Decratonization by Rifting followed by Orogeny and Transcurrent Dispersal of Old Terranes in NE Brazil: A Common Feature of Gondwana Amalgamation?

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Abstract

Dispersion and deformation of cratonic fragments within orogens in the periphery of cratons require weakening of the craton margins in a process of decratonization. The Borborema orogenic province, in NE Brazil, is one of several Brasiliano/Panafriican late Neoproterozoic orogens that led to the amalgamation of Gondwana. A common feature of these orogens is that a period of extension and opening of narrow oceans preceded inversion and collision. For the case of the Borborema Province, the São Francisco Craton was pulled away from its other half, the Benino-Nigerian Shield, during an extension event lasting between 1 Ga and 0.65 Ma. This was followed by inversion and a transpressional orogeny from c. 0.60 Ga onwards. Here we investigate the boundary region between the north São Francisco Craton and the Borborema Province and demonstrate how cratonic blocks became physically involved in the orogeny. We combine these results with a wide compilation of U-Pb and Nd-isotopic model ages to show that the BP consists of up to 65% of strongly sheared ancient rocks affiliated with the Sao Francisco/Benino-Nigerian Craton, separated by major transcurrent shear zones, with only ~ 15 % addition of juvenile material during the orogeny. This evolution is repeated across a number of Brasiliano/Panafriican orogens, with significant local variations, and indicate that extension weakened entire cratonic regions in a process of decratonization that prepared them for involvement in the orogenies that led to the amalgamation of Gondwana.

Background

Cratons are old, stable continental regions with thick buoyant keels that resist deformation, protecting them from tectonic reworking. Their thick and cold refractory lithospheric keel is taken to be responsible for their integrity\(^1\). However, during continental collisions, colliding cratonic blocks can be partially reworked to generate continental tracts that are no longer cratons but that are not typical orogens either\(^2\). Thus, understanding the origin of these old continental crust within orogenic areas must address the specific mechanisms for both the weakening of the craton lithosphere (c.f. decratonization) and their subsequent reworking. First order controls in the reworking of these strong lithospheres are temporal and spatial variations of their thermal state and pre-existing mechanical anisotropies or major compositional boundaries\(^3\)–\(^8\). The North China Craton is a classic example where lithospheric thinning, asthenospheric decompression and magmatism changed the thermal and chemical state of the cratonic lithosphere resulting in wholesale decratonization\(^9\)–\(^12\).

Here we describe the process of decratonization of the São Francisco Craton (SFC) during the Neoproterozoic in northeast Brazil. This craton is bound to the north by the late Neoproterozoic orogenic Borborema Province. In the province, pre-orogenic extension started as early as 1000-900 Ma and resulted in the development of intracontinental extensional basins\(^13\), passive margin basins flanking the SFC\(^14\)–\(^16\), and separation of the SFC from the African Benino-Nigerian Shield\(^17\),\(^18\). Remarkably, this orogenic province includes a number of reworked and deformed Archean-Paleoproterozoic terranes among the Neoproterozoic sedimentary basins and granitic intrusions\(^19\). These old terranes are relatively small
(10,000 to 40,000 km²) and bounded by large-scale continental shear zones\textsuperscript{19,20} (Fig. 1A and B). Although no quantitative crustal growth curves of the orogenic Borborema Province have been reported, present models range from purely intracontinental reworking\textsuperscript{21}, to juvenile arc accretion\textsuperscript{22,23} and docking followed by reworking of unrelated terranes\textsuperscript{24}, or even to questionable autochthonous accretion surrounding old small Archean crust\textsuperscript{25}.

The Borborema Orogen comprises two separate and interacting collisions: one on the west side as part of the vast West Gondwana Orogen (WGO)\textsuperscript{26} and one in the south against the SFC and termed here Southern Borborema Orogen (SBO). These two collisions were partly contemporaneous and interacted involving the entire Borborema Province (BP). In this paper we will use the term BP to refer to the entire orogenic area. The current configuration of the Province seems to be controlled by these collisions as indicated by the record of UHP metamorphism and eclogites\textsuperscript{26,27}, marginal ophiolites\textsuperscript{28,29} and arc sequences\textsuperscript{16,23,30} that together suggest two separate but related collisions: an oceanic subduction followed by collision along the WGO\textsuperscript{19,26}, and a later but in part contemporaneous collision with the SFC. The two different orogens interacted in a complex collisional zone, giving rise to an intricate network of continental shear zones that controlled deformation\textsuperscript{19}. In this context, the large Transbrasiliano-Kandi shear zone, that developed as a result of the WGO, acted as a dextrally transfer zone leading to collision and development of the Southern Borborema Orogen\textsuperscript{17}.

In this paper, we compile large volumes of whole-rock Nd isotope data, zircon U-Pb geochronology data, as well as geological and geophysical data of the Borborema Province and northern part of the SFC and the Benino-Nigerian Shield. We use the data to first quantify the Neoproterozoic continental growth of the Borborema Province and establish the dominance of recycled cratonic material, and then to investigate how the decratonization allowed former cratonic Archean-Paleoproterozoic terranes to be entrained within the BP during the Neoproterozoic Orogeny.

**Geological Setting Of The Borborema Province**

The distribution of lithologies in the triangular wedge-shaped orogenic BP (Fig. 1) was ultimately controlled by a set of Neoproterozoic strike-slip shear zones\textsuperscript{19,20}. These shear zones bound the north, central and south sub-provinces and within them several other informal domains\textsuperscript{31}. Shearing was accompanied by granitoids with intrusions concentrated at 585-565 Ma\textsuperscript{19}. Archean and Paleoproterozoic lithologies are found as blocks all over the BP, always limited by Neoproterozoic shear zones (Fig. 1). Early Neoproterozoic extensional events starting as early as 1000-900 Ma are marked by granitoid intrusions, bimodal volcanism and deposition of immature terrigenous and minor carbonatic sediments in the so-called Cariris Velhos event\textsuperscript{13}. In the southern BP this event culminated in the development of a passive margin sequence along the edge of the SFC associated to 900-800 Ma mafic-ultramafic intrusions, proximal margin-type ophiolites and A-type granites\textsuperscript{14,16,28,32}. In this region, extensional tectonics may have lasted most of the Neoproterozoic, with the last pulses of rifting recorded by the 720-680 Ma Canindé Group, a sequence of mafic-ultramafic rocks and subvolcanic A-type igneous rocks\textsuperscript{16}.
Early Neoproterozoic passive margin and intracontinental sedimentation was overlain by orogenic sedimentary successions as young as 580 Ma\(^{16}\) contemporaneous with other basins within the central and north BP\(^{33}\). The lithological boundary of the SFC and BP is defined in many geological maps (Fig. 1A), however seismic data indicate that the lithospheric cratonic signature at 100 km depth extend further north ending within the central portion of BP\(^{34}\) (Fig. 1C).

During the Late Neoproterozoic, from 650 to 610 Ma, predating continental collisional events, continental magmatic arcs developed in the west\(^{23}\) and south\(^{35}\) parts of the province, closing intervening oceanic basins. During the collisions that ensued the province was squeezed between two impinging continents, one continent coming in from the west and the other, the São Francisco Craton, coming in from the south\(^{19}\). As a consequence, the BP “escaped” obliquely with the development of a throughgoing network of transcurrent shear zones\(^{19,20}\) that shear and limits Archean-Paleoproterozoic terranes of unknown origin\(^{36–38}\), such as the Alto Moxotó Terrane\(^{24}\) (Fig. 1). Just how these old terranes became involved in the orogen remains unclear.

**Results**

**U-Pb ages, Nd isotopic spatial distribution and crustal growth**

The U-Pb ages of igneous rocks in the northern SFC and Benino-Nigerian Shield show a similar pattern to those of the ancient basement terranes in the BP, recording similar episodes of crust production during the Archean and mostly the Paleoproterozoic (Figs. 2A). In the Neoproterozoic, U-Pb age of igneous rocks from the BP shows two intervals of crust production at 1.0-0.92 Ga and 0.67-0.52 Ga, with a few ages < 0.50 Ga (Fig. 2B). Both intervals are characterized by production of new juvenile crust combined with recycling of old pre-existing crust. The spatial distribution of the interpolated U-Pb ages and \(\varepsilon_{Nd}(t)\) values (Fig. 1D and E), excluding the areas covered by sedimentary and metasedimentary rocks, was used to estimate the crustal growth during the Borborema Province Orogen (see methods and supplementary figure S1).

The gridded values resulted in a map with 46,426 pixels with a pixel size of 3.2 x 3.2 km (pixel area=10.24 km\(^2\)). These pixels where clipped to the crystalline basement area of the Borborema Province, excluding the Neoproterozoic metasedimentary belts, Phanerozoic basins and more recent cover, resulting in a map with 17,235 pixels with a total area of 176,486 km\(^2\). Pixel values of Nd model ages (Fig. 1B) were binned into 100 m.yr. interval, from 500 to 3400 Ma, and so were the U-Pb crystallization ages from individual rock samples. Positive \(\varepsilon_{Nd}(t)\) values were used to distinguish juvenile addition of new crust to the Borborema Province through time.

The results based on the exposed surface area, incorporating both zircon U-Pb and Nd isotopes, indicate that 65-60% of the province was already formed by the end of the Paleoproterozoic, with a rapid growth
rate between 2.3 to 2.0 Ga, when 55-50% of the continental crust of the Borborema Province formed (Fig. 2C). During the Early Neoproterozoic, from 1.0 to 0.7 Ga, new juvenile additions accounts for ~ 20% of the crust. This period includes the early stages of the Santa Quitéria arc at c. 0.85 Ga and magmatism related to the Cariris Velhos event from c. 1.0 to 0.92 Ga. The production of new continental crust during the main Neoproterozoic orogenic period, between 0.67 and 0.52 Ga, accounts for only ~ 15% of the new continental crust in the province, suggesting the orogeny was characterized by whole-sale lithospheric reworking with minor juvenile magma input.

Transpression and correlation of terranes

Another aspect revealed by our data compilation and geophysical image investigation is the link between old Paleoproterozoic and Archean terranes across the province. The Southern Borborema Orogen (Figs. 1A, 1B and 3), is split into the Sergipano and Riacho do Pontal fold-and-thrust belts by a promontory of the São Francisco Craton, well-defined in the Nd isotopic model age map (Fig. 1B) and geological maps. This promontory forms the Entremontes block and may mark an inherited feature of the paleocontinental passive margin inverted during onset of the Southern Borborema Orogen. It comprises mainly Archean gneisses and migmatites and Paleoproterozoic gneisses and supracrustal rocks.

The combination of our field data and available geological maps, isotopic data and geophysical images show that the Entremontes Block is bound by the Pernambuco shear zone in the north and the Boa Vista shear zone in the south (Fig. 3A). Movement on these shear zones forced block rotation and internal deformation of the block under a transpressive regime (Fig. 3B) leading to the folds documented in the aeromagnetic images at wavelengths of 5 to 20 km with 2D axial planes subparallel to the shear zones (block diagram in Fig. 3B). In outcrop, folds are tight and fold a previous foliation (Sn), generating a steep axial plane (Sn+1) permeated by leucosomes indicative of syn-tectonic partial melting (Fig. 3B). Stretching lineation has low rake and is commonly parallel to the fold axes plunging at low angles to WSW or ENE. Kinematic indicators on Sn+1 planes indicate consistent top-to-NE or E transport in the Entremontes block (Fig. 3A). This direction could either be a result of rotation of early-formed shear zones, or formed contemporaneously with transcurrent movement, defining a constrictional transpressional belt. The metasedimentary Riacho do Pontal fold-and-thrust belt, west of the Entremontes block, includes the Afeição domain comprising Tonian metasedimentary rocks. In contrast to the Entremontes, the direction of tectonic transport for the entire Riacho do Pontal belt is dominantly top-to SW, thrusting the belt over the SFC (Fig. 3A).

The geophysical and Nd isotopic characteristics of the ancient Entremontes block and the Tonian-age Afeição domain can be recognized in the central Borborema province, north of the Pernambuco shear zone, displaced dextrally by ≈ 200 km and deformed into sigmoidal terranes characteristic of the BP (Fig. 3 and supplementary figure S1). U-Pb ages and Eps Nd(t), as well as K-Th-U contents, as recorded in the radiometric images (supplementary figure S1), show that the Afeição domain can be linked with the contemporaneous Alto Pajeú domain, and the Entremontes block can be tracked into the Alto Moxotó
domain, also composed of Paleoproterozoic and Archean gneisses and migmatites\textsuperscript{24,37}. The Alto Moxotó terrane includes high-grade Late Neoproterozoic metasedimentary rocks of the Surubim Complex that can be correlated to the lower-grade equivalents of the Riacho do Pontal fold-and-thrust belt and of the Cabrobó Complex overthrusting the Entremontes block. The Surubim Complex and these lower grade-rocks share similar detrital zircon age signatures\textsuperscript{40–42}.

In summary, much of the Borborema province has old Nd model ages and zircon population signatures similar to the São Francisco Craton/Benino-Nigerian Shield (Fig. 1 and 2A), suggesting direct or indirect derivation from these areas. The stepwise process of breakdown and involvement of cratonic blocks is preserved at the margin of the craton, where increased deformation of cratonic blocks is recorded across the Pernambuco shear zone and associated with a dextral displacement of \( \approx 200 \) km.

**Discussion: Decratonization, Terrane Dispersion And Reworking**

We suggest that Tonian extension, recorded by bimodal magmatism and rift-related sedimentation followed by passive margin sedimentation, would have opened a narrow ocean recorded by marginal ophiolites dated at ca. 0.82 Ga, breaking apart the greater São Francisco Craton/Benino-Nigerian Shield\textsuperscript{18} (Fig. 4A). This process pulled out crustal ribbons, such as the Pernambuco-Alagoas terrane (PEAL, Fig. 4A), from the cratonic margin by ca. 0.82 Ga\textsuperscript{15} and continued to 0.72-0.68 Ga with the last pulses of rifting recorded by the mafic-ultramafic intrusive rocks of the Canindé Group in the Southern Borborema Province\textsuperscript{16}.

The break-up of the conjoined São Francisco Craton/Benino-Nigerian Shield during extension indicates that decratonization started already in the Early Neoproterozoic, in a manner akin to the Mesozoic decratonization of the North China Craton\textsuperscript{9}, where extension associated with metasomatism\textsuperscript{10} transferred continental lithospheric mantle to the asthenosphere\textsuperscript{43} and facilitated continental breakup\textsuperscript{44}. This hypothesis is supported by alkaline volcanism (e.g. kimberlites) in the northern SFC from 1150 to 680 Ma\textsuperscript{45,46}.

The long-term effect of extension on lithospheric strength depends on the relative thinning of the crust in relation to the sub-continental lithospheric mantle (SCLM)\textsuperscript{47,48}. Starting from a thick Archean lithosphere, as for the SFC\textsuperscript{49,50}, Tonian thinning and refertilization of the SCLM (indicated by the alkaline volcanism), would have led to weakening that persisted long-after extension ended. Thus, the Tonian extensional event would have made sections of the cratonic paleocontinent amenable to subsequent reworking within the orogenic realm.

This weakened, decratonized lithosphere between the Benino-Nigerian Shield and the São Francisco Craton was reworked in two steps during the construction of the Borborema Province Orogen. The first step was a result of oblique continental collision with the West African Craton being thrust under the Benino-Nigerian Shield\textsuperscript{17,26,51,52}. This was preceded by oceanic lithosphere subduction and magmatism in the aforementioned Santa Quiteria arc, and terminal collision led to the development of the dextral
Transbrasiliano-Kandi strike-slip belt (Fig. 4B and C). The second step was a result of dextral movement on the Transbrasiliano-Kandi strike-slip belt. This movement brought the Benino-Nigerian Shield closer to the São Francisco Craton deforming the weakened decratonized area in between these two stiffer lithospheric domains leading to the transpressional Borborema Province Orogeny (see cross section in Fig. 4D).

The transcurrent shear zones that characterize the Borborema Province splayed out of the Transbrasiliano-Kandi shear zone and deformed the weakened cratonic margin. Deformation was a result of these two quasi-contemporaneous collisions (Fig. 4D). In the north part of the Borborema Province, old Paleoproterozoic and minor volumes of Archean rocks dominate and represent the southern continuation of the Benino-Nigerian Shield (north of the Patos shear zone in Figure 1B). To the south, the Borborema Province record the interaction of the decratonized lithosphere and the São Francisco Craton. In this region, the transcurrent shear zones wrenched the blocks of the northern margin of the São Francisco Craton that had been previously weakened by the Cariris Velho extension. Deformation included a number of continental ribbons (e.g. PEAL terrane) pulled away from the craton and the intervening Tonian sedimentary basins (Fig. 4C and D).

The exact geometry of the decratonized terrane at the start of wrenching, and the source region of individual blocks now embedded in the BP are generally unknown. However, using rock ages, isotopic and geophysical signatures, we have linked the Tonian-aged Afeicão domain and the ancient Entremontes block south of the Pernambuco shear zone, with the Tonian-age Alto Pajeú and the ancient Alto Moxotó terranes, north of the shear zone. This implies a ≈ 200 km dextral wrenching across the Pernambuco shear zone (Fig. 3). The rocks south of the shear zone record only incipient deformation, whereas those to the north are intensely strained into sigmoidal terranes, in harmony with the regional transcurrent deformation and geological-geophysical structure of this region.

It is also possible to recognize signatures of specific sections of the SFC in the old blocks now within the BP. For example, the geological features of the Gavião Block in the SFC can be found in blocks within the Central and Northern Borborema Province. These features include rare occurrences of Paleoarchean rocks (>3.4 Ga) embedded in Neoarchean (2.8-2.6 Ga) to Paleoproterozoic (2.1-2.0 Ga) rocks imprinted by ca. 2.0 Ga high-grade metamorphism. We conclude that deformation of craton margin blocks, such as the Entremontes block, into the sigmoidal-shaped Alto Moxotó terrane within the Borborema Province, illustrates how a number of other Archean-Paleoproterozoic blocks may have been pulled away from the original craton to form inliers within the orogeny. It is important to note, however, that dispersal of São Francisco Craton decratonized blocks was more effective along the southern and central zones of the Borborema Province, where evidence for Cariris Velhos extensional events has been better defined. The Benino-Nigerian Shield also comprises Paleoarchean rocks of ca. 3.5 Ga such as the Kaduna Massif that could be linked to the São José do Campestre Massif of the northern Borborema Province, unrelated to the orogenic dispersal of former cratonic fragments documented in the province’s southern and central zones.
Decratonization related to early to late Neoproterozoic extension and juvenile magmatism could have been widespread throughout West Gondwana, related to the break-up of Rodinia. For example, it might account for thinning of the cratonic lithosphere in the Ribeira and Araçuaí belts of southeastern Brazil, decratonizing the eastern margin of the SFC, preparing it for later involvement in the transcurrent Brasiliano tectonics. In the Araçuaí Belt fissural mafic magmatism preceded the opening of the Adamastor Ocean starting at 1.0 Ga with subsequent Tonian rift-related, A-type continental plutonism, dated at c. 0.87 Ga. Further south, in the Dom Feliciano-Kaoko belt, rift-related siliciclastic and bimodal volcanic rocks preserved in the Neoproterozoic schist belts from both the Rio de la Plata/Paranapanema and Congo/Kalahari cratonic margins suggest a continental rifting phase between 0.9 and 0.78 Ga. In the African side of these orogens (e.g. Gariep, Kaoko and Damara-Lufilian belts) extensional tectonics and breakup of surrounding cratons are also constrained to between 0.85 to 0.77 Ga. These protracted extensional events preceding the Brasiliano/Panafrican orogens of coastal South America and their African equivalents, disrupted and weakened the surrounding cratons enabling orogenic reworking and transcurrent dispersal of old terranes such as the São Luiz, Curitiba, and Cabo Frio terranes. The same could account for Archean/Paleoproterozoic lithosphere in the West Gondwana Orogen in Africa where c. 1.1-1.0 Ga extension in the Tuareg Shield allowed reworking during the Pan-African Orogeny.

Global estimates for the construction of Gondwana between 0.5-0.6 Ga indicate only a minor mantle addition, in accordance to our observations. This final stage of reworking and transcurrent tectonics was accompanied by abundant syn-transcurrent magmatism with dominant lithospheric mantle affinities from 590 to 560 Ma, but peaking at c. 580 Ma. The orogenic collisional period of BP resulted in crustal thickening (>80 km), especially along the West Gondwana Orogen, however, Rayleigh wave tomography indicate that this orogen are marked by thinner lithosphere, thus suggesting that the orogenic roots have been delaminated after collision. The lithospheric mantle signatures of the 590 to 560 Ma syn-transcurrent and post-collisional magmatism may reflect the delamination of the orogenic lithosphere, resulting in low-viscosity zones that would facilitate lateral crustal flow leading to the processes of scape tectonics and terrane dispersion in the Borborema Province (cross section in Figure 4B). Finally, Ar-Ar cooling ages and emplacement of poorly deformed to isotropic granitoids indicate slow cooling rates with continuous heat supply by the delamination process until the Cambrian (530-500 Ma).

We conclude that the cratonic roots of the São Francisco Craton/Benino-Nigerian Shield, responsible for craton integrity, were weakened by Tonian-age extension, similar to the evolution of the North China Craton where extension and alkaline magmatism provided a mechanism for decratonization. This created the conditions required for the involvement and dispersal of decratonized inliers within the Brasiliano orogen. We suggest that this may have been the general sequence of events for many of the Brasiliano/Panafrican orogens, where extension related to the break-up of cratonic masses and opening
of oceanic realms with varying degrees of maturity were followed by convergence and wrench tectonics during Gondwana amalgamation.

**Methods**

**Nd isotopic maps.**

In order to discriminate terranes with similar signatures, a large compilation comprising 360 zircon U-Pb ages and 1331 Sm-Nd whole-rock isotope analyses of samples from the BP and the northern SFC were used (Fig. 1B). Sm-Nd isotope distribution of a large number of samples is suitable to identify correlated terranes due to resistance of the Sm-Nd isotope system to post-crystallization thermal disturbance. Data were downloaded from the open sources DateView and the Geological Survey of Brazil database (http://geosgb.cpr.m.gov.br). Due to the scarcity of the U-Pb crystallization ages from the Benino-Nigerian Shield, for this region we use the individual zircon ages for dated metaigneous rocks available in the global zircon compilation of reference [73]. The compilation was augmented with data from the literature. Most of the data is from (meta)igneous rocks with subordinated input from metasedimentary rocks.

In general, Nd model ages (TDM) do not correspond to a specific crust-formation event but instead reflect mixing of material derived from the mantle at different times and are determined by calculating the time when a sample had an isotopic composition identical to that of its source, so they can be understood as minimum ages of crust formation. For figure 1B we used Sm-Nd TDM ages as originally reported by different authors (Table 1 of supplementary material). The Sm-Nd TDM ages were gridded in the ArcGIS software using the Inverse-Distance-Weighted Interpolation (IDW). Since significant discontinuities modify the surrounding geological environment, we define the major shear zones as interpolation barriers. We also applied the Gaussian low-pass filter to attenuate high frequencies due to variable spacing between samples. We compared compiled U-Pb zircon crystallization ages and freely available geological maps (http://geosgb.cpr.m.gov.br) of the Northern SFC and BP to cross-check terrane affinity based on the Sm-Nd TDM map, to identify old terranes within the Borborema orogenic province. From the compiled Sm-Nd dataset only data with reported ppm content of Nd, Sm and $^{143}$Nd/$^{144}$Nd ratio associated with reliable reported U-Pb ages for the magmatic crystallization were considered for building the eNd$_{t}$ maps and further crustal growth curve for the Borborema Province. This resulted in 889 data points with assigned geographical position and recalculated $^{147}$Sm/$^{144}$Nd ratio. A new screening was applied to eliminate unreliable $^{147}$Sm/$^{144}$Nd resulting in the 837 data points that were used for further gridding of eNd$_{t}$ values, as described above (Fig. 3). The gridded values resulted in a map with 46,426 pixels with a pixel size of 3.2 x 3.2 km (pixel area=10.24 km$^2$). These pixels where clipped to the igneous crystalline area of the Borborema Province, excluding the Neoproterozoic metasedimentary belts, Phanerozoic basins and more recent cover, resulting in a map with 17,235 pixels with a total area of 176,486 km$^2$. Pixel values were further binned to 100 m.yr. interval, from 500 to 3400 Ma, along with U-Pb crystallization ages from individual rock samples. The eNd$_{t}$ cut-off value of zero where used to distinguish juvenile addition of new crust from reworked crust in the Borborema Province through time.
The pixels with eNd > 0 were binned to 100 m.yr. and the cumulative percentage area covered by juvenile rocks was used to infer the crustal growth of Borborema Province from 3.4 to 0.5 Ga. Figure S1 (supplementary material) show the data distribution used to grid the Sm-Nd TDM ages.

**Magnetic maps.**

The airborne magnetic database comprises data from seven surveys between 2001 and 2010, with 500 m flight-line spacing in the N-S direction and flight height of 100 m ([http://geosgb.cprm.gov.br](http://geosgb.cprm.gov.br)). The Total Magnetic Intensity map (TMI) was created by interpolating the magnetic data into a 125 m grid cell size using the bi-directional method and subsequently filtered by a Gaussian low-pass filter. To highlight the regional tectonic framework, we calculated the first vertical derivative of TMI (1VD).

**Declarations**

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**AUTHOR CONTRIBUTIONS**

C.E.G. and R.F.W. conceived the idea and wrote the paper. F.A.C. contributed to the discussion and revised the paper. C.E.G., R.F.W., L.B.L.L., L.R.T. conducted the field investigation and image interpretation. C.E.G, L.B.L.L. and I.C compiled the isotopic data and conducted the 2-D griding of the data into isotopic maps.

**References**

1. Jordan, T. H. The continental tectosphere. Rev. Geophys. 13, 1 (1975).
2. Liégeois, J. P, Abdelsalam, M. G., Ennih, N. & Ouabadi, A. Metacraton: Nature, genesis and behavior. Gondwana Res. 23, 220–237 (2013).
3. Sonder, L. J. & England, P. Vertical averages of rheology of the continental lithosphere: relation to thin sheet parameters. Earth Planet. Sci. Lett. 77, 81–90 (1986).
4. England, P. C. Diffuse continental deformation: length scales, rates and metamorphic evolution. Philos. Trans. R. Soc. London. Ser. A, Math. Phys. Sci. 321, 3–22 (1987).
5. Neil, E. A. & Houseman, G. A. Geodynamics of the Tarim Basin and the Tian Shan in central Asia. Tectonics 16, 571–584 (1997).
6. Ziegler, P. A., Cloetingh, S. & van Wees, J.-D. Dynamics of intra-plate compressional deformation: the Alpine foreland and other examples. Tectonophysics 252, 7–59 (1995).

7. Butler, R. W. H., Holdsworth, R. E. & Lloyd, G. E. The role of basement reactivation in continental deformation. J. Geol. Soc. London. 154, 69–71 (1997).

8. Holdsworth, R. E., Butler, C. A. & Roberts, A. M. The recognition of reactivation during continental deformation. J. Geol. Soc. London. 154, 73–78 (1997).

9. Yang, J. H., Wu, F. Y., Wilde, S. A., Belousova, E. & Griffin, W. L. Mesozoic decretion of the North China block. Geology 36, 467–470 (2008).

10. Wang, C., Song, S., Niu, Y. & Su, L. Late Triassic adakitic plutons within the Archean terrane of the North China Craton: Melting of the ancient lower crust at the onset of the lithospheric destruction. Lithos 212–215, 353–367 (2015).

11. Kusky, T. M., Windley, B. F. & Zhai, M.-G. Tectonic evolution of the North China Block: from orogen to craton to orogen. In Mesozoic Sub-Continental Lithospheric Thinning Under Eastern Asia (eds. Zhai, M.-G., Windley, B. F., Kusky, T. M. & Meng, Q. R.) 280, 1–34 (Geological Society, London, Special Publications, 2007).

12. Griffin, W. L., O'Reilly, S. Y., Afonso, J. C. & Begg, G. C. The Composition and Evolution of Lithospheric Mantle: a Re-evaluation and its Tectonic Implications. J. Petrol. 50, 1185–1204 (2009).

13. Guimarães, I. P. et al. U-Pb zircon ages of orthogneisses and supracrustal rocks of the Cariris Velhos belt: Onset of Neoproterozoic rifting in the Borborema Province, NE Brazil. Precambrian Res. 192–195, 52–77 (2012).

14. Salgado, S. S. et al. The Ni-Cu-PGE mineralized Brejo Seco mafic-ultramafic layered intrusion, Riacho do Pontal Orogen: Onset of Tonian (ca. 900 Ma) continental rifting in Northeast Brazil. J. South Am. Earth Sci. 70, 324–339 (2016).

15. Caxito, F. de A., Uhlein, A. & Dantas, E. L. The Afeição augen-gneiss Suite and the record of the Cariris Velhos Orogeny (1000–960 Ma) within the Riacho do Pontal fold belt, NE Brazil. J. South Am. Earth Sci. 51, 12–27 (2014).

16. Oliveira, E. P., Windley, B. F. & Araújo, M. N. C. The Neoproterozoic Sergipano orogenic belt, NE Brazil: A complete plate tectonic cycle in western Gondwana. Precambrian Res. 181, 64–84 (2010).

17. Ganade, C. E. et al. Tightening-up NE Brazil and NW Africa connections: New U-Pb / Lu-Hf zircon data of a complete plate tectonic cycle in the Dahomey belt of the West Gondwana Orogen in Togo and Benin. Precambrian Res. 276, 24–42 (2016).

18. Caxito, F. de A. et al. Toward an integrated model of geological evolution for NE Brazil-NW Africa: The Borborema Province and its connections to the Trans-Saharan (Benino-Nigerian and Tuareg shields) and Central African orogens. Brazilian J. Geol. 50, (2020).

19. Ganade de Araujo, C. E., Weinberg, R. F. & Cordani, U. G. Extruding the Borborema Province (NE-Brazil): a two-stage Neoproterozoic collision process. Terra Nova 26, 157–168 (2013).

20. Vauchez, A. et al. The Borborema shear zone system, NE Brazil. J. South Am. Earth Sci. 8, 247–266 (1995).
21. Neves, S. P., Araújo, A. M. B., Correia, P. B. & Mariano, G. Magnetic fabrics in the Cabanas Granite (NE Brazil): Interplay between emplacement and regional fabrics in a dextral transpressive regime. J. Struct. Geol. 25, 441–453 (2003).
22. Fetter, A. H. et al. Evidence for Neoproterozoic continental arc magmatism in the Santa Quitéria Batholith of Ceará State, NW Borborema Province, NE Brazil: Implications for the assembly of West Gondwana. Gondwana Res. 6, 265–273 (2003).
23. Ganade de Araújo, C. E. et al. Tracing Neoproterozoic subduction in the Borborema Province (NE-Brazil): Clues from U-Pb geochronology and Sr-Nd-Hf-O isotopes on granitoids and migmatites. Lithos 202–203, 167–189 (2014).
24. Santos, L. C. M. d. L. et al. Accretion Tectonics in Western Gondwana Deduced From Sm-Nd Isotope Mapping of Terranes in the Borborema Province, NE Brazil. Tectonics 37, 2727–2743 (2018).
25. Ferreira, A. C. D., Dantas, E. L., Fuck, R. A. & Nedel, I. M. Arc accretion and crustal reworking from late Archean to Neoproterozoic in Northeast Brazil. Sci. Rep. 10, 7855 (2020).
26. Ganade de Araújo, C. E. et al. Ediacaran 2,500-km-long synchronous deep continental subduction in the West Gondwana Orogen. Nat. Commun. 5, 5198 (2014).
27. Santos, T. J. S. dos et al. U-Pb age of the coesite-bearing eclogite from NW Borborema Province, NE Brazil: Implications for western Gondwana assembly. Gondwana Res. 28, 1183–1196 (2015).
28. Caxito, F., Uhlein, A., Stevenson, R. & Uhlein, G. J. Neoproterozoic oceanic crust remnants in northeast Brazil. Geology 42, 387–390 (2014).
29. Pitombeira, J. P. A. et al. Vestiges of a continental margin ophiolite type in the Novo Oriente region, Borborema Province, NE Brazil. J. South Am. Earth Sci. 73, 78–99 (2017).
30. da Silva, L. C., Pedrosa-Soares, A. C., Teixeira, L. R. & Armstrong, R. Tonian rift-related, A-type continental plutonism in the Araçuaí Orogen, eastern Brazil: New evidence for the breakup stage of the São Francisco–Congo Paleocontinent. Gondwana Res. 13, 527–537 (2008).
31. Brito Neves, B. B. de, dos Santos, E. J. & Van Schmus, W. R. Tectonic history of the Borborema Province. in Tectonic Evolution of South America (eds. Cordani, U. G., Milani, E. J., Thomaz Filho, A. & Campos, D. A.) 31, 151–182 (31st International Geological Congress Rio de Janeiro, 2000).
32. Neves, S. P., Lages, G. A., Brasilino, R. G. & Miranda, A. W. A. Paleoproterozoic accretionary and collisional processes and the build-up of the Borborema Province (NE Brazil): Geochronological and geochemical evidence from the Central Domain. J. South Am. Earth Sci. 58, 165–187 (2015).
33. Van Schmus, W. R., Kozuch, M. & de Brito Neves, B. B. Precambrian history of the Zona Transversal of the Borborema Province, NE Brazil: Insights from Sm-Nd and U-Pb geochronology. J. South Am. Earth Sci. 31, 227–252 (2011).
34. Simões Neto, F. L., Julià, J. & Schimmel, M. Upper-mantle structure of the Borborema Province, NE Brazil, from P-wave tomography: Implications for rheology and volcanism. Geophys. J. Int. 216, 231–250 (2019).
35. Silva, T. R. da, Ferreira, V. P., Lima, M. M. C. de, Sial, A. N. & Silva, J. M. R. da. Synkinematic emplacement of the magmatic epidote bearing Major Isidoro tonalite-granite batholith: Relicts of an
36. Dantas, E. L. et al. Crustal growth in the 3.4-2.7Ga São José de Campestre Massif, Borborema Province, NE Brazil. Precambrian Res. 227, 120–156 (2013).

37. Cruz, R. F. da, Pimentel, M. M., Accioly, A. C. de A. & Rodrigues, J. B. Geological and isotopic characteristics of granites from the Western Pernambuco-Alagoas Domain: implications for the crustal evolution of the Neoproterozoic Borborema Province. Brazilian J. Geol. 44, 627–652 (2014).

38. Pitarello, M. Z., Santos, T. J. S. do. & Ancelmi, M. F. Syn-to post-depositional processes related to high grade metamorphic BIFs: Geochemical and geochronological evidences from a Paleo to Neoarchean (3.5–2.6Ga) terrane in NE Brazil. J. South Am. Earth Sci. 96, 102312 (2019).

39. Guimarães, I. P. et al. Tonian granitic magmatism of the Borborema Province, NE Brazil: A review. J. South Am. Earth Sci. 68, 97–112 (2016).

40. Caxito, F. A. et al. A complete Wilson Cycle recorded within the Riacho do Pontal Orogen, NE Brazil: Implications for the Neoproterozoic evolution of the Borborema Province at the heart of West Gondwana. Precambrian Res. 282, 97–120 (2016).

41. Cruz, R. F. da, Pimentel, M. M. & Accioly, A. C. de A. Provenance of metasedimentary rocks of the Western Pernambuco-Alagoas Domain: Contribution to understand the crustal evolution of southern Borborema Province. J. South Am. Earth Sci. 56, 54–67 (2014).

42. Neves, S. P. et al. The age distributions of detrital zircons in metasedimentary sequences in eastern Borborema Province (NE Brazil): Evidence for intracontinental sedimentation and orogenesis? Precambrian Res. 175, 187–205 (2009).

43. Carlson, R. W., Pearson, D. G. & James, D. E. Physical, chemical, and chronological characteristics of continental mantle. Rev. Geophys. 43, 1–24 (2005).

44. Tappe, S. et al. Craton reactivation on the Labrador Sea margins: 40Ar/39Ar age and Sr–Nd–Hf–Pb isotope constraints from alkaline and carbonatite intrusives. Earth Planet. Sci. Lett. 256, 433–454 (2007).

45. Pereira, R. S. & Fuck, R. A. Archean Nucleii and The Distribution of Kimberlite and Related Rocks in the São Francisco Craton, Brazil. Rev. Bras. Geociências 35, 93–104 (2005).

46. Donatti-Filho, J. P., Tappe, S., Oliveira, E. P. & Heaman, L. M. Age and origin of the Neoproterozoic Brauna kimberlites: Melt generation within the metasomatized base of the São Francisco craton, Brazil. Chem. Geol. 353, 19–35 (2013).

47. Tommasi, A. & Vauchez, A. Continental-scale rheological heterogeneities and complex intraplate tectono-metamorphic patterns: Insights from a case-study and numerical models. Tectonophysics 279, 327–350 (1997).

48. Burov, E. B. Rheology and strength of the lithosphere. Mar. Pet. Geol. 28, 1402–1443 (2011).

49. Grand, S. P. Mantle shear structure beneath the Americas and surrounding oceans. J. Geophys. Res. 99, (1994).
50. VanDecar, J. C., James, D. E. & Assumpção, M. Seismic evidence for a fossil mantle plume beneath South America and implications for plate driving forces. Nature 378, 25–31 (1995).

51. Caby, R. Precambrian terranes of Benin-Nigeria and northeast Brazil and the Late Proterozoic south Atlantic t. in Terranes in the Circum-Atlantic Paleozoic Orogens (ed. Dallmeyer, R. D.) 145–158 (1989). doi:10.1130/SPE230-p145

52. Castaing, C., Feybesse, J. L., Thiéblemont, D., Triboulet, C. & Chèvremont, P. Palaeogeographical reconstructions of the Pan-African/Brasiliano orogen: closure of an oceanic domain or intracontinental convergence between major blocks? Precambrian Res. 69, 327–344 (1994).

53. Oliveira, E. P., McNaughton, N. J., Zincone, S. A. & Talavera, C. Birthplace of the São Francisco Craton, Brazil: Evidence from 3.60 to 3.64 Ga Gneisses of the Mairi Gneiss Complex. Terra Nova 1–9 (2020). doi:10.1111/ter.12460

54. Barbosa, J. S. F. & Sabaté, P. Archean and Paleoproterozoic crust of the São Francisco Craton, Bahia, Brazil: geodynamic features. Precambrian Res. 133, 1–27 (2004).

55. Kröner, A., Ekwueme, B. N. & Pidgeon, R. T. The Oldest Rocks in West Africa: SHRIMP Zircon Age for Early Archean Migmatitic Orthogneiss at Kaduna, Northern Nigeria. J. Geol. 109, 399–406 (2001).

56. Heilbron, M. et al. The Ribeira Belt. in São Francisco Craton, Eastern Brazil: Tectonic Genealogy of a Miniature Continent (eds. Heilbron, M., Cordani, U. G. & Alkmim, F. F.) 277–302 (Springer International Publishing, 2017). doi:10.1007/978-3-319-01715-0_15

57. Egydio-Silva, M., Vauchez, A., Fossen, H., Gonçalves Cavalcante, G. C. & Xavier, B. C. Connecting the Araçuaí and Ribeira belts (SE – Brazil): Progressive transition from contractional to transpressive strain regime during the Brasiliano orogeny. J. South Am. Earth Sci. 86, 127–139 (2018).

58. Pedrosa-Soares, A. C. & Alkmim, F. F. de. How many rifting events preceded the development of the Araçuaí-West Congo orogen? Geonomos 19, 244–251 (2011).

59. Chaves, A. de O., Ernst, R. E., Söderlund, U., Wang, X. & Naeraa, T. 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 (2019).

60. Basei, M. A. S. et al. The Tectonic History of the Southern Adamastor Ocean Based on a Correlation of the Kaoko and Dom Feliciano Belts. in Geology of Southwest Gondwana (eds. Siegesmund, S., Basei, M. A. S., Oyhantçabal, P. & Oriolo, S.) 63–85 (Springer International Publishing, 2018). doi:10.1007/978-3-319-68920-3_3

61. Johnson, S. P. et al. Geochronology of the Zambezi Supracrustal Sequence, Southern Zambia: A Record of Neoproterozoic Divergent Processes along the Southern Margin of the Congo Craton. J. Geol. 115, 355–374 (2007).

62. Frimmel, H. E., Basei, M. S. & Gaucher, C. Neoproterozoic geodynamic evolution of SW-Gondwana: a southern African perspective. Int. J. Earth Sci. 100, 323–354 (2011).

63. Konopásek, J., Košler, J., Tajčmanová, L., Ulrich, S. & Kitt, S. L. 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. London. 165, 153–165 (2008).
64. Passarelli, C. R., Basei, M. A. S., Siga, O. & Harara, O. M. M. The Luis Alves and Curitiba Terranes: Continental Fragments in the Adamastor Ocean. in Geology of Southwest Gondwana (eds. Siegesmund, S., Basei, M. A. S., Oyhantçabal, P. & Oriolo, S.) 189–215 (Springer International Publishing, 2018). doi:10.1007/978-3-319-68920-3_8

65. Schmitt, R. da S., Trouw, R., Van Schmus, W. R., Armstrong, R. & Stanton, N. S. G. The tectonic significance of the Cabo Frio Tectonic Domain in the SE Brazilian margin: a Paleoproterozoic through Cretaceous saga of a reworked continental margin. Brazilian J. Geol. 46, 37–66 (2016).

66. Dhuime, B., Hawkesworth, C. J., Cawood, P. A. & Storey, C. D. A Change in the Geodynamics of Continental Growth 3 Billion Years Ago. Science 335, 1334–1336 (2012).

67. Neves, S.P et al. Intralithospheric differentiation and crustal growth: Evidence from the Borborema province, northeastern Brazil. Geology 28, 519-522 (2000).

68. Guimarães, I.P. et al. Brasiliano (Pan-African) granite magmatism in the Pajeú-Paraíba belt, Northeast Brazil: anisotopic and geochronological approach. Precambr. Res. 135, 23–53 (2004).

69. McKenzie, D., Daly, M. C., & Priestley, K. The lithospheric structure of Pangea. Geology 43, 783-786 (2015).

70. Meissner, R., & Mooney, W. Weakness of the lower continental crust: a condition for delamination, uplift, and escape. Tectonophysics 296, 47-60 (1998).

71. Schoene, B., Dudas, F. O. L., Bowring, S. A. & de Wit, M. Sm-Nd isotopic mapping of lithospheric growth and stabilization in the eastern Kaapvaal craton. Terra Nova 21, 219–228 (2009).

72. Eglington, B. M. DateView: A windows geochronology database. Comput. Geosci. 30, 847–858 (2004).

73. Puetz, S. J. et al. Quantifying the evolution of the continental and oceanic crust. Earth-Science Rev. 164, 63–83 (2017).

74. Arndt, N. T. & Goldstein, S. L. Use and abuse of crust-formation ages. Geology 15, 893 (1987).