Precambrian Research 379 (2022) 106805

Contents lists available at ScienceDirect

Precambrian Research

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

The Dynamic Neoproterozoic Evolution of eastern Brazil: Crustal evolution, supercontinent assembly and breakup

1. Introduction

The Neoproterozoic was a dynamic time in Earth's evolution, hosting the breakup of the supercontinent Rodinia and formation of the subsequent supercontinent Gondwana. This change in plate tectonic organization resulted in extreme global climate changes, including several global glaciation events (Hoffman and Li, 2009; Rooney et al., 2015). The Neoproterozoic was also a time when significant changes occurred to the global crustal volume and thickness (Dhuime et al., 2015; Cawood and Hawksworth, 2019) as well as the widespread appearance of blueschists (Stern, 2005; Palin and White, 2016), indicating fundamental changes in plate tectonic processes at this time (Brown, 2010; Palin and White, 2016).

Eastern Brazil has an excellent record of Neoproterozoic geological processes with well-preserved sedimentary sequences (i.e., Macaúbas Group and São Francisco Supergroup) as a result of crustal extension in the early Neoproterozoic. Later continental collision due to the formation of Gondwana has created several linked orogenic belts, here divided into three main provinces: Tocantins, Mantiqueira and Borborema (Fig. 1). In spite of the excellent rock record, eastern Brazil is an area where more work is necessary to resolve the nature of supercontinent formation and breakup. The rocks can also provide insights into processes such as ultra-high temperature metamorphism, as several of the Neoproterozoic collisional belts in eastern Brazil (collectively referred to as Brasiliano belts) record high temperature metamorphism (i.e., Moraes and Fuck, 2000; Campos Neto and Caby, 2000).

Lately, the Neoproterozoic record of eastern Brazil has been a topic of controversy, with some workers suggesting that the previously accepted model of a confined ocean basin that later closed during the Araçuaí orogeny (Alkmim et al., 2006; Pedrosa-Soares et al., 2001) actually contained no oceanic crust, and that instead, the Araçuaí orogen was the result of an intracratonic orogeny (Cavalcante et al., 2019; Fossen et al., 2017). Some workers also extend this intracratonic orogeny down to the Ribeira orogen (Meira et al., 2015; Fig. 1). Many of the works presented in this volume have some bearing on this debate. However, at present there, is no consensus on this topic, which we have chosen to reflect in this volume by including at least one work presenting each side in this debate.

We have several contributions on the Dom Feliciano Belt, the southernmost of the Brasiliano belts (Fig. 1), which add to the discussion on supercontinent break up and amalgamation using novel techniques such as boron isotopes in tourmaline analysed by laser ablation ICP-MS and *in situ* U-Pb dating of garnet (Werle et al., 2020; Cerva Alves et al., 2021).

The Brasilia belt is situated between the São Francisco Craton and Paranapanema block (Fig. 1). It has a protracted record of high temperature metamorphism with contributions in this volume aimed at understanding the cooling history of this metamorphism (Westin et al., 2021) and identifying and typifying UHT metamorphism within the belt (Motta et al., 2021).

The following nine contributions which make up our special issue represent the state-of-the-art for the Neoproterozoic evolution of eastern Brazil. The contributions are grouped based on the location where the work was carried out. Most contributions were carried out on samples from Brasiliano belts, with one study targeting the Borborema Province (Fig. 1).

2. Mantiqueira Province

2.1. Araçuaí Belt

The work of Santiago et al. (2020) presents geochemical and isotopic data from the Caxixe batholith. This batholith occurs on the transition zone of the Araçuaí and Ribeira orogens (Fig. 1). Results suggest that the batholith crystallized at ca. 860–850 Ma based on U-Pb analyses obtained from zircon cores. Based on hafnium isotopic data in zircon, the authors suggest that the Caxixe batholith represents part of a juvenile magmatic arc with a strong mantle contribution, similar to modern island arcs forming in a supra-subduction zone setting. This suggests the existence of a large ocean in the Tonian that underwent intraoceanic subduction.

Cavalcante et al. (2021) investigate the orogenic evolution of the hot Araçuaí belt using geochemical data of granitic rocks from the eastern domain of the Araçuaí belt. The results indicate that the Carlos Chagas domain (CCD) and Nova Venécia Complex of the Araçuaí belt contain high contents of heat producing elements (Th, U and K) and likely are the result of partial melting of the continental crust. In addition, macro- and micro-scales show that the CCD contains remnants of residuum material from metamorphic reactions associated with textures that attest to melt crystallization, suggesting that the CCD is locally derived. They propose that the CCD represents an in-source subhorizontal rheologically weak layer, which could have formed an orogenic plateau, sustaining lower crustal high-T conditions for tens of millions of years. The compositionally diverse magmatism of the Araçuaí belt is interpreted to be a result of this protracted evolution.

Souza et al. (2022) present new field, geochemical, isotope geochemistry and zircon U-Pb geochronology from two mafic suites associated with the Macaúbas basin of southeast Brazil. Mafic dikes of

https://doi.org/10.1016/j.precamres.2022.106805

Available online 30 July 2022

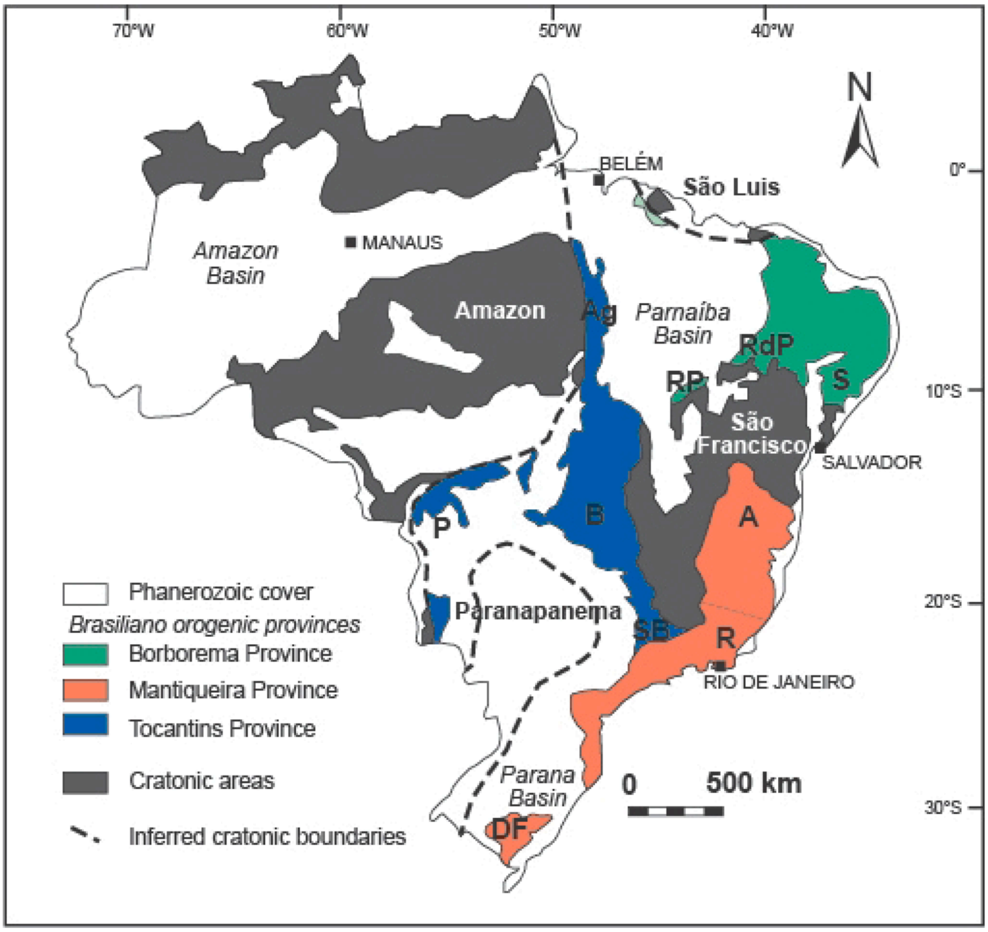

Fig. 1. Map of Brazil with locations of cratons and Brasiliano orogenic systems. Bold letters indicate the locations of Brasiliano aged orogenic belts. Abbreviations are: A, Araçuaí belt; Ag, Araguaia belt; B, Brasília belt; DF, Dom Feliciano belt, P, Paraguay belt, R, Ribeira belt, RdP, Riacho do Pontal belt, RP, Rio Preto belt; S, Sergipiano belt; SB, Southern Brasília belt. Adapted from Heilbron et al. (2017).

the Pedro Lessa suite produced ages between 951 and 940 Ma with a broad range of crustal contamination (εHf: −22 to +4.7). The Planalto de Minas Formation volcaniclastic rocks have a crystallisation age of 889 ± 10 Ma and a broad range of εHf_t contents (−19.27 to +10), with associated sediments producing maximum depositional ages of 867 ± 10 Ma. The results compiled with existing data suggest a time dependent evolution to more juvenile magma sources. The long lasting (ca. 100 My) anorogenic magmatism is attributed to more than one extensional event and related aborted continental rifts, despite its duration the mantle plume was not successful at breaking up the Sao Francisco-Congo landmass at this time.

2.2. Dom Feliciano Belt

The contribution of Werle et al. (2020) targets ophiolites and associated granites in the Dom Feliciano Belt (Fig. 1). This study uses boron isotopes in metasomatic tourmaline in conjunction with a U-Pb-Hf study of zircon from the intrusive granites. The results of this study suggest that the ophiolites formed at ca. 920 Ma as abyssal peridotite based on the Cr-spinel mineral chemistry. Dravite tourmaline formed in response to intense serpentinization of the original abyssal peridotite. Serpentinization is consistent with the positive $\delta^{11}B$ values obtained from the tourmaline, which indicate altered oceanic crust. The intrusive granites contain zircon with crystallization ages of ca. 610–580 Ma and enriched Hf isotope compositions. The authors interpret that the oceanic crust was overthrust onto the craton, resulting in melting of the cratonic rocks and granite emplacement.

Cerva Alves et al. (2021) present a novel study combining B isotopes in tourmaline with U-Pb dating of low-U content garnet. The study targeted a key sample from the Serrinha Formation of the São Gabriel terrane, Dom Feliciano Belt (Fig. 1). The sample produced *P-T* conditions of 4.5–5 kbar and 536–555 °C and a U-Pb garnet crystallization age of 721 ± 14 Ma. Tourmaline boron isotope compositions ($\delta^{11}B$ = 0.51–3.39 ‰) are consistent with the presence of oceanic crustal components. This led them to propose that the Serrinha basin had formed as a forearc basin to the São Gabriel arc with metamorphism occurring shortly after deposition as a result of arc accretion to the Rio de La Plata Craton.

Pinto et al. (2021) interpret the metamorphic evolution of a Tonian eclogite related to the southern Brasiliano Orogen. This study also targets the São Gabriel terrane of the Dom Feliciano Belt (Fig. 1). The São Gabriel terrane hosts Tonian and Cryogenian juvenile arcs along with the Três Vendas eclogite. The high-pressure assemblage of the eclogite consists of garnet, rutile, phengite and omphacite. Zircon from the eclogite produce core ages of 909.5 ± 5.3 Ma and metamorphic rims of 891.9 ± 8.2 Ma. Zircon Hf isotope compositions are radiogenic suggesting a juvenile nature for these rocks. In combination, the results suggest that the Três Vendas eclogite belonged to a Tonian arc and was buried to > 45 km. This arc is correlated with similar arcs in the Brasília and Ribeira belts indicating large scale processes related to Rodinia breakup.

3. Borborema Province

Antonio et al. (2021) present a new paleomagnetic pole for the Monteiro dyke swarm in the Borborema Province of NE Brazil. The pole was obtained from a fine-grained hornblende diorite which produced a U-Pb zircon age of ca. 538 Ma. The Neoproterozoic-Cambrian transition is a geologically dynamic time with the evolution from the Rodinia to Gondwana supercontinents, the emergence of modern-style plate tectonics, the first complex animals and the rise of oxygen in the atmosphere. However, the global paleogeography is controversial (see Cavalcante et al., 2019) due in part to a poor paleomagnetic database for different cratons at this time. The new pole is not consistent with the classic apparent polar wander path of Gondwana but rather is consistent with rapid small oscillations of the apparent polar wander path during the Cambrian. These short oscillations are concomitant with short lived carbon excursions potentially indicating a link with biochemical cycles.

Porto et al. (2022) analyse geophysical and geological datasets in order to propose tectonic configurations for the basement of the Phanerozoic Parnaíba basin, that partially overlays the Borborema Province and the Brasília and Araguaia belts. The study uses seismic interpretation, gravity modelling, Moho depth, well log data and a compilation of recent geophysical studies. They suggest that the basement consists of two major crustal blocks that represent pre-Brasiliano inliers. The Grajaú block is interpreted to belong to the Amazonian-West Africa block, whereas the geophysically distinct Teresina block is interpreted to belong to the Central Africa block. These two blocks are separated from surrounding cratonic blocks, and each other, by Brasiliano mobile belts. The complex collisional tectonic model presented in this study is at odds with previous interpretations suggesting that the basement of the Parnaíba basin consisted of a single stable cratonic block.

4. Tocantins Province

4.1. Brasília Belt

Westin et al. (2021) work on the exhumation temperature–time trajectory of the nappe systems of the southern Brasília orogen. They use U-Th-Pb_T in monazite and $^{40}Ar/^{39}Ar$ ages of hornblende, biotite and muscovite in combination with previously published data to show that each nappe has a different cooling trajectory. They found that there is a progressive decrease in the metamorphic age peaks in the main transport direction indicating that the nappe pile propagated progressively from the upper to lower nappes. The upper nappes register a collision to exhumation/cooling path from 620–625 to 590–580 Ma with fast exhumation for the amalgamation of West Gondwana.

Motta et al. (2021) utilise thermodynamic modelling in conjunction with U-Pb-Hf on zircon to constrain the *P-T-t* history of the Socorro-Guaxupé nappe (upper nappe). Their results show that the region experienced a protracted regional metamorphic event, with the lower crust remaining at granulite facies for at least 30 Myr during collision. The investigated rocks dominantly contained high variance mineral assemblages, rather than the typical mineralogy of Mg-Al-rich samples diagnostic of ultrahigh-temperature metamorphism, but peak conditions could be obtained using mineral chemistry of garnet and orthopyroxene, as well as detailed petrological analysis. Thus, this study shows that it is possible that some more common high variance garnet-orthopyroxene granulites may record UHT conditions.

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

We would like to thank all the authors who contributed to this special issue as well as the reviewers who put their time into constructively commenting on earlier versions of submitted manuscripts. We believe this Special Issue highlights the current high-level of work done by Brazilian researchers and also showcases the current state of knowledge of the Neoproterozoic of eastern Brazil. These papers also demonstrate that Brazil is now host to research groups using advanced and innovative analytical techniques to further interrogate and understand Brazilian geology, for example, in situ U-Pb geochronology of garnet, and boron isotope compositions of tourmaline. We enjoyed organising and assembling this special issue. Thanks also to Wilson Teixeira and the editorial board of Precambrian Research for supporting the production of this special issue.

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