Earth-Science Reviews 205 (2020) 103201

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Adamastor – an ocean that never existed?

Jiří Konopásek[a,b,*], Carolina Cavalcante[a,c], Haakon Fossen[d], Vojtěch Janoušek[b]

[a] Department of Geosciences, UiT – The Arctic University of Norway, Dramsveien 201, 9037 Tromsø, Norway
[b] Czech Geological Survey, Klárov 3, 118 21 Praha 1, Czech Republic
[c] Departamento de Geologia, Universidade Federal do Paraná, Av. Cel. Francisco Heráclito dos Santos, 100, Centro Politécnico, Curitiba, PR 81531-980, Brazil
[d] Museum of Natural History/Department of Earth Science, University of Bergen, Allégaten 41, 5007 Bergen, Norway

ARTICLE INFO

Keywords:
Adamastor Rift
Araçuaí–Ribeira–Congo Belt
Dom Feliciano–Kaoko–Gariep Belt
intracontinental orogeny
Neoproterozoic
Rodinia to Gondwana

ABSTRACT

Existing models of tectonic evolution of the Neoproterozoic orogenic system rimming the shores of the South Atlantic Ocean (the Araçuaí–Ribeira–Congo and Dom Feliciano–Kaoko–Gariep belts) interpret the belts as subduction-related orogens and emphasize the role of the "Adamastor Ocean" in their pre-collisional evolution. A critical problem in such an interpretation is the confined nature of the northern termination of the orogenic system, as well as a very short time span between the end of rifting and onset of convergence recognized in its southern part. In this contribution, we review the data for the pre- and synorogenic evolution of this system of orogens (here collectively called the South Atlantic Neoproterozoic Orogenic System) and show that the data speak against the presence of a large oceanic domain before the onset of its orogenic evolution.

We propose a new and simple intracontinental model, suggesting that Neoproterozoic oceanic crust played only a minor role in the development of the South Atlantic Neoproterozoic Orogenic System and that its overall architecture and thermal evolution is the result of inversion of large-scale rift structures with a protracted, and probably episodic, extensional history. True oceanic crust probably developed only in the southern part of the rift system, but it must have been narrow, akin to the Red Sea–Gulf of Aden stage of the "Adamastor Rift" evolution just before the onset of convergent thickening.

1. Introduction

Discussions on how the Neoproterozoic orogenic belts exposed along the coasts of the South Atlantic Ocean (Fig. 1) fit the plate tectonic model commenced shortly after its introduction in the late 1960's. Porada (1979, 1989) provided the first detailed interpretation of geological evolution of the orogenic belts today known as the Dom Feliciano, Ribeira and Araçuaí belts on the South American side, and the Gariep, Damara, Kaoko and West Congo belts on the African side of the South Atlantic, herein referred to as the South Atlantic Neoproterozoic Orogenic System (SANOS). Porada (l.c.) suggested that the Wilson Cycle started by the development of a three-armed rift that continued to open along its north–south branches as a "proto-South Atlantic Ocean", the closure of which culminated by continental collision giving rise to the Neoproterozoic orogenic system. Later on, Hartnady et al. (1985) introduced the idea of the Adamastor Ocean and since then, the presence, extent and subduction of oceanic crust preceding the formation of the above orogenic belts have been discussed under this name.

The early idea of a subduction-related nature of the SANOS suggested by Porada (1989) was questioned in the 1990s, and its origin was for some time discussed in terms of intra-continental deformation without major intervention of oceanic crust (Trompette, 1994, 1997, 2000; Dürr and Dingeldey, 1996). However, at the turn of the millennium, tectonic models involving subduction of a wide Adamastor Ocean as a driving force for the late Neoproterozoic convergent evolution of the SANOS were re-introduced (Pedrosa-Soares et al., 1998; Basei et al., 2000; Heilbron and Machado, 2003) and since then generally accepted. Despite the lack of evidence for low-temperature/high-pressure metamorphism, authors have presented mainly two arguments for the subduction-related convergence models. The first is the occurrence of mafic and locally ultramafic metamorphic rocks with early Neoproterozoic protolith ages and MORB-like geochemistry, interpreted as relics of the Adamastor oceanic crust (Pedrosa-Soares et al., 1992, 1998; Heilbron and Machado, 2003; Ramos et al., 2018; Amaral et al., 2020). The second argument is the presence of linear plutonic complexes with apparent subduction-related geochemical imprint. These ca. 630–575 Ma (see Table 1 in supplementary material) plutonic associations are interpreted as exhumed deep parts of magmatic arcs that formed above subducting oceanic crust (Basei et al., 2000, 2018; Heilbron and Machado, 2003; Pedrosa-Soares et al., 2001, 2011; Heilbron et al.,

---

* Corresponding author at: Department of Geosciences, UiT – The Arctic University of Norway, Dramsveien 201, 9037 Tromsø, Norway.
E-mail address: jiri.konopasek@uit.no (J. Konopásek).

https://doi.org/10.1016/j.earscirev.2020.103201
Received 9 January 2020; Received in revised form 1 April 2020; Accepted 5 May 2020

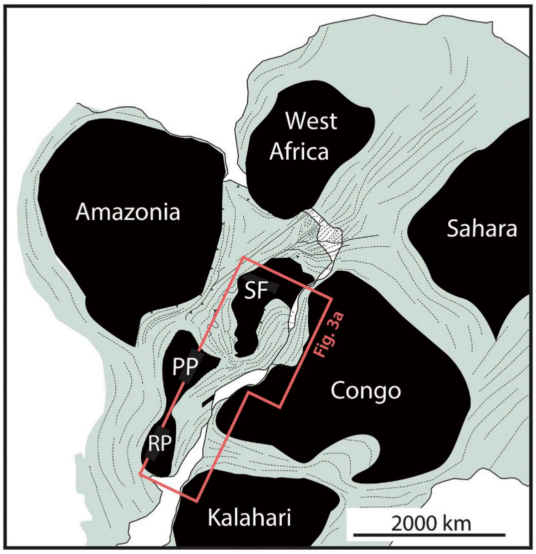


Fig. 1. Schematic reconstruction of the Africa–South America connection prior to opening of the Atlantic Ocean. (Meta)cratonic complexes are shown in black. Abbreviations: RP – Rio de la Plata, PP – Paranapanema, SF – São Francisco.

2013; Tedeschi et al., 2016).

The purpose of this review is to critically evaluate various geological data from the SANOS that have direct consequence for the presence or absence of an oceanic domain that was potentially consumed prior to its formation (Fig. 2). We show that the oceanic subduction model has important spatial and temporal implications that complicate interpretations of granitoid rocks in the hinterland of the orogenic system as magmatic arc complexes. Altogether, the data summarized in this contribution favor a largely intracontinental orogenic setting in the northern part, and a Red Sea/Gulf of Aden-type setting in the southern part of the South Atlantic Neoproterozoic Orogenic System, without the need for a wide oceanic domain.

2. Large-scale structure of the South Atlantic Neoproterozoic Orogenic System (SANOS)

Altogether, the SANOS with all its different elements, the Ribeira–Araçuaí–West Congo belts in the north and the Kaoko–Dom Feliciano–Gariep belts in the south, represents a ca. 3000 km long orogen (Fig. 3). Like most other orogenic belts, its overall structure can broadly be described in terms of an external low- to high-grade *foreland* section surrounding an internal *hinterland* characterized by higher metamorphic temperatures, partial melting and extensive magmatic activity (Fig. 3b).

The western (South American) and eastern (African) forelands of the SANOS are represented by Archean–Paleoproterozoic basement domains (Seth et al., 1998; Kröner et al., 2004; Engler, 2009; Thomas et al., 2016; Fossen et al., 2017; Egydio-Silva et al., 2018; Oyhantçabal et al., 2018; Passarelli et al., 2018; Cavalcante et al., 2019) with variable Mesoproterozoic magmatic and/or metamorphic reworking (e.g. Tack et al., 2001; Becker et al., 2006; Drüppel et al., 2007; Chemale et al., 2011; Guadagnin et al., 2015; Kröner and Rojas-Agramonte, 2017; Oriolo et al., 2019), and their deformed and metamorphosed Paleo- to Neoproterozoic cover sequences (Guj, 1970; Hoffmann and Prave, 1996; Tack et al., 2001; Hoffman and Halverson, 2008; Konopásek et al., 2014, 2017; Alkmim et al., 2017; Frimmel, 2018; Hueck et al., 2018).

The northern part of the hinterland consists of high-temperature mylonites and migmatites generally formed at temperatures exceeding 700 °C and pressures of 6–8 kbar (e.g. Vauchez et al., 2007; Monié et al., 2012; Heilbron et al., 2008; Bento dos Santos et al., 2011; Cavalcante et al., 2018a, 2018b). The southern part is represented by uppermost amphibolite- to granulite-facies rocks metamorphosed at medium to low pressures (Goscombe and Gray, 2007; Gross et al., 2009). In large parts of the hinterland, metamorphosed igneous rocks appear with protolith ages ranging ca. 860–770 Ma, which have been interpreted as either remnants of an early magmatic arc (Heilbron and Machado, 2003; Masquelin et al., 2012; Lenz et al., 2013; Koester et al., 2016; Martil et al., 2017; Peixoto et al., 2017; De Toni et al., 2020) or products of rifting-related igneous activity (Konopásek et al., 2008, 2018; Will et al., 2019; Passarelli et al., 2019; Meira et al., 2019a). The high-grade metamorphism and associated partial melting in various parts of the hinterland domain took place between ca. 650 and 570 Ma (Franz et al., 1999; Goscombe et al., 2005; Konopásek et al., 2008; Lenz et al., 2011; Cavalcante et al., 2018a), accompanied and also post-dated by 170 m.y. of massive magmatism between ca. 650 and 480 Ma (Fig. 4). Along the entire orogenic system, the late Neoproterozoic plutonic rocks are arranged into linear complexes, with early igneous activity (ca. 630–575 Ma) mostly concentrated along the western flank of the hinterland (Philipp and Machado, 2005; Oyhantçabal et al., 2007; Pedrosa-Soares et al., 2011; Florisbal et al., 2012b, Peixoto et al., 2017, Lara et al., 2020 and references therein), and later magmatism (ca. 585–480 Ma) in its interior or along its eastern flank (Seth et al., 1998; Kröner et al., 2004; Janoušek et al., 2010; Pedrosa-Soares et al., 2011; Konopásek et al., 2016) (Fig. 3c).

3. The Araçuaí–Ribeira–West Congo belts – the northern domain of the SANOS

The Brazilian part of the northern SANOS trends N–S in the north (Araçuaí Belt) and NE–SW in the south (Ribeira Belt; Fig. 3). The African part – the West Congo Belt – is situated along the west coast of central Africa, from Gabon in the north to Angola in the south. However, the African side lacks exposure of Neoproterozoic rocks and Pan-African orogenic structures south of a fault-controlled structure known as the Kwanza Horst south of Luanda (Fig. 3a). The Ribeira Belt is in continuity with the Araçuaí Belt (e.g, Egydio-Silva et al., 2018), but different groups of researchers have made independent tectonic subdivisions and interpretations. Most of these are quite complex, involving multiple magmatic arcs and collisional events (Heilbron et al., 2017a) recorded by tectonic units of the Ribeira Belt that are difficult to extend northward into the Araçuaí Belt. The entire orogen is considered to terminate within a continental environment defined by the pre-Atlantic horse-shoe shape of the São Francisco–Congo Craton (Alkmim et al., 2006).

3.1. *The pre-orogenic rift basin, possible ophiolites and sutures*

Rift sedimentation and associated magmatism in the northern part of the SANOS is known to have occurred from close to 1000 Ma. This is recorded in a ca. 10 km thick unit of metasedimentary and metavolcanic rocks on both the African (West Congo Supergroup) and Brazilian (Macaúbas Group and Andrêlandia Megasequence) sides (Fig. 5). Together, these units constituted a Tonian–Cryogenian rift basin in the northern SANOS, with sedimentation continuing into the Ediacaran. The relatively poorly understood Tonian–Cryogenian rifting history of the northern SANOS is generally considered to consist of two main episodes.

The first rift episode (ca. 950–870 Ma) is linked to extensive volcanism in the West Congo Supergroup (De Paepe et al., 1975; Kampunzu et al., 1991) and tholeiitic magmatism on the Brazilian side. This magmatism has been explained in terms of mantle plume activity as a part of a Large Igneous Complex (Kuchenbecker et al., 2015; Castro et al., 2019; Chaves et al., 2019).

The second rift episode has been linked to ca. 730–675 Ma alkaline magmatism in the São Francisco basement along the Atlantic coast (Teixeira et al., 1997; Rosa et al., 2007), tholeiitic basalts with pillow

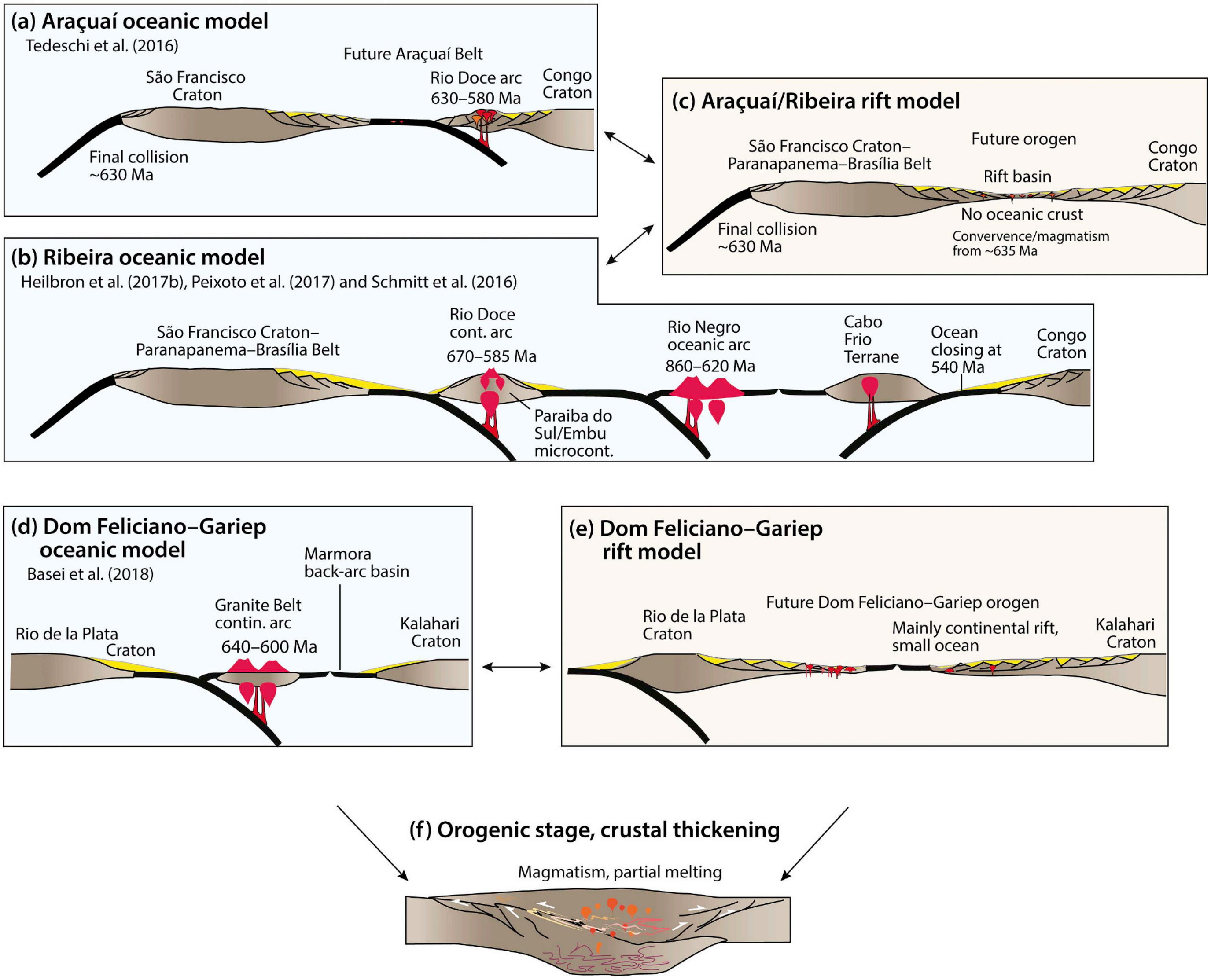


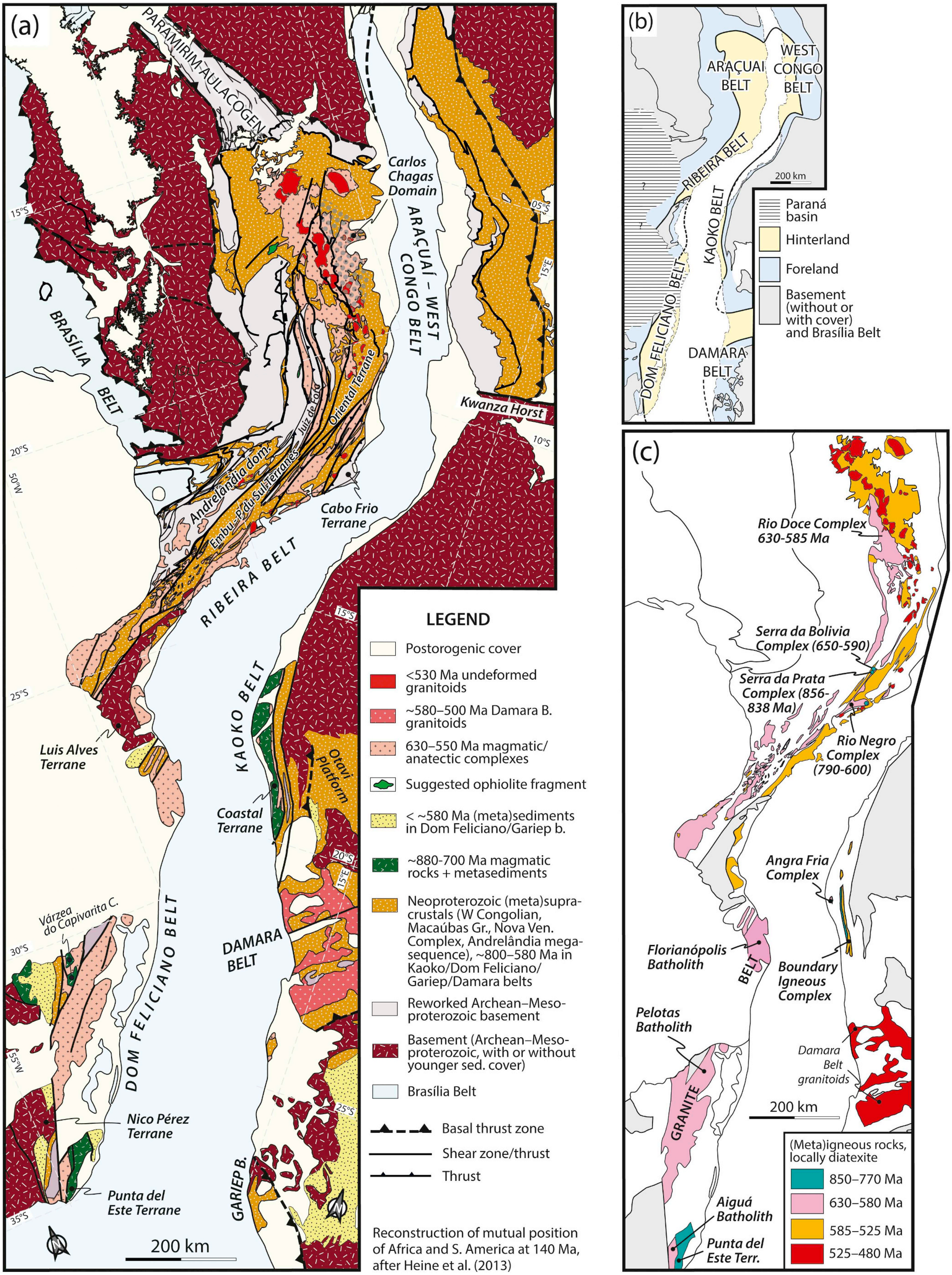
Fig. 2. Schematic presentation and comparison of the two discussed tectonic models for the origin of the SANOS. Subduction-driven models for (a) the Araçuaí Belt based on Tedeschi et al. (2016) and (b) for the Ribeira Belt based on Heilbron et al. (2017a, 2017b), Peixoto et al. (2017) and Schmitt et al. (2016). The models are compared with an intracontinental model (c) for both belts. Similarly, the subduction-driven model for the Dom Feliciano–Gariep Orogen (d) is compared with a largely intracontinental model with only a small amount of oceanic crust (e). The resulting orogenic stage of maximum crustal thickening in the SANOS is schematically shown in (f).

structures in the Macaúbas Group (Pedrosa-Soares et al., 2008) and basaltic volcanism at ca. 700 Ma in the West Congo Supergroup (Kuchenbecker et al., 2015 and references therein). Glacial units were deposited during the second rift event, most extensively on the Brazilian side, and capped by carbonates on the African side. On top are synorogenic deposits (Fig. 5; Tack et al., 2001) of very low metamorphic grade on the West Congo and São Francisco cratons, and of higher grade in the internal parts of the Araçuaí Belt.

Formation of oceanic crust in the Macaúbas Basin has been suggested, based on limited occurrences of rather poorly dated (816 ± 72 Ma) amphibolite and ultramafic rocks on the Brazilian side of the orogen (Pedrosa-Soares et al., 1998, 2001). This led Pedrosa-Soares et al. (1998) to interpret these rocks as remnants of an ophiolite marking an orogenic suture zone. Recently, Amaral et al. (2020) suggested that the formation of oceanic crust lasted from ca. 675 Ma until its early subduction at ca. 630 Ma, thereby disregarding the ca. 816 Ma age presented by Pedrosa-Soares et al. (1998). Based on an unpublished U–Pb zircon age, Amaral et al. (2020) further argued that oceanic crust was forming at 600 Ma in the southern Araçuaí Belt. From gravimetric data in the West Congo Belt, Byamungu et al. (1987) proposed a suture zone underneath the sedimentary cover along the Congo coast. However, no record of oceanic rocks has been found on the African side of the orogen.

In the Ribeira Belt, MORB-type metabasic rocks dated at 848 ± 11 Ma (Heilbron and Machado, 2003) have been interpreted as products of a "magmatic event compatible with the generation of oceanic lithosphere" between the São Francisco margin and the higher nappes (Oriental Terrane; Fig. 3a) of the Ribeira Belt (Heilbron et al., 2008). According to Heilbron and Machado (2003), such an ocean would be forming over ca. 58 million years and be 1160 km wide.

In summary, the temporal extent of the Neoproterozoic rifting, and the timing of possible rift–drift transition is poorly constrained, as is the potential time interval between the termination of rifting and onset of convergence followed by deposition of flysch sediments in the northern part of the SANOS.



Reconstruction of mutual position of Africa and S. America at 140 Ma, after Heine et al. (2013)

(caption on next page)

Fig. 3. a) Simplified geological map of the SANOS showing the geological units mentioned in the text. The mutual position of the African and South American continents (from Heine et al., 2013) is shown shortly before the onset of opening of the Atlantic Ocean. b) Overview map showing position of the hinterland (yellow) and foreland (blue) geological units of the SANOS. c) Distribution of main Neoproterozoic magmatic complexes within the SANOS. Magmatic rocks are divided into four groups based on their intrusion ages.

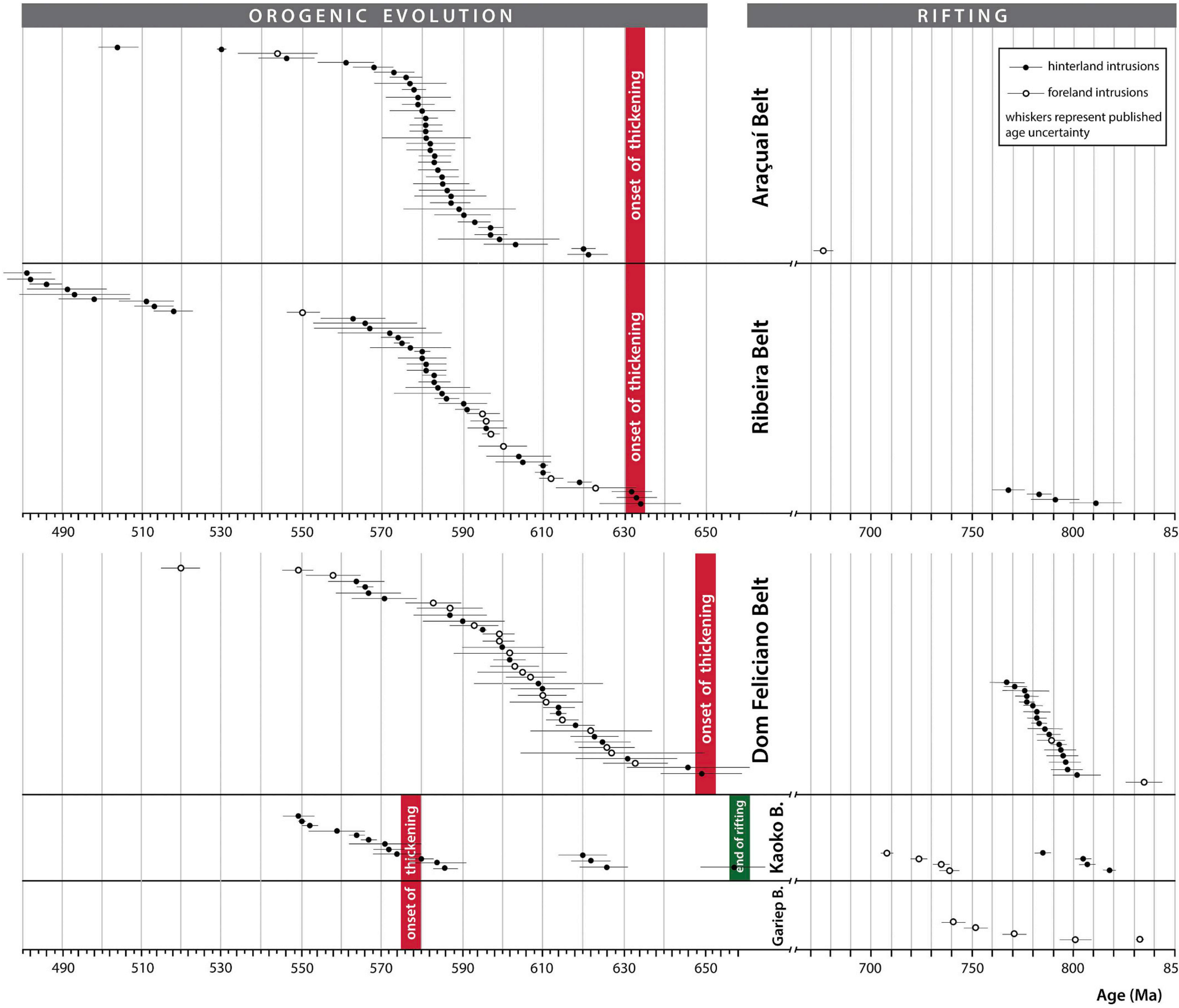


Fig. 4. Summary of published geochronological data, showing extent of igneous activity in different parts (orogenic belts) of the SANOS. In accord with the interpretation provided in the text, the data were separated into magmatic activity related to rifting and that associated with orogenic evolution. Note different scale of the horizontal axis of the diagram for the two tectonic regimes. The data used for the diagram are provided as a supplementary table. The estimated timing for onset of orogenic thickening in the Araçuaí Belt is after Cavalcante et al. (2018a) and in the Ribeira Belt after Meira et al. (2019b). The onset of orogenic thickening in the Dom Feliciano Belt is constrained from the age of granulite-facies metamorphism in the hinterland (Lenz et al., 2011; Martil et al., 2016) and the discussion presented in Sections 5.3 and 5.5. The commencement of crustal thickening in the western foreland of the SANOS is constrained by ages provided by Goscombe et al. (2003) for the Kaoko Belt and Frimmel and Frank (1998) for the Gariep Belt. The timing for end of rifting in the Kaoko Belt is based on data by Hoffman and Halverson (2008) and the discussion in Sections 5.3 and 5.5.

3.2. The foreland of the Araçuaí–Ribeira–West Congo belts

The foreland of the northern SANOS is a classical fold-and-thrust belt that developed on both continental margins. The kinematics is predominantly thrusting onto the craton, i.e. top-W along the São Francisco margin and top-E in the West Congo Belt. The foreland successions consist of metamorphosed Paleo- to Mesoproterozoic supracrustal rocks (Espinhaço Supergroup), and the Neoproterozoic Macaúbas Group and West Congo Supergroup, deformed under sub-metamorphic to amphibolite-facies conditions (Tack et al., 2001; Alkmim et al., 2017).

While deformation in the most peripheral parts mainly affected the metasedimentary cover of the São Francisco and Congo cratons, basement was involved towards the hinterland. In the Araçuaí Belt, a major mylonite zone characterizes the transition from the foreland to the high-temperature hinterland (e.g., Vauchez et al., 2007). The timing of deformation and metamorphism in the low-grade foreland north of the SANOS is reflected by illite K–Ar ages ranging from 645 to 603 ± 9 Ma

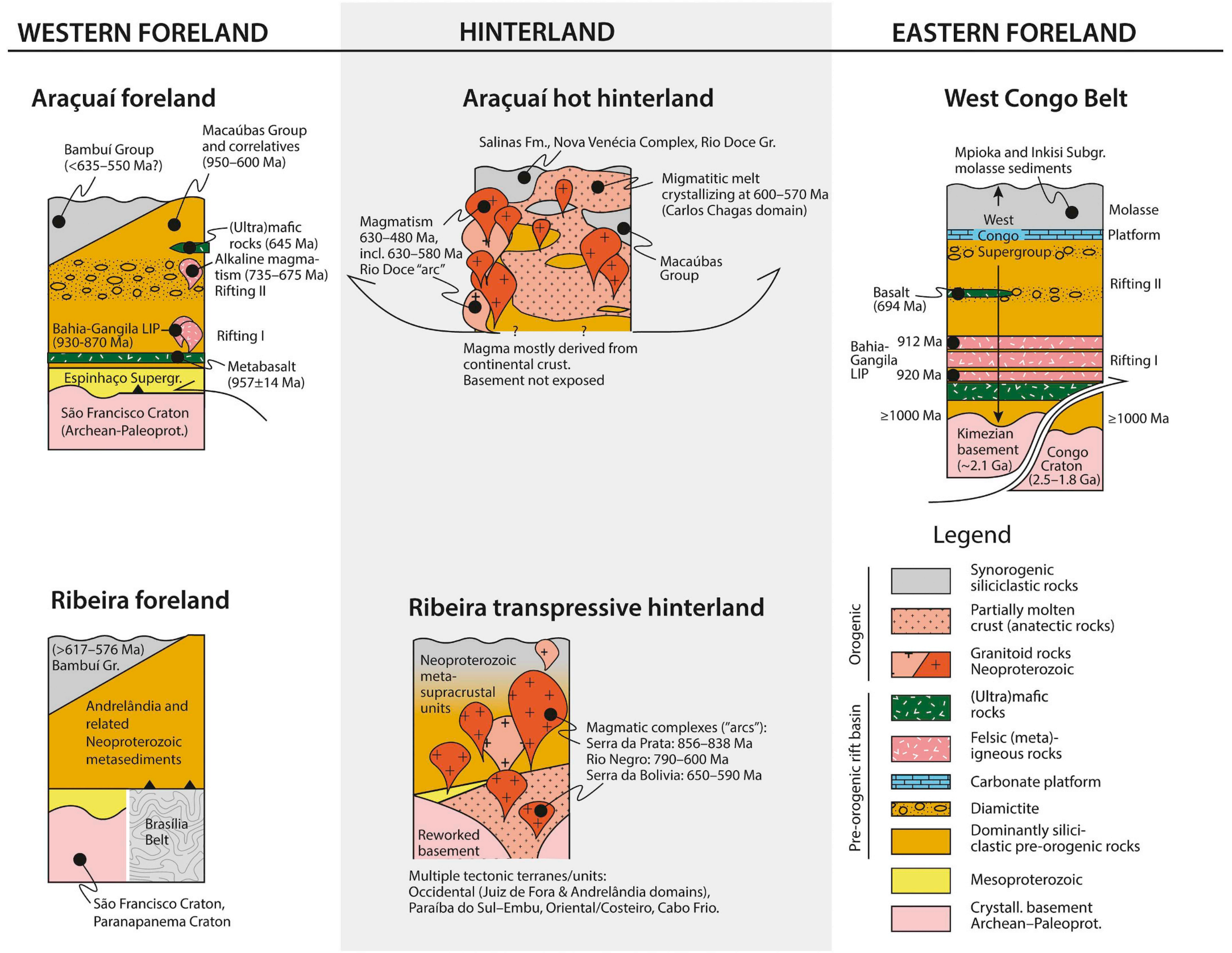


Fig. 5. Schematic tectonostratigraphic columns for the foreland and hinterland domains in the northern part of the SANOS. See Section 3 for references related to timing of geological processes.

in low-grade sediments on the São Francisco Craton (Espinhaço Supergroup; Süssenberger et al., 2014). Deformation of the Araçuaí foreland basin affected synorogenic sediments possibly as young as the latest Ediacaran (ca. 550–542 Ma; Warren et al., 2014), suggesting that foreland thrusting was still going on in the latest Ediacaran and possibly into the Cambrian.

Along the southeastern rim of the São Francisco Craton, the rift-related basin fill (Andrelândia Megasequence; Paciullo et al., 2000) was deposited on the São Francisco continental crust throughout most of the Neoproterozoic, with the youngest part being younger than 620 Ma (zircon U–Pb ages; Belém et al., 2011). In the western Ribeira Belt, this deformed Neoproterozoic cover occurs together with reworked basement rocks in the westerly tectonic units (Juiz de Fora and Andrelândia tectonic domains; Fig. 3a).

3.3. The hinterland of the Araçuaí–Ribeira–West Congo belts

The hinterland evolution in the northern part of the SANOS (Fig. 3b) was characterized by extensive magmatism and high-temperature (> 700 °C) deformation associated with partial melting. Most of the hinterland is found in the Araçuaí Belt, where it consists of (from west to east): (1) high-temperature (ca. 750 °C) mylonites thrust onto reworked São Francisco Craton, and associated leucocratic veins suggesting a melting event at ca. 577 Ma (Petitgirard et al., 2009; Vauchez et al., 2007); (2) tonalites and granodiorites emplaced in metasediments between ca. 650 and 585–580 Ma, and interpreted as both synorogenic and arc magmatism (Mondou et al., 2012; Tedeschi et al., 2016), and (3) migmatites associated with peraluminous leucogranites (Carlos Chagas Domain in Fig. 3a; Cavalcante et al., 2013, 2018a). These migmatites were formed during orogenic crustal thickening involving extensive crustal heating and partial melting of the middle–lower crust, and slowly crystallized from ca. 600 to 572 Ma (Cavalcante et al., 2018a). Peak pressures of 6–8 kbar characterize the entire hinterland, with no evidence of high-pressure mineral assemblages (Petitgirard et al., 2009; Cavalcante et al., 2014).

The African part of the hinterland is exposed along the western edge of the West Congo Belt (Fig. 3b) as migmatized metasediments thrust eastward onto younger metasedimentary units. In terms of geochronology, this area is poorly studied, and we define it as a part of the hinterland based on preliminary Cambrian ages of melt crystallization in the southernmost part of the West Congo Belt (Monié et al., 2012).

The northern SANOS hinterland hosts a large amount of magmatic rocks dated between ca. 860 and 570 Ma. These rocks have been interpreted as the roots of four different magmatic arcs: Serra da Prata Complex or arc – 856–838 Ma (Peixoto et al., 2017), Rio Negro arc – 790–600 Ma (Tupinamba et al., 2012), Serra da Bolivia arc – 650–590

Ma (Heilbron et al., 2013), all in the Ribeira Belt, and Rio Doce arc – 630–585 (Tedeschi et al., 2016), in the Araçuaí Belt (Fig. 3c). The youngest (525–480 Ma) batch of granitic intrusions in the hinterland has been explained by late- to post-orogenic gravitational collapse (Marshak et al., 2006) involving delamination and removal of lithospheric mantle (Pedrosa-Soares et al., 2011), or very late slab break-off (Valeriano et al., 2016).

In the Araçuaí hinterland there are migmatitic high-grade metasedimentary rocks whose protolith deposition was synorogenic, some with maximum depositional ages around 600 Ma (Richter et al., 2016). In line with the magmatic-arc tectonic model, these rocks have been interpreted as fore-arc or back-arc deposits (Peixoto et al., 2015; Richter et al., 2016). Various high-grade metasedimentary units in the Ribeira Belt hinterland have been also interpreted as being deposited in fore-arc or back-arc settings (Heilbron et al., 2017a), even though most of the units are demonstrably associated with Mesoproterozoic/Archean basement.

Recent contributions by Meira et al. (2019a, 2019b) discarded the complicated evolution of multiple arcs and terrane-margin collisions and presented evidence for intracontinental orogeny. According to their model, crustal thickening related to convergent movements between the São Francisco and Congo cratons would heat the middle crust and produce some partially molten rocks at ca. 615 Ma, followed by a more widespread partial melting event at around 580 Ma, which the authors tentatively related to extensional collapse. Crustal thickening and initial melting at around 620–615 Ma followed by more pervasive partial melting at ca. 590–560 Ma fit well with the data and model presented for the Araçuaí Belt by Cavalcante et al. (2018a, 2019) and are largely consistent with the model favored in this work.

4. The Kaoko–Dom Feliciano–Gariep belts – the southern domain of the SANOS

Similar to the northern part of the SANOS, the southern part also shows a distinct W–E tectonic zonation (Fig. 6). The Archean–Paleoproterozoic crust of the Nico Pérez–Luis Alves terranes (Oyhantçabal et al., 2018; Passarelli et al., 2018, Figs. 3a and 6a,f) represents the western foreland, which is along its eastern flank covered by metamorphosed Mesoproterozoic and Neoproterozoic volcano-sedimentary cover (Hueck et al., 2018; Oriolo et al., 2019). The hinterland is represented by the granulites and high-grade ortho- and paragneisses of the Punta del Este–Coastal Terrane (Fig. 3a). The protolith ages of metaigneous rocks in this unit fall between ca. 820 and 770 Ma, whereas the ages of their low-pressure granulite/amphibolite-facies metamorphism range between ca. 650 and 630 Ma (Konopásek et al., 2008, 2018; Oyhantçabal et al., 2009; Lenz et al., 2011; Will et al., 2019). Large volumes of granitoid rocks collectively named as the Granite Belt (Figs. 3c and 6b,g) intruded between ca. 635 and 580 Ma along the contact of the foreland with the Punta del Este–Coastal Terrane (see summary in Philipp and Machado, 2005; Konopásek et al., 2016 and Figs. 3c and 4). Basei et al. (2008, 2018) interpreted the Granite Belt as a magmatic arc related to subduction of the Adamastor Ocean. Other authors emphasized the syn- to post-collisional nature of granitoid rocks of the Granite Belt and associated their emplacement with collision of the western foreland with the easterly Punta del Este–Coastal Terrane (Bitencourt and Nardi, 1993; Oyhantçabal et al., 2007; Florisbal et al., 2012a, 2012b).

On the African side of the southern SANOS, the hinterland has been thrust over the foreland represented by the Archean–Paleoproterozoic Congo Craton in the north and by the Paleoproterozoic–Mesoproterozoic rocks at the western edge of the Kalahari Craton in the south (Figs. 3a and 6d,e,i). Similar to the South American part of the southern SANOS, the African foreland is covered by relics of Mesoproterozoic volcano-sedimentary rocks (Becker et al., 2006; Kröner and Rojas-Agramonte, 2017; Fig. 6d) and by an extensive Neoproterozoic (meta)sedimentary unit recording the pre-collisional rifting to early syn-collisional period (Guj, 1970; Hoffmann and Prave, 1996; Hoffman and Halverson, 2008; Konopásek et al., 2014, 2017; Frimmel, 2018; Figs. 3a and 6d,e,i).

4.1. Neoproterozoic rifting in the Kaoko–Dom Feliciano–Gariep belts

The oldest dated manifestation of the early Neoproterozoic extension is recorded by sporadic granitic–syenitic magmatism in the basement of the foreland domains (ca. 835 Ma; Frimmel et al., 2001; Basei et al., 2008; Figs. 6a,i). The first period of extensive igneous activity is dated between ca. 800 and 770 Ma in the hinterland domain collectively called the Punta del Este–Coastal Terrane (Konopásek et al., 2008, 2018; Oyhantçabal et al., 2009; Lenz et al., 2011; Fig. 6b,c,g). In the Punta del Este Terrane in Uruguay and in associated units in Brazil, magmatism of this age was interpreted as representing an early Neoproterozoic magmatic arc (Lenz et al., 2013; Koester et al., 2016; Martil et al., 2017; De Toni et al., 2020). However, this largely felsic igneous activity was contemporaneous with deposition of early rifting-related sedimentary rocks in the Kaoko–Dom Feliciano–Gariep (and Damara) belts, and the rare mafic plutonic rocks are devoid of arc-like geochemical imprint. Therefore, Konopásek et al. (2018) suggested that the ca. 800–770 Ma igneous rocks in the Punta del Este Terrane represented products of rifting-related lower/mid-crustal magmatism.

In the Coastal Terrane, which represents a supracrustal part of the Punta del Este–Coastal Terrane, the ca. 820–785 Ma volcanic activity accompanied clastic sedimentation sourced in the neighboring pre-Neoproterozoic basement (Konopásek et al., 2014, 2018). Volcanic rocks of similar age also appear as a part of the western foreland cover in the central Dom Feliciano Belt (ca. 810–770 Ma; Saalmann et al., 2011; Pertille et al., 2017). Along the edge of the exposed eastern foreland (Congo Craton), the early stage of rifting was manifested by the sedimentation of the > ca. 780 Ma coarse-grained fluvial clastic rocks (Martin, 1965; Guj, 1970; Fig. 6d,e) followed by igneous activity dated at ca. 755–745 Ma (Hoffman et al., 1996). In the Gariep Belt, the rifting-related sedimentation started after ca. 770 Ma by deposition of fluvial to fluvio-deltaic sediments accompanied by ca. 750–740 Ma volcanic activity (Borg et al., 2003; Frimmel et al., 1996; Frimmel, 2018; Fig. 6i).

The next stage of the rift development is best characterized along the southwestern edge of the Congo Craton. Metamorphosed clastic sediments in the foreland part of the Kaoko Belt are intercalated with ca. 740–710 Ma metavolcanic rocks (Fig. 6d) and the source of the clastic sedimentation was still the Congo Craton basement (Konopásek et al., 2014). According to the data from the eastern part of the Kaoko Belt and from the Otavi Platform (Figs. 3a and 6e), the rifting terminated shortly after the development of a thick glaciogenic horizon related to the Sturtian global glaciation (Hoffman and Halverson, 2008; Konopásek et al., 2017).

In the Gariep Belt, the sedimentation post-dating the ca. 750–740 Ma volcanic activity has been dominated by calcareous deposits (Fig. 6i), followed by a major unconformity that hinders any correlation with the evolution in the Kaoko Belt or Otavi Platform (Frimmel, 2018).

4.2. Early (ca. 650–630 Ma) crustal thickening in the Kaoko–Dom Feliciano–Gariep belts

On the western side of the southern SANOS, the beginning of crustal thickening is constrained indirectly by several features. The hinterland (Punta del Este Terrane) in the southernmost Dom Feliciano Belt underwent an early granulite-facies metamorphism at ca. 7–10 kbar and 830–950 °C, followed by decompressional reequilibration at ca. 5.0–5.5 kbar and 790–830 °C (Gross et al., 2009) at ca. 650 Ma (Oyhantçabal et al., 2009; Lenz et al., 2011). Cooling of the Punta del Este Terrane was determined at ca. 630–620 Ma (Ar–Ar in amphibole and K–Ar in white mica – Oyhantçabal et al., 2009; Will et al., 2019), so the time interval of 650–630 Ma represents the best estimate of compression-

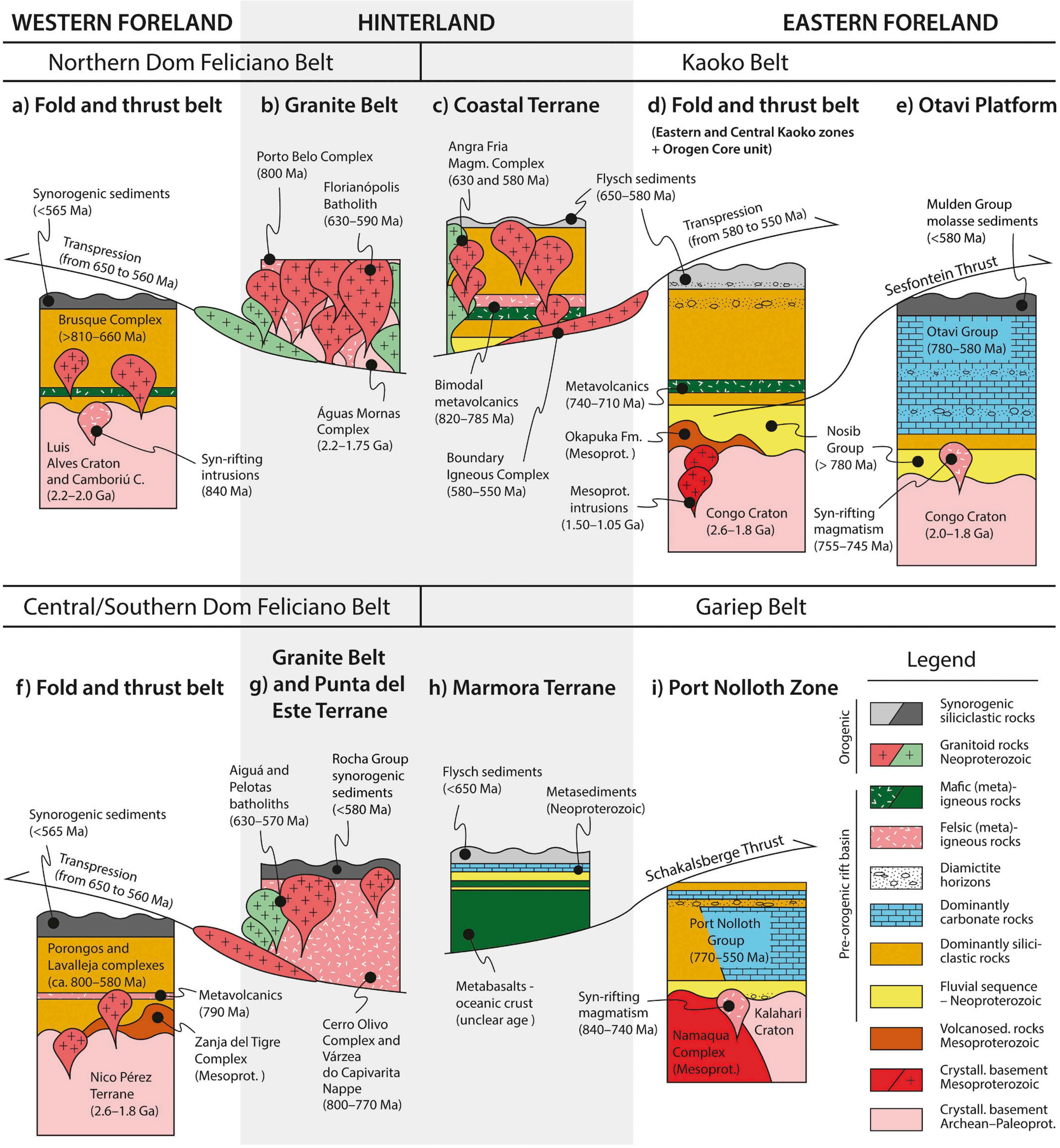


Fig. 6. Schematic tectonostratigraphic columns for the foreland and hinterland domains in the southern part of the SANOS. See Section 4 for references related to timing of geological processes.

driven exhumation of the Punta del Este Terrane. Similar timing was determined for early movements along shear zones crosscutting the foreland (Oriolo et al., 2016). In the central Dom Feliciano Belt, an early compression-related exhumation of the hinterland is documented in Rio Grande do Sul state in Brazil. A granulitic nappe with protolith ages and geochemistry very similar to the Punta del Este Terrane basement rocks has been emplaced onto the foreland during, or shortly after, the metamorphic peak estimated at ca. 650 Ma (Martil et al., 2016; Battisti et al., 2018; Fig. 6f,g).

The only exposed part of the hinterland on the African side of the southern SANOS is the Coastal Terrane in the Kaoko Belt. The rifting-related volcanosedimentary rocks in this unit record a ca. 650–630 Ma partial melting event (Franz et al., 1999; Goscombe et al., 2005; Konopásek et al., 2008) at ca. 680–730°C and 6–7 kbar (Goscombe and Gray, 2007). This early metamorphism was followed by intrusion of plutonic rocks (Figs. 3c and 6c) that have been correlated with early intrusions of the Granite Belt in the northern Dom Feliciano Belt (Konopásek et al., 2016).

The early collision in the western part of the southern SANOS is also manifested on the African side by the deposition of flysch sediments, which have been recognized along the entire eastern foreland of the southern SANOS (Konopásek et al., 2017; Fig. 6c,d,h). The presence of the Marinoan (ca. 645–635 Ma) glaciogenic deposits within these flysch sediments in the Kaoko Belt already containing ca. 650 Ma detrital zircon provides another evidence that the crustal thickening in the Kaoko–Dom Feliciano–Gariep belts and exhumation of its core commenced at, or shortly before, ca. 650 Ma (Konopásek et al., 2017).

4.3. *Late (ca. 580–550 Ma and beyond) convergence in the Kaoko and Gariep belts*

Crustal thickening along the eastern edge of the southern SANOS started at ca. 580–575 Ma. This was documented in the Kaoko Belt by the dating of garnet growth in the gneisses and schists of the foreland (Goscombe et al., 2003) and of the earliest magmatism (Figs. 3c and 6c) along the contact of the foreland with the overriding Coastal Terrane representing the hinterland domain (Seth et al., 1998; Konopásek et al., 2008). In the low-grade Gariep Belt, Ar–Ar ages of ca. 573–576 Ma (hornblende) were interpreted by Frimmel and Frank (1998) as the timing of building of an accretionary wedge. The metamorphic peak in the Kaoko Belt is recorded by low-pressure granulite-facies mineral assemblages and partial melting of the foreland basement with its metasedimentary cover directly underneath the hinterland (Goscombe et al., 2003). The metamorphic peak took place at ca. 550 Ma (Kröner et al., 2004; Goscombe et al., 2005; Konopásek et al., 2008) and was accompanied by voluminous magmatism (Seth et al., 1998; Janoušek et al., 2010). Similarly, Frimmel and Frank (1998) interpreted the Ar–Ar ages of 547–543 Ma (hornblende) as the timing of culmination of thrusting in the Gariep Belt. Ar–Ar dating of micas and amphibole from the Kaoko Belt has suggested cooling of the eastern foreland between ca. 530–500 Ma and the late activity of major shear zones as young as 490–480 Ma (Gray et al., 2006). Frimmel and Frank (1998) obtained similar ages for cooling of white mica in the Gariep Belt.

4.4. *Granitoid magmatism in the Kaoko–Dom Feliciano–Gariep belts*

The Granite Belt at the western edge of the southern SANOS is a unit that, due to its position and shape, was interpreted as a continental magmatic arc (Basei et al., 2000, 2018). Apart from isolated ca. 650 Ma intrusions (Chemale Jr. et al., 2012), the main magmatic activity started at ca. 625 Ma and persisted until ca. 570 Ma (Fig. 4; Table 1 as supplementary material and references therein). In addition to this voluminous magmatism that took place along the foreland–hinterland transition, coeval magmatic rocks intruded the foreland itself (Oyhantçabal et al., 2009; Florisbal et al., 2012b; Lara et al., 2020).

The thrusting of the hinterland Coastal Terrane over the eastern foreland in the Kaoko Belt commenced at ca. 580–575 Ma, which is documented by the age of the oldest magmatic rocks along the contact, as well as by the dating of the associated early prograde metamorphism (Seth et al., 1998; Goscombe et al., 2003; Konopásek et al., 2008). This is also the time when the magmatism in the Granite Belt was on the decline, because most of the tectonic activity had shifted to the African side of the orogenic system. A still elevated thermal gradient in the hinterland produced large volumes of ca. 565–550 Ma granitoid rocks. These are exposed within, or along eastern flank of, the Coastal Terrane where they seal the contact with the underlying foreland represented by the Congo Craton with its Neoproterozoic cover (Seth et al., 1998; Kröner et al., 2004; Konopásek et al., 2008; Janoušek et al., 2010).

5. Discussion

5.1. *Was there an ocean prior to formation of the Araçuaí–West Congo belts?*

The northern part of the SANOS has been classified as a confined or partially confined orogen (e.g. Pedrosa-Soares et al., 2001; Alkmim et al., 2006), because it was, until the opening of the Atlantic, surrounded by Archean and Paleoproterozoic continental lithosphere to the east (Congo Craton), north and west (São Francisco Craton). However, the same and other authors considered its pre-orogenic evolution as involving a long period of subduction and associated arc magmatism (e.g., Pedrosa-Soares et al., 2001; Tedeschi et al., 2016; Richter et al., 2016; Amaral et al., 2020). This magmatic arc model appears incompatible with the confined nature of the orogenic system, which is defined by an uninterrupted connection between the São Francisco and Congo cratons called the “São Francisco–Congo cratonic bridge” (Alkmim et al., 2006). Such a connection makes the development of a wide ocean virtually impossible. Therefore, the existence of a large oceanic domain between the São Francisco and Congo cratons, and development of a long-lived magmatic arc as a consequence of its subduction, have been questioned (Fossen et al., 2017, 2020; Cavalcante et al., 2019) by pointing out two critical problems: (1) The model involves ca. 50 m.y. (630–580 Ma) of subduction of oceanic crust (Gonçalves et al., 2016; Tedeschi et al., 2016; Amaral et al., 2020), which implies an ocean on the order of > 1000 km in width (Fig. 7). Such a wide ocean is incompatible with the confined intracontinental environment of the Araçuaí–West Congo Belt; (2) Reconstruction of the thickened Araçuaí–West Congo orogenic crust shows that the amount of shortening possible within the continental embayment of the São Francisco and Congo cratons was fully taken up by shortening of the continental crust under the Macaúbas Basin (Cavalcante et al., 2019).

Cavalcante et al. (2018a) have shown that there is an overlap between the U–Pb crystallization ages for the rocks from central (Rio Doce arc, 580 Ma; Fig. 3c) and eastern (Carlos Chagas Domain; 600–570 Ma; Fig. 3a) hinterland regions of the Araçuaí Belt. The migmatites and associated leucogranites of the eastern Araçuaí hinterland were interpreted as the result of partial melting of the middle/lower crust due to crustal thickening (Cavalcante et al., 2018a). The granitic rocks of the

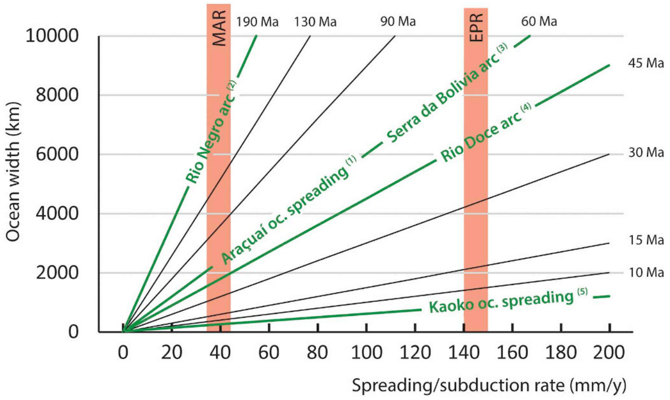


Fig. 7. A diagram showing the relationship between the spreading/subduction rate and width of the developed/consumed oceanic domain. The diagram is contoured for the duration of the spreading/subduction process, with highlighted estimated duration of: 1) development of oceanic domain in the Araçuaí Belt (Amaral et al., 2020); 2) consumption of oceanic lithosphere and related building of the Rio Negro magmatic arc in the Ribeira Belt (Tupinamba et al., 2012); 3) magmatism in the Serra da Bolivia arc in the Ribeira Belt (Heilbron et al., 2013); 4) magmatism in the Rio Doce arc in the Araçuaí Belt (Tedeschi et al., 2016), and 5) possible development of oceanic domain in the Kaoko–Dom Feliciano part of the southern SANOS (this work). MAR – Mid-Atlantic Ridge, EPR – East-Pacific Rise. Note that contemporaneous subduction and spreading is not taken into account.

central Araçuaí hinterland were interpreted either as a magmatic arc (Tedeschi et al., 2016), or as intrusions synkinematic to the orogenic deformation promoted by the Africa–South America convergence (Mondou et al., 2012). The later interpretation is consistent with the age overlap mentioned by Cavalcante et al. (2018a). Furthermore, the time span of synkinematic magmatic activity plus the > 60 km crustal thickness estimated for the Araçuaí Belt (Cavalcante et al., 2014), imply onset of the São Francisco and Congo cratons convergence and related crustal thickening well before 600 Ma. Such a time frame is incompatible with subduction of oceanic crust from 630 to 580 Ma, as suggested by the widely published subduction-related models (e.g. Amaral et al., 2020 and references therein).

5.2. Was there an ocean prior to formation of the Ribeira Belt?

This question was discussed by Tupinamba et al. (2012), who realized that the interpretation of extensive arc magmatism (790–600 Ma – Tupinamba et al. (2012); 860–580 Ma – Heilbron et al., 2017b; Peixoto et al., 2017) implies consumption of an extensive oceanic domain between continents on opposite sides of the orogenic system (Fig. 7). The situation is similar to that of the Araçuaí–West Congo section, although the “nutcracker” kinematic model of Alkmim et al. (2006) allows for some more kinematic flexibility in the Ribeira section of the SANOS. Some workers have tried to resolve the obvious spatial problem by assuming a lithospheric-scale shear zone on the African side of the system that would allow for thousands of kilometers of lateral offset (Heilbron et al., 2008; Tupinamba et al., 2012; Almeida et al., 2013). We have not been able to find evidence for such a shear zone in these articles or in any of the published literature, so we consider this interpretation to be a solely model-driven and speculative attempt to create space for a wide oceanic domain in the Ribeira section. Hence a simpler model that takes into consideration only extension and crustal thinning without the formation of a major ocean should be considered, as suggested by Trompette (1994, 1997), and more recently by Meira et al. (2015, 2019a, 2019b).

5.3. Time constraints for possible extent of an oceanic domain in the Kaoko–Dom Feliciano–Gariep belts

In contrast with the northern part of the SANOS, there are no obvious spatial limitations for the development of an oceanic domain in the Kaoko–Dom Feliciano–Gariep section prior to its convergent evolution. However, the exposure of weakly metamorphosed to unmetamorphosed sedimentary rocks in the easternmost Kaoko Belt and in the Otavi Platform in Namibia provides two independent constraints on a possible time gap between the end of rifting and earliest manifestation of convergence in the northern Kaoko–Dom Feliciano–Gariep orogen.

Hoffman and Halverson (2008) provided a wealth of sedimentological and structural data from the Otavi Platform that show a major change in tectonostratigraphic evolution between the deposition of sediments related to Sturtian and Marinoan global glaciations. While the glaciogenic deposits associated with the Sturtian glaciation and the directly overlying sedimentary rocks were deposited during active development of crustal-scale normal faults, the overlying strata including the Marinoan glaciogenic deposits were laid down during regional subsidence compatible with cooling of the lithosphere after active stretching. As the current estimate for the extent of the Sturtian global glaciation is ca. 717–660 Ma (Macdonald et al., 2010; Rooney et al., 2014, 2015) and for the Marinoan glaciation ca. 645–635 Ma (Hoffmann et al., 2004; Condon et al., 2005; Rooney et al., 2015; Prave et al., 2016), the possible break-up or at least the end of active rifting must have taken place between ca. 660 and 645 Ma.

The onset of convergence in the Kaoko–Dom Feliciano–Gariep Orogen is dated indirectly by the deposition of orogenic flysch on its African side. The flysch sedimentary rocks are present along the entire eastern foreland of the southern SANOS and their maximum age is set at ca. 650 Ma based on the youngest detrital zircon age peak (Konopásek et al., 2014, 2017). The real age of deposition of the flysch is not known for any of its exposures except the deposits in the eastern Kaoko Belt, where they appear below the Marinoan (645–635 Ma) glaciogenic horizon (Konopásek et al., 2017). Such finding places the onset of deposition of the flysch sediments in a narrow time interval between ca. 650 and 645 Ma.

Finally, the initial convergence is manifested by thickening-related metamorphism along the western edge of the Dom Feliciano Belt. Unfortunately, no precise ages exist for the metamorphism of the sedimentary cover of its foreland. So far, the only time estimate for the initial contraction in the southern SANOS comes from dating of peak metamorphism of the hinterland (Lenz et al., 2011), and from dating of thrusting-related flat fabrics in the granulitic nappe in the central Dom Feliciano Belt (Figs. 3a and 6g; Martil et al., 2016). All these data point to active thrust tectonics at ca. 650 Ma.

The formation of the Granite Belt along the western edge of the hinterland not only started shortly after the crustal stretching has ceased, but first and foremost ca. 25–15 m.y. after compression-driven exhumation of the hinterland and its thrusting onto the foreland, and the synkinematic character of the early Granite Belt intrusions was discussed by several authors (Bitencourt and Nardi, 1993; Oyhantçabal et al., 2007; Florisbal et al., 2012a). Thus, instead of being a subduction-related magmatic arc, we suggest that the Granite Belt originated during early inversion of the rift basin as a result of indentation of the western rift shoulder into a thinned and hot lithosphere of the rift center represented by the Punta del Este–Coastal Terrane.

All the presented data show that the maximum possible lifetime of an oceanic domain (i.e. its opening and closure) preceding the orogenic evolution of the southern SANOS is only ca. 10–15 Ma. Within this time span, a potential oceanic domain would reach a large extent (ca. 1000–1500 km) only at extreme spreading rates of 20 cm/y, which is considerably more than the maximum current spreading rate on the planet of about 15 cm/y, as observed across the Pacific–Nazca boundary along the East Pacific Rise (DeMets et al., 2010). If we take into account a more conservative value of 4 cm/y that has been the opening rate throughout most of the history of the South Atlantic Ocean (e.g. Müller et al., 2008), the oceanic crust would only reach a width of ca. 400–600 km (Fig. 7).

5.4. On the origin of the arc-like whole-rock geochemical signature of plutonic complexes along the western hinterland edge of the SANOS

As discussed above, the pre-orogenic evolution in the SANOS is characterized by too limited space to accommodate any large oceanic domain in its northern segment and too short time for its development in the south. These are our key objections against the geodynamic models invoking the formation and subsequent subduction of the Adamastor Ocean. Yet, a problem that merits discussion is the apparent continental-arc geochemical signature of a large number of plutons in the Araçuaí and Ribeira belts. Many authors have claimed that the distribution of largely linear Tonian–Ediacaran plutonic complexes along the whole western hinterland edge of the orogenic system, as well as their broad compositional range (including intermediate–basic rocks) and whole-rock composition have to reflect a long-lived subduction of oceanic crust with attending formation of island- and/or continental arcs.

Arguably the best studied case is the so-called G1 Supersuite or “Rio Doce arc” connecting the central part of the Araçuaí Belt with the Ribeira Belt (Pedrosa-Soares et al., 1998, 2001). Here, the ca. 625 and 574 Ma association of westerly Opx-bearing rocks and easterly tonalites–granites ± minor diorites/gabbros was interpreted as a tilted crustal section of an arc, including its lower crustal roots (Gonçalves et al., 2014, 2018; Tedeschi et al., 2016). Similar arguments were put forward for the magmatic complexes in the Ribeira Belt: the older Serra da Prata (856–838 Ma: Peixoto et al., 2017) and younger Rio Negro (790–605 Ma: Tupinamba et al., 2012). The whole association has been interpreted as a Tonian primitive intra-oceanic arc evolving to more continental or transitional arcs during the Rio Negro stage (Peixoto et al., 2017). Lastly, some authors viewed also the southerly Granite Belt that rims the Punta del Este–Coastal Terrane in southern Brazil and Uruguay as a vestige of a large Neoproterozoic magmatic arc (Basei et al., 2000, 2018; Da Silva et al., 2005). However, these authors never published any geochemical data supporting a subduction-related origin of the Granite Belt.

The whole-rock geochemical evidence for presumed arc-related origin in the studies from the Araçuaí and Ribeira belts came mainly from the major-element discrimination diagrams (Batchelor and Bowden, 1985), the calc-alkaline character of the magmatic rocks and their enrichment in Large Ion Lithophile Elements (LILE) over High-Field Strength Elements (HFSE). This enrichment has been variously expressed as negative Ta–Nb–Ti (aka 'TNT') anomalies in the NMORB- or Primitive Mantle-normalized spiderplots or, simply projected in trace-element based geotectonic diagrams (Pearce et al., 1984). As will be shown below, such arguments can be equivocal, and certainly do not rule out an alternative interpretation.

5.4.1. *'Calc-alkaline' chemistry*

We emphasize that the term "calc-alkaline" is not rigorously defined anymore (Bonin et al., 2020 and references therein), which represents a problem in this discussion. Having been originally introduced by Peacock (1931), it should refer to rock suites that show moderate enrichment in calcium over alkalis. Unfortunately, over the years, the term calc-alkaline became synonymous to subalkaline magmatic suites lacking the strong progressive iron enrichment that characterizes the tholeiitic trend (Irvine and Baragar, 1971). Thus defined calk-alkaline rocks (actually ranging from calcic to alkali-calcic *sensu* Peacock) are often associated with arcs, active or ancient. However, such compositions can also be found within regions of continental extension, e.g. in the Basin and Range Province and the Gulf of California, as well as within continental collision settings, both syn- and post-collisional (Barbarin, 1999; Sheth et al., 2002; Arculus, 2003).

5.4.2. *Presence of the negative 'TNT' anomalies*

A characteristic feature of mafic subduction-related magmas is enrichment in elements of low ionic potential, such as LILE (Cs, Rb, Ba, K…), Pb, Th and U. These elements are readily mobile in hydrous fluids and thus thought to be transported from the subducting slab to the mantle wedge (Saunders et al., 1991; Pearce and Peate, 1995; Tatsumi and Eggins, 1995). On the other hand, the water-insoluble, "conservative" elements with high ionic potential, typically represented by the HFSE, are retained in the slab and thus their budget in arc-related magmas is controlled solely by the mantle wedge contribution (Pearce et al., 2005). As a consequence, the NMORB-normalized spiderplots should be characterized by the presence of significant negative Ta, Nb, Ti ('TNT') anomalies.

These anomalies will persist in products of fractional crystallization from the primary arc-related basaltic melts, a process considered important in the lower crustal roots of arcs (Hildreth and Moorbath, 1988; Grove et al., 2003; Annen et al., 2006; Ulmer et al., 2018). On the mass-balance basis, it would have to be followed by delamination of the heavy, garnet-bearing lowermost crust into the asthenospheric mantle (Arndt and Goldstein, 1989; Kay and Kay, 1993; Lee and Anderson, 2015). Moreover, the negative Ti anomaly would be further amplified by the fractionation of Ti-magnetite and/or Ti-bearing ferromagnesian minerals.

On the other hand, melt-inclusion study has demonstrated a dearth of andesitic liquids in some arcs (Reubi and Blundy, 2009). Then the andesitic magmas are assumed to originate mostly by mixing–mingling of siliceous and basaltic magmas in the upper crustal reservoirs. Indeed, many arcs show overwhelming field, petrological and geochemical evidence of interaction between compositionally dissimilar magmas, as well as microtextural record for chemical and thermal disequilibria and exchange of xenocrysts (Didier and Barbarin, 1991; Vernon, 1991; Hibbard, 1995; Barbarin, 2005).

In contrast, the felsic magmatic rocks originating by anatexis of continental crustal sources – regardless whether in arcs, collisional and post-collisional orogenic settings or rifts – may yield very confusing geochemical signal. The most difficult part is geochemical fingerprinting of post-collisional granitoids that can be potentially generated from the greatest range of sources and thus acquire variable compositions, including a subduction-like one (Pearce, 1996).

Rather than the true geodynamic setting, the whole-rock geochemistry in such cases tends to reflect the composition of the source, which is often characterized by long crustal residence and complex recycling history (Pearce et al., 1984; Pearce, 1996; Förster et al., 1997; Frost et al., 2016). Critically, partial melting of metasedimentary rocks coming from ancient subduction-related sources would produce granitic magmas characterized by LILE/HFSE enrichment and thus also the eye-catching TNT anomalies resembling genuinely subduction-related suites (Janoušek et al., 2010; Konopásek et al., 2018).

The strong enrichment of LILE over HFSE is not only one of the principal characteristics of the arc-related magmas but also of the continental crust as a whole (Rudnick and Gao, 2003; Taylor and McLennan, 2009 and references therein). This geochemical signature has been taken by many workers as evidence that subduction zones may represent an important place of crustal growth (Kelemen, 1995; Jagoutz and Schmidt, 2012). Taken together, the presence of TNT anomalies in NMORB- or Primitive Mantle normalized spider plots on its own may represent a poor indicator of tectonic setting and thus cannot be recommended in absence of further evidence coming from structural, petrological and geotectonic research.

5.5. *A predominantly intracontinental orogen model*

Obvious spatial problem with the presence of an extensive oceanic domain between the São Francisco and Congo cratons in the northern part (Fossen et al., 2017, 2020; Cavalcante et al., 2019), as well as the short time span between the active crustal stretching and onset of orogenic evolution in the southern part (Konopásek et al., 2017, 2018) are the critical features reviewed in this paper that point at a largely intracontinental setting of the SANOS. Such a tectonic setting would not be unique, as intracontinental orogeny has been described from several continents, notably the Pyrenees (Beaumont et al., 2000), the Peterman (Cambrian) and Alice Springs (Devonian–Carboniferous) orogens in Australia (Raimondo et al., 2010), the central Asian examples north of the Tibetan Plateau (Raimondo et al., 2009), or the Paleoproterozoic (Li et al., 2011) and early Paleozoic (Faure et al., 2009) orogens in China. Intracontinental orogens show a range of features characteristic of orogens in general, including high-temperature metamorphism and migmatization, magmatism and even continental subduction (Faure et al., 2009). They also show a range in orogenic width, from the 150 km wide Pyrenees to the 1300 km width estimated for the early Paleozoic orogen of SE China (Faure et al., 2009). The ca. 500 km wide SANOS falls in the middle of this range, although it represents a longer intracontinental orogenic belt than e.g. the Pyrenees or the Australian examples. The SANOS can be said to differ with respect to the large amount of melt involved, consistent with the general notion that the system was unusually hot (e.g., Bento dos Santos et al., 2015; Cavalcante et al., 2018a; Vauchez et al., 2019), regardless of whether it is considered as inter- or intracontinental.

The above-summarized data point to a very limited extent or even non-existence of oceanic crust between the exposed African (Congo–Kalahari) and South American (São Francisco–Luis Alves–Nico Pérez) foreland basement domains prior to Neoproterozoic (Brasiliano/Pan-African) convergence. A large number of data suggests that the Neoproterozoic period of episodic rifting lasted from ca. 840 Ma up to ca. 660 Ma in the southern SANOS (see the summary in Konopásek et al., 2018) and from ca. 950 up to ca. 650 in the northern SANOS (Castro et al., 2019). It is thus very likely that the so-called "ophiolites", i.e. associations of metamorphosed ultramafic and/or mafic rocks in the Araçuaí and Ribeira belts dated at ca. 850–820 Ma (Pedrosa-Soares et al., 1992, 1998; Heilbron and Machado, 2003) and 645 Ma (Amaral et al., 2020), and also undated analogous occurrences in the southern Dom Feliciano Belt (e.g. Will et al., 2014; Peel et al., 2018; Ramos et al., 2018), represent mafic underplates or syn-sedimentary volcanics and pieces of the sub-crustal mantle incorporated into the crust during rifting and/or orogenic convergence. This interpretation is in line with that of Trompette (1994, 1997), who due to dubious geochemical affinities of the magmatism and numerous fragments of cratonic crust interpreted the Araçuaí–West Congo–Ribeira belts as mainly intracontinental. Also Meira et al. (2019b) suggested that the ca. 800–750 Ma mafic and granitic magmatism in the central Ribeira Belt was related to crustal thinning during an extensional event.

The ages of the oldest (ca. 860–760 Ma; Tupinamba et al., 2012; Heilbron et al., 2017b; Meira et al., 2019b) metamorphosed igneous rocks with apparent subduction-related geochemical signature in the northern SANOS (Ribeira Belt) also overlap with the timing of rifting in its southern part (see Section 4.1). Metaigneous rocks of similar age and geochemistry are omnipresent in the hinterland domain of the Kaoko–Dom Feliciano–Gariep belts (see summary in Konopásek et al., 2018). However, as has been discussed by Konopásek, loc.cit. and above (Section 5.1.), the apparent subduction-related imprint (calc-alkaline chemistry and LILE–HFSE enrichments), especially in felsic magmatic rocks, may reflect the geochemical signature of the source rather than the true geodynamic setting. In line with this argument, we suggest that, just like in the Kaoko–Dom Feliciano–Gariep hinterland, the 860–760 Ma granitoid rocks in the Ribeira Belt hinterland originated during rifting-related melting of the local lower crust with, or without, contribution of the underlying lithospheric mantle.

There are no reliable age data that would document igneous activity in the hinterland of the entire SANOS between ca. 760 (± 20) Ma and ca. 650 (± 10) Ma (Fig. 4). This time gap has been either interpreted as the time of already established and continuing subduction activity (e.g. Heilbron et al., 2008; Peixoto et al., 2017), or in the majority of cases as the period of continental drift and formation of the Adamastor Ocean (e.g. Pedrosa-Soares et al., 2001, 2008; Basei et al., 2000, 2008; Frimmel, 2018). However, at least in the southern SANOS foreland, the above-mentioned period shows igneous activity and faulting suggesting active stretching of the lithosphere (Frimmel et al., 1996; Borg et al., 2003; Hoffman and Halverson, 2008; Konopásek et al., 2014, 2018) compatible with ongoing rifting.

The data from the Kaoko–Dom Feliciano–Gariep belts suggest that inversion of the "Adamastor Rift" (*sensu* Konopásek et al., 2018) in the southern SANOS started along its western shoulder at ca. 650 Ma. This is recorded by the granulite-facies metamorphism in the lower–mid-crustal rocks of the hinterland in the southern SANOS and their thrusting over the western foreland (Lenz et al., 2011; Battisti et al., 2018). The timing of early orogenic thickening in the southern SANOS corresponds closely with the period of inversion of the Paramirim aulacogen (Fig. 3a) in the Araçuaí Belt of the northern SANOS (Süssenberger et al., 2014), as well as with the inferred onset of orogenic thickening in the Ribeira Belt (Meira et al., 2015, 2019b).

5.6. A relic of the "Adamastor" oceanic crust in the southernmost part of SANOS?

Despite the evidence for largely intracontinental setting of the SANOS, some oceanic crust may have developed, as manifested by the interpreted oceanic origin of the allochthonous uppermost tectonic unit in its southernmost part (the Marmora Terrane in the Gariep Belt; see e.g. Frimmel, 2018). Based on their tectonic position east of the assumed magmatic arc, as well as imprecise Ar–Ar ages of 630–600 Ma determined by Frimmel and Frank (1998), these oceanic rocks were interpreted by Frimmel (2018) as a relic of a back-arc basin. However, data from the central and southern Dom Feliciano Belt presented above show that the basement of the Granite Belt (i.e. the assumed magmatic arc) was undergoing contraction from ca. 650 Ma and was exhumed already by ca. 630 Ma. This means that the formation of oceanic crust at 630–600 Ma in this overall contractional setting is unlikely.

Some of the mafic metaigneous lithologies in the Marmora Terrane of the Gariep Belt represent metamorphosed tholeiitic basaltic–andesitic rocks with low Ti, Th/Nb and primitive (strongly radiogenic) Nd isotopic compositions. Their characteristic features are LREE-depleted chondrite-normalized REE patterns and Primitive-mantle-normalized spiderplots lacking negative Nb–Ta anomalies, resembling NMORBs (Will et al., 2014). The other metabasic rocks from the Marmora Terrane are alkaline, showing more enriched REE patterns but likewise lacking negative Nb–Ta anomalies. They thus resemble EMORB- or OIB-like basalts unrelated to subduction (Dilek and Furnes, 2011, 2014; Pearce, 2014).

Based on the geological evidence presented above, we interpret the remnants of the ocean floor in the Gariep Belt as the only exposed relics of the Adamastor "Ocean". The fact that these rocks were obducted on top of the eastern foreland is in line with our interpretation that they represented a narrow domain of oceanic lithosphere that was not dense and strong enough to initiate subduction (Doglioni et al., 2007). We also note that the oceanic crust must have formed in the rather short time interval of ca. 660–650 Ma. For this reason, we suggest that the pre-convergence geometry in the southern part of the Kaoko–Dom Feliciano–Gariep orogen was similar to the present-day Red Sea–Gulf of Aden rift zone, and the large-scale geometry of the entire Adamastor rift system was probably reminiscent of the present-day East African Rift Zone, although probably wider (Fig. 8).

5.7. Final note about paleogeographic reconstructions of the transition from Rodinia to Gondwana

As discussed by Konopásek et al. (2018), the developing Adamastor rift system was probably situated along an active margin of a large continental domain (Rodinia) and not in its deep interior, as suggested by some of the current paleogeographic reconstructions (e.g. Evans, 2009; Li et al., 2013). Also, the summary of pre-convergent evolution of the SANOS presented in this work rules out any reconstruction that places the São Francisco–Congo, Kalahari and Rio de la Plata (including the Nico Pérez–Luis Alves) cratonic domains far apart from each other in post-Mesoproterozoic times (e.g. Evans, 2009; Merdith et al., 2017). In fact, recent paleomagnetic data from the southern edge of the Congo and northern edge of the Kalahari cratons by Salmien et al. (2018) suggest that their present mutual position is largely the same as it was at the end of the Mesoproterozoic, only partly modified during the Neoproterozoic. It has to be noted that Salmien et al. (2018) suggested rifting and large-scale drift of the Congo and Kalahari cratons between ca. 1.1 and 1.0 Ga, however the geological record shows continuous rifting between adjacent margins of these cratons from ca. 800–660 Ma (Hoffmann et al., 2004; Hoffman and Halverson, 2008), which disqualifies such an interpretation.

In our view, the best published paleogeographic reconstruction related to the pre-convergent evolution of the SANOS is the one by Johansson (2014), though also this reconstruction needs modification based on the geological record and implications presented in the current work. Johansson (2014) presented a reconstruction of Rodinia, in which all the basement blocks present along the eastern edge of the South American continent are attached to the Congo and Kalahari cratons during the early development of the Adamastor Rift between 850 and 750 Ma, and these blocks represent a continental margin facing an open ocean to the east (Fig. 9a). In the next step, based on published literature, Johansson (2014) presented the break-up and drift of the São Francisco, Paranapanema and Rio de la Plata blocks away from the

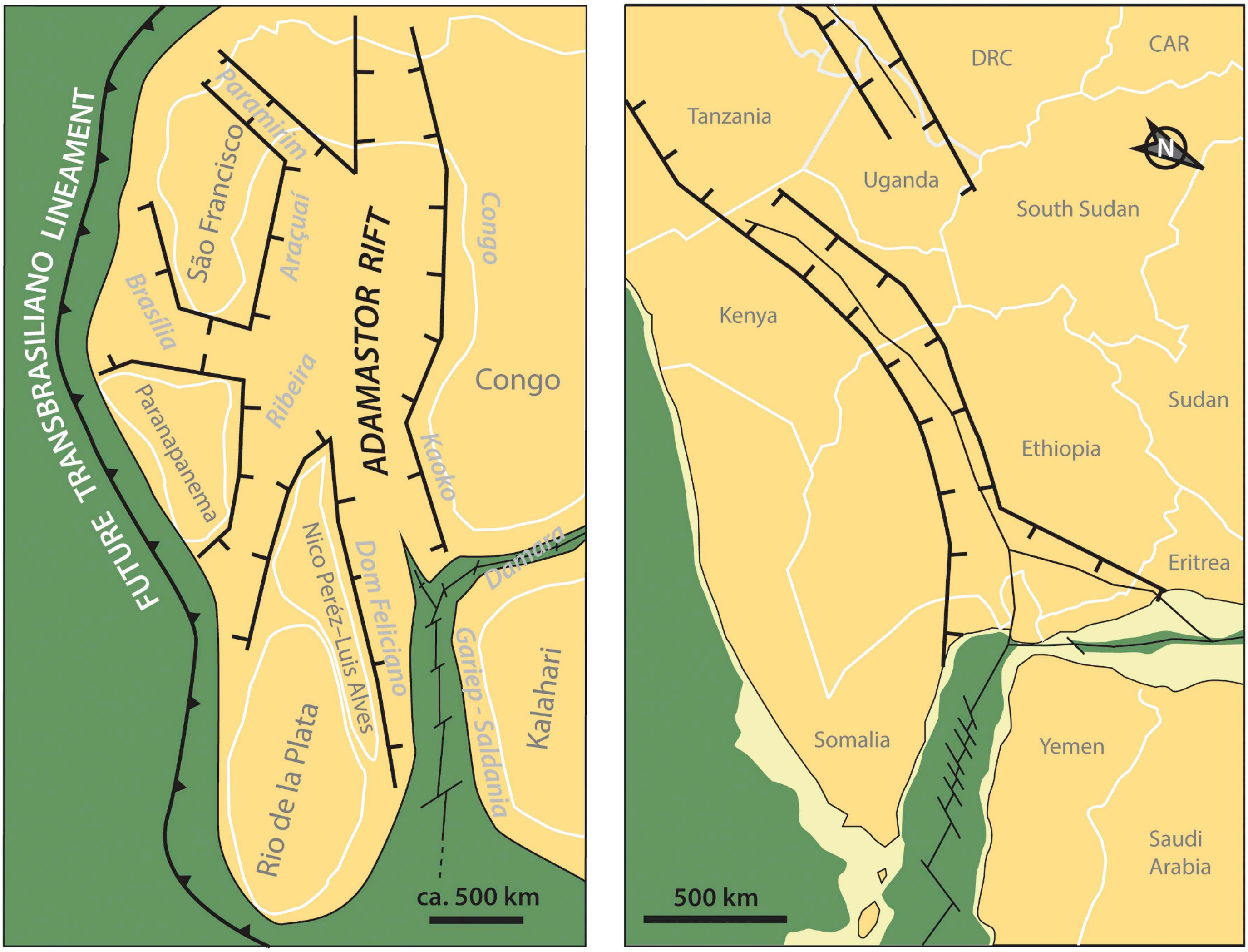


Fig. 8. Interpretative figure showing possible configuration and extent of separation of pre-Neoproterozoic crustal blocks representing the basement units of the SANOS close to the end of active crustal stretching. Pre-convergent architecture of the SANOS is interpreted as an extensively rifted continental margin (Adamastor Rift), resembling the geometry of the present-day Red Sea–Gulf of Aden–East Africa rift system. Note that there is no general agreement about subduction polarity west of the rift system.

Congo and Kalahari cratons associated with the growth of the Adamastor Ocean from ca. 750 Ma (see Fig. 4 in Johansson, 2014). At this point, we suggest modification of the reconstruction based on the data presented above. The Adamastor Ocean with its later subduction is removed, and the evolution continues by ongoing closure of the Brasiliano (Clymene) Ocean (Fig. 9b). The gradual closure of this oceanic domain is compensated by ongoing widening of the Adamastor Rift and by the opening of the Mozambique Ocean (Fig. 9b). Final closure of the Brasiliano (Clymene) Ocean at ca. 650 Ma and beyond leads to collision of the Amazonian Craton and surrounding crustal blocks with the São Francisco, Paranapanema and Rio de la Plata cratons. This collision initiates inversion of the Adamastor Rift and orogenic development of the SANOS between ca. 650 and 480 Ma (Fig. 9c), leading to assembly of western Gondwana.

6. Conclusions

1) The confined character of the northern SANOS, which terminates against rifted, but unbroken, São Francisco–Congo cratonic basement, poses a space problem for existence of a large oceanic domain (Adamastor Ocean) that could be subducted prior to the orogenic evolution.
2) No obvious space problem for the presence of an oceanic domain exists in the southern SANOS. However, sedimentological data from the Neoproterozoic sedimentary cover of the Congo Craton in Namibia, timing of early convergence and thickening in the Dom Feliciano Belt and orogenic flysch deposition on the African side of the orogenic system suggest only 10–15 m.y. of life time (i.e. between opening and closure) for a potential Adamastor Ocean.
3) Apparent subduction-related geochemical signatures (calc-alkaline character and LILE/HFSE enrichments expressed as negative Ta–Nb–Ti anomalies in NMORB-normalized spiderplots) of voluminous magmatic rocks along the entire SANOS are interpreted as spurious, largely inherited from their sources.
4) In the southern part of the SANOS, the voluminous magmatism along the western edge of the hinterland commenced ca. 20–25 m.y. after the onset of crustal thickening, which is incompatible with its earlier proposed subduction-related origin.
5) Regarding the presumed ophiolite sequences, metamorphosed juvenile mafic volcanic rocks (of largely unconstrained age) associated with fragments of mantle rocks are interpreted as mafic underplates or syn-sedimentary volcanics and pieces of the local lithospheric mantle incorporated into the crust during rifting and/or orogenic convergence.
6) The reviewed data point to an intracontinental character of the SANOS, i.e. to a much simpler model than previous models that

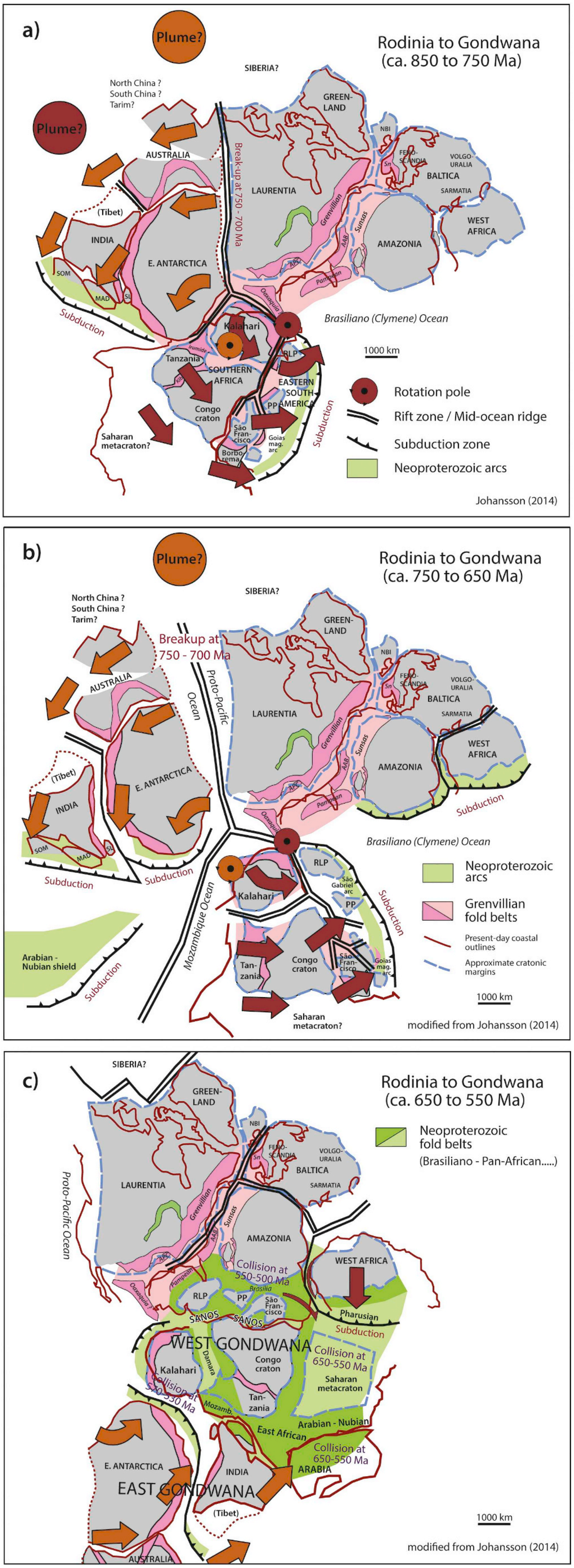


Fig. 9. Modified paleogeographic reconstruction of the transition from Rodinia to Gondwana by Johansson (2014). Abbreviations: RLP – Rio de la Plata Craton, PP – Paranapanema Craton, Sn – Sveconorwegian Belt, SANOS – South Atlantic Neoproterozoic Orogenic System. Other abbreviations as in Johansson (2014). Reprinted from Precambrian Research 244, Johansson, Å: From Rodinia to Gondwana with the 'SAMBA' model—A distant view from Baltica towards Amazonia and beyond, 226–235, Copyright (2014), with permission from Elsevier. Figures (b) and (c) were modified from originals based on the interpretation presented in this article.

considered numerous arc complexes, terrane collisions and related deformation phases. Our model involves a long period of episodic crustal stretching between ca. 950 and ca. 650 Ma in the northern, and between ca. 835 and ca. 660–650 Ma in the southern SANOS. This rifting only evolved into the formation of a narrow oceanic domain (max. 400–600 km wide at a spreading rate of 4 cm/y) in the southernmost SANOS, where the former oceanic crust is now exposed as an allochthonous unit in the Gariep Belt. Further to the north, the "Adamastor Rift" probably never opened into an oceanic domain.

7) Such an interpretation implies that the pre-convergence geometry in the southern part of the Kaoko–Dom Feliciano–Gariep Orogen was similar to the present-day Red Sea–Gulf of Aden rift zone, and the large-scale pre-convergence geometry of the entire SANOS resembled the present-day East African Rift Zone.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was financially supported by the Czech Science Foundation (grant no. 18-24281S to JK) and by Fundação de Amparo à Pesquisa do Estado de São Paulo (grants no. 2010/03537-7, no. 2013/19061-0 and 2014/10146-5 to CC, and no. 2015/23572-5 to HF). JK greatly appreciates numerous discussions about pre-convergent evolution of the Kaoko Belt with Charlie Hoffmann (Geological Survey of Namibia). The authors appreciate suggestions for improvement of the article provided by Yildirim Dilek and an anonymous reviewer, as well as the journal's editor Carlo Doglioni.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.earscirev.2020.103201.

References

Alkmim, F.F., Marshak, S., Pedrosa-Soares, A.C., Peres, G.G., Cruz, S.C.P., Whittington, A., 2006. Kinematic evolution of the Aracuai–West Congo orogen in Brazil and Africa: nutcracker tectonics during the Neoproterozoic assembly of Gondwana. Precambrian Res. 149, 43–64. https://doi.org/10.1016/j.precamres.2006.06.007.

Alkmim, F.F., Kuchenbecker, M., Reis, H.L.S., Pedrosa-Soares, A.C., 2017. The Araçuai Belt. In: Heilbron, M., Cordani, U.G., Flecha de Alkmim, F. (Eds.), São Francisco Craton, Eastern Brazil. Springer, Regional Geology Reviews, pp. 255–276. https://doi.org/10.1007/978-3-319-01715-0_14.

Almeida, J., Dios, F., Mohriak, W.U., Valeriano, C.D.M., Heilbron, M., Eirado, L.G., Tomazzoli, E., 2013. Pre-rift tectonic scenario of the Eo-Cretaceous Gondwana break-up along SE Brazil–SW Africa: insights from tholeiitic mafic dyke swarms. In: Mohriak, W.U., Danforth, A., Post, P.J., Brown, D.E., Tari, G.C., Nemčok, M., Sinha, S.T. (Eds.), Conjugate Divergent Margins. Geol. Soc. London Spec. Pub. 369. pp. 11–40. https://doi.org/10.1144/SP369.24.

Amaral, L., Caxito, F.d.A., Pedrosa-Soares, A.C., Queiroga, G., Babinski, M., Trindade, R., Lana, C., Chemale, F., 2020. The Ribeirão da Folha ophiolite-bearing accretionary wedge (Araçuaí orogen, SE Brazil): new data for Cryogenian plagiogranite and metasedimentary rocks. Precambrian Res. 336, 105522. https://doi.org/10.1016/j.precamres.2019.105522.

Annen, C., Blundy, J.D., Sparks, R.S.J., 2006. The genesis of intermediate and silicic magmas in deep crustal hot zones. J. Petrol. 47, 505–539. https://doi.org/10.1093/petrology/egi084.

Arculus, R.J., 2003. Use and abuse of the terms calcalkaline and calcalkalic. J. Petrol. 44, 929–935. https://doi.org/10.1093/petrology/44.5.929.

Arndt, N.T., Goldstein, S.L., 1989. An open boundary between lower continental crust and mantle: its role in crust formation and crustal recycling. Tectonophysics 161, 201–212. https://doi.org/10.1016/0040-1951(89)90154-6.

Barbarin, B., 1999. A review of the relationships between granitoid types, their origins and their geodynamic environments. Lithos 46, 605–626. https://doi.org/10.1016/S0024-4937(98)00085-1.

Barbarin, B., 2005. Mafic magmatic enclaves and mafic rocks associated with some granitoids of the central Sierra Nevada Batholith, California: nature, origin, and relations with the hosts. Lithos 80, 155–177. https://doi.org/10.1016/j.lithos.2004.05.010.

Basei, M.A.S., Siga Jr., O., Masquelin, H., Harara, O.M., Reis Netto, J.M., Preciozzi, F., Cordani, U.G., 2000. The Dom Feliciano Belt of Brazil and Uruquay and its foreland domain, the Rio de la Plata Craton. In: Milani, E.J., Thomaz Filho, A., Campos, D.A. (Eds.), Tectonic Evolution of South America. Rio de Janeiro, pp. 311–334.

Basei, M.A.S., Nutman, A., Grasso, C.B., Vlach, S., Siga Jr., O., Osako, L., 2008. The Cryogenian rift-related granitogenesis of the Dom Feliciano Belt, southern Brazil. In: 4th SHRIMP Workshop, VSEGEI, Saint-Petersburg, Russia, Abstract Volume, pp. 24–26.

Basei, M.A.S., Frimmel, H.E., Campos Neto, M.C., Araújo, C.E.G., Castro, N.A., Passarelli, C.R., 2018. The tectonic history of the southern Adamastor ocean based on a correlation of the Kaoko and Dom Feliciano belts. In: Siegesmund, S., Basei, M., Oyhantçabal, P., Oriolo, S. (Eds.), Geology of Southwest Gondwana. Springer, Regional Geology Reviews, pp. 63–85. https://doi.org/10.1007/978-3-319-68920-3_3.

Batchelor, R.A., Bowden, P., 1985. Petrogenetic interpretation of granitoid rock series using multicationic parameters. Chem. Geol. 48, 43–55. https://doi.org/10.1016/0009-2541(85)90034-8.

Battisti, M.A., Bitencourt, M.F., De Toni, G.B., Nardi, L.V.S., Konopásek, J., 2018. Metavolcanic rocks and orthogneisses from Porongos and Várzea do Capivarita complexes: a case for identification of tectonic interleaving at different crustal levels from structural and geochemical data in southernmost Brazil. J. S. Am. Earth Sci. 88, 253–274. https://doi.org/10.1016/j.jsames.2018.08.009.

Beaumont, C., Muñoz, J.A., Hamilton, J., Fullsack, P., 2000. Factors controlling the Alpine evolution of the central Pyrenees inferred from a comparison of observations and geodynamical models. J. Geophys. Res. Solid Earth 105, 8121–8145. https://doi.org/10.1029/1999JB900390.

Becker, T., Schreiber, U., Kampunzu, A.B., Armstrong, R., 2006. Mesoproterozoic rocks of Namibia and their plate tectonic setting. J. Afr. Earth Sci. 46, 112–140. https://doi.org/10.1016/j.jafrearsci.2006.01.015.

Belém, J., Pedrosa-Soares, A.C., Noce, C.M., Silva, L.C., Armstrong, R., Fleck, A., Gradim, C.T., Queiroga, G.N., 2011. Bacia precursora versus bacias orogênicas: exemplos do Grupo Andrelândia com base em datações U–Pb (LA–ICP–MS) em zircão e análises litoquímicas. Geonomos 19, 224–243. https://doi.org/10.18285/geonomos.v19i2.55.

Bento dos Santos, T.M., Munhá, J.M., Tassinari, C.C.G., Fonseca, P.E., Neto, C.D., 2011. Metamorphic P–T evolution of granulites in the central Ribeira Fold Belt, SE Brazil. Geosci. J. 15, 27–51. https://doi.org/10.1007/s12303-011-0004-1.

Bento dos Santos, T.M., Tassinari, C.C.G., Fonseca, P.E., 2015. Diachronic collision, slab break-off and long-term high thermal flux in the Brasiliano–Pan-African orogeny: implications for the geodynamic evolution of the Mantiqueira Province. Precambrian Res. 260, 1–22. https://doi.org/10.1016/j.precamres.2014.12.018.

Bitencourt, M.F., Nardi, L.V.S., 1993. Late- to post-collisional brasiliano magmatism in southernmost Brazil. An. Acad. Bras. Cienc. 65, 3–16.

Bonin, B., Janoušek, V., Moyen, J.F., 2020. Chemical variation, modal composition and classification of granitoids. In: Janoušek, V., Bonin, B., Collins, W.J., Farina, F., Bowden, P. (Eds.), Post-Archean Granitic Rocks: Contrasting Petrogenetic Processes and Tectonic Environments. Geol. Soc. London Spec. Pub. 491. pp. 9–51. https://doi.org/10.1144/SP491-2019-138.

Borg, G., Kärner, K., Buxton, M., Armstrong, R., Merwe, S.W., 2003. Geology of the Skorpion supergene zinc deposit, southern Namibia. Econ. Geol. 98, 749–771. https://doi.org/10.2113/gsecongeo.98.4.749.

Byamungu, B.R., Louis, P., Caby, R., 1987. Reconnaissance gravimétrique de la chaîne Ouest-congolienne, Congo-Bas–Zaïre. J. Afr. Earth Sci. 6, 767–772. https://doi.org/10.1016/0899-5362(87)90012-1.

Castro, M.P., Queiroga, G., Martins, M., Alkmim, F., Pedrosa-Soares, A., Dussin, I., Souza, M.E., 2019. An Early Tonian rifting event affecting the São Francisco–Congo paleocontinent recorded by the Lower Macaúbas Group, Araçuaí Orogen, SE Brazil. Precambrian Res. 331, 105351. https://doi.org/10.1016/j.precamres.2019.105351.

Cavalcante, G.C.G., Egydio-Silva, M., Vauchez, A., Camps, P., Oliveira, E., 2013. Strain distribution across a partially molten middle crust: insights from the AMS mapping of the Carlos Chagas Anatexite, Araçuaí belt (East Brazil). J. Struct. Geol. 55, 79–100. https://doi.org/10.1016/j.jsg.2013.08.001.

Cavalcante, G.C.G., Vauchez, A., Merlet, C., Berzerra de Holanda, M.H., Boyer, B., 2014. Thermal conditions during deformation of partially molten crust from TitaniQ geothermometry: rheological implications for the anatectic domain of the Araçuaí belt, eastern Brazil. Solid Earth 5, 1223–1242. https://doi.org/10.5194/se-5-1223-2014.

Cavalcante, C., Hollanda, M.H., Vauchez, A., Kawata, M., 2018a. How long can the middle crust remain partially molten during orogeny? Geology 46, 839–842. https://doi.org/10.1130/G45126.1.

Cavalcante, C., Lagoeiro, L., Fossen, H., Egydio-Silva, M., Morales, L.F.G., Ferreira, F., Conte, T., 2018b. Temperature constraints on microfabric patterns in quartzofeldsphatic mylonites, Ribeira belt (SE Brazil). J. Struct. Geol. 115, 243–262. https://doi.org/10.1016/j.jsg.2018.07.013.

Cavalcante, C., Fossen, H., Almeida, R.P., Hollanda, M.H.B.M., Egydio-Silva, M., 2019. Reviewing the puzzling intracontinental termination of the Araçuaí–West Congo orogenic belt and its implications for orogenic development. Precambrian Res. 322, 85–98. https://doi.org/10.1016/j.precamres.2018.12.025.

Chaves, A.d.O., Ernst, R.E., Söderlund, U., Wang, X., Naeraa, T., 2019. The 920–900 Ma Bahia–Gangila LIP of the São Francisco and Congo cratons and link with Dashigou–Chulan LIP of North China craton: new insights from U–Pb geochronology and geochemistry. Precambrian Res. 329, 124–137. https://doi.org/10.1016/j.precamres.2018.08.023.

Chemale Jr., F., Mallmann, G., Bitencourt, M.F., Kawashita, K., 2012. Time constraints on magmatism along the Major Gercino Shear Zone, southern Brazil: Implications for West Gondwana reconstruction. Gondwana Res. 22, 184–199. https://doi.org/10.1016/j.gr.2011.08.018.

Chemale, F., Philipp, R.P., Dussin, I.A., Liquintinie Formoso, M.L., Kawashita, K., Losangela Berttotti, A., 2011. Lu–Hf and U–Pb age determination of Capivarita Anorthosite in the Dom Feliciano Belt, Brazil. Precambrian Res. 186, 117–126. https://doi.org/10.1016/j.precamres.2011.01.005.

Condon, D., Zhu, M., Bowring, S., Wang, W., Yang, A., Jin, Y., 2005. U–Pb ages from the Neoproterozoic Doushantuo Formation, China. Science 308, 95–98. https://doi.org/10.1126/science.1107765.

Da Silva, L.C., McNaughton, N.J., Fletcher, I.R., 2005. SHRIMP U–Pb zircon geochronology of Neoproterozoic crustal granitoids (Southern Brazil): a case for discrimination of emplacement and inherited ages. Lithos 82, 503–525. https://doi.org/10.1016/j.lithos.2004.09.029.

De Paepe, P., Hertogen, J., Tack, L., 1975. Mise en évidence de laves en coussin dans les faciès volcaniques basiques du massif de Kibungu (Bas-Zaire) et implications pour le magmatisme ouest-congolien. Ann. Soc. Geol. Belg. 98, 251–270.

De Toni, G.B., Bitencourt, M.F., Nardi, L.V.S., Florisbal, L.M., Almeida, B.S., Geraldes, M., 2020. Dom Feliciano Belt orogenic cycle tracked by its pre-collisional magmatism: the Tonian (ca. 800 Ma) Porto Belo Complex and its correlations in southern Brazil and Uruguay. Precambrian Res. https://doi.org/10.1016/j.precamres.2020.105702. in press, 105702.

DeMets, C., Gordon, R.G., Argus, D.F., 2010. Geologically current plate motions. Geophys. J. Int. 181, 1–80. https://doi.org/10.1111/j.1365-246X.2009.04491.x.

Didier, J., Barbarin, B. (Eds.), 1991. Enclaves and Granite Petrology. Developments in Petrology 13 Elsevier, Amsterdam.

Dilek, Y., Furnes, H., 2011. Ophiolite genesis and global tectonics: geochemical and tectonic fingerprinting of ancient oceanic lithosphere. Geol. Soc. Am. Bull. 123, 387–411. https://doi.org/10.1130/B30446.1.

Dilek, Y., Furnes, H., 2014. Ophiolites and their origins. Elements 10, 93–100. https://doi.org/10.2113/gselements.10.2.93.

Doglioni, C., Carminati, E., Cuffaro, M., Scrocca, D., 2007. Subduction kinematics and dynamic constraints. Earth Sci. Rev. 83, 125–175. https://doi.org/10.1016/j.earscirev.2007.04.001.

Drüppel, K., Littmann, S., Romer, R.L., Okrusch, M., 2007. Petrology and isotope geochemistry of the Mesoproterozoic anorthosite and related rocks of the Kunene Intrusive Complex, NW Namibia. Precambrian Res. 156, 1–31. https://doi.org/10.1016/j.precamres.2007.02.005.

Dürr, S.B., Dingeldey, D.P., 1996. The Kaoko Belt (Namibia): part of a late Neoproterozoic continental-scale strike-slip system. Geology 24, 503–506. https://doi.org/10.1130/0091-7613(1996)024 < 0503:TKBNPO > 2.3.CO;2.

Egydio-Silva, M., Vauchez, A., Fossen, H., Cavalcante, G.C.G., Xavier, B.C., 2018. Connecting the Araçuaí and Ribeira belts (SE Brazil): Progressive transition from contractional to transpressive strain regime during the Brasiliano orogeny. J. S. Am. Earth Sci. 86, 127–139. https://doi.org/10.1016/j.jsames.2018.06.005.

Engler, A., 2009. The geology of South America. In: De Vivo, B., Grasemann, B., Stüwe, K. (Eds.), Geology. Encyclopedia of Life Support Systems. Vol. IV Eolss Publishers, Oxford 457 pp.

Evans, D.A.D., 2009. The palaeomagnetically viable, long-lived and all-inclusive Rodinia supercontinent reconstruction. In: Murphy, J.B., Keppie, J.D., Hynes, A.J. (Eds.), Ancient Orogens and Modern Analogues. Geol. Soc. London Spec. Pub. 327. pp. 371–404. https://doi.org/10.1144/SP327.16.

Faure, M., Shu, L., Wang, B., Charvet, J., Choulet, F., Monie, P., 2009. Intracontinental subduction: a possible mechanism for the Early Palaeozoic Orogen of SE China. Terra Nova 21, 360–368. https://doi.org/10.1111/j.1365-3121.2009.00888.x.

Florisbal, L.M., Bitencourt, M.F., Janasi, V.A., Nardi, L.V.S., Heaman, L.M., 2012a. Petrogenesis of syntectonic granites emplaced at the transition from thrusting to transcurrent tectonics in post-collisional setting: Whole-rock and Sr–Nd–Pb isotope geochemistry in the Neoproterozoic Quatro Ilhas and Mariscal Granites, Southern Brazil. Lithos 153, 53–71. https://doi.org/10.1016/j.lithos.2012.04.031.

Florisbal, L.M., Janasi, V.A., Bitencourt, M.F., Heaman, L.M., 2012b. Space–time relation of post-collisional granitic magmatism in Santa Catarina, southern Brazil: U–Pb LA-MC-ICP-MS zircon geochronology of coeval mafic–felsic magmatism related to the Major Gercino Shear Zone. Precambrian Res. 216–219, 132–151. https://doi.org/10.1016/j.precamres.2012.06.015.

Förster, H.-J., Tischendorf, G., Trumbull, R.B., 1997. An evaluation of the Rb vs. (Y + Nb) discrimination diagram to infer tectonic setting of silicic igneous rocks. Lithos 40, 261–293. https://doi.org/10.1016/S0024-4937(97)00032-7.

Fossen, H., Cavalcante, G.C., Almeida, R., 2017. Hot versus cold orogenic behavior: comparing the Araçuaí–West Congo and the Caledonian Orogens. Tectonics 36, 1–20. https://doi.org/10.1002/2017TC004743.

Fossen, H., Cavalcante, C., Konopásek, J., Meira, V.T., de Paes Almeida, R., Hollanda, M.H.B.M., Trompette, R., 2020. A critical discussion of the subduction–collision model for the Neoproterozoic Araçuaí–West Congo orogen. Precambrian Res. https://

doi.org/10.1016/j.precamres.2020.105715. in press, 105715.

Franz, L., Romer, R.L., Dingeldey, D.P., 1999. Diachronous Pan-African granulite-facies metamorphism (650 Ma and 550 Ma) in the Kaoko Belt, NW Namibia. Eur. J. Mineral. 11, 167–180.

Frimmel, H.E., 2018. The Gariep Belt. In: Siegesmund, S., Basei, M.A.S., Oyhantçabal, P., Oriolo, S. (Eds.), Geology of Southwest Gondwana. Springer, Regional Geology Reviews, pp. 353–386. https://doi.org/10.1007/978-3-319-68920-3_13.

Frimmel, H.E., Frank, W., 1998. Neoproterozoic tectono-thermal evolution of the Gariep Belt and its basement, Namibia and South Africa. Precambrian Res. 90, 1–28. https://doi.org/10.1016/S0301-9268(98)00029-1.

Frimmel, H.E., Klötzli, U.S., Siegfried, P.R., 1996. New Pb–Pb single zircon age constraints on the timing of Neoproterozoic glaciation and continental break-up in Namibia. J. Geol. 104, 459–469. https://doi.org/10.1086/629839.

Frimmel, H.E., Zartman, R.E., Späth, A., 2001. The Richtersveld Igneous Complex, South Africa: U–Pb zircon and geochemical evidence for the beginning of Neoproterozoic continental breakup. J. Geol. 109, 493–508. https://doi.org/10.1086/320795.

Frost, C.D., Frost, B.R., Beard, J.S., 2016. On silica-rich granitoids and their eruptive equivalents. Am. Mineral. 101, 1268–1284. https://doi.org/10.2138/am-2016-5307.

Gonçalves, L., Farina, F., Lana, C., Pedrosa-Soares, A.C., Alkmim, F., Nalini, H.A., 2014. New U–Pb ages and lithochemical attributes of the Ediacaran Rio Doce magmatic arc, Araçuaí confined orogen, southeastern Brazil. J. S. Am. Earth Sci. 52, 129–148.

Gonçalves, L., Alkmim, F.F., Pedrosa-Soares, A.C., Dussin, I.A., Valeriano, C.d.M., Lana, C., Tedeschi, M., 2016. Granites of the intracontinental termination of a magmatic arc: an example from the Ediacaran Araçuaí orogen, southeastern Brazil. Gondwana Res. 36, 439–458. https://doi.org/10.1016/j.gr.2015.07.015.

Gonçalves, L., Alkmim, F.F., Pedrosa-Soares, A., Gonçalves, C.C., Vieira, V., 2018. From the plutonic root to the volcanic roof of a continental magmatic arc: a review of the Neoproterozoic Araçuaí Orogen, southeastern Brazil. Int. J. Earth Sci. 107, 337–358. https://doi.org/10.1007/s00531-017-1494-5.

Goscombe, B., Gray, D.R., 2007. The Coastal Terrane of the Kaoko Belt, Namibia: outboard arc-terrane and tectonic significance. Precambrian Res. 155, 139–158. https://doi.org/10.1016/j.precamres.2007.01.008.

Goscombe, B., Hand, M., Mawby, J., Gray, D., 2003. The metamorphic architecture of a transpressional orogen: the Kaoko Belt, Namibia. J. Petrol. 44, 679–711. https://doi.org/10.1093/petrology/44.4.679.

Goscombe, B., Gray, D., Armstrong, R., Foster, D.A., Vogl, J., 2005. Event geochronology of the Pan-African Kaoko Belt, Namibia. Precambrian Res. 140https://doi.org/10.1016/j.precamres.2005.07.003. 103.e1–103.e41.

Gray, D.R., Foster, D.A., Goscombe, B., Passchier, C.W., Trouw, R.A.J., 2006. ^{40}Ar/^{39}Ar thermochronology of the Pan-African Damara Orogen, Namibia, with implications for tectonothermal and geodynamic evolution. Precambrian Res. 150, 49–72. https://doi.org/10.1016/j.precamres.2006.07.003.

Gross, A.O.M.S., Droop, G.T.R., Porcher, C.C., Fernandes, L.A.D., 2009. Petrology and thermobarometry of mafic granulites and migmatites from the Chafalote Metamorphic Suite: new insights into the Neoproterozoic P–T evolution of the Uruguayan–Sul-Rio-Grandense shield. Precambrian Res. 170, 157–174. https://doi.org/10.1016/j.precamres.2009.01.011.

Grove, T.L., Elkins-Tanton, L.T., Parman, S.W., Chatterjee, N., Müntener, O., Gaetani, G.A., 2003. Fractional crystallization and mantle-melting controls on calc-alkaline differentiation trends. Contrib. Mineral. Petrol. 145, 515–533. https://doi.org/10.1007/s00410-003-0448-z.

Guadagnin, F., Chemale Jr., F., Magalhães, A.J.C., Santana, A., Dussin, I., Takehara, L., 2015. Age constraints on crystal-tuff from the Espinhaço Supergroup – insight into the Paleoproterozoic to Mesoproterozoic intracratonic basin cycles of the Congo–São Francisco Craton. Gondwana Res. 27, 363–376. https://doi.org/10.1016/j.gr.2013.10.009.

Guj, P., 1970. The Damara Mobile Belt in the south-western Kaokoveld, South West Africa. In: University of Cape Town Precambrian Research Unit Bulletin 8, pp. 1–168.

Hartnady, C., Joubert, P., Stowe, C., 1985. Proterozoic crustal evolution in southwestern Africa. Episodes 8, 236–244. https://doi.org/10.18814/epiiugs/1985/v8i4/003.

Heilbron, M., Machado, N., 2003. Timing of terrane accretion in the Neoproterozoic–Eopaleozoic Ribeira orogen (SE Brazi). Precambrian Res. 125, 87–112. https://doi.org/10.1016/S0301-9268(03)00082-2.

Heilbron, M., Valeriano, C.M., Tassinari, C.C.G., Almeida, J., Tupinambá, M., Siga, O., Trouw, R., 2008. Correlation of Neoproterozoic terranes between the Ribeira Belt, SE Brazil and its African counterpart: comparative tectonic evolution and open questions. In: Pankhurst, R.J., Trouw, R.A.J., de Brito Neves, B.B., de Wit, M.J. (Eds.), West Gondwana: Pre-Cenozoic Correlations Across the South Atlantic Region. Geol. Soc. London Spec. Pub. 294. pp. 211–237. https://doi.org/10.1144/SP294.12.

Heilbron, M., Tupinambá, M., Valeriano, C.M., Armstrong, R., Silva, L.G.E., Melo, R.S., Simonetti, A., Pedrosa-Soares, A.C., Machado, N., 2013. The Serra da Bolívia complex: the record of a new Neoproterozoic arc-related unit at Ribeira belt. Precambrian Res. 238, 158–175. https://doi.org/10.1016/j.precamres.2013.09.014.

Heilbron, M., Ribeiro, A., Valeriano, C.M., Paciullo, F.V., Almeida, J.C.H., Trouw, R.J.A., Tupinambá, M., Eirado Silva, L.G., 2017a. The Ribeira Belt. In: Heilbron, M., Cordani, U.G., Flecha de Alkmim, F. (Eds.), São Francisco Craton, Eastern Brazil. Springer, Regional Geology Reviews, pp. 277–302. https://doi.org/10.1007/978-3-319-01715-0_15.

Heilbron, M., Cordani, U.G., Alkmim, F.F., Reis, H.L.S., 2017b. Tectonic genealogy of a miniature continent. In: Heilbron, M., Cordani, U.G., Flecha de Alkmim, F. (Eds.), São Francisco Craton, Eastern Brazil. Springer, Regional Geology Reviews, pp. 321–331. https://doi.org/10.1007/978-3-319-01715-0_17.

Heine, C., Zoethout, J., Müller, R.D., 2013. Kinematics of the South Atlantic rift. Solid Earth 4, 215–253. https://doi.org/10.5194/se-4-215-2013.

Hibbard, M.J., 1995. Mixed Magma rocks. In: Petrography to Petrogenesis. Prentice Hall, New Jersey, pp. 242–260.

Hildreth, W., Moorbath, S., 1988. Crustal contributions to arc magmatism in the Andes of Central Chile. Contrib. Mineral. Petrol. 98, 455–489. https://doi.org/10.1007/BF00372365.

Hoffman, P.F., Halverson, G.P., 2008. Otavi Group of the western Northern Platform, the Eastern Kaoko Zone and the western Northern Margin Zone. In: Miller, R.McG (Ed.), The Geology of Namibia. Vol. 2 Geol. Surv. Namibia, Windhoek 13-69–13-136.

Hoffman, P.F., Hawkins, D.P., Isachsen, C.E., Bowring, S.A., 1996. Precise U–Pb zircon ages for early Damaran magmatism in the Summas Mountains and Welwitschia Inlier, northern Damara Belt, Namibia. Comm. Geol. Surv. Namibia 11, 47–52.

Hoffmann, K.H., Prave, A.R., 1996. A preliminary note on a revised subdivision and regional correlation of the Otavi Group based on glaciogenic diamictites and associated cap dolostones. Comm. Geol. Surv. Namibia 11, 83–88.

Hoffmann, K.H., Condon, D.J., Bowring, S.A., Crowley, J.L., 2004. U–Pb zircon date from the Neoproterozoic Ghaub Formation, Namibia: constraints on Marinoan glaciation. Geology 32, 817–820. https://doi.org/10.1130/G20519.1.

Hueck, M., Oyhantçabal, P., Philipp, R.P., Basei, M.A.S., Siegesmund, S., 2018. The Dom Feliciano Belt in Southern Brazil and Uruguay. In: Siegesmund, S., Basei, M.A.S., Oyhantçabal, P., Oriolo, S. (Eds.), Geology of Southwest Gondwana. Springer, Regional Geology Reviews, pp. 267–302. https://doi.org/10.1007/978-3-319-68920-3_11.

Irvine, T.N., Baragar, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci. 8, 523–548. https://doi.org/10.1139/e71-055.

Jagoutz, O., Schmidt, M.W., 2012. The formation and bulk composition of modern juvenile continental crust: the Kohistan arc. Chem. Geol. 298–299, 79–96. https://doi.org/10.1016/j.chemgeo.2011.10.022.

Janoušek, V., Konopásek, J., Ulrich, S., Erban, V., Tajčmanová, L., Jeřábek, P., 2010. Geochemical character and petrogenesis of Pan-African Amspoort suite of the Boundary Igneous Complex in the Kaoko Belt (NW Namibia). Gondwana Res. 18, 688–707. https://doi.org/10.1016/j.gr.2010.02.014.

Johansson, Å., 2014. From Rodinia to Gondwana with the 'SAMBA' model—a distant view from Baltica towards Amazonia and beyond. Precambrian Res. 244, 226–235. https://doi.org/10.1016/j.precamres.2013.10.012.

Kampunzu, A.B., Kapenda, D., Manteka, B., 1991. Basic magmatism and geotectonic evolution of the Pan African belt in central Africa: evidence from the Katangan and West Congolian segments. Tectonophysics 190, 363–371. https://doi.org/10.1016/0040-1951(91)90438-X.

Kay, R.W., Kay, S.M., 1993. Delamination and delamination magmatism. Tectonophysics 219, 177–189. https://doi.org/10.1016/0040-1951(93)90295-U.

Kelemen, P.B., 1995. Genesis of high Mg# andesites and the continental crust. Contrib. Mineral. Petrol. 120, 1–19. https://doi.org/10.1007/BF00311004.

Koester, E., Porcher, C.C., Pimentel, M.M., Fernandes, L.A.D., Vignol-Lelarge, M.L., Oliveira, L.D., Ramos, R.C., 2016. Further evidence of 777 Ma subduction-related continental arc magmatism in Eastern Dom Feliciano Belt, southern Brazil: the Chácara das Pedras Orthogneiss. J. S. Am. Earth Sci. 68, 155–166. https://doi.org/10.1016/j.jsames.2015.12.006.

Konopásek, J., Košler, J., Tajčmanová, L., Ulrich, S., Kitt, S.L., 2008. Neoproterozoic igneous complex emplaced along major tectonic boundary in the Kaoko Belt (NW Namibia): ion probe and LA-ICP-MS dating of magmatic and metamorphic zircons. J. Geol. Soc. Lond. 165, 153–165. https://doi.org/10.1144/0016-76492006-192.

Konopásek, J., Košler, J., Sláma, J., Janoušek, V., 2014. Timing and sources of pre-collisional Neoproterozoic sedimentation along the SW margin of the Congo Craton (Kaoko Belt, NW Namibia). Gondwana Res. 26, 386–401. https://doi.org/10.1016/j.gr.2013.06.021.

Konopásek, J., Sláma, J., Košler, J., 2016. Linking the basement geology along the Africa–South America coasts in the South Atlantic. Precambrian Res. 280, 221–230. https://doi.org/10.1016/j.precamres.2016.05.011.

Konopásek, J., Hoffmann, K.H., Sláma, J., Košler, J., 2017. The onset of flysch sedimentation in the Kaoko Belt (NW Namibia) – implications for the pre-collisional evolution of the Kaoko–Dom Feliciano–Gariep Orogen. Precambrian Res. 298, 220–234. https://doi.org/10.1016/j.precamres.2017.06.017.

Konopásek, J., Janoušek, V., Oyhantçabal, P., Sláma, J., Ulrich, S., 2018. Did the circum-Rodinia subduction trigger the Neoproterozoic rifting along the Congo–Kalahari Craton margin? Int. J. Earth Sci. 107, 1859–1894. https://doi.org/10.1007/s00531-017-1576-4.

Kröner, A., Rojas-Agramonte, Y., 2017. Mesoproterozoic (Grenville-age) granitoids and supracrustal rocks in Kaokoland, northwestern Namibia. Precambrian Res. 298, 572–592. https://doi.org/10.1016/j.precamres.2017.07.008.

Kröner, S., Konopásek, J., Kröner, A., Passchier, C.W., Poller, U., Wingate, M.T.D., Hofmann, K.H., 2004. U–Pb and Pb–Pb zircon ages of metamorphic rocks in the Kaoko Belt of Northwestern Namibia: a Palaeo- to Mesoproterozoic basement reworked during the Pan-African orogeny. S. Afr. J. Geol. 107, 455–476. https://doi.org/10.2113/107.3.455.

Kuchenbecker, M., Pedrosa-Soares, A.C., Babinski, M., Fanning, M., 2015. Detrital zircon age patterns and provenance assessment for pre-glacial to post-glacial successions of the Neoproterozoic Macaúbas Group, Araçuaí orogen, Brazil. Precambrian Res. 266, 12–26. https://doi.org/10.1016/j.precamres.2015.04.016.

Lara, P., Oyhantçabal, P., Belousova, E., 2020. Two distinct crustal sources for Late Neoproterozoic granitic magmatism across the Sierra Ballena Shear Zone, Dom Feliciano Belt, Uruguay: Whole-rock geochemistry, zircon geochronology and Sr–Nd–Hf isotope evidence. Precambrian Res. 341, 105625. https://doi.org/10.1016/j.precamres.2020.105625.

Lee, C.T., Anderson, D.L., 2015. Continental crust formation at arcs, the arclogite 'delamination' cycle, and one origin for fertile melting anomalies in the mantle. Sci. Bull. 60, 1141–1156. https://doi.org/10.1007/s11434-015-0828-6.

Lenz, C., Fernandes, L.A.D., McNaughton, N.J., Porcher, C.C., Masquelin, H., 2011. U–Pb SHRIMP ages for the Cerro Bori orthogneisses, Dom Feliciano Belt in Uruguay:

evidences of a ~800 Ma magmatic and ~650 Ma metamorphic event. Precambrian Res. 185, 149–163. https://doi.org/10.1016/j.precamres.2011.01.007.

Lenz, C., Porcher, C.C., Fernandes, L.A.D., Masquelin, H., Koester, E., Conceição, R.V., 2013. Geochemistry of the Neoproterozoic (800–767 Ma) Cerro Bori orthogneisses, Dom Feliciano Belt in Uruguay: tectonic evolution of an ancient continental arc. Mineral. Petrol. 107, 785–806. https://doi.org/10.1007/s00710-012-0244-4.

Li, S.Z., Zhao, G.C., Santosh, M., Liu, X., Dai, L.M., 2011. Palaeoproterozoic tectonothermal evolution and deep crustal processes in the Jiao-Liao-Ji Belt, North China Craton: a review. Geol. J. 46, 525–543. https://doi.org/10.1002/gj.1282.

Li, Z.X., Evans, D.A.D., Halverson, G.P., 2013. Neoproterozoic glaciations in a revised global palaeogeography from the breakup of Rodinia to the assembly of Gondwanaland. Sediment. Geol. 294, 219–232. https://doi.org/10.1016/j.sedgeo.2013.05.016.

Macdonald, F.A., Schmitz, M.D., Crowley, J.L., Roots, C.F., Jones, D.S., Maloof, A.C., Strauss, J.V., Cohen, P.A., Johnston, D.T., Schrag, D.P., 2010. Calibrating the cryogenian. Science 237, 1241–1243. https://doi.org/10.1126/science.1183325.

Marshak, S., Alkmim, F.F., Whittington, A., Pedrosa-Soares, A.C., 2006. Extensional collapse in the Neoproterozoic Araçuaí orogen, eastern Brazil: a setting for reactivation of asymmetric crenulation cleavage. J. Struct. Geol. 28, 129–147. https://doi.org/10.1016/j.jsg.2005.09.006.

Martil, M.M.D., Bitencourt, M.F., Armstrong, R., Nardi, L.V.S., Pimentel, M.M., Schmitt, R.S., Florisbal, L.M., Chemale Jr., F., 2016. Cryogenian granulitic orthogneisses of the Várzea do Capivarita Complex thrust pile and implications for the timing of magmatic arc activity and continental collision in the southern Mantiqueira Province, Brazil. In: Martil, M.M.D. (Ed.), O magmatismo de arco continental pré-colisional (790 Ma) e a reconstitução espaço–temporal do regime transpressivo (650 Ma) no complexo Várzea do Capivarita, sul da província Mantiquera. Federal University of Rio Grande do Sul, Porto Alegre, pp. 73–112 Unpublished PhD. thesis.

Martil, M.M.D., Bitencourt, M.F., Nardi, L.V.S., Koester, E., Pimentel, M.M., 2017. Pre-collisional, Neoproterozoic (ca. 790 Ma) continental arc magmatism in southern Mantiqueira Province, Brazil: geochemical and isotopic constraints from the Várzea do Capivarita Complex. Lithos 274–275, 39–52. https://doi.org/10.1016/j.lithos.2016.11.011.

Martin, H., 1965. The Precambrian geology of South West Africa and Namaqualand. In: University of Cape Town Precambrian Research Unit Bulletin 4, 159 p.

Masquelin, H., Fernandes, L.A.D., Lenz, C., Porcher, C.C., McNaughton, N.J., 2012. The Cerro Olivo Complex: a pre-collisional Neoproterozoic magmatic arc in Eastern Uruguay. Int. Geol. Rev. 54, 1161–1183. https://doi.org/10.1080/00206814.2011.626597.

Meira, V.T., García-Casco, A., Juliani, C., Almeida, R.P., Schorscher, J.H.D., 2015. The role of intracontinental deformation in supercontinent assembly: insights from the Ribeira Belt, Southeastern Brazil (Neoproterozoic West Gondwana). Terra Nova 27, 206–217. https://doi.org/10.1111/ter.12149.

Meira, V.T., Garcia-Casco, A., Hyppolito, T., Juliani, C., Schorscher, J.H.D., 2019a. Tectono-metamorphic evolution of the Central Ribeira Belt, Brazil: a case of Late Neoproterozoic intracontinental orogeny and flow of partially molten deep crust during the assembly of West Gondwana. Tectonics 38, 3182–3209. https://doi.org/10.1029/2018TC004959.

Meira, V.T., García-Casco, A., Juliani, C., Schorscher, J.H.D., 2019b. Late Tonian within-plate mafic magmatism and Ediacaran partial melting and magmatism in the Costeiro Domain, Central Ribeira Belt, Brazil. Precambrian Res. 334, 105440. https://doi.org/10.1016/j.precamres.2019.105440.

Merdith, A.S., Collins, A.S., Williams, S.E., Pisarevsky, S., Foden, J.D., Archibald, D.B., Blades, M.L., Alessio, B.L., Armistead, S., Plavsa, D., Clark, C., Müller, R.D., 2017. A full-plate global reconstruction of the Neoproterozoic. Gondwana Res. 50, 84–134. https://doi.org/10.1016/j.gr.2017.04.001.

Mondou, M., Egydio-Silva, M., Vauchez, A., Raposo, M.I.B., Bruguier, O., Oliveira, A.F., 2012. Complex, 3-D strain patterns in a synkinematic tonalite batholith from the Araçuaí Neoproterozoic orogen (Eastern Brazil): evidence from combined magnetic and isotopic chronology studies. J. Struct. Geol. 39, 158–179. https://doi.org/10.1016/j.jsg.2012.02.015.

Monié, P., Bosch, D., Bruguier, O., Vauchez, A., Rolland, Y., Nsungani, P., Buta Neto, A., 2012. The late Neoproterozoic/Early Palaezoic evolution of the West Congo Belt of NW Angola: geochronological (U–Pb and Ar–Ar) and petrostructural constraints. Terra Nova 24, 238–247. https://doi.org/10.1111/j.1365-3121.2012.01060.x.

Müller, R.D., Sdrolias, M., Gaina, C., Roest, W.R., 2008. Age, spreading rates, and spreading asymmetry of the world's ocean crust. Geochem. Geophys. Geosyst. 9, Q04006. https://doi.org/10.1029/2007GC001743.

Oriolo, S., Oyhantçabal, P., Wemmer, K., Heidelbach, F., Pfänder, J., Basei, M.A.S., Hueck, M., Hannich, F., Sperner, B., Siegesmund, S., 2016. Shear zone evolution and timing of deformation in the Neoproterozoic transpressional Dom Feliciano Belt, Uruguay. J. Struct. Geol. 92, 59–78. https://doi.org/10.1016/j.jsg.2016.09.010.

Oriolo, S., Oyhantçabal, P., Konopásek, J., Basei, M.A.S., Frei, R., Sláma, J., Wemmer, K., Siegesmund, S., 2019. Late Paleoproterozoic and Mesoproterozoic magmatism of the Nico Pérez Terrane (Uruguay): tightening up correlations in southwestern Gondwana. Precambrian Res. 327, 296–313. https://doi.org/10.1016/j.precamres.2019.04.012.

Oyhantçabal, P., Siegesmund, S., Wemmer, K., Frei, R., Layer, P., 2007. Post-collisional transition from calc-alkaline to alkaline magmatism during transcurrent deformation in the southernmost Dom Feliciano Belt (Braziliano–Pan-African, Uruguay). Lithos 98, 141–159. https://doi.org/10.1016/j.lithos.2007.03.001.

Oyhantçabal, P., Siegesmund, S., Wemmer, K., Presnyakov, S., Layer, P., 2009. Geochronological constraints on the evolution of the southern Dom Feliciano Belt (Uruguay). J. Geol. Soc. Lond. 166, 1075–1084. https://doi.org/10.1144/0016-76492008-122.

Oyhantçabal, P., Oriolo, S., Philipp, R.P., Wemmer, K., Siegesmund, S., 2018. The Nico Pérez Terrane of Uruguay and Southeastern Brazil. In: Siegesmund, S., Basei, M.A.S., Oyhantçabal, P., Oriolo, S. (Eds.), Geology of Southwest Gondwana. Springer, Regional Geology Reviews, pp. 161–188. https://doi.org/10.1007/978-3-319-68920-3_7.

Paciullo, F.V.P., Ribeiro, A., Andreis, R.R., Trouw, R.A.J., 2000. The Andrelândia Basin, a Neoproterozoic intraplate continental margin, southern Brasília belt, Brazil. Rev. Bras. Geocienc. 30, 200–202.

Passarelli, C.R., Basei, M.A.S., Siga Jr., O., Harara, O.M.M., 2018. The Luis Alves and Curitiba terranes: continental fragments in the Adamastor Ocean. In: Siegesmund, S., Basei, M.A.S., Oyhantçabal, P., Oriolo, S. (Eds.), Geology of Southwest Gondwana. Springer, Regional Geology Reviews, pp. 189–215. https://doi.org/10.1007/978-3-319-68920-3_8.

Passarelli, C.R., Verma, S.K., McReath, I., Basei, M.A.S., Siga Jr., O., 2019. Tracing the history from Rodinia break-up to the Gondwana amalgamation in the Embu Terrane, southern Ribeira Belt, Brazil. Lithos 342, 1–17. https://doi.org/10.1016/j.lithos.2019.05.024.

Peacock, M.A., 1931. Classification of igneous rock series. J. Geol. 39, 54–67. https://doi.org/10.1086/623788.

Pearce, J.A., 1996. Sources and settings of granitic rocks. Episodes 19, 120–125. https://doi.org/10.18814/epiiugs/1996/v19i4/005.

Pearce, J.A., 2014. Immobile element fingerprinting of ophiolites. Elements 10, 101–108. https://doi.org/10.2113/gselements.10.2.101.

Pearce, J.A., Peate, D.W., 1995. Tectonic implications of the composition of volcanic arc magmas. Annu. Rev. Earth Planet. Sci. 23, 251–285. https://doi.org/10.1146/annurev.ea.23.050195.001343.

Pearce, J.A., Harris, N.B.W., Tindle, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol. 25, 956–983. https://doi.org/10.1093/petrology/25.4.956.

Pearce, J.A., Stern, R.J., Bloomer, S.H., Fryer, P., 2005. Geochemical mapping of the Mariana arc-basin system: implications for the nature and distribution of subduction components. Geochem. Geophys. Geosyst. 6, Q07006. https://doi.org/10.1029/2004GC000895.

Pedrosa-Soares, A.C., Noce, C.M., Vidal, P., Monteiro, R.L.B.P., Leonardos, O.H., 1992. Toward a new tectonic model for the Late Proterozoic Araçuaí (SE Brazil)–West Congolian (SW Africa) Belt. J. S. Am. Earth Sci. 6, 33–47. https://doi.org/10.1016/0895-9811(92)90015-Q.

Pedrosa-Soares, A.C., Vidal, P., Leonardos, O.H., de Brito Neves, B.B., 1998. Neoproterozoic oceanic remnants in eastern Brazil: Further evidence and refutation of an exclusively ensialic evolution for the Araçuaí–West Congo orogen. Geology 26, 519–522. https://doi.org/10.1130/0091-7613(1998)026<0519:NORIEB>2.3.CO;2.

Pedrosa-Soares, A.C., Noce, C.M., Wiedemann, C.M., Pinto, C.P., 2001. The Araçuaí–West-Congo Orogen in Brazil: an overview of a confined orogen formed during Gondwanaland assembly. Precambrian Res. 110, 307–323. https://doi.org/10.1016/S0301-9268(01)00174-7.

Pedrosa-Soares, A.C., Alkmim, F.F., Tack, L., Noce, C.M., Babinski, M., Silva, L.C., Martins-Neto, M.A., 2008. Similarities and differences between the Brazilian and African counterparts of the Neoproterozoic Araçuaí–West Congo orogen. In: Pankhurst, R.J., Trouw, R.A.J., Brito Neves, B.B., de Wit, M.J. (Eds.), West Gondwana: Pre-Cenozoic Correlations Across the South Atlantic Region. Geol. Soc. London Spec. Pub. 294. pp. 153–172. https://doi.org/10.1144/SP294.9.

Pedrosa-Soares, A.C., De Campos, C.P., Noce, C.M., Silva, L.C., Novo, T., Roncato, J., Medeiros, S., Castaneda, C., Queiroga, G., Dantas, E., Dussin, I.A., Alkmim, F.F., 2011. Late Neoproterozoic–Cambrian granitic magmatism in the Araçuaí orogen (Brazil), the Eastern Brazilian Pegmatite Province and related mineral resources. In: Sial, A.N., Bettencourt, J.S., De Campos, C.P., Ferreira, V.P. (Eds.), Granite-Related Ore Deposits. Geol. Soc. London Spec. Pub. 350. pp. 25–51. https://doi.org/10.1144/SP350.3.

Peel, E., Bettucci, L.S., Basei, M.A.S., 2018. Geology and geochronology of Paso del Dragon Complex (northeastern Uruguay): implications on the evolution of the Dom Feliciano Belt (Western Gondwana). J. S. Am. Earth Sci. 85, 250–262. https://doi.org/10.1016/j.jsames.2018.05.009.

Peixoto, E., Pedrosa-Soares, A.C., Alkmim, F.F., Dussin, I.A., 2015. A suture-related accretionary wedge formed in the Neoproterozoic Araçuaí orogen (SE Brazil) during Western Gondwanaland assembly. Gondwana Res. 27, 878–896. https://doi.org/10.1016/j.gr.2013.11.010.

Peixoto, C.D., Heilbron, M., Ragatky, D., Armstrong, R., Dantas, E., Valeriano, C.D., Simonetti, A., 2017. Tectonic evolution of the Juvenile Tonian Serra da Prata magmatic arc in the Ribeira belt, SE Brazil: implications for early west Gondwana amalgamation. Precambrian Res. 302, 221–254. https://doi.org/10.1016/j.precamres.2017.09.017.

Pertille, J., Hartmann, L.A., Santos, J.O.S., McNaughton, N.J., Armstrong, R., 2017. Reconstructing the Cryogenian–Ediacaran evolution of the Porongos fold and thrust belt, Southern Brasiliano Orogen, based on Zircon U–Pb–Hf–O isotopes. Int. Geol. Rev. 59, 1532–1560. https://doi.org/10.1080/00206814.2017.1285257.

Petitgirard, S., Vauchez, A., Egydio-Silva, M., Bruguier, O., Camps, P., Monié, P., Babinski, M., Mondou, M., 2009. Conflicting structural and geochronological data from the Ibituruna quartz-syenite (SE Brazil): effect of protracted "hot" orogeny and slow cooling rate? Tectonophysics 477, 174–196. https://doi.org/10.1016/j.tecto.2009.02.039.

Philipp, R.P., Machado, R., 2005. The Late Neoproterozoic granitoid magmatism of the Pelotas Batholith, southern Brazil. J. S. Am. Earth Sci. 19, 461–478. https://doi.org/10.1016/j.jsames.2005.06.010.

Porada, H., 1979. The Damara–Ribeira Orogen of the Pan-African/Brasiliano Cycle in Namibia (South-West Africa) and Brazil as interpreted in terms of continental collision. Tectonophysics 57, 237–265. https://doi.org/10.1016/0040-1951(79)90150-1.

Porada, H., 1989. Pan-African rifting and orogenesis in southern to equatorial Africa and eastern Brazil. Precambrian Res. 44, 103–136. https://doi.org/10.1016/0301-

9268(89)90078-8.

Prave, A.R., Condon, D.J., Hoffmann, K.H., Tapster, S., Fallick, A.E., 2016. Duration and nature of the end-Cryogenian (Marinoan) glaciation. Geology 44, 631–634. https://doi.org/10.1130/G38089.1.

Raimondo, T., Collins, A.S., Hand, M., Walker-Hallam, A., Smithies, R.H., Evins, P.M., Howard, H.M., 2009. Ediacaran intracontinental channel flow. Geology 37, 291–294. https://doi.org/10.1130/G25452A.1.

Raimondo, T., Collins, A.S., Hand, M., Walker-Hallam, A., Smithies, R.H., Evins, P.M., Howard, H.M., 2010. The anatomy of a deep intracontinental orogen. Tectonics 29https://doi.org/10.1029/2009TC002504. TC4024.

Ramos, R.C., Koester, E., Vieira, D.T., Porcher, C.C., Gezatt, J.N., Silveira, R.L., 2018. Insights on the evolution the Arroio Grande Ophiolite (Dom Feliciano Belt, Brazil) from Rb–Sr and SHRIMP U–Pb isotopic geochemistry. J. S. Am. Earth Sci. 86, 38–53. https://doi.org/10.1016/j.jsames.2018.06.004.

Reubi, O., Blundy, J., 2009. A dearth of intermediate melts at subduction zone volcanoes and the petrogenesis of arc andesites. Nature 461, 1269–1273. https://doi.org/10.1038/nature08510.

Richter, F., Lana, C., Stevens, G., Buick, I.S., Pedrosa-Soares, A.C., Alkmim, F.F., Cutts, K., 2016. Sedimentation, metamorphism and granite generation in a back-arc region: records from the Ediacaran Nova Venécia Complex (Araçuaí Orogen, Southeastern Brazil). Precambrian Res. 272, 78–100. https://doi.org/10.1016/j.precamres.2015.10.012.

Rooney, A.D., Macdonald, F.A., Strauss, J.V., Dudás, F.Ö., Hallmann, C., Selby, D., 2014. Re–Os geochronology and coupled Os–Sr isotope constraints on the Sturtian snowball. Nat. Acad. Sci. Proceed. 111, 51–56. https://doi.org/10.1073/pnas.1317266110.

Rooney, A.D., Strauss, J.V., Brandon, A.D., Macdonald, F.A., 2015. A Cryogenian chronology: two long-lasting synchronous Neoproterozoic glaciations. Geology 43, 459–462. https://doi.org/10.1130/G36511.1.

Rosa, M., Conceicao, H., Macambira, M., Galarza, M., Cunha, M., Menezes, R., Marinho, M., Filho, B., Rios, D., 2007. Neoproterozoic anorogenic magmatism in the Southern Bahia Alkaline Province of NE Brazil: U–Pb and Pb–Pb ages of the blue sodalite syenites. Lithos 97, 88–97. https://doi.org/10.1016/j.lithos.2006.12.011.

Rudnick, R.L., Gao, S., 2003. The composition of the continental crust. In: Holland, H.D., Turekian, K.K. (Eds.), Treatise on Geochemistry vol. 3, The Crust. Elsevier-Pergamon, Oxford, pp. 1–64.

Saalmann, K., Gerdes, A., Lahaye, Y., Hartmann, L.A., Remus, M.V.D., Läufer, A., 2011. Multiple accretion at the eastern margin of the Rio de la Plata Craton: the prolonged Brasiliano Orogeny in southernmost Brazil. Int. J. Earth Sci. 100, 355–378. https://doi.org/10.1007/s00531-010-0564-8.

Salmien, J., Hanson, R., Evans, D.A.D., Gong, Z., Larson, T., Walker, O., Gumsley, A., Söderlund, U., Ernst, R., 2018. Direct Mesoproterozoic connection of the Congo and Kalahari cratons in proto-Africa: strange attractors across supercontinental cycles. Geology 46, 1011–1014. https://doi.org/10.1130/G45294.1.

Saunders, A.D., Norry, M.J., Tarney, J., 1991. Fluid influence on the trace element compositions of subduction zone magmas. In: Tarney, J., Pickering, K.T., Knipe, R.J., Dewey, J.F. (Eds.), The Behaviour and Influence of Fluids in Subduction Zones. The Royal Society, London, pp. 151–166.

Schmitt, R.d.S., Trouw, R., Van Schmus, W.R., Armstrong, R., Stanton, N.S.G., 2016. The tectonic significance of the Cabo Frio Tectonic Domain in the SE Brazilian margin: a Paleoproterozoic through Cretaceous saga of a reworked continental margin. Braz. J. Geol. 46, 37–66. https://doi.org/10.1590/2317-4889201620150025.

Seth, B., Kröner, A., Mezger, K., Nemchin, A.A., Pidgeon, R.T., Okrusch, M., 1998. Archaean to Neoproterozoic magmatic events in the Kaoko Belt of NW Namibia and their geodynamic significance. Precambrian Res. 92, 341–363. https://doi.org/10.1016/S0301-9268(98)00086-2.

Sheth, H.C., Torres-Alvarado, I.S., Verma, S.P., 2002. What is the "Calc-alkaline Rock Series"? Int. Geol. Rev. 44, 686–701. https://doi.org/10.2747/0020-6814.44.8.686.

Süssenberger, A., Brito-Neves, B.B., Wemmer, K., 2014. Dating low-grade metamorphism and deformation of the Espinhaço Supergroup in the Chapada Diamantina (Bahia, NE Brazil): a K/Ar fine-fraction study. Braz. J. Geol. 44, 207–220. https://doi.org/10.5327/Z2317-4889201400020003.

Tack, L., Wingate, M.T.D., Liégois, J.P., Fernandez-Alonso, M., Deblond, A., 2001. Early Neoproterozoic magmatism (1000–910 Ma) of the Zadinian and Mayumbian Groups (Bas-Congo): onset of Rodinia rifting at the western edge of the Congo craton. Precambrian Res. 110, 277–306. https://doi.org/10.1016/S0301-9268(01)00192-9.

Tatsumi, Y., Eggins, S., 1995. Subduction Zone Magmatism. Frontiers in Earth Sciences. Blackwell, Cambridge, Mass.

Taylor, S.R., McLennan, S.M., 2009. Planetary Crusts: Their Composition, Origin and Evolution. Cambridge University Press, Cambridge.

Tedeschi, M., Novo, T., Pedrosa-Soares, A., Dussin, I., Tassinari, C., Silva, L.C., Gonçalves, L., Alkmim, F., Lana, C., Figueiredo, C., Dantas, E., Medeiros, S., De Campos, C., Corrales, F., Heilbron, M., 2016. The Ediacaran Rio Doce magmatic arc revisited (Araçuaí–Ribeira orogenic system, SE Brazil). J. S. Am. Earth Sci. 68, 167–186. https://doi.org/10.1016/j.jsames.2015.11.011.

Teixeira, W., Kamo, S.L., Arcanjo, J.B.A., 1997. U–Pb zircon and baddeleyite age and tectonic interpretation of the Itabuna Alkaline Suite, São Francisco Craton, Brazil. J. S. Am. Earth Sci. 10, 91–98. https://doi.org/10.1016/S0895-9811(97)00008-4.

Thomas, R.J., Macey, P.H., Spencer, C., Dhansay, T., Diener, J.F.A., Lambert, C.W., Frei, D., Nguno, A., 2016. The Sperrgebiet Domain, Aurus Mountains, SW Namibia: A ~2020–850 Ma window within the Pan-African Gariep Orogen. Precambrian Res. 286, 35–58. https://doi.org/10.1016/j.precamres.2016.09.023.

Trompette, R., 1994. Geology of Western Gondwana (2000–500 Ma). Balkema, Amsterdam.

Trompette, R., 1997. Neoproterozoic (~600 Ma) aggregation of Western Gongwana: a tentative scenario. Precambrian Res. 82, 101–112. https://doi.org/10.1016/S0301-9268(96)00045-9.

Trompette, R., 2000. Gondwana evolution; its assembly at around 600 Ma. C. R. Acad. Sci. 330, 305–315 Paris, Sciences de la Terre et des planétes.

Tupinamba, M., Heilbron, M., Valeriano, C., Porto, R., de Dios, F.B., Machado, N., Silva, L.G.D., de Almeida, J.C.H., 2012. Juvenile contribution of the Neoproterozoic Rio Negro Magmatic Arc (Ribeira Belt, Brazil): implications for Western Gondwana amalgamation. Gondwana Res. 21, 422–438. https://doi.org/10.1016/j.gr.2011.05.012.

Ulmer, P., Kaegi, R., Müntener, O., 2018. Experimentally derived intermediate to silica-rich arc magmas by fractional and equilibrium crystallization at 1.0 GPa: an evaluation of phase relationships, compositions, liquid lines of descent and oxygen fugacity. J. Petrol. 59, 11–58. https://doi.org/10.1093/petrology/egy017.

Valeriano, C.d.M., Mendes, J.C., Tupinambá, M., Bongiolo, E., Heilbron, M., Junho, M.d.C.B., 2016. Cambro–Ordovician post-collisional granites of the Ribeira belt, SE-Brazil: a case of terminal magmatism of a hot orogen. J. S. Am. Earth Sci. 68, 269–281. https://doi.org/10.1016/j.jsames.2015.12.014.

Vauchez, A., Egydio-Silva, M., Babinski, M., Tommasi, A., Uhlein, A., Liu, D., 2007. Deformation of a pervasively molten middle crust: insights from the Neoproterozoic Ribeira–Araçuaí orogen (SE Brazil). Terra Nova 19, 278–286. https://doi.org/10.1111/j.1365-3121.2007.00747.x.

Vauchez, A., Hollanda, M.H.M.Z., Monié, P., Mondou, M., Egydio-Silva, M., 2019. Slow cooling and crystallization of the roots of the Neoproterozoic Araçuaí hot orogen (SE Brazil): implications for rheology, strain distribution, and deformation analysis. Tectonophysics 766, 500–518. https://doi.org/10.1016/j.tecto.2019.05.013.

Vernon, R.H., 1991. Interpretation of microstructures of microgranitoid enclaves. In: Didier, J., Barbarin, B. (Eds.), Enclaves and Granite Petrology. Elsevier, Amsterdam, pp. 277–291.

Warren, L.V., Quaglio, F., Riccomini, C., Simoes, M.G., Poire, D.G., Strikis, N.M., Anelli, L.E., Strikis, P.C., 2014. The puzzle assembled: Ediacaran guide fossil Cloudina reveals an old proto-Gondwana seaway. Geology 42, 391–394. https://doi.org/10.1130/G35304.1.

Will, T.M., Frimmel, H.E., Gaucher, C., Bossi, J., 2014. Geochemical and isotopic composition of Pan-African metabasalts from southwestern Gondwana: evidence of Cretaceous South Atlantic opening along a Neoproterozoic back-arc. Lithos 202–203, 363–381. https://doi.org/10.1016/j.lithos.2014.05.034.

Will, T.M., Gaucher, C., Ling, X.-X., Li, X.-H., Li, Q.-L., Frimmel, H.E., 2019. Neoproterozoic magmatic and metamorphic events in the Cuchilla Dionisio Terrane, Uruguay, and possible correlations across the South Atlantic. Precambrian Res. 320, 303–322. https://doi.org/10.1016/j.precamres.2018.11.004.