the southern Sergipano fold belt records a subduction to the north with a syn-collision stage between 605-540 Ma [53].

4. Correlations

Many hypotheses have been proposed to correlate the belts now cropping out in west Africa and northeast South America. Before presenting our model, we provide a brief review of the various correlations that have been proposed until now.

4.1. History of correlations

There is a long history of attempts to correlate the west African fold belts with their counterparts in northeast Brazil, and this section only reports the evolution of general ideas regarding these correlations without aiming to propose an exhaustive review of existing models. In the 80s, taking into account the extension of the Trans-Saharan gravimetric anomalies, Lesquer et al. [10] correlated all the northeastern Brazilian belts with the Trans-Saharan belts. Later, during the 90s, Castaing et al. [6] proposed to correlate the Trans-Saharan belts and northeastern Brazilian belts with the central African belts and particularly with the Oubanguides, while Villeneuve and Cornée [11] correlated the Rokelide with the Araguay and Paraguay belts and the Trans-Saharan belts with the Pampeanas belt by cutting the Brasilian belt. During the 2000s [5] suggested correlating the Paraguay belt with the Borborema belt, and Cordani et al. [2] used the "Trans-Brazilian lineament" to separate the Paraguay and the Brasília belts. Another model was put forward by De Wit et al. [8] who linked the Brasília belt with the Central African Orogen. Later, D'el Rey Silva et al. [7] proposed that the Brasília belt resulted from the closure of the Quatipuru and Paraguay Oceans. Ganade de Araujo et al. [9] proposed a model with three distinct branches: a western branch with the Araguay and Gurupi basins, a central branch with the Pharusian and Goiás Ocean and an eastern branch with the Pernambuco Ocean. Their model [9] comprises 4 tectonic stages from the oceans to the belt building: a pre-collision stage (800-650 Ma), a collision I stage (620-600 Ma), a collision II stage (590-570 Ma) and the last tectonic stage with the extrusion of the whole Borborema block to the northeast (580-550 Ma). Cordani et al. [39] suggested a model extending the Trans-Brazilian lineament to the west of the Rio de la Plata Craton.

4.2. Correlations from the Mauritanide to the Paraguay belt

Our focus here is to correlate the belts occurring in the western side of the WAC (Bassaride and Rokelide) with their counterparts in the eastern side of the GAC (Gurupi, Araguay and Paraguay).

4.2.1. Correlation between the Araguay and Rokelide belts

The Luizia granites in the Araguay belt (Figure 4) are consistent with a Panafrican I magmatism, and the Carito granites (530 Ma) are consistent with the Panafrican II event. However, the lack of geodynamic interpretation prevents a solid correlation although the vergence of thrusts toward the GAC suggests a suture dipping to the east, similarly to the Rokelide belt.

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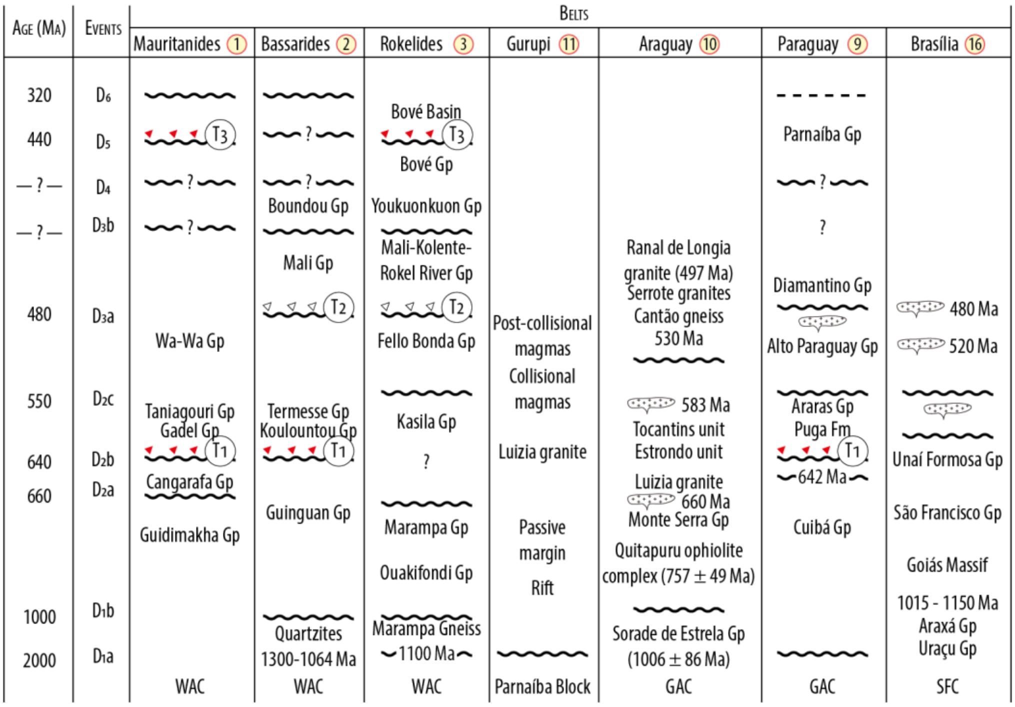

Figure 4. Correlations between the groups and tectonic events belonging to the belts cropping out between the WAC and GAC. T1- Walidiala diamictite, probable glacial origin (tillite; ca. 635 Ma), T2 - Warnani diamictite, (post 485 Ma), T3 - Hirnantian diamictite, probable glacial origin (tillite, 446 Ma). D1a and D1b (Paleo- and Mesoproterozoic Unconformities), D2a, D2b, D2c (Neoproterozoic Unconformities), D3, D4 and D5 (Palaeozoic unconformities), D6 (Variscan unconformity).

4.2.2. Correlation between the Paraguay and Rokelide belts

Both belts present some similarities, noticeably two different tectono-metamorphic stages consistent with the Panafrican I and the Panafrican II orogenic events. Correlations between the two belts (Figure 3) pointed out large consistencies in their stratigraphy and tectonic events. However, suture zones and magmatic arcs are not yet clearly evidenced. The lack of the Rokel-River orogenic event (III) is consistent considering that this orogen is linked to the Iapetus Ocean, which did not extend in Brazil.

4.2.3. Correlation between the Brasília and Rokelide belts

The evolution of the Brasília belt is consistent with those of the Trans-Saharan belts (Pharusides, Adrar des Iforas and Dahomeyides) noticeably by the lack of Panafrican I tectonic event and the inception of collision around 620-600 Ma. However, if the Goiás magmatic arc located to the west is linked to the Brasília belt this would imply a subduction toward the west, which is the contrary to the African belts. Thus, the Goiás magmatic arc is questioning. First, it is separated from the Araguay–Paraguay belts by the Trans-Brazilian lineament which is a strike-slip fault but not by a thrust fault related to the collision between the Brasília and the Araguay belts. According to Trompette [20] the early Pan-African molasses in the Trans-Saharan belts were intruded by alkaline ring plutons dated between 570 Ma and 540 Ma, while the Panafrican II molasses in the Kemberra inlier (Rokelide) contain detrital zircon giving a maximum depositional age of ca. 530 Ma [54]. Second, in the southern part of the Goiás magmatic arc, Pimentel and Fuck [45]. dated some granitic intrusions at about 508 Ma and 485 Ma, which are known in the northern Rokelide and in the Borborema belts but not in the Trans-Saharan belts. In our opinion, the Goiás magmatic arc is more consistent with the Araguay–Paraguay belts than with the Brasília belt.

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4.3. Overall stratigraphic correlations

Tectonic events underlined by unconformities allow us to propose some consistent correlations between the stratigraphic groups belonging to different belts (Figure 4). In addition, a major, worldwide glacial events that occurred during the late Neoproterozoic and referred to as the Marinoan glacial event (T1; ca. 635 Ma; [19]) is recorded in the Mauritanide, Bassaride and Paraguay belts, allowing to correlate these belts located on each side of the Atlantic Ocean. In addition, another glacial event occurred during the Upper Ordovician (T3; Hirnantian glacial event; 446-444 Ma; [55]). Glaciogenic rocks associated with this glacial event are found at high paleo-latitudes and altitudes and can be present or missing according to the paleogeographic position of the basins or to their regional geodynamic setting [56,57]. Other diamictites occurs in early Ordovician deposits of the Bassaride and Rokelide belts (T2; Warnani diamictites, younger than 485 Ma). These diamictites could represent another potential glacial event, of regional extent, as the Early to Middle Ordovician epochs correspond to globally hot climate conditions [55].

5. Discussion

Although it is difficult to have a definitive opinion about these correlations without a direct connection in the field, we remark that belts on the western side underwent two distinct Panafrican orogenic events while the Brasília and the Trans Saharan belts underwent only one orogenic event. Although the two orogenic events are not as clear and evident in Brazil as they are in the Rokelide belt, a correlation involving the Bassarides, Rokelide, Araguay, Paraguay and Gurupi belts should be considered (Figure 5).

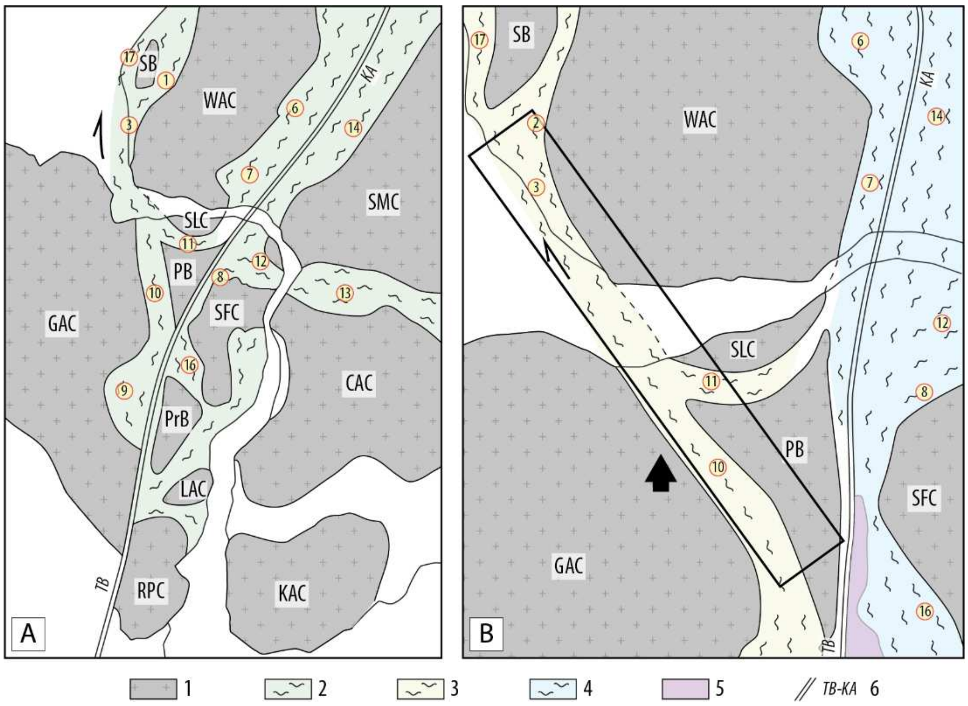

Figure 5. Hypothesis on the connections between the African and Brazilian Neoproterozoic to Early Palaeozoic belts. A - Trans African/Brazilian system. B - Correlations adapted from Cordani et al. [39]. 1 - Cratons, 2 - Belts (undifferentiated), 3 - Western belts, 4 - Eastern belts, 5 - Goiás magmatic arc. Belt numbers: see Figure 1. TB –Trans – Braziliano fault zone, KA- Kandi fault zone.

A geodynamic evolution model relying on new data on the Bassaride and Rokelide belts and taking into account their correlation with their Brazilian counterparts is proposed as follow (Figure 6):

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1- Opening of N-S oceans at 900-800 Ma together with an E-W rift in the Gurupi zone,

2- Subduction to the west of these oceans and collisions around 650-660 Ma (Panafrican I orogen Figure 6A). The Gurupi rift is not yet inverted.

3- Opening of ocean to the west (WANO or Clymene Ocean?)

4- Subduction to the east until 620-600 Ma (Figure 6B)

5- Collision and dextral strike-slip with closure of the Gurupi belt inducing the northern motion of the WAC and dextral strike slip along the KA and TB faults (Figure 6C).

6- Molassic grabens and post-collisional magmas until 485 Ma.

7- Opening of N-S trough parallel and coeval with the opening of the Iapetus Ocean after 485 Ma in the northern (African) part only.

8- Deposits of molassic sediments and alluvial plain sediments in Palaeozoic basins (Bové, Amazon, Maranhão, etc,).

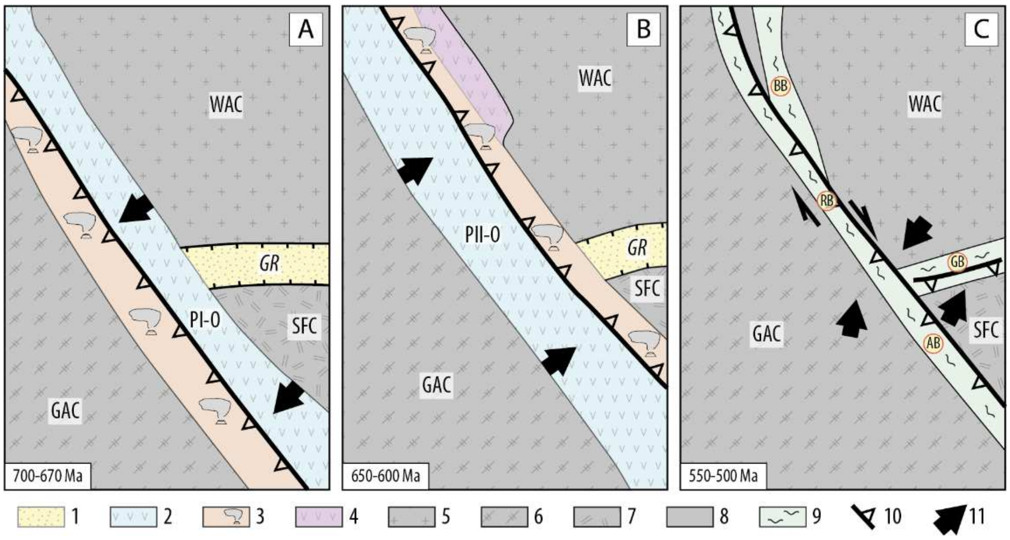

Figure 6. Proposed evolution for the Neoproterozoic belt from the Bassarides (Senegal) to the Paraguay belts (Brazil). 1 - Rifts, 2 - Oceanic domains, 3 - Volcanic-magmatic arc, 4 - Back-arc basin, 5 - West African Craton, 6 - Gupaporé Amazonian Craton, 7 - São Francisco Craton, 8 - Senegal Block, 9 - Neoproterozoic belts, 10 - Subduction and suture zones, 11 - Moving directions. GR - Gurupi rift, GB - Gurupi belt, RB - Rokelide belt, AB - Araguay belt. PI-O - Panafrican I Ocean (Bassaride Ocean?), PII-O - Panafrican II Ocean (WANO or Clymene Ocean).

Although some elements of this geodynamic model remain speculative, it provides a way to better understand the links between various orogenic belts that share a common geodynamic history. Importantly, this geodynamic model can (and will) be tested by further research in the Araguay and Paraguay belts, and on the Goiás magmatic arc.

6. Conclusions

Our model adds to a long list of hypotheses related to the correlations between the belts on both sides of the Equatorial Atlantic Ocean. It results from new data in West Africa not yet published and particularly the distinction between four distinct orogenic events. All these four orogenic events are not documented in every belt, but they provide a general framework for these correlations. However, if our hypothesis seems to be coherent in the western belts, their delimitation with the Eastern ones is still unclear particularly to the South of the Parnaiba Block. New investigations, noticeably in geophysics, are necessary to satisfy at a consistent and solid geological scheme.

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