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PALEOMAGNETISM OF THE MAIN SOUTH AMERICAN PRECAMBRIAN CRATONS

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ABSTRACT. Here, we discuss the role of the main South American cratonic units in the Columbia and Rodinia supercontinents, and Gondwana megacontinent. According to paleomagnetic and geological data Amazonia and West Africa were linked to Baltica, Laurentia and Siberia forming West Columbia at ca. 1.78–1.75 Ga. The 1.78 to 1.42 Ga paleomagnetic data for Amazonia, Baltica and Laurentia suggest either, that West Columbia preserved its integrity, at least, up to 1.42 Ga, or Amazonia-West Africa broke-up from West Columbia at some time between 1.53 and 1.42 Ga. On the other hand, the Congo-São Francisco, North China, Río de la Plata, India and proto-Australia formed the East Columbia at ca. 1.78 Ga. However, the presently available Paleo to Mesoproterozoic paleomagnetic data for these cratonic blocks suggest that East Columbia was short-lived. At 1.1 Ga ago, Amazonia-West Africa, Congo-São Francisco, Kalahari and India probably formed a megacontinent that later collided with Laurentia and Baltica forming Rodinia at ca. 1.0 Ga. Most probably, Rodinia broke-up at ca. 750 Ma, when Congo-São Francisco, Kalahari and other smaller blocks rotated ca. 90° counterclockwise, closing the Brasiliano/Clymene Ocean and docked against Amazonia-West Africa and Río de la Plata at ca. 600–570 Ma ago forming West Gondwana.

Keywords: Amazonian Craton; São Francisco Craton; Río de la Plata Craton; supercontinents.

INTRODUCTION

Understanding the role of continental masses on assembling and break-up of supercontinents through geological time is crucial to decipher the Earth's geological and dynamic evolution (e.g., Condie, 2002; Nanci et al., 2014). Geological and geochronological data suggest that in at least three times supercontinents amalgamated: at 1.8–1.6 Ga when most of the existing continental blocks formed the Columbia supercontinent, at ca. 1.0–0.9 Ga when Rodinia supercontinent formed following break-up of Columbia, and at 0.32–0.28 with the amalgamation of Pangea (e.g., Li et al., 2008; Meert, 2012; Pisarevsky et al., 2014). Geochronological evidence suggests that a fourth supercontinent could have existed at ca. 2.7–2.6 Ga (Hawkesworth et al., 2010), although any attempt to reconstruct an Archean supercontinent is very speculative due to the scarcity of adequate Archean geological units for paleomagnetic analysis (e.g., Buchan et al., 2000; Pesonen et al., 2003; Evans, 2013).

For such old period, we have scarce data that may permit to compare and eventually correlate a few cratonic blocks – the supercratons after Bleeker (2003) – as the Zimgarn (Zimbabwe-Rhodesia-Yilgarn) supercraton of Smirnov et al. (2013) and the Vaalbara (Kaapvaal-Pilbara) Supercraton of De Kock et al. (2009). More recently, based on 2.7–2.5 Ga paleomagnetic data and magmatic correlations, Salminen et al. (2019) proposed the Supervaalbara Supercraton, which would include part of the São Francisco Craton and the Superior, Wyoming, Kola-Karelia, Zimbabwe, Kaapvaal, Tanzania, Yilgarn and Pilbara Cratons.

Rogers (1996) proposed that some South American and African Cratons (Guyana or proto-Amazonia, Río de la Plata, West Africa and Congo-São Francisco) assembled into a continent called "Atlantica" at around 2.2 Ga. The proposed configuration was one very much resembling that of West Gondwana for these crustal blocks. In several paleogeographic models (Pehrsson et al., 2016, Grenholm, 2019, among others), Atlantica, with its original or a slightly different configuration, assembled into the Columbia supercontinent a few hundred million years later. Paleomagnetic testing of the Atlantica hypothesis (Franceschinis et al., 2019; and references therein) refuted such configuration and casted doubts on the mere existence of that continent. However, the same paleomagnetic data allowed its existence if a very different configuration was accepted for Atlantica.

Several paleogeographic reconstructions of the Paleo- to Mesoproterozoic Columbia supercontinent have been proposed in the literature (e.g., Rogers, 1996; Rogers and Santosh, 2002; Zhao et al., 2002; 2003; 2004; 2006; Meert, 2002; Pesonen et al., 2003; Hou et al., 2008a; b; Johansson, 2009; 2014; Yakubchuk, 2010; Piper, 2010; 2018; Evans and Mitchell, 2011; Zhang et al., 2012; Xu et al., 2014; Meert and Santosh, 2017; D'Agrella-Filho et al., 2021). Most of these authors favors its maximum amalgamation at ca. 1.85–1.80 Ga, although other authors argue for a later maximum packing of Columbia, at ca. 1.6 Ga (Pisarevsky et al., 2014), supported by paleomagnetic and geological constraints. In this context, Wang et al. (2020) used the term Nuna for a megacontinent composed by Laurentia, Baltica and Siberia that existed at ca. 1.8 Ga. Probably, this large landmass also included Amazonia and West Africa at this time (Johansson 2009; Bispo-Santos et al., 2014a), which eventually formed Columbia supercontinent some 0.2 Ga later, with the amalgamation of other blocks, such as Australia (Wang et al., 2020). Also, Wang et al. (2020) suggest that megacontinents formed ca. 0.2 Ga before complete amalgamation of Rodinia (megacontinent Umkondia, Choudhary et al., 2019) and Pangea (megacontinent Gondwana).

A long-lived Columbia, up to 1.27 Ga, has been advocated by some authors, based on Paleo- to Mesoproterozoic geological evidence (e.g., Vigneresse, 2005; Silver and Behn, 2008; Johansson, 2009, 2014; Piper, 2010, 2018), although a break-up in two stages has also been proposed, one between 1.45 Ga and 1.38 Ga, followed by a later one at 1.27 Ga (Pisarevsky et al., 2014).

Most of the continental masses that formed Columbia eventually composed Rodinia at ca. 0.9 Ga (McMenamim and McMenamim, 1990; Li et al., 2008). Several reconstructions of Rodinia have been proposed (Hoffman, 1991; Weil et al., 1998; D'Agrella-Filho et al., 1998; Tohver et al., 2002; 2006; Pisarevsky et al., 2003; Meert and Torsvik, 2003; Li et al., 2008; Evans et al., 2016). The Rodinia configuration proposed by Li et al. (2008) is the most complete, because it includes all cratonic blocks of the world, and it is based on compiled geological information and paleomagnetic data. Based on geological evidence, however, some authors argue that some cratonic blocks of West Gondwana may not have participated in Rodinia (Cordani et al., 2003; Kröner and Cordani, 2003; D'Agrella-Filho et al., 2004a; and references therein). Finally, Gondwana was formed after the rupture of the Rodinia supercontinent. However, the time West Gondwana was formed and kinematics of a likely protracted process are still a matter of dispute although some paleomagnetic data suggest this may have happened at ca. 0.58-0.57 Ga (e.g., Robert et al., 2017; Rapalini et al., 2021).

In this paper, we discuss the role of the Amazonian, São Francisco and Río de la Plata Cratons in the formation of Columbia, Rodinia and West Gondwana, based on paleomagnetic and geological evidence. First, description of the geological evolution of these main South American cratons is presented, which is followed by a brief discussion of the paleomagnetic database. Then, we discuss the role these cratons played in the formation of Columbia, Rodinia and Gondwana. Some available models for supercontinents are presented and discussed taking into account paleomagnetic, geochronological and geologic data. Finally, conclusions are presented.

GEOLOGY OF THE MAIN SOUTH AMERICAN PRECAMBRIAN CRATONS

Amazonian Craton

The Amazonian Craton is situated in the north of South America, being the largest tectonic unit of this continent (Figure 1; inset), encompassing more than 4 million square kilometers, which stresses its importance in the Proterozoic geological evolution of the Earth. The Neoproterozoic to Eo-Cambrian Brasiliano Araguaia and Paraguay belts border the eastern/southeastern Amazonian Craton (Figure 1).

The northwestern and southwestern parts of the Amazonian Craton were affected by the Andean orogen, and most of this area is covered by Phanerozoic sedimentary rocks, including its central part, named as the Amazon Basin.

Precambrian rocks are exposed in two major areas that form the Guiana Shield to the north and the Central-Brazil Shield (also known as Guaporé Shield) to the south (Schobbenhaus et al., 1984; Santos et al., 2000

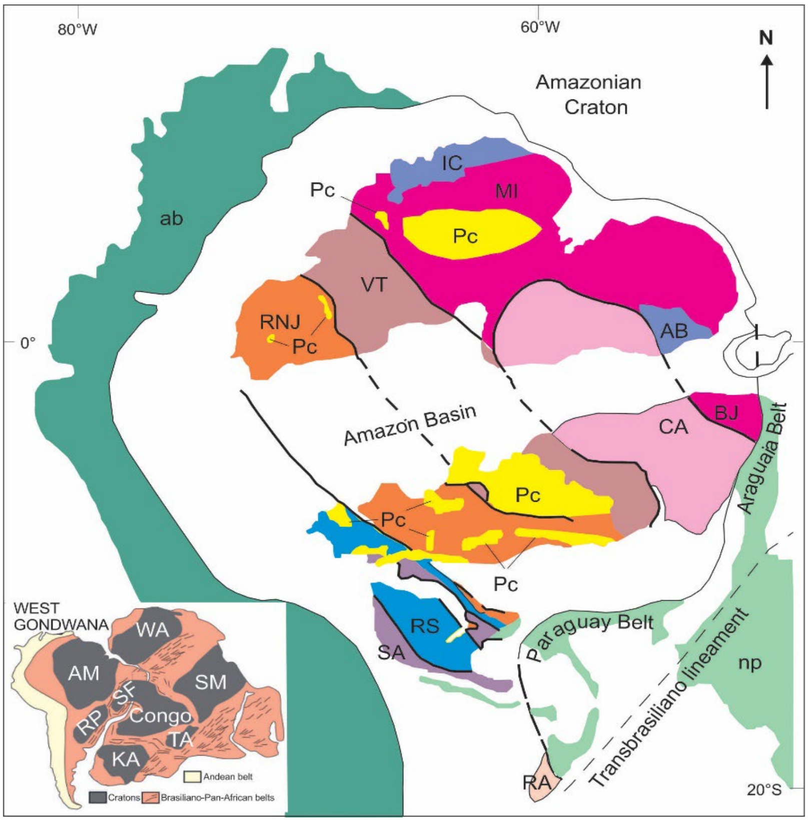

Figure 1: Amazonian Craton and its geotectonic provinces [adapted from Cordani and Teixeira (2007), Teixeira et al. (2019a) and D'Agrella-Filho et al. (2021)]. Provinces: CA - Central Amazonian (> 2.6 Ga); Archean partially reworked in Rhyacian: IC - Imataca Complex; AB - Amapá Block; BJ - Bacajá Domain; MI - Maroni-Itacaiúnas (2.45–1.95 Ga); VT - Ventuari-Tapajós (2.01–1.80 Ga); RNJ - Rio Negro-Juruena (1.82–1.60 Ga); RS - Rondonian-San Ignacio (1.59–1.30 Ga); SA - Sunsas-Aguapeí (1.20–0.95 Ga); RA - Rio Apa Terrane; np - Neoproterozoic Provinces; ab - Andean Belt; Pc - Precambrian covers; Phanerozoic covers (white). Inset: South America and Africa as in West Gondwana: AM - Amazonian Craton; WA - West African Craton; SF - São Francisco Craton; RP - Río de la Plata Craton; SM - Sahara Metacraton; TA - Tanzania Craton; KA - Kalahari Craton.

Lacerda-Filho et al., 2004; Scandolara et al., 2017). The Amazonian Craton was divided in tectonic provinces, according to geologic/geochronologic data by Tassinari and Macambira (1999, 2004), and this tectonic framework (described below) is largely followed in the literature (e.g., Schobbenhaus et al., 2004; Cordani et al., 2010; Bettencourt et al., 2010; Teixeira et al., 2019a; D'Agrella-Filho et al., 2021): Central Amazonian Province (>2.6 Ga), Maroni-Itacaiúnas Province (2.45–1.95 Ga), Ventuari-Tapajós Province (2.01–1.80 Ga), Rio Negro-Juruena Province (1.82–1.60 Ga), Rondonian-San Ignacio Province (1.59–1.30 Ga) and Sunsas-Aguapeí Province (1.20–0.95 Ga) (Figure 1). We are aware that other tectonic framework has been proposed for the Amazonian Craton (Santos et al., 2000), but here we follow the original model proposed by Tassinari and Macambira (1999; 2004). Also, modifications on the organization, evolution and tectonic subdivisions have been proposed on these provinces, based on more recent geological and geophysical investigations (Fraga et al., 2009; Bettencourt et al., 2010; Fernandes et al., 2011; Rizzotto and Hartmann, 2012; Rizzotto et al., 2013; 2014; 2019; Kroonenberg et al., 2016; Scandolara et al., 2017).

Archean granite-greenstone terranes and high-grade metamorphic rocks make up the Central Amazonian Province, which are mainly exposed in the Central-Brazil shield (Figure 1). These Archean terranes are surrounded by Paleoproterozoic rocks (2.45–1.95 Ga) to the north, which form the Bacajás domain (Central-Brazil Shield) and the Maroni-Itacaiúnas Province in the Guiana Shield. These Paleoproterozoic rocks are predominantly composed of granite-greenstone and granite-gneissic terranes and granulite belts (e.g., Bakhuis, Kanuku, Cauarane-Coeroeni) (e.g., Delor et al., 2003; Tassinari and Macambira, 2004; Cordani and Teixeira, 2007; Vasquez et al., 2008; Fraga et al., 2009;

Reis et al., 2013; Kroonenberg et al., 2016). The accretionary growth involved also some Archean blocks (e.g., the Imataca Complex and Amapá Block) from present-day South America and probably other cratonic units from the West African Craton and Baltica (see, D'Agrella-Filho et al., 2016a; Terentiev and Santosh, 2020). However, later crustal reworking in the Siderian and Rhyacian times affected the Imataca Complex and Amapá Block (e.g., Onstott et al., 1989; Tassinari and Macambira, 2004; Borghetti et al., 2018; Milhomem Neto et al., 2019). In this scenario, after the stability of such continental core, a long-lived system of magmatic arcs and collisional processes developed in its southwestern border, through Paleo- and Mesoproterozoic times (Cordani and Teixeira, 2007). Reflex-intraplate reactivations and partial reworking of the already cratonized provinces are also detected.

During the Orosirian to the Statherian time, three intraplate large igneous provinces (LIPs) affected the Maroni-Itacaiúnas and the Central Amazonia provinces. The first is a 1.99–1.95 Ga volcano-plutonic magmatism named as Orocaima Igneous belt (Reis et al., 2003), which borders (to the north) the older high-grade supracrustal rocks – the Bakhuis, Kanuku, Cauarane-Coeroeni units mentioned above. This LIP is formed mainly by ignimbrites, rhyolites, and andesites, assigned to the Pedra Pintada and Surumu Groups and it underlies the clastic sedimentary rocks of the Roraima Supergroup, whose age is established by 1.87 Ga interbedded tuff layers (Santos et al., 2003).

A second bimodal magmatic event is represented by the 1.88 Ga Uatumã silicic large igneous province (SLIP) (Klein et al., 2012). It covers a large portion of southern Guiana and northeastern Central-Brazil Shields, and so, it is known by different local names (Uatumã, Iriri and Iricoumé Groups). In the São Felix do Xingu area, basic to intermediate rocks from the Sobreiro Formation and felsic volcanic rocks of the Santa Rosa Formation were also dated at 1.88 Ga (Fernandes et al., 2011; Antonio et al., 2017). The 1.88 Ga basic to felsic dyke swarm from the Tucumã area (Tucumã bimodal magmatic event) also belongs to the Uatumã event (Silva et al., 2016; Teixeira et al., 2019b; Antonio et al., 2021a). The slightly younger 1.86 Ga A-type granitoid rocks from the Velho Guilherme Suite cut the 1.88 Ga felsic and mafic rocks described above (Antonio et al., 2017; 2021a).

A third event corresponds to the 1.79–1.78 Ga Avanavero magmatism (Guiana Shield) which crosscut the Roraima sedimentary rocks as mafic dykes and sills (Reis et al., 2013). During the Mesoproterozoic, several intracratonic AMCG (anorthosite, mangerite, charnockite and rapakivi granite) magmatic episodes affected the Columbia supercontinent (e.g., Vigneresse, 2005). In the Guiana Shield they are represented by the rapakivi granites of the Parguaza Suite (1.55 Ga; 1.40–1.39 Ga) of Venezuela (Gaudette et al., 1978; Bonilla-Perez et al., 2013), the Surucucus Suite (1.55 Ga; Dardenne and Schobbenhaus, 2001) on the border between Venezuela and Brazil, the Mucajaí AMG association (1.55–1.51 Ga; Fraga et al., 2009; Heinonen et al., 2012) in the Roraima State. A coeval (1.53 Ga) magmatic event in Suriname is represented by the Kaïser Dolerite swarm (De Roever et al., 2014, Baratoux et al., 2019).

During the Statherian to the Ectasian period, the Central-Brazil Shield was also affected by magmatic activity. The Rio Negro-Juruena Province hosts extensive 1.79–1.78 Ga felsic and volcanoclastic rocks, and associated intermediate to mafic rocks (the Colider Suite), together with A-type granitic rocks (Teles Pires Suite). These magmatic events were named as the Western Amazonia Igneous belt by Rizzotto et al. (2019) who suggested an intracratonic origin (melting of the lower crust) for them, based on isotopic constraints. Other authors, however, favor an orogenic environment for the origin of these magmatic events (e.g., Cordani and Teixeira, 2007; Scandolara et al., 2017).

During Calymian-Ectasian time, 1.61–1.51 Ga A-type granitoid rocks and associated mafic terms (Serra da Providência Suite) (Payolla et al., 2002; Bettencourt et al., 2010; Scandolara et al., 2017), and other suites and dykes, crosscut the southern part of the Rio Negro-Juruena Province (Cordani and Teixeira, 2007; Bettencourt et al., 2010; Teixeira et al., 2019a). Scandolara et al. (2017) named this as the Juruena orogeny, composed by the Juruena terrane and associated volcanic-plutonic units: Teles Pires Suite, Colider Suite and Roosevelt Formation.

To the south of the Juruena terrane, the Central-Brazil Shield hosts Statherian to Ectasian rocks that form the Jauru terrane in the Mato Grosso State (Bettencourt et al., 2010). The Jauru terrane includes 1.78–1.72 basement rocks and arc-type complexes: the 1.56–1.52 Ga Cachoeirinha orogen and the 1.48–1.42 Ga Santa Helena orogen. This terrane corresponds to the Rondonian-San Ignacio Province, whose evolution occurred until the final collision of the Paraguá terrane, about 1320 Ma ago (Bettencourt et al., 2010). This collisional model was reinforced by the finding of the Trincheira ophiolite by Rizzotto and Hartmann (2012) in the Rondônia state. These authors interpret these ophiolitic rocks as relicts of oceanic crust during the collision of the proto-Amazonian Craton with the Paraguá terrane along the Alto Guaporé belt (Rizzotto et al., 2013).

Calymmian and Ectasian aged felsic and mafic rocks intrude all segments of the Rondonian-San Ignacio Province, exemplified in the Jauru and Jamari terranes. Several 1.47–1.38 Ga magmatic events crosscut the Mato Grosso State: the 1.47–1.42 Ga Rio Branco bimodal Suite (Geraldes et al., 2001; 2004), the 1.44 Ga Salto do Céu mafic sills and dykes (Teixeira et al., 2015a; D'Agrella-Filho et al., 2016b), the 1.42 Ga Nova Guarita mafic dyke swarm (Bispo-Santos et al., 2012), the 1.42 Ga Indiavaí mafic intrusion (Teixeira et al., 2011; D'Agrella-Filho et al., 2012) and the 1.38 Ga Nova Lacerda mafic dykes (also known as Rancho de Prata Intrusive Suite, Lima et al., 2019) (Girardi et al., 2012; Teixeira et al., 2015a). The sedimentary rocks whose Salto do Céu sills and dykes intrude were previously interpreted as belonging to the 1.2–1.0 Ga Aguapeí Group (Saes and Leite, 1993; D'Agrella-Filho et al., 2008; Elming et al., 2009a). In fact, these sedimentary rocks are older than 1.44 Ga, and maybe they best correlate with Mesoproterozoic sedimentary rocks from northwestern Mato Grosso State (Leite and Saes, 2003).

In the same way, several generations of granitoid and mafic rocks crosscut the Jamari Terrane: the 1.40–1.36 Ga Santo Antonio Intrusive Suite, the 1.38 Ga Teotônio Intrusive Suite, the 1.36–1.34 Ga Alto Candeias Suite and the 1.31–1.30 Ga São Lourenço-Caripunas Intrusive Suite (e.g., Payolla et al., 2002; Bettencourt et al., 2010; Scandolara et al., 2017). These events are roughly contemporaneous with the evolution of the Alto Guaporé belt.

At the end of Ectasian time a ca. 1.2 Ga wide-spread tectonic-thermal event affected several parts of the Guiana Shield, interpreted as intracratonic reactivations of Paleoproterozoic structures (e.g., Cordani et al., 2010). This event is known as the K'Mudku in the Roraima State (Fraga and Reis, 1996), the Orinoquean in Venezuela (Martin-Bellizzia, 1972), and Nickerie in Suriname and Colombia (Priem et al., 1971). At the same time, in the Jamari terrane, the 1.2 Ga Nova Floresta Formation, composed by mafic sills and flows intrude the granites of the Alto Candeias Suite (Tohver et al., 2002).

The last phase of cratonization of the Amazonian Craton occurred during the Sthenian to early Tonian (1.25–0.9 Ga) time in its southwestern part, marked by the Sunsas collisional orogeny. The evolution of this orogen is characterized by sediment deposition of the Sunsas and Vibosi Groups over a passive margin, followed by a main deformation phase between 1.1 Ga and 1.0 Ga (e.g., Litherland et al., 1989; Sadowski and Bettencourt, 1996; Cordani and Teixeira, 2007; Teixeira et al., 2010; 2019b). This crustal segment was crosscut by the 1.1 Ga Rincón del Tigre-Huanchaca LIP (Teixeira et al., 2015a) which includes the distal 1.1 Ga Rio Perdido mafic dyke swarm in the Rio Apa Terrane (Teixeira et al., 2019b).

Simultaneously with the Sunsas orogeny, distal intracratonic reactivations occurred over the already stable continental mass. An example is the E-W Nova Brasilândia Belt (NBB - 1.1–1.0 Ga) developed in the Jamari Province whose rocks have undergone crustal shortening and medium-grade metamorphism (Rizzotto, 1999; Rizzotto et al., 2001; 2002; Cordani et al., 2010; D'Agrella-Filho et al., 2016a). Sinistral transcurrent tectonics (named as the Ji-Paraná shear zone) occurred to the north of NBB at ca. 1.18–1.15 Ga (Ruiz, 2005; Tohver et al., 2005).

Tectonic basins (1.30–1.00 Ga) and anorogenic granites (1.08–0.99 Ga) observed in the Jamari and Juruena Terranes may also be intracratonic reflex of the distal Sunsas collisional belt (e.g., Payolla et al., 2002; Bettencourt et al., 2010; Teixeira et al., 2010).

Finally, the Aguapeí Belt in the Mato Grosso State (Jauru Terrane) is interpreted as an aborted continental rift (aulacogen) (e.g., Fortuna Formation), that is, a branch to the north of the Sunsas belt (Litherland et al., 1989; Sadowski and Bettencourt, 1996; Ruiz, 2005).

São Francisco Craton

The São Francisco Craton (SFC) is situated in the eastern part of South America and it is considered to be an extension of the Congo Craton (CC) in a pre-Atlantic configuration (Figure 2). After Archean to Paleoproterozoic polycyclic events, the Congo-São Francisco paleocontinent reached its tectonic stability at ca. 2.0 Ga (Teixeira et al., 2017a; b; Alkmim and Teixeira, 2017). This paleocontinent is surrounded by the Brasiliano-Pan-African belts developed between 630 and 550 Ma, represented by supracrustal units thrusted over the cratonic domain (e.g., Teixeira et al., 2000).

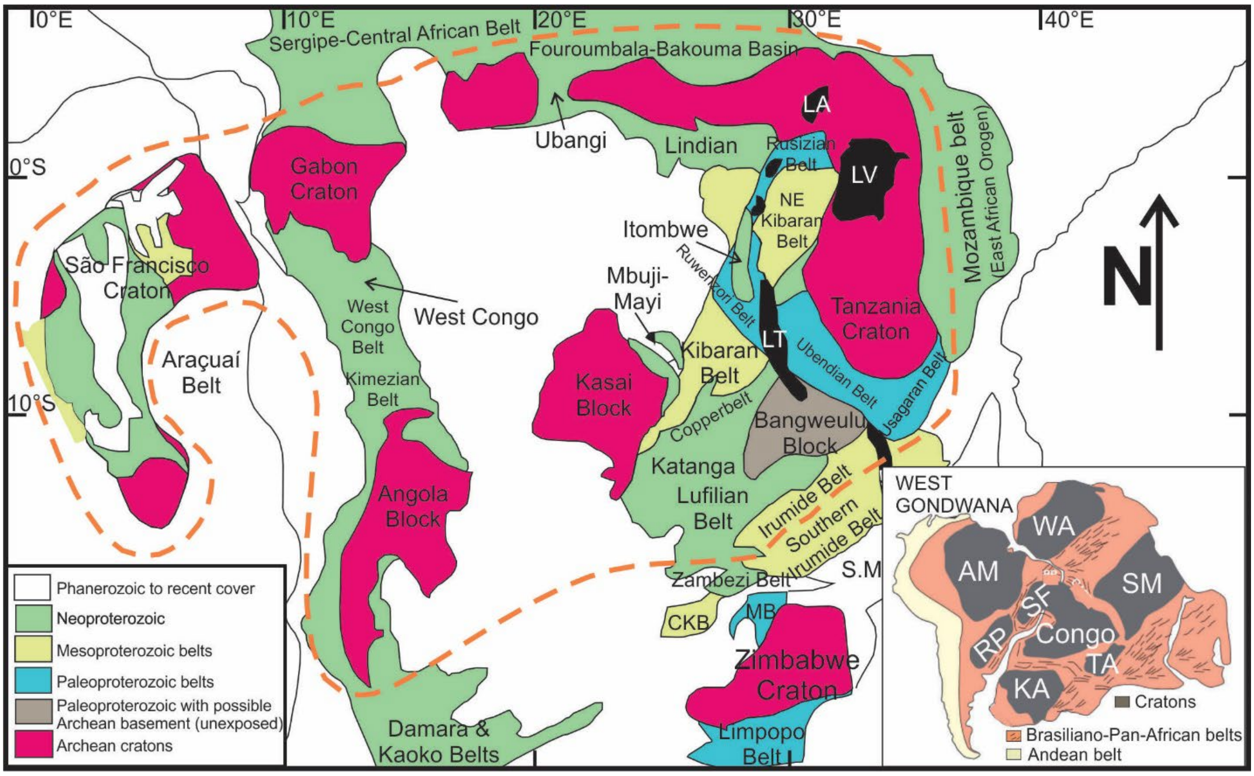

Figure 2: General map of Congo Craton plus São Francisco Craton in a pre-drift configuration, whose outline is represented by the dashed line (carrot color) (modified from Tait et al., 2011). CKB - Choma Kaloma Block; MB - Magohdi Belt. Lakes (in black): LM - Lake Malawi; LT - Lake Tanganyika; LV - Lake Victoria; LA - Lake Albert. Inset: South America and Africa as in West Gondwana. AM - Amazonian Craton; WA - West African Craton; SF - São Francisco Craton; RP - Río de la Plata Craton; SM - Sahara Metacraton; TA - Tanzania Craton; KA - Kalahari Craton.

The Angola-Kasai Block, the NE-Congo-Uganda Block, the Bangweulu Block, the Ntem-Gabon Block and the Tanzania Craton represent the main Archean to Paleoproterozoic blocks in the Congo Craton. These different Archean and Paleoproterozoic blocks collided forming Paleo- to Mesoproterozoic fold belts (e.g., the 2.2–1.9 Ga Usagaran, Unbendian belts in southern Tanzania Craton – Figure 2) resulting in the Congo Craton (see descriptions in De Waele et al., 2008).

In the central and northern São Francisco Craton (SFC), the Archean Gavião, Jequié and Serrinha blocks amalgamated to form the Paleoproterozoic Itabuna/Salvador/Curaçá (ISC) belt, also named Eastern Bahia orogenic domain (e.g., Barbosa and Sabaté, 2002; Oliveira et al., 2004; Barbosa and Barbosa, 2017). Tonalitic, trondhjemitic and charnockitic rocks and associated arc-type volcano-sedimentary sequences are components of this belt. Roughly coeval to the Eastern Bahia orogen, in the southern São Francisco Craton, the 2.47–2.00 Ga Minas orogeny evolved through a series of accretionary-collisional belts (Alkmim and Teixeira, 2017; and references therein). This orogen resulted in the Mineiro, Mantiqueira and Juiz de Fora belts formed by plutonic and volcano-sedimentary rocks (e.g., Noce et al., 2007; Heilbron et al., 2010; Ávila et al., 2014; Teixeira et al., 2015b; 2017a; b; Barbosa et al., 2019). The final stabilization of this orogen in the southern SFC occurred after crustal exhumation and final regional cooling between ca. 2.1–1.9 Ga (Teixeira et al., 2000; 2017a).

The Congo-São Francisco Block is then regarded as a stable unit by the late Paleoproterozoic, which was only affected by the Mesoproterozoic Kibaran, Irumide and Southern Irumide belts in its southeastern border (Johnson and Oliver, 2000; Tack et al., 2010; Trindade et al., 2021) and by intracratonic events, such as the 1780–1750 Ma Espinhaço rift and the Brasiliano Paramirim Aulacogen, forming intracontinental sedimentary basins, since late Paleoproterozoic up to early Phanerozoic. In the Congo Craton, the Congo basin is situated in its center covering most of the today's Democratic Republic of Congo, the People's Republic of Congo and the Central African Republic (Daly et al., 1992). Its long depositional history has the counterpart in the São Francisco Craton as is the case of the West Congo and Araçuaí sedimentary successions (Babinski et al., 2012).

Intracratonic events in the Congo-São Francisco entity are also represented by igneous rocks (e.g., Teixeira et al., 2017a), such as the 1.79 Ga Pará de Minas dyke swarm, the 1.5 Ga Curaçá mafic dyke swarm (Silveira et al., 2013; Salminen et al., 2016a), the 1.37 Ga Kunene anorthosites, the 1.24 Ga Late Kibaran Intrusions, the 1.10 Ga Huila-Epembe dykes, the 0.926 Ga Salvador and Ilhéus/Olivença dyke swarms (Evans et al., 2016), the 0.795 Ga Gagwe lavas, the 0.765 Luakela volcanic, and the 0.743 Ga Mbozi Complex. Other important mafic dyke swarms occurred in the Borborema Province and in the Brasiliano belt, such as the ~0.54 Ga Monteiro dyke swarm (Antonio et al., 2021b) and the 0.52 Ga Itabaiana dykes (Trindade et al., 2006).

Río de la Plata Craton

The Río de la Plata Craton (RP) is located in southeastern South America (Figure 3a), covering the province of Buenos Aires in Argentina, most of the territory of Uruguay, and southern Brazil. A large part of the craton is overlayed by Phanerozoic sediments, forming the Chaco-Paranaense basin (e.g., Rossello et al., 2006), which makes it difficult to establish the actual extension of the craton (Dragone et al., 2017; Oyhantçabal et al., 2010; Rapela et al., 2007; 2011; Santos et al., 2017). As a fact, the Precambrian rocks are exposed only in its eastern and southern parts (Figure 3). Geochronologic and geochemical data from basement rocks extracted from oil-well cores extend its limit approximately 500 km to the west, at the foothills of the Pampean Ranges, Córdoba Province, in Argentina (Rapela et al., 2007), fact that was confirmed later by geophysical data (Favetto et al., 2008; Ramé and Miró, 2011; Álvarez et al., 2012; Peri et al., 2013, 2015). Its northern limit is yet controversial, as depicted by different models (Rapela et al., 2007; 2011; Oyhantçabal et al., 2010; Dragone et al., 2017; Santos et al., 2017). The southern limit of RP is defined by the allochtonous or para-autochtonous North Patagonian Massif (Ramos, 2008; Luppo et al., 2019; and references therein). The RP is well exposed in its eastern side, mainly in Uruguay. There, three contrasting terranes compose the west, central and east parts, respectively, described by the Piedra Alta terrane (PA), the Nico Pérez terrane, and the Dom Feliciano Belt, including the Punta del Este (or Cuchilla Dioniso) terrane (Sánchez Bettucci et al., 2010; Oyhantçabal et al., 2011; 2018). The Nico Pérez (NP) and Punta del Este terranes have been considered as independent terranes or associated to other cratonic blocks, like Congo and Kalahari, respectively (Basei et al., 2009; Oriolo et al., 2017). The Tandilia terrane (T) is situated in the Buenos Aires Province and forms the Tandilia system (Figure 3b). It shows similarities to PA. Below we describe a synthesis of the geology of the two Precambrian components of RP, the Piedra Alta (PA) and Tandilia (T) terranes.

The basement of the PA terrane is composed of granitic-gneissic rocks crosscut by two ENE/WSW metavolcanic and metasedimentary belts, the Arroyo Grande in the north and the San José in the south (Figure 3b). Although an age around 2.0 Ga was attributed to the deformation and metamorphic phase of these rocks, based on Rb-Sr and Sm-Nd results (Preciozzi et al., 1999), older ages (2.1 Ga) are now established to the metamorphic event (e.g., Oyhantçabal et al., 2011; 2018), and a back-arc or trench basin environment was proposed for these supracrustal sequences (Sánchez Bettucci et al., 2010).

The volcano-sedimentary sequence of the Arroyo Grande Belt reached greenschist facies, whose metamorphic age of 2.113 ± 0.008 Ga was established by U-Pb dating in zircon of a metavolcanite (Oyhantçabal et al., 2018; and references therein). The post-orogenic ca. 2.1 Ga granites from the Marincho Complex intruded this belt. These granites are in tectonic contact with the granitic-gneissic terrain through the Paleoproterozoic sinistral strike-slip Paso Lugo shear zone (Preciozzi and Bourne, 1993). The southern San José metavolcano-sedimentary belt (Figure 3b) was affected by the approximately E-W Paleoproterozoic sinistral strike-slip Cufré Shear Zone (Sánchez Bettucci et al., 2010). The San José belt was dated at 2.146 ± 0.007 Ga through U-Pb (SHRIMP) dating in zircons extracted from a metadacite (Santos et al., 2003). Several 2.10 to 2.05 Ga plutonic bodies, represented by late to post-orogenic granites, tonalities and gabbros cut the San José belt. The Cufré granite (2.086 ± 0.004 Ga, U-Pb LA-ICP-MS in zircon, Basei et al., 2016), and the Isla Mala granite (2.074 ± 0.006 Ga, U-Pb SHRIMP in zircon, Hartmann et al., 2008) are the most accurately dated. This belt also crops out to the south of the Santa Lucia Mesozoic basin (see Rossello et al., 2017) where it is intruded by the 2.056 ± 0.006 Ga Soca granite (U-Pb SHRIMP in zircons, Santos et al., 2003). In this area the belt was affected by the E-W sinistral strike-slip Mosquitos Shear Zone (MSZ) (Sánchez Bettucci et al., 2010), whose period of activity is

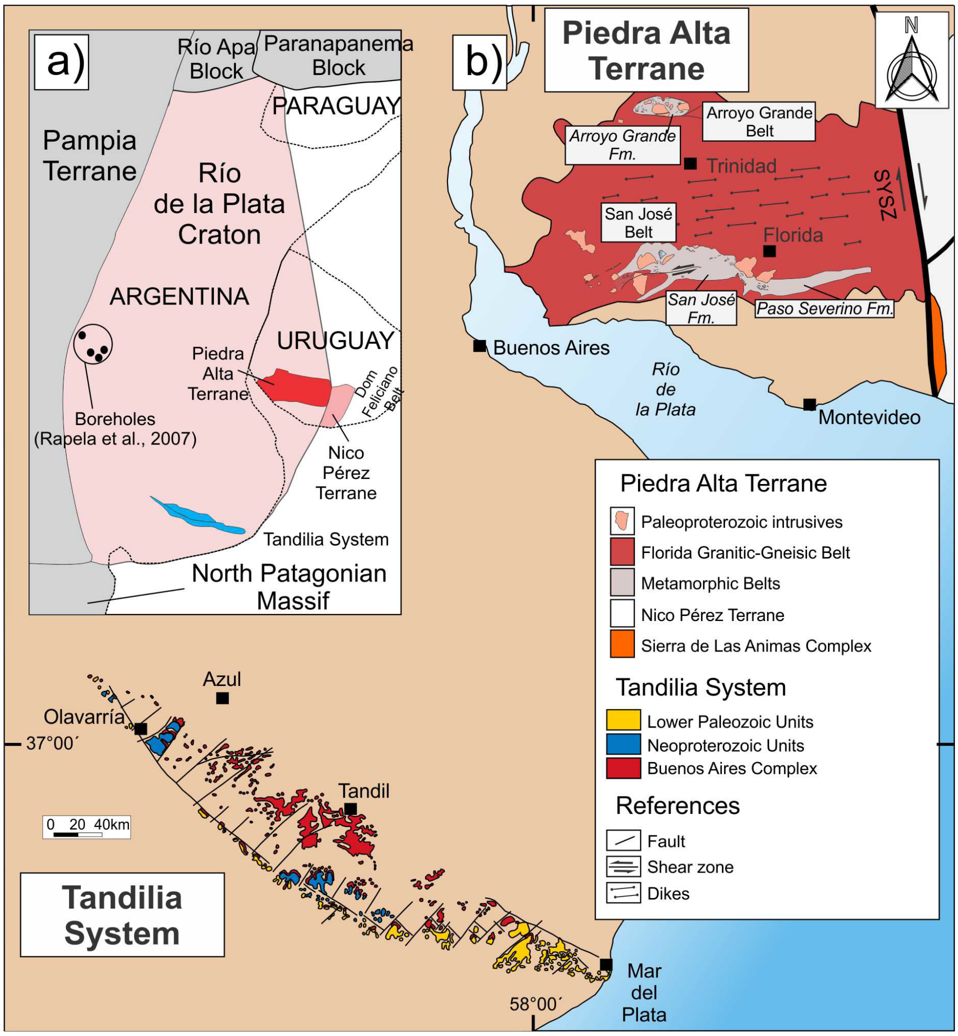

Figure 3: (a) Sketch of the Río de la Plata Craton and neighboring terranes (modified from Sánchez Bettucci et al., 2010; Rapela et al., 2011; Oyhantçabal et al., 2011, 2018). (b) Geologic sketch of the Piedra Alta terrane and the Tandilia System. Source: Modified from Cingolani (2011). The Tandilia system of Argentina as a southern extension of the Río de la Plata Craton (after Franceschinis et al., 2019).

established between 2.05 and 1.90 Ga (Oyhantçabal et al., 2006). Pamoukaghlian et al. (2017) have recently supported an original idea by Bossi and Cingolani (2009) who suggested that the boundary between the T and PA terranes is located in southern Uruguay, along the Colonia Shear Zone (Gianotti et al., 2010). In this model, most of the rocks exposed to the south of the Santa Lucía Basin should belong to Tandilia

The Piedra Alta crust stabilization is marked by the intrusion of these late to post-orogenic plutons (Peel and Preciozzi, 2006; Oyhantçabal et al., 2018) and by K-Ar cooling ages between 2.1 and 1.9 Ga (Oyhantçabal et al., 2018) reflecting that it became tectocnically stable since Orosirian time. The Neoproterozoic sub-horizontal Piedras Afilar sandstones are found covering the basement in reduced outcrops in southern areas of this terrane (see Oyhantçabal et al., 2018; and references therein). Excepting the small 0.59 Ga La Paz granite near the city of Montevideo, the 1.79 Ga large Florida tholeiitic dyke swarm represents the youngest magmatic event affecting the PA terrane (Halls et al., 2001; Teixeira et al., 2013). In the model by Pamoukaghlian et al. (2017), both the Piedras de Afilar Formation and the La Paz Granite belong to Tandilia.

The Tandilia terrane in the south-central areas of the province of Buenos Aires in Argentina (Figure 3), also known as Tandilia system, is represented by 300 km long and 60 km wide low hills forming an orographic system elongated in a WNW-ESE direction (e.g., Cingolani, 2011; Oyhantçabal et al., 2018; and references therein). Paleoproterozoic basement rocks represented by granitic gneisses, amphibolites, schists, and some marbles crop out in its central and northern areas, which are named as the Buenos Aires Complex (Marchese and Di Paola, 1975). The Buenos Aires Complex was dated by U-Pb (SHRIMP) on zircons which yielded ages between 2.23 to 2.11 Ga (Cingolani et al., 2002; Hartmann et al., 2002), and their rocks are more evolved than those from PA, as revealed by isotopic signatures. The El Cortijo Formation is composed by low-grade metacherts, metagraywackes, and metabasites (Teruggi et al., 1988), which is described as a piece of oceanic crust obducted from the collision of an intraoceanic arc and a small continental block during Rhyacian (Ramos et al., 1990; Chernicoff et al., 2014).

Late to post-orogenic rocks, as the Chacofi tonalite (2.073 ± 0.007 Ga), intruded the Tandilia Terrane (Hartmann et al., 2002), which are coeval with similar intrusions in PA. Up to 3-km wide mylonitic zones are attributed to E/W trending major shear zones in the Tandilia System (Dalla Salda, 1981; Frisicale, 1999). A 1.59 Ga tholeiitic dyke swarm intrudes the Paleoproterozoic rocks in T (Teixeira et al., 2013) which is less well-prominent than the Florida dyke swarm in PA. An unmetamorphosed Cryogenian to Ediacaran sedimentary succession covers the Paleoproterozoic basement of Tandilia. It is composed of a ca. 400m thick succession of unmetamorphosed marine carbonates and siliciclastic deposits (see Arrouy et al., 2019; and references therein) which have been recently separated into two groups: the lower Sierras Bayas Group of Cryogenian to early late Ediacaran age, and the late Ediacaran La Providencia Group. Detrital zircon dates constrain the age of these groups very loosely (Rapela et al., 2007, Gaucher et al., 2008, Cingolani et al., 2010). Stromatolites assemblages and correlation of 87Sr/86Sr ratios have been used to suggest a Cryogenian age for the basal levels of the Sierras Bayas Group (Villa Mónica Formation, Gómez Peral et al., 2017; 2018; and references therein). An age of c. 0.58 Ga was attributed to the top unit of that Group (the Loma Negra Formation), based on 87Sr/86Sr ratios obtained in these limestones (Gómez Peral et al., 2018; 2019). δC^{13} anomalous values for the basal unit of the La Providencia Group (Avellaneda Formation, Gómez Peral et al., 2017, Afonso et al., 2023) have been interpreted as indicative of c. 0.57 Ga. Finally, an age of c. 0.55–0.56 Ga was attributed to the top levels of this Group (the Cerro Negro Formation) based on the finding of Ediacaran fossils assigned to Aspidella sp. (Arrouy et al., 2016).

PALEOMAGNETIC DATABASE

Recent compilations of the Precambrian paleomagnetic data for Amazonian, São Francisco and Río de la Plata Cratons were presented by D'Agrella-Filho et al. (2021); Trindade et al. (2021) and Rapalini et al. (2021), respectively. This database is updated in Table 1, summarizing the paleomagnetic poles between 2.8 and 0.5 Ga for these three cratons published between 2021 and 2023.

For Amazonian Craton 42 paleomagnetic poles between 2.20 and 0.53 Ga were described by D'Agrella-Filho et al. (2021). Recently, other two poles were obtained: for the ca. 2.75 Ga Parauabebas Formation (Martins et al., 2021) and for the well-dated 1.11 Ga Huanchaca sills from the Paraguá terrane (Bispo-Santos et al., 2023) (Table 1). In view of the involved long time interval of more than 2 b.y., the 44 described poles are still very scarce. Several poles are of low quality, since only 33% (15 poles) of them are qualified with Q-factor ≥ 5, according to the Van der Voo's criteria (Van der Voo, 1990). In fact, only three poles are characterized with a positive baked contact test (BCT) and 5 present an inverse baked contact test (i-BCT). Paleomagnetic data involving our research group (PaleoMag Lab.) represents 44% (20 poles) from the total, and from these 65% (13 poles) are qualified with Q-factor ≥ 5. Also, all poles classified as BCT and i-BCT are associated to this group of poles. If we compare with a global Precambrian paleomagnetic database (not incuding the three cratons discussed here) classified with A or B quality (Evans et al., 2021), the Amazonian database represents 16% of the total. If only poles with Q ≥ 5 are considered, this percentage decreases to 5%. So, the scarcity of paleomagnetic poles implies that the construction of apparent polar wander (APW) paths for the Amazonian Craton is limited to short time intervals (e.g., D'Agrella-Filho et al., 2021). An exception is the late Paleoproterozoic, for which paleomagnetic data permitted to construct an APW path between 2.16 and 1.97 Ga (e.g., Théveniaut et al., 2006). For later times, the position of Amazonia relative to other cratonic blocks must be made using individual poles, turning reconstructions more uncertain due to the indeterminations of relative paleolongitudes that single poles have as well as the polarity (south or north) uncertainty of the paleomagnetic field allowing the continent to be in any hemisphere (see also, D'Agrella-Filho et al., 2016a).

Table 1: Updated Precambrian paleomagnetic poles for South America after D'Agrella-Filho et al. (2021), Trindade et al. (2021) and Rapalini et al. (2021).

Cratonic unit - Rock unit	Nominal age (Ga)	N	Plat (°N)	Plong (°E)	A95 (°)	Key pole	R-score criteria	R	Ref.
Amazonian Craton									
Parauabebas Formation - C2	2.742–2.756	28	-44.6	40.5	6.5		1110010	4	1
Huanchaca sills	1.110–1.114	10	30.1	225.7	9.9		1110101	5	2
São Francisco Craton									
Salvador dykes	0.918–0.926	10	3.7	301.6	14.5	BCT	1111101	6	3, 4
Santa Angélica/Venda Nova Plutons	0.493–0.505	35	4.7	332.2	4.1	BCT	1111111	7	5, 6
Borborema Province									
Monteiro dyke swarm	0.534–0.543	19	-18.2	344.9	11.7	BCT	1111111	7	7
Río de la Plata Craton									
Avellaneda Formation	0.570	51	-1.0	313.4	5.9	BCT	1111101	6	8
Cerro Negro Formation	0.550	11	-3.6	37.8	16.6		1110101	5	8

N - number of sites used to calculate the paleomagnetic pole. Plat - Pole latitude; Plong - Pole longitude. A95 - semi-angle of the confidence cone. BCT - positive baked contact test. R-score - reliability R-quality score (after Meert et al., 2020). References: 1 - Martins et al., 2021; 2 - Bispo-Santos et al., 2023; 3 - Hu et al., 2022; 4 - Evans et al., 2016; 5 - Temporim et al., 2021; 6 - Bellon et al., 2022; 7 - Antonio et al., 2021b; 8 - Franceschinis et al., 2022.

Precambrian paleomagnetic data for the São Francisco Craton are yet smaller, reduced to the 2.62 Ga Uauá paleomagnetic pole (Salminen et al., 2019), the 2.03 Ga Jequié Complex pole (D'Agrella-Filho et al., 2011), the 1.79–1.78 Ga Pará de Minas dykes pole (D'Agrella-Filho et al., 2020), the ca. 1.5 Ga Curaçá pole (Salminen et al., 2016a), the 0.92 Ga Salvador, Ilhéus-Olivença and Itaju do Colônia poles (D'Agrella-Filho et al., 1990; 2004a; Evans et al., 2016), some paleomagnetic poles determined for cap carbonates, from the Bambuí Group (D'Agrella-Filho et al., 2000) and the Salitre Formation (Trindade et al., 2004), for which it is assigned an age of 0.52–0.51 Ga as a result of remagnetization of these rocks during the final amalgamation of Gondwana (D'Agrella-Filho et al., 2000; Trindade et al., 2004). Recently, the Salvador dyke swarm was revisited and a new pole was calculated (Hu et al., 2022, Table 1) which is similar to the prior paleomagnetic poles calculated for these dykes and for the coeval, 0.924 Ga Ilhéus-Olivença dykes (D'Agrella-Filho et al., 2004; Evans et al., 2016). Also, a paleomagnetic pole was obtained for two post-tectonic plutons of the Araçuaí orogen, dated at 0.5 Ga (Temporim et al., 2021, Table 1). Excluding the carbonate rocks and the Jequié Complex, all other units passed baked contact tests which attest the primary nature of the remanence in the studied rocks. Other Cambrian paleomagnetic poles were obtained for units of the Borborema Province and Brasiliano belts surrounding the São Francisco Craton: the well-dated 0.52 Ga Itabaiana pole (Trindade et al., 2006) and the ~0.54 Ga Monteiro pole from the Borborema Province (Antonio et al., 2021b), both with a positive baked contact test, and the Juiz de Fora Complex (D'Agrella-Filho et al., 2004b) and Piquete Complex (D'Agrella-Filho et al., 1986) poles, which are interpreted to be of 0.52–0.51 Ga. Most of these poles (85%) was partially or fully obtained at the PaleoMag Laboratory of the São Paulo University, and all of them had the collaboration of at least one of our research group. Compared with the Global paleomagnetic database cited above, the 12 poles from the São Francisco Craton represents 4% of the total. But if we consider only those with Q ≥ 5, this percentage decreases to 2.5%. If we consider that the Congo and São Francisco Cratons formed a single cratonic block since 2.0 Ga, however, some paleomagnetic poles belonging to the Congo Craton can be added to the São Francisco paleomagnetic database. In this case, some short APW paths may be defined, between 1.1–0.92 Ga, 0.80–0.74 Ga and 0.57–0.5 Ga (see Trindade et al., 2021).

Concerning Río de la Plata Craton (RP), Precambrian paleomagnetic data are almost exclusively limited to two periods: for the Paleoproterozoic period between 2.11 and 2.05 Ga and for the Late Neoproterozoic period, between 0.6 and 0.55 Ga, which allowed tracing APW paths during these short time intervals (Rapalini et al., 2021). Exception is the paleomagnetic pole obtained for the 1.79 Ga Florida dyke swarm (Teixeira et al., 2013). This pole, together with the ca. 0.6 Ga Campo Alegre Formation pole (D'Agrella-Filho and Pacca, 1988), were obtained in our PaleoMag laboratory (IAG-USP). One of the authors of this article (A.E. Rapalini) participated of all other published poles, which were obtained at the Paleomagnetic Laboratory of the Buenos Aires University (Argentina). Compared with the Global paleomagnetic database cited above, the 12 poles from the RP represents ~7% of the total. If we consider only poles with $Q \geq 5$, this percentage decreases to 2.9%.

Despite this, available RP poles permitted to test proposed paleogeographic reconstructions that are grounded on geological and geochronological evidence. Below, we present an updated discussion on the role of the Amazonian, São Francisco and Río de la Plata Cratons in the Proterozoic during amalgamation of Columbia, and assembly of Rodinia and Gondwana in view of new paleomagnetic and geological data.

MAIN SOUTH AMERICAN CRATONS IN PRECAMBRIAN SUPERCONTINENTS

Columbia supercontinent

Rogers (1996) proposed that several South American (proto-Amazonia, São Francisco and Río de la Plata) and African (Congo and West Africa) Cratons integrated a single landmass in the Orosirian called "Atlantica". According to this hypothesis, these blocks remained united from the Paleoproterozoic until the opening of the South Atlantic in the Cretaceous (Rogers and Santosh, 2004), and therefore should have integrated the Precambrian supercontinents as a single crustal block. Following previous analyses of paleomagnetic data by D'Agrella-Filho et al. (2011) and Rapalini et al. (2015), Franceschinis et al. (2019) demonstrated that the available paleomagnetic record rules out the originally proposed Atlantica configuration and the conclusions proposed by Rogers and Santosh (2004). However, a single APWP for these cratons can be defined for the late Paleoproterozoic assuming a radically different configuration (Figure 4). Such configuration is consistent with an Atlantica-type continent which may explain the geological similarities among the South American and African Cratons that indicate Rhyacian to early Orosirian period of crustal accretion processes of juvenile magmatic arcs and collision of smaller Archean to Early Paleoproterozoic crustal blocks (e.g., Rapalini et al., 2015). On the other hand, it does not impose a joint kinematic evolution of these blocks for most of the Paleoproterozoic and Paleozoic. Nevertheless, this hypothesis needs further paleomagnetic testing as, for instance, the Congo-São Francisco Craton is represented by a single reliable paleomagnetic pole and the time of accretion of West Africa to the other blocks is not well constrained.

Based on geological evidence, Johansson (2009) proposed that proto-Amazonian Craton was part of Columbia supercontinent, linked to West African Craton and Baltica in a configuration known as SAMBA (South AMerica and BAltica) connection (Figure 5a). Johansson (2009) also included Laurentia linked to Baltica in the SAMBA model and proposed that the SAMBA connection lasted since 1.8 up to 1.3 Ga. Since then, this model has been tested on paleomagnetic and geological grounds. Several authors followed this model in the reconstruction of Columbia, although the relative positions of these cratonic blocks were slightly or more greatly modified (e.g., Evans and Mitchell, 2011; Zhang et al., 2012; Bispo-Santos et al., 2014a, 2020; Xu et al., 2014; Meert and Santosh, 2017; D'Agrella-Filho et al., 2020; Terentiev and Santosh, 2020; Reis et al., 2022; and references therein). However, there are some authors suggesting that SAMBA (Amazonia and Baltica) link has never existed, with proto-Amazonia-West Africa drifting as a separate cratonic block up to its collision with Laurentia to form Rodinia supercontinent (Pisarevsky et al., 2014; Cawood and Pisarevsky, 2017).

In the Johansson's model, west/northwestern Baltica is linked to northwestern Laurentia (North America in its present position). Paleomagnetic data at different ages between 1.78 Ga and 1.27 Ga for Baltica and Laurentia indicate a possible connection between these cratonic blocks, but not in the position suggested by Johansson (2009). Compared to the SAMBA model, these paleomagnetic data indicate that Laurentia is rotated some 90° clockwise relative to Baltica, so that southwestern Laurentia is linked to northern Baltica (Buchan et al., 2000; Salminen and Pesonen, 2007; Evans and Pisarevsky, 2008; Salminen et al., 2009; 2014; 2016b; 2017; Hamilton and Buchan, 2010; Lubnina et al., 2010; Pisarevsky and Bylund, 2010).

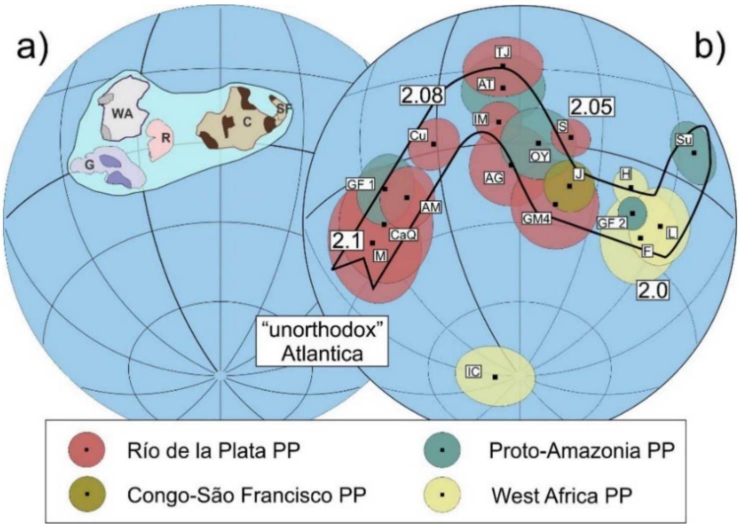

Figure 4: a) Proposed configuration of "unorthodox" Atlantica (Franceschinis et al., 2019); b) ca. 2.1–2.0 Ga paleomagnetic poles from Río de la Plata, Congo-São Francisco, proto-Amazonia (Guyana) and West Africa Cratons according to reconstruction shown in (a). Modified from Franceschinis et al. (2019). GF1 - Mean granitoids (2.07–2.05 Ga); AT - Armontabo Tonalite (2.09–2.07 Ga); OY - Oyapok granitoid (2.05–2.02 Ga); GF2 - Mean granitoids (2.05–1.97 Ga); SG - Surumu Volcanic Rocks (1.98–1.86 Ga); Cu - Cufré Cerro Albornoz Complex (2.09–2.08 Ga); CaQ - Carreta Quemada Complex; TJ - Tía Josefa Tonalite; AG - Arroyo Grande Granite (2.12–2.08 Ga); GM4 - Arroyo Marinche Tonalite; AM - Arroyo Marinche Sur Granite (2.13–2.06 Ga); IM - Isla Mala Granite (2.08–2.07 Ga); S - Soca Granite (2.06–2.05 Ga); M - Mahoma granite; J - Jequié Complex (2.04–2.03 Ga); IC - Ivory Coast Granite (2.10–2.07 Ga); F - Ferke Granite (2.10–2.09 Ga); L - Liberia Granulite (2.04–2.03 Ga); H - Harper Amphibolite (2.0–1.9 Ga). Euler rotation poles and paleomagnetic poles in Franceschinis et al. (2019).

Admitting the existence of the SAMBA configuration, D'Agrella-Filho et al. (2016a) proposed the paleogeography at 2.0 Ga of the several cratonic blocks that later integrated it, based on geological and partially on paleomagnetic data (Figure 5b). It is well known that Laurentia and Baltica formed at ca. 1.85–1.75 Ga, almost contemporaneously with the formation of the SAMBA configuration (e.g., Bogdanova et al., 2013; Mitchell et al., 2014). Laurentia formed at ca. 1.85 Ga after collision of the Archean Slave, Rae, Hearne and Superior cratonic blocks, closing the Manikewan Ocean (e.g., Mitchell et al., 2014). In their reconstruction at 2.0 Ga, D'Agrella-Filho et al. (2016a) proposed that proto-Amazonia was formed by the Central Amazonia Province (Cordani and Teixeira, 2007), which collided with West Africa and Sarmatia/Volgo-Uralia blocks during the Transamazonian/Eburnean orogeny at ca. 2.2–2.0 Ga (see also, Johansson, 2009; Terentiev and Santosh, 2020).

The position of proto-Amazonia relative to West Africa in Figure 5b is the same proposed by several authors (Onstott and Hargraves, 1981; Nomade et al., 2003; Bispo-Santos et al., 2014b). Based on paleomagnetic data, these authors suggested the collision of proto-Amazonia and West Africa occurred at ca. 2.0–1.96 Ga, in a position where the Sassandra (in West Africa) and the Guri (in Guiana Shield) lineaments were aligned (Figure 5b). However, due to uncertaints in the Precambrian paleomagnetic poles, other slightly different configurations of these two cratonic blocks are also possible (see Reis et al., 2022). For example, Johansson (2009) proposed that the São Luís Craton was located between the embayment outboard in the Amazonian coast and the Ivory Coast in Africa (Figure 5a) (see also, Terentiev and Santosh, 2020; Reis et al., 2022). Based on paleomagnetic and geological evidence, Antonio et al. (2021a) proposed a slightly different position of proto-Amazonia and West Africa, where North Guiana Trough and other shear zones in Guiana Shield (according to Chardon et al., 2020) and the Sassandra shear zone (in West Africa) were aligned. However, as stressed by Antonio et al. (2021a) and Reis et al. (2022), the age uncertainties associated to the Precambrian paleomagnetic poles from both cratonic blocks turn a difficult task to choose which of the proposed reconstructions best represents the proto-Amazonia-West Africa link at 2.0 Ga ago, and new better quality poles are needed for both cratons.

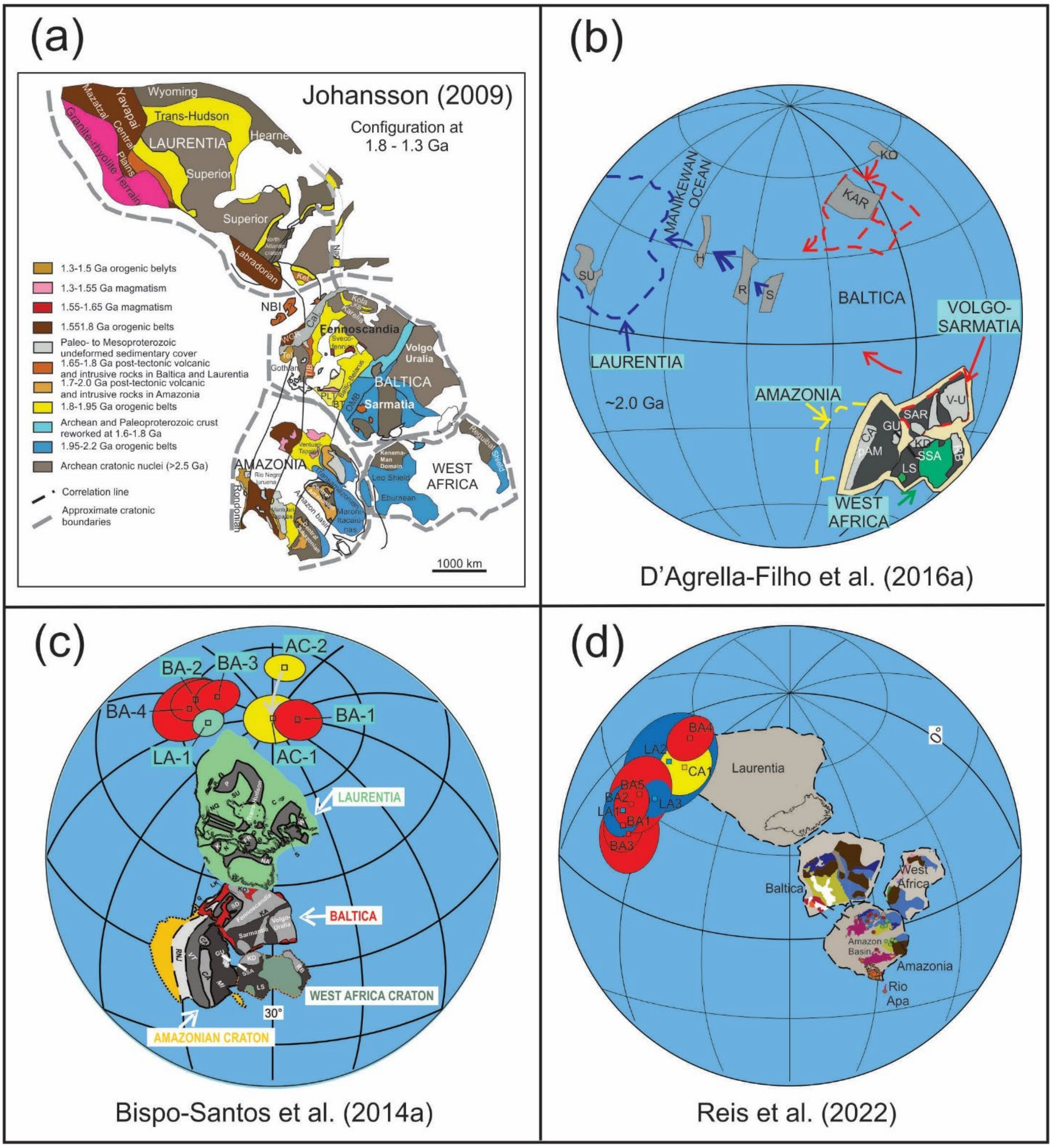

Figure 5: (a) SAMBA model of Johansson (2009). Abbreviations: Nag - Nagssugtoqidian Belt; Ket - Ketilidian Belt; NBI - Northern British Isles; LKB - Lapland-Kola Belt; WGR - Western Gneiss Region; Tel - Telemarkia; TIB - Transscandinavian Igneous Belt; PLT - Polish-Lithuanian Terrane; LBT - Lithuanian-Belarus Terrane; OMB - Osnitsk-Mikashevichi Belt; SLC - São Luis Craton. (b) Proposed reconstruction at 2.0 Ga by D'Agrella-Filho et al. (2016a). Su - Superior Craton; H - Hearne Block; R - Rae Block; S - Slave Block; KO - Kola Block; KAR - Karelia Block; pAM - Proto-Amazonia; V-U - Volgo-Uralia; SAR - Sarmatia; LS - Leo Shield; KD - Kenemanan Domain; RB - Requibat Shield; CA - Central Amazonian Province; MI - Maroni-Itacaiúnas Province; GU - Guri lineament; SSA - Sassandra lineament. (c) SAMBA reconstruction based on paleomagnetic data (after Bispo-Santos et al., 2014a). Euler rotation poles and Paleomagnetic poles (and symbols) in the referred article. (d) SAMBA configuration as proposed by Reis et al. (2022). Euler rotation poles and Paleomagnetic poles (and symbols) in the referred article.

The first paleomagnetic test that corroborates the proto-Amazonia-Baltica connection (SAMBA model) was provided by the well-dated 1.79 Ga Avanavero pole (Bispo-Santos et al., 2014a). Comparison with other poles of similar ages from Baltica and Laurentia led these authors to propose the reconstruction shown in Figure 5c. The Baltica-Amazonia-West Africa link proposed by Bispo-Santos et al. (2014a) at 1.78 Ga is not exactly that of Johansson's SAMBA connection. The problem is that no Euler rotation poles were described for the SAMBA link by Johansson (2009) that could be used for a paleomagnetic test. Trying to resolve this problem, Reis et al. (2022) calculated Euler rotation poles for Amazonia, Baltica and West Africa that best reconstruct the SAMBA model (Figure 5d). Reis and co-authors show that the 1.78–1.75 Ga paleomagnetic poles for Baltica and Amazonia, within error, corroborate the SAMBA configuration of Figure 5d.

The SAMBA model has been considered the nucleus of Columbia, and other cratonic blocks probably were accreted to this large continental mass. For example, in many reconstructions, Siberia (present southern side) appears linked to the present northern Laurentia based mainly on barcode matches of coeval dyke swarms and some paleomagnetic support (e.g., Evans and Mitchell, 2011; Zhang et al., 2012; Youbi et al., 2013; Xu et al., 2014; Chaves and Rezende, 2019; Caxito et al., 2020).

The participation of other cratonic units (as proto-Australia, Congo-São Francisco, Río de la Plata, North China Craton, South China Craton, among others) in Columbia and the time of its complete assembly are yet controversial, mainly due to the scarcity of paleomagnetic data. Based on geological and paleomagnetic data, Pisarevsky et al. (2014) suggest that Columbia was only completely assembled at about 1.6 Ga with the collision of proto-Australia, North China, Siberia, Congo-São Francisco and Kalahari with the nucleus of Columbia formed by Laurentia, Baltica and India. As already stressed, these authors argue that Amazonia-West Africa has never participated of Columbia. On the other hand, D'Agrella-Filho and Cordani (2017) admit that the continental block formed by Río de la Plata, Kalahari, Congo-São Francisco and Borborema-Trans-Sahara cratonic units behaved as an independent continental mass (called the Central African Block by Cordani et al., 2013a) since 2.0–1.9 Ga until the formation of Gondwana at ca. 0.6 Ga. However, other different paleogeographies for these cratonic units have been proposed in the literature. For example, a paleomagnetic study of the well-dated 1.5 Ga Curaçá dykes from the São Francisco Craton, led Salminen et al. (2016a) to propose a possible connection of the southeastern Congo-São Francisco (Congo in its present position) Craton (CSF Craton) and the present eastern Baltica, among other cratonic blocks, as Amazonia, Siberia and Laurentia.

On the other hand, several authors have suggested a possible connection of North China Craton and the CSF Craton, based on the barcode match of the 1.79–1.78 Ga mafic dyke swarms of North China and São Francisco Cratons, although different relative positions have been proposed for these two cratonic blocks (e.g., Peng et al., 2011; Peng, 2015; Cederberg et al., 2016; Xu et al., 2017; Girelli et al., 2018; Chaves and Resende, 2019; Caxito et al., 2020). Teixeira et al. (2017b) suggest that this link can have existed since 2.0 Ga, based on geologic-tectonic matches between the Minas Orogen (southern São Francisco Craton) and the Jiao-Liao-Ji Orogen (North China Craton).

Based on the 1.79–1.75 Ga paleomagnetic data available for several cratonic blocks, D'Agrella-Filho et al. (2020) proposed the paleogeographic reconstruction of Columbia at 1.79 Ga shown in Figure 6. In this reconstruction, proto-Amazonian, West Africa, Baltica, Siberia and Laurentia formed the West Block of Columbia (named here as West Columbia), and proto-Australia, CSF, Río de la Plata, North China and India formed the East Block of Columbia (named here as East Columbia). The evolution in time of the Paleoproterozoic (2.4–1.9 Ga) orogens developed in each cratonic block that composed the East Block is compatible with the amalgamation of this large continental mass as shown in Figure 6 (see D'Agrella-Filho et al., 2020). Also, the Xiong'er plume center in southern North China (red star in Figure 6) is considered the source for the 1.79–1.78 Ga dykes in the São Franco Craton (1 - Pará de Minas dyke swarm), North China Craton (2 - Taihang-Yinshan swarm), Río de la Plata (3 - Florida dyke swarm), North Australia Craton (4 - Hart dolerite) and India (5 - Pipilia dyke swarm and 6 - Pebbair dyke swarm). Coeval dyke swarms are described in the West Block of Columbia, in Amazonia (AV - Avanavero sills and dykes) and in Baltica (H - Hoting gabbro; S - Småland dykes, T - Tomashgorod dyke swarm). In the same West Block, the Siberian Rift System (black symbol) is considered the source of the 1750 Ma dyke swarms (Youbi et al., 2013) in West Africa (i - Tagraga of Akka swarm), Siberia (ii - Siberian radiating swarm) and Laurentia (iii - MacRae Lake dykes, iv - Hadley Bay dykes and v - Cleaver dykes). Wang et al. (2020) consider that Columbia was only

Figure 6: Proposed paleogeographic reconstruction of Columbia supercontinent at 1.78 Ga (after D'Agrella-Filho et al., 2020). Euler rotation poles and paleomagnetic poles (and symbols) in the referred article. Proto-Amazonian Craton (p-AC); West African Craton (WA); Baltica (BA); Laurentia (LA); Siberia (SIB); India (IN); North China (NC); Río de La Plata (LP); São Francisco Craton (SF); Congo Craton (C); North Australia (NAU), West Australia (WAU), South Australia (SAU), East Antarctica (EA). The Xiong'er plume center (in North China) and possible related dyke swarms are identified as: 1 - Pará de Minas swarm (Cederberg et al., 2016); 2 - Taihang-Yinshan swarm (Xu et al., 2014); 3 - Florida swarm (Teixeira et al., 2013); 4 - Hart dolerite (Kirscher et al., 2019); 5 - Pipilia swarm (Srivastava et al., 2019); 6 - Pebbair swarm (Samal et al., 2019; Söderlund et al., 2019). Coeval magmatic events are described in proto-Amazonian Craton: AV - Avanavero sills and dykes (Reis et al., 2013) and Baltica: H - Hoting Gabbro (Elming et al., 2009b); S - Småland dykes (Pisarevsky and Bylund, 2010); T - Tomashgorod swarm (Bogdanova et al., 2013). Also shown is the ca. 1750 Ma Siberian Rift System (black symbol), and their possible related radial dyke swarms (Youbi et al., 2013): i - Tagraga of Akka swarm; ii - Siberian radiating swarm; iii - MacRae Lake dykes; iv - Hadley Bay dykes; v - Cleaver dykes.

completely formed at ca. 1.6 Ga when the megacontinent Nuna, formed by Laurentia, Baltica and Siberia collided with proto-Australia and other cratonic blocks, forming the Columba supercontinent. Most probably, proto-Amazonia and West Africa were part of the Wang et al.'s Nuna megacontinent forming the West Block in Figure 6.

The longitude uncertainty in paleomagnetism permit an alternative model for the formation of Columbia: an ocean separating the East Block (Figure 6) and West Block (the Nuna megacontinent of Wang et al., 2020), both formed at around 1.78 Ga ago. Then, at ca. 1.6 Ga, they docked forming Columbia supercontinent.

Columbia longevity

Testing the longevity of Columbia is hampered by the scarcity and low quality of paleomagnetic poles available for the several cratonic blocks that composed it. Trindade et al. (2021) tried to compare apparent polar wander paths for North China, Congo-São Francisco and India between 1.5 and 1.1 Ga assuming the configuration of East Columbia, as shown in Figure 6 (see Figure 14.6 of Trindade et al., 2021). They concluded that if this configuration at 1.78 Ga really existed it was not long-lived (< 0.3 Ga). However, new reliable paleomagnetic poles for all these cratons must be produced to confirm this. For example, Peng (2015) proposed a long-lived CSF-North China link, based on barcode matches of the 1.79–1.78 Ga and 0.92 Ga mafic dyke swarms found in both cratonic blocks, besides other similar geological features. A CSF-North China link at 0.92 Ga has been proposed by several authors, based on the coeval 0.92 Ga mafic dyke swarms in both cratons (e.g., Peng et al., 2011; Chaves et al., 2019; Su et al., 2021; Hu et al., 2022), although with a configuration different from that shown in Figure 6 for 1.78 Ga.

For west Columbia (Figure 6), a long-lived (between 1.8 and 1.27) connection of Laurentia, Baltica and Siberia has been proposed, based on geological and paleomagnetic data (e.g., Hou et al., 2008a; Evans and Mitchell, 2011). A yet long-lived Laurentia-Baltica link is proposed by other authors, some of them suggesting a break-up at 1.18 Ga (Yakubchuk, 2019), or even after 1.10 Ga (Cawood and Pisarevsky, 2017), when Baltica rotated clockwise and collided with Laurentia and Amazonia at ca. 1.0–0.9 Ga, during formation of Rodinia (see below).

For the Baltica-Amazonia-West Africa link, Bispo-Santos et al. (2020) proposed that it lasted from 1.78 Ga up to, at least, 1.53 Ga, based on the paleomagnetic study of the ca. 1.53 Ga Mucajaí AMG-Complex. Four 1.44 to 1.42 Ga paleomagnetic poles are presently available for the Amazonian Craton: the 1.44 Ga Salto do Céu sills and dykes, the Rio Branco sedimentary rocks where the Salto do Céu dykes and sills intrude (D'Agrella-Filho et al., 2016b), the 1.42 Ga Indiavaí Intrusive (D'Agrella-Filho et al., 2012) and the 1.42 Nova Guarita dyke swarm (Bispo-Santos et al., 2012). Comparison of these poles with an APW path traced for Baltica (Salminen et al., 2017) between 1.8 and 1.4 Ga (Figure 7a, also including Laurentian poles) suggest either, that Amazonia broke-up from Columbia at ca. 1.42 Ga, or a clockwise rotation of Amazonia-West Africa occurred at some time between 1.53 and 1.44 Ga ago (e.g., Bispo-Santos et al., 2020; D'Agrella-Filho et al., 2021). In this case, the best Amazonia-Baltica configuration at 1.44–1.42 Ga is that proposed by Pehrsson et al. (2016) (Figure 7b).

Rodinia Supercontinent

The most comprehensive configuration of Rodinia was proposed by Li et al. (2008), which, according to the authors, would be fully amalgamated at ca. 0.9 Ga (Figure 8). In their reconstruction, Kalahari, CSF, Río de la Plata (RP) and Amazonia amalgamated along the Grenvillian orogen. The position of Río de la Plata Craton in Rodinia is very speculative since no paleomagnetic poles are presently available to constrain a possible RP-Laurentia link at 0.9 Ga. Amazonia-West Africa Block was attached along southwestern Laurentia, based on collision of these two blocks through the 1.2–0.9 Ga Sunsas (in Amazonia) and Grenville (in Laurentia) orogenic belts. However, the position where the Amazonian Craton docked in Laurentia is greatly debated. An oblique collision of Amazonia and Laurentia along the Grenvillian Llano orogen, in the Texas coast, was proposed by Tohver et al. (2002), based on the paleomagnetic results of the well-dated 1.2 Ga Nova Floresta mafic rocks (Amazonian Craton). Thereon, Tohver et al. (2004a) argued that after this oblique collision, Amazonian Craton underwent a transcurrent movement relative to Laurentia up to its collision with Baltica at ca. 1.0 Ga (Figure 9). This model received geologic and paleomagnetic support (e.g., Tohver et al., 2004a; b; D'Agrella-Filho et al., 2008; Ibañez-Mejia et al., 2011; Ibañez-Mejia, 2020). An alternative model was proposed by Dalziel (1992; 1994), who advocates a frontal collision of southwestern Amazonia along the Laurentian area formed by Labrador, Scotland. Greenland, Ireland and Rockall Plateau. This model was rejected by Loewy et al. (2003), based on dissimilar Pb isotopic data obtained for this area and for southwestern Amazonian Craton. Instead, these authors suggest a collision along the Appalachian area, in view of best similarities in ages and isotopic signatures from both Appalachian and southwestern Amazonia rocks (see also, Cawood and Pisarevsky, 2017). A similar position for the Amazonian Craton relative to Laurentia is also suggested by Johansson (2014) in his configuration of Rodinia (Figure 10).

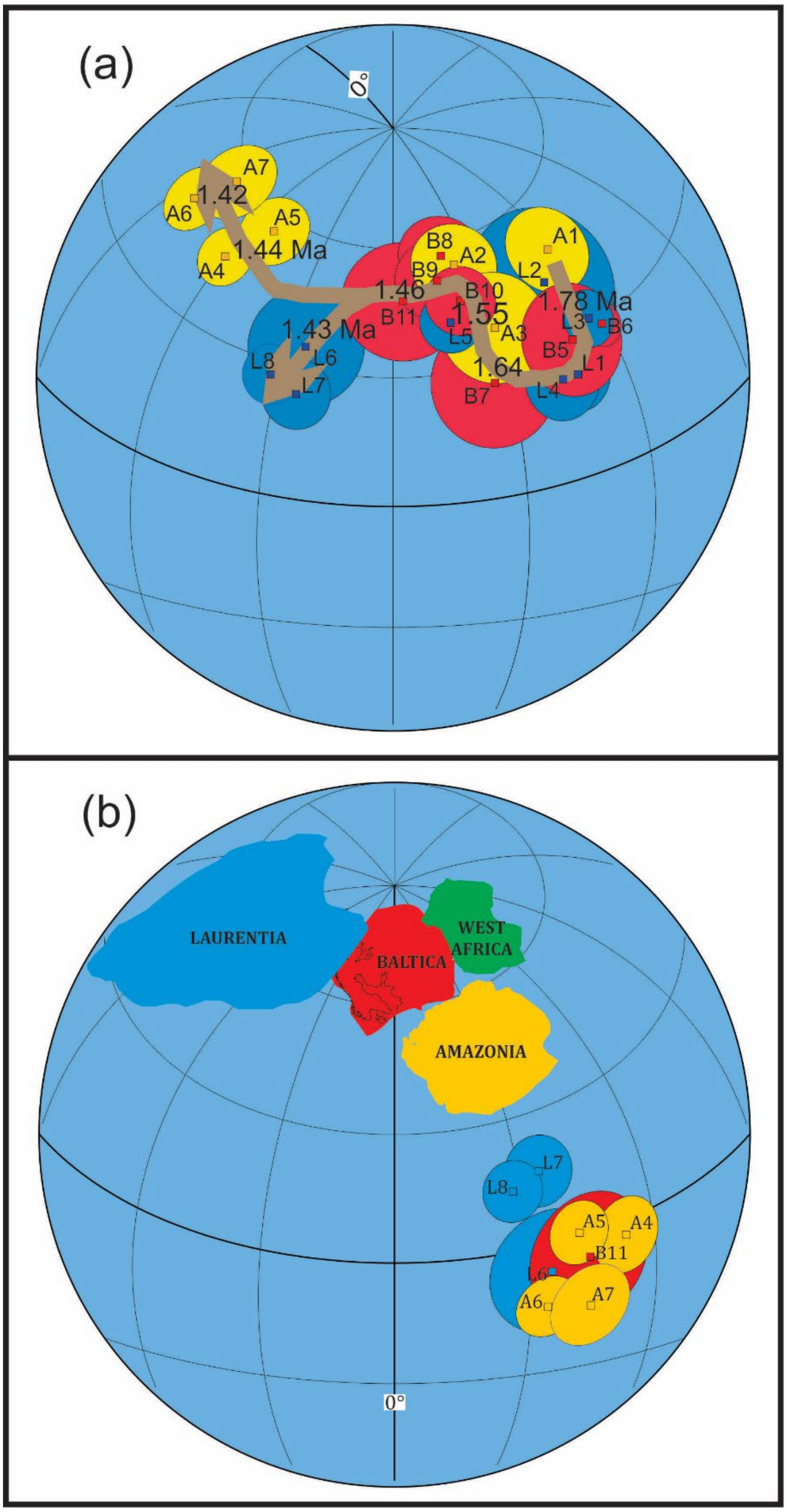

Figure 7: (a) Comparison of the Amazonia (in yellow) and Laurentian (in blue) paleomagnetic poles with the apparent polar wander path between 1.79 and 1.40 Ga traced for Baltica (poles in red) (Salminen et al., 2017), according to the reconstruction proposed in Figure 5d for Laurentia, Baltica and Amazonia (after Reis et al., 2022). Euler rotation poles and paleomagnetic poles (and symbols) in Reis et al. (2022). (b) Reconstruction proposed by Pehrsson et al. (2016) at 1.44 Ga for Laurentia, Baltica, Amazonia and West Africa. Euler rotation poles and paleomagnetic poles (and symbols) in Reis et al. (2022). Paleomagnetic poles are represented in the same color as the respective continental blocks. Circles represent the 95% confidence cones (A95).

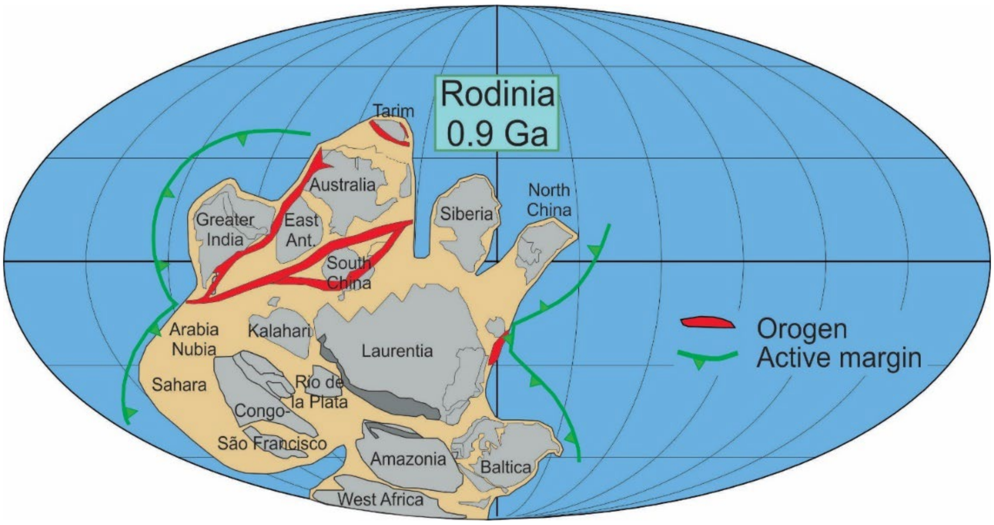

Figure 8: Rodinia at 0.9 Ga according to Li et al. (2008). Euler rotation poles in the referred article.

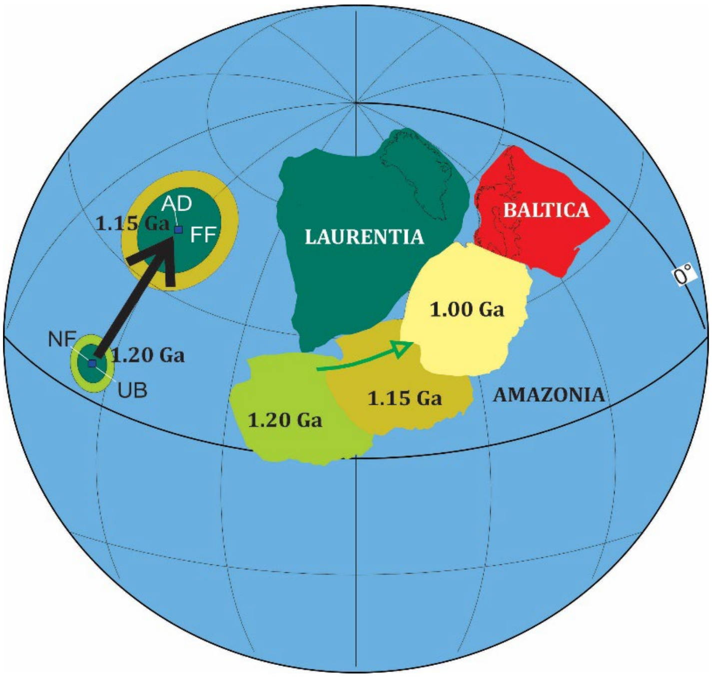

Figure 9: Sketch showing strike-slip movement of Amazonia relative to Laurentia (in today's coordinates). The figure shows the positions of Amazonia at 1.2 Ga, 1.15 Ga, and 1.0 Ga relative to Laurentia (D'Agrella-Filho et al., 2021). At 1.0 Ga, Amazonia and Baltica are plotted as in Li et al. (2008). Selected Amazonian and Laurentian poles at 1.2 Ga and 1.15–1.14 Ga define a short apparent polar wander path between 1.2 Ga and 1.5 Ga. Circles represent the 95% confidence cones - A95. NF - Nova Floresta pole (Tohver et al., 2002); UB - Upper Bylot pole (Fahrig et al., 1981; Kah et al., 2001); FF - Fortuna Formation (D'Agrella-Filho et al., 2008); AD - Abitibi dykes (Irving and Naldrett, 1977; Krogh et al., 1987; Ernst and Buchan, 1993). Euler rotation poles and poles (and symbols) in D'Agrella-Filho et al., (2021).

In their model of Rodinia at 0.9 Ga, Li et al. (2008) suggested that the present southern Kalahari collided with Laurentia at 1.05 Ga along the Llano orogen (Texas Coast), after which CSF collided with Kalahari at ca. 1.0 Ga (Figure 8). However, a paleomagnetic test of the paleogeography proposed for CSF in Rodinia failed, based on the well-dated 0.92 Ga Bahia Coastal paleomagnetic pole obtained for the São Francisco Craton (Evans et al., 2016). Also, CSF and Amazonia are situated close each other in this reconstruction (Figure 8), which contrasts with the geological evidence that a large ocean existed between CSF and Amazonian Craton at ca. 0.9 Ga ago (e.g., Cordani et al., 2003; Kröner and Cordani 2003; D'Agrella-Filho et al., 2004b; and references therein). Taking this last evidence as correct, the model proposed by Johansson (2014) for Rodinia (Figure 10) is more appropriate since he suggests the presence of a large ocean between CSF and Amazonia at ca. 0.9 Ga.

Recently, Choudhary et al. (2019) proposed a paleogeographic reconstruction at 1.1 Ga, formed by Kalahari, Amazonia-West Africa, CSF and India, named by them as UMKONDIA (Figure 11a). In their model they propose that a radial plume center located at the present northwestern Kalahari was the source of the following 1.1 Ga magmatic events: Rincón del Tigre/Huanchaca intrusions in Amazonia (Teixeira et al., 2015a), the Umkondo intrusions in Kalahari (Swanson-Hysell et al., 2015), the Huila-Epembe dykes in the Congo Craton (Salminen et al., 2018), and Mahoba dykes in India (Pradhan et al., 2012). This model received support from paleomagnetic studies of the Umkondo intrusions (Swanson-Hysell et al., 2015), Huila-Epembe dykes (Salminen et al., 2018) and Mahoba dykes (Pradhan et al., 2012), whose paleomagnetic poles cluster around the north pole after they were rotated using the respective Euler rotation poles used for each cratonic block in the reconstruction of Figure 11a.

A paleomagnetic study of the 1.1 Ga Huanchaca sills (Bispo-Santos et al., 2023) also corroborates the model proposed by Choudhary et al. (2019) (see Figure 11a). UMKONDIA is considered the 1.1 Ga megacontinent that collided with Laurentia (and other cratonic blocks) at ca. 1.0 Ga forming the Rodinia supercontinent (see Wang et al., 2020). Based on this assumption, Bispo-Santos et al. (2023) proposed two paleomagnetically possible models for the UMKONDIA relative to Laurentia and Baltica at 1.1 Ga (Figures 11b and 11c). In both, we can envisage a collision of Kalahari along the Texas Coast and Amazonia along the Appalachian area at ca. 1.0–0.9 Ga. The first model (Figure 11b) admit that SAMBA configuration (Amazonia-Baltica link) persisted until 1.1 Ga, and that UMKONDIA was linked to Baltica-Laurentia. After 1.1 Ga, Baltica broke-up from Laurentia, and together with UMKONDIA, rotated clockwise and collided with Laurentia at ca. 1.0–0.9 Ga (e.g., Bispo-Santos et al., 2023; and references therein).

However, a direct connection of northwestern Amazonian Craton and Baltica at 1.1 Ga appears to oppose the development of the ca. 1.0 Ga Putumayo orogeny in northwestern Amazonian Craton (e.g., Ibañez-Mejia et al., 2011; Cawood and Pisarevsky, 2017; Ibañez-Mejia, 2020). So, Figure 11c shows UMKONDIA separated from Baltica, which permit the development of the Colombian-Oaxaquian fringing-arc system at the northwestern Amazonian Craton. In this context, Cawood and Pisarevsky (2017) suggest that Baltica broke-up from Columbia after 1.1 Ga, with the Agder Ocean opening, which culminated with the collision with Amazonia forming the 1.05–0.98 Ga Sveconorwegian belt. On the other hand, in a recent paper, Li et al. (2023) show the Oaxaquia block in Rodinia between Amazonia and Laurentia, which could enable the paleogeography shown in Figure 11b at 1.1 Ga.

Recently, Antonio et al. (2021c), based on paleomagnetic data, proposed that **W**est Africa, **Ba**ltica, **Am**azonia and Con**go**-São Francisco Cratons formed a single, long-lived 1.2–0.8 Ga continental mass, named by them as WABAMGO (Figure 11d). According to these authors, after 1.1 Ga this megacontinent rotated clockwise in a V-shaped movement up to its collision with Laurentia to form Rodinia, closing the Nuna Ocean. Note that this model is similar to that of Choudhary et al. (2019) related to the formation of Rodinia, where Kalahari and Amazonia collide with Laurentia at Texas and Appalachian areas, respectively, although Antonio et al. (2021c) did not consider India as a component of this megacontinent, and CSF is in a different position.

Gondwana

Unlike the paleogeographic configurations of Columbia and Rodinia that are yet not well-defined (see above), the relative positions of the cratonic blocks that formed Gondwana are well-established (Figure 12a). However, an intense debate occurs concerning the time Rodinia broke-up and when Gondwana was finally formed, in particular, the time Amazonia-West Africa collided with CSF closing the large Pharusian-Brasiliano or Clymene Ocean (e.g., Trindade et al., 2006; Tohver et al., 2012; Cordani et al., 2013b; Ganade de Araújo et al., 2014). While some authors argue for a collision at ca. 0.65–0.60 Ga, along the Transbrasiliano-Kandy mega-suture, which produced eclogitic rocks at 130 km depth, whose exhumation was dated at 0.62 Ga (Cordani et al., 2013b; Ganade de Araújo et al., 2014), other authors proposed a later collision, at 0.53–0.52 Ga, based on geological, paleomagnetic and paleontological evidence (e.g., Tohver et al., 2010; 2012; Bandeira et al., 2012; McGee et al., 2012; 2015a; 2015b). This uncertainty is fed by the scarcity of paleomagnetic poles between 0.9 and 0.6 Ga for most of the cratonic blocks that formed West Gondwana (South America and Africa).

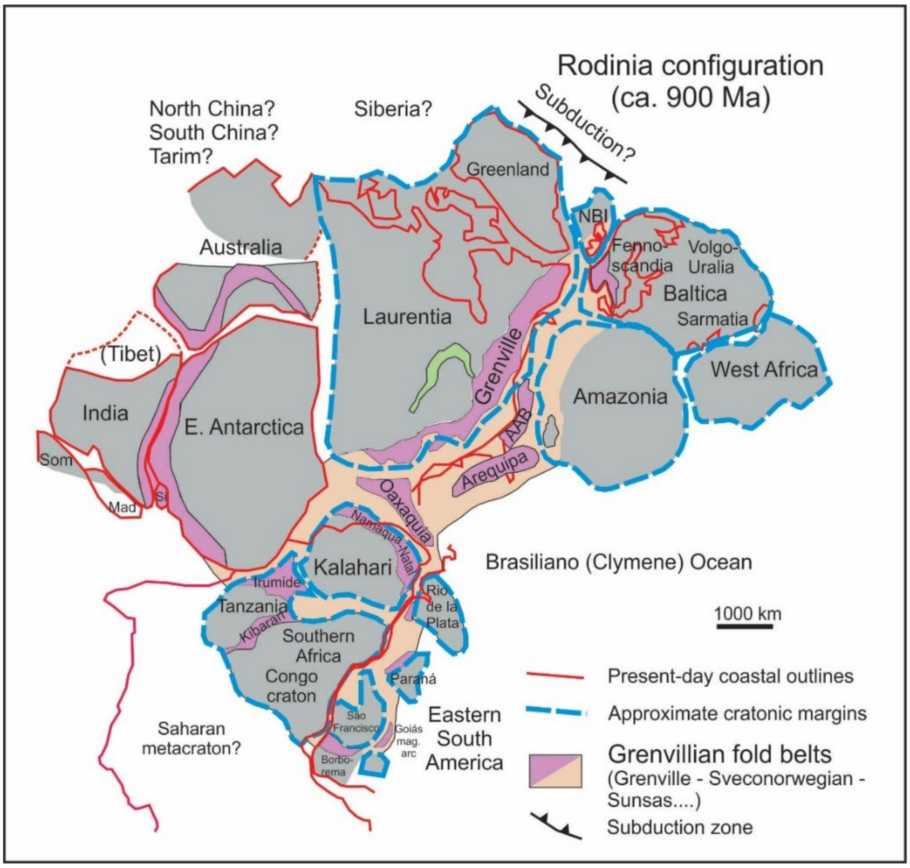

Figure 10: Proposed Rodinia reconstruction at ca. 900 Ma, after Johansson (2014).

Based only on geological evidence, the Rodinia reconstruction proposed by Li et al. (2008) shows the Amazonia-West Africa, CSF and Río de la Plata Cratons close to each other at ca. 0.9 Ga (Figure 8). Li et al. (2008) also suppose small rotational movements of these cratons up to the complete formation of West Gondwana. However, most probably, a large ocean existed between CSF and Amazonia-West Africa at 0.9 Ga ago (e.g., Cordani et al., 2003; Kröner and Cordani, 2003; D'Agrella-Filho et al., 2004b) which contrasts with this model. The model proposed by Johansson (2014) for Rodinia (Figure 9) seems more viable since he considers the existence of a large ocean (the Brasiliano or Clymene Ocean) between CSF and Amazonia. According to Johansson (2014), between 0.75 and 0.6 Ga, the CSF, together with Kalahari rotated ca. 90° counterclockwise docking Amazonia-West Africa, with the closure of the Clymene Ocean (see Figure 4 of Johansson, 2014).

The lack of paleomagnetic poles for the 0.75 and 0.65 Ga interval precludes a more strict test of the Johansson's hypothesis. Yet, there is another factor that complicates a full assessment of this movement with the help of paleomagnetism for the Neoproterozoic, which is the possibility of true polar wander (TPW), corresponding to the rotation of the silicate shell of the Earth with respect to its spin axis. The apparent polar wander path (APWP) of cratonic units is the sum of plate motion and TPW. There is strong evidence for TPW events occurring in the late Ediacaran (e.g., Mitchell et al., 2011; Robert et al., 2018; Antonio et al., 2021b) and in the Tonian (Li et al.,2004). Mitchell et al. (2012) have proposed that a series of TPW intervals with ~90° in longitude occurred through Earth's history following each supercontinent association. These events may hold the key for paleolongitidunal constraints on paleogeographic reconstructions.

Unfortunately, paleomagnetic data for West Gondwana are practically restricted to the time interval between 0.6 and 0.5 Ga. Figure 12b shows an APW path for the 0.60–0.56 Ga time interval, based mainly on paleomagnetic poles for the Río de la Plata Craton. Paleomagnetic poles dated at 0.58–0.57 Ga for Río de la Plata, West Africa and Congo Cratons agree within error, after they are rotated to the Gondwana configuration (Africa in its present position), suggesting that large areas of West Gondwana were already formed at that time (see also, Robert et al., 2017, Rapalini et al., 2021, Franceschinis et al., 2022). These poles also suggest that the Clymene Ocean was already closed or very narrow at those times.

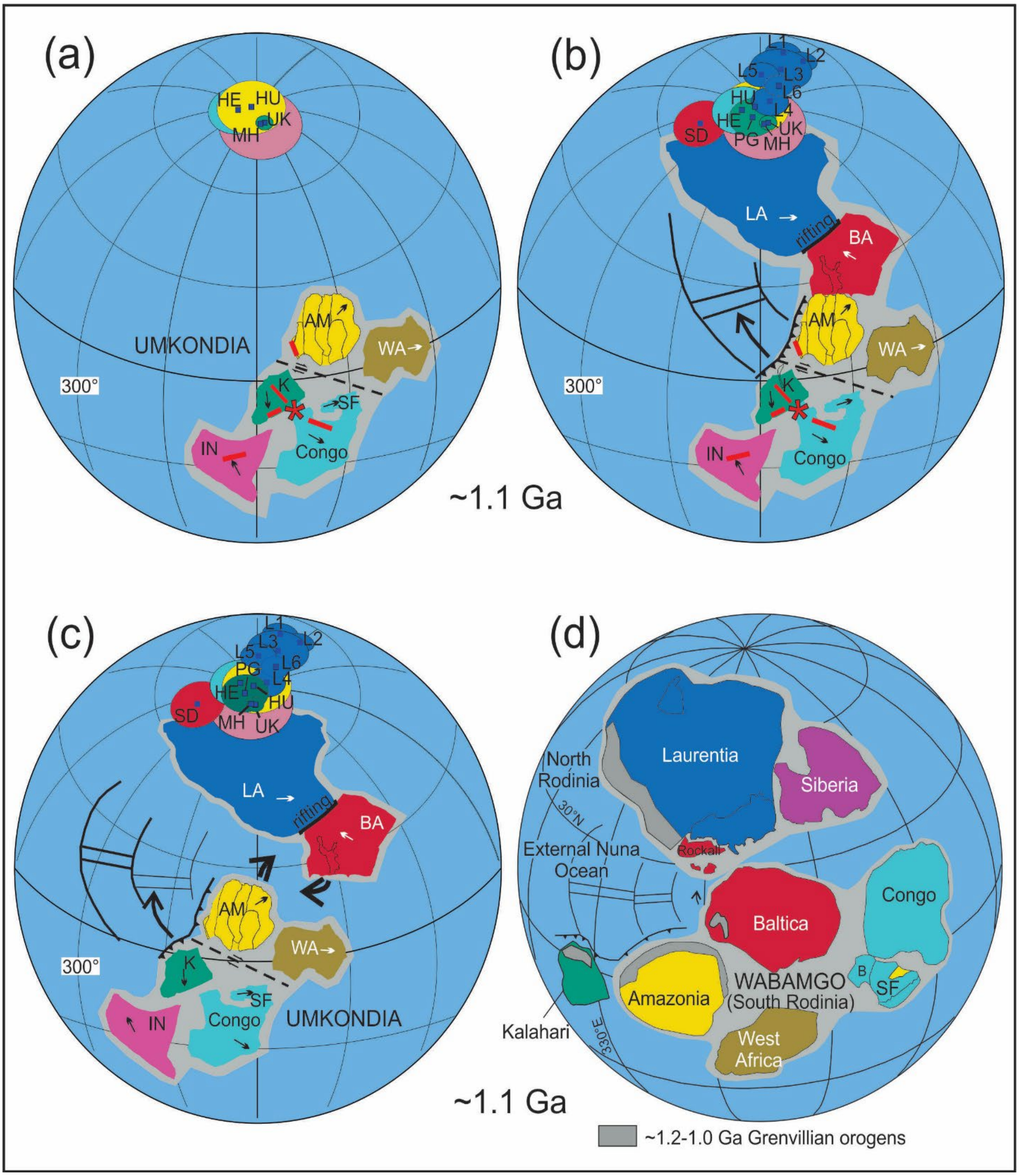

Figure 11: (a) UMKONDIA megacontinent (Choudhary et al., 2019) tested paleomagnetically by Bispo-Santos et al. (2023). Paleomagnetic poles in the same color as the respective continents. (b) Paleogeography of UMKONDIA (Choudhary et al., 2019) relative to Laurentia-Baltica (LA-BA) at 1.1 Ga. This model considers a very long-lived for the SAMBA link, since 1.78 Ga up to 1.1 Ga (modified from Bispo-Santos et al., 2023). (c) Paleogeography of UMKONDIA relative to Laurentia-Baltica (LA-BA) at 1.1 Ga. This model considers that Amazonian Craton was not more linked to Baltica at 1.1 Ga (modified from Bispo-Santos et al., 2023). AM – Amazonian Craton; WA – West African Craton; K – Kalahari Craton; SF – São Francisco Craton; IN – India. Arrows in each cratonic block indicate the present north direction. (d) Paleogeography of WABAMGO relative to Laurentia-Siberia at 1.1 Ga (modified from Antonio et al., 2021c). SF – São Francisco Craton; B – Borborema Province.

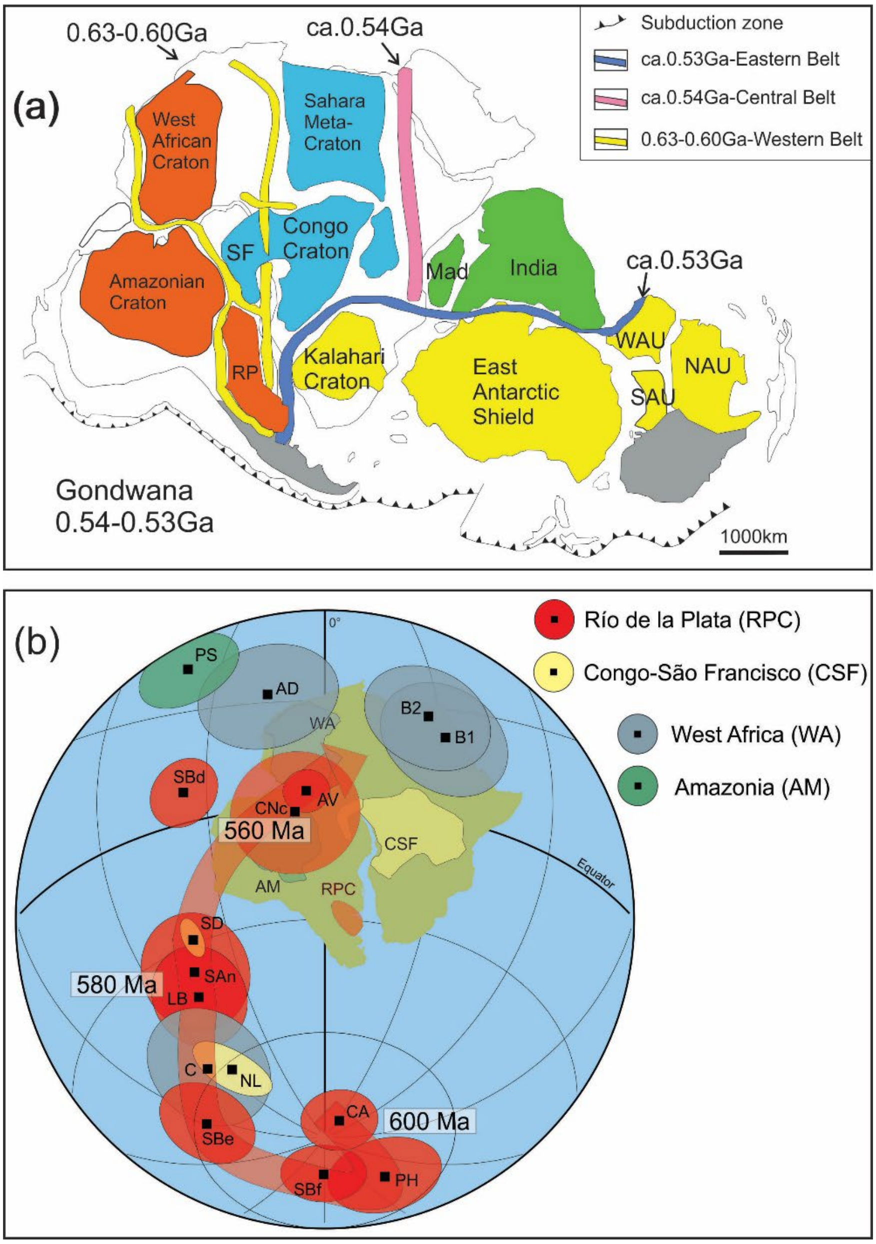

Figure 12: (a) Gondwana reconstruction (modified from Li et al., 2017). SF - São Francisco Craton; RP, Río de la Plata Craton; Mad - Madagascar; WAU - West Australia; SAU - South Australia; NAU - North Australia. (b) Ediacaran apparent polar wander path for West Gondwana forming blocks. The Planalto da Serra (PS) and Adma Dykes (AD) are ca. 0.62 Ga paleomagnetic poles from Amazonia and West Africa, respectively, suggesting close proximity between these two blocks in the Early Ediacaran. Consistent pole positions from West Africa (C pole - Adrar-n-Takoucht volcanic), C-SF (NL pole - Nola dykes) and Río de la Plata (SAn pole - Sierra de las Ánimas Complex) for around 0.58 Ga suggest most of West Gondwana was already assembled or nearly so by such age (taken from Franceschinis et al., 2022). CA - Campo Alegre Formation (0.60 Ga, Basei et al., 1998); PH - Playa Hermosa Fm. (0.59 Ga); SBf - Villa Mónica Fm. (0.59 Ga); SBe - Cerro Largo Fm. (0.58 Ga); LB - Los Barrientos (0.57 Ga); SD - Sinyai dolerite (0.55 Ga); CNc - Cerro Negro Fm. (0.56 Ga); AV - Avellaneda Fm. (0.57 Ga); SBd - Olavarria Fm. (0.56 Ga); B1 - Fajjoud and Boho volcanic (0.57–0.55 Ga); B2 - Djebel Boho volcanic (0.55–0.53 Ga). Details of paleomagnetic poles in Franceschinis et al. (2022). South America and respective poles were rotated to Africa according to the Euler rotation pole 47.5° N, 33.3° W, 56.2° ccw (Torsvik et al., 2012).

FINAL REMARKS / SUMMARY

This work overviews the participation of the main South American cratonic blocks (Amazonian, São Francisco and Río de la Plata Cratons) on the formation of Columbia, Rodinia and Gondwana. The main conclusions are:

- Amazonia-West Africa, CSF and Río de la Plata Craton most probably were part of Columbia at ca. 1.78 Ga;
- Amazonia-West Africa was linked to Baltica at 1.78 Ga in a configuration similar to the SAMBA model of Johansson (2009), and together with Laurentia and Siberia, formed West Columbia;
- The Amazonia-West Africa-Baltica link may have lasted up to 1.53 Ga, at least. The 1.42–1.44 Ga Amazonian paleomagnetic data imply either, the Amazonia-West Africa broke-up from Baltica at some time between 1.53 and 1.44 Ga, or Amazonia-West Africa rotated counterclockwise relative to Baltica keeping the integrity of West Columbia;
- At 1.78 Ga, CSF was linked to Río de la Plata, North China, India and proto-Australia forming East Columbia. Together with West Columbia, they eventually formed the Columbia supercontinent at 1.78 Ga;
- Available Paleo to Mesoproterozoic paleomagnetic data for the blocks that composed East Columbia suggest this great continental mass was short-lived (< 0.3 Ga);
- Available 1.1 Ga paleomagnetic poles favor the existence of a megacontinent formed by Amazonia-West Africa, CSF, Kalahari and India, named as UMKONDIA (Choudhary et al., 2019). This megacontinent collided with Laurentia and Baltica at ca. 1.0 Ga forming Rodinia;
- Most probably, Rodinia broke-up after 750 Ma when CSF-Kalahari, and other blocks, like Río de la Plata, rotated ca. 90° counterclockwise colliding with Amazonia-West Africa forming West Gondwana;
- The 570 Ma paleomagnetic data for West Africa, Río de la Plata and Congo Cratons suggest that most of West Gondwana was already assembled by those times.

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