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New zircon U-Pb dating and review of geological and geochronological data with implications for lithostratigraphy and crustal evolution of North Borborema Province, northeastern Brazil

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Abstract

The northern portion of the Borborema Province, located north of the Patos Shear Zone (northeast of Brazil) is formed by litho-stratigraphic units dating from the Archean to the Neoproterozoic, with complex evolution resulting from several orogenic and extensional events occurring in this interval. In this work, the litho-stratigraphic units of the Northern Borborema Province were reviewed and ordered here, regarding the rock associations and their chronological positioning. Zircon U-Pb dating of three samples of migmatitic orthogneisses from the Rio Piranhas-Seridó Domain, defined crystallization ages of 561 ± 2 Ma, 574 ± 6 Ma and 547 ± 5 Ma for their protoliths. Thus, the origin of the orthogneisses is related to the syn- to late-tectonic magmatism in relation to the Brasiliano Orogeny. From the Jaguaretama Complex, U-Pb dating of detrital zircons of a migmatitic schist indicates Paleoproterozoic sources, with a maximum deposition age of 2144 Ma. The protolith of a migmatitic orthogneiss has crystallization age of 2186 ± 10 Ma, therefore, contemporary compared to other litho-stratigraphic units of the Borborema Province, which are interpreted as having been developed in the Rhyacian Orogeny.

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1. Introduction

The Borborema Province, located in the extreme northeast of Brazil, was consolidated during the Brasiliano Pan-African Orogeny related to the formation of the West Gondwana supercontinent between 625 and 510 Ma, and comprises Mesoproterozoic to Neoproterozoic associations of supracrustal rocks and granitoids, which respectively border and intruded Archean to Paleoproterozoic sequences (Almeida et al. 1981; Brito Neves et al. 2000; Caxito et al. 2021) (Fig. 1A, B). The Borborema Province is commonly subdivided in the North, Central and South sub-provinces (Brito Neves et al. 2000; Delgado et al. 2003), and the North Sub-province is the subject of this work.

The advance on the understanding of the geodynamic processes that worked in each crustal segment that composes the Borborema Province is notorious. Recent emphasis can be given to work on the geodynamic evolution of the Archean and Paleoproterozoic terrains (e.g. Ferreira et al. 2020a; Costa et al. 2021a, b; Santos et al. 2022a, b), of the Neoproterozoic terrains (e.g. Araujo et al. 2012, 2014; Caxito et al. 2020, 2021; Santos et al. 2021; Neves 2021), as well as a broader approach, when dealing with the geological processes that acted from Archean to Neoproterozoic (e.g. Ferreira et al. 2020b). However, it is evident the lack of an integrated approach of the main litho-stratigraphic units constituent of the Borborema Province, regarding its lithological constitution, geochronology and tectonic settings of formation.

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In order to reevaluate the geodynamic processes that have acted in each crustal segment of the North Borborema Province, a review of its lithostratigraphic units is presented, covering the lithological constitution and geochronological data obtained by the zircon U-Pb method, based on information already published in maps, added to unpublished geochronological data (zircon U-Pb in five samples of paraderived and orthoderived migmatitic rocks). Furthermore, a correlation is made between coeval litho-stratigraphic units and similar lithological constitution, but located in different tectonic domains, such as the Granja and Arábia complexes and the Ceará and Seridó groups.

The results and interpretations are presented in the stratigraphic stacking of the units and in the suggested geodynamic model, depicting a long period of geological evolution for the Northern Borborema Province, with rocks dating back to and evolved from the Paleoarchean to the Phanerozoic.

2. Tectonic subdivision of the Borborema Province

The North Borborema Province is located north of the Patos Shear Zone, consisting of five tectonic domains, limited by dextral shear zones (Medeiros et al. 2017) (Fig. 1B): (1) Médio Coreaú Domain, positioned between the Parnaiba Province and the Sobral-Pedro II Shear Zone; (2) Ceará Central Domain, located between the Sobral-Pedro II and Senador Pompeu shear zones; (3) Jaguaribeano Domain, situated between the Senador Pompeu and Portalegre/ Farias Brito shear zones; (4) The Rio Piranhas-Seridó Domain, limited by the Portalegre/Farias Brito and Picuí-João Câmara shear zones; (5) the São Jose do Campestre Domain, located between the Picuí-João Câmara and Patos shear zones.

2.1 Médio Coreaú Domain

The Médio Coreaú Domain, located northwest of the Sobral-Pedro II Shear Zone (Fig. 1B), has a basement formed by Siderian to Rhyacian orthogneisses, migmatites, granulite gneisses and paraderived rocks of the Granja Complex, with ages ranging between 2.47 and 2.23 Ga (Appendix 2) (Santos 1999; Almeida 2019); in addition to the Statherian metavolcano-sedimentary rocks of the Saquinho Unit (1.78 Ga; Appendix 2) (Santos 1999; Santos et al. 2004; Benedetti 2012). This basement is superimposed by metavolcanic-sedimentary rocks of Neoproterozoic age (777 Ma; Appendix 2) constituents of the Martinópole and Ubajara groups (Costa et al. 1973; Santos et al. 2009). Two molassic basins are composed of volcano-sedimentary rocks (Jaibaras and Riacho Sairi groups) of Cambrian-Ordovician age (Appendix 2; Costa et al. 1973; Garcia et al. 2018; Pivetta 2021).

2.2 Ceará Central Domain

The Ceará Central Domain, located between the Sobral-Pedro II and Senador Pompeu shear zones (Fig. 1B), has an Archean nucleus with ages ranging between 2.79 and 2.69 Ga (Appendix 2), composed of orthogneisses and orthoderived migmatites of dioritic, and tonalitic to granodioritic compositions, as well as amphibolite, metaultramafic rocks and metasedimentary rocks, which make up the Cruzeta Complex (Brito Neves 1975; Oliveira and Cavalcante 1993; Ganade et al. 2017; Naleto and Araujo 2018).

The Paleoproterozoic basement of the Ceará Central Domain (Fig. 1B) is formed by associations of metaplutonic and metavolcano-sedimentary rocks of Rhyacian ages ranging between 2.23 and 2.10 Ga (Appendix 2), grouped in the Tróia, Algodões, Canindé do Ceará and Boa Viagem complexes (Martins et al. 2009; Costa et al. 2015a; Naleto and Araujo 2018; Muniz et al. 2022). There are also Rhyacian units with ages between 2.19 and 2.07 Ga (Appendix 2), consisting only of metaplutonic rocks: Madalena, Itapiúna and Cedro suites, Cipó, Serra da Palha and Bananeira units (Oliveira and Cavalcante 1993; Castro 2004; Martins et al. 2009; Costa et al. 2015a; Costa and Palheta 2017). Sequences of Neoproterozoic metavolcano-sedimentary rocks (Fig. 1B), with ages of about 770 Ma and 610 Ma (Appendix 2), are gathered in the Morro dos Torrões Unit and in the Novo Oriente and Ceará groups (Fetter 1999; Castro 2004; Amaral 2010; Araujo et al. 2010; Araujo et al. 2012; Ancelmi et al. 2015; Arthaud et al. 2015; Costa 2017). Orthoderived rocks off Tonian ages ranging between 892 and 833 Ma (Appendix 2), correspond to Lagoa Caiçara Unit (Castro 2004; Araujo et al. 2014; Pinéo et al. 2020) and an association of migmatites, metaplutonic rocks and plutonic rocks of Ediacaran age, between 674 and 610 Ma (Appendix 2), correspond to the Tamboril-Santa Quitéria complex (Appendix 2; Brito Neves 1975; Fetter 1999; Costa et al. 2013; Araujo et al. 2014; Pitombeira et al. 2021).

The Cococi Basin, located in the southern end of the Ceará Central Domain, consists of a volcano-sedimentary association of Cambrian-Ordovician age (Appendix 2) of the Rio Jucá Group (Vasconcelos and Gomes 1998).

2.3. Jaguaribeano Domain

The Jaguaribeano Domain comprises associations of metaplutonic and metavolcano-sedimentary rocks (Fig. 1B) of Rhyacian age between 2.20 and 2.10 Ga (Appendix 2) grouped in the Jaguaretama, Acopiara and São Gonçalo complexes (Silva et al. 1997; Gomes e Vasconcelos 2000; Sá et al. 2014; Calado et al. 2019; Gomes et al. 2021). Sequences of Statherian metavolcano-sedimentary rocks (1.75 Ga; Appendix 2) correspond to the Serra de São José and Orós groups (Sá 1991; Cavalcante 1999; Magini 2001). The Serra do Deserto Suite is composed of augen gneisses (from granitic to granodiorite compositions), with crystallization age around 1.79 Ga (Appendix 2; Cavalcante 1999; Sá et al. 2014). The Jaguaribeano Domain also has rocks from the Ceará Group and the Tamboril-Santa Quitéria complexes.

2.4. Rio Piranhas-Seridó Domain

The Rio Piranhas-Seridó Domain (Fig. 1B) contains small Archean nuclei with ages in the range of 3.74 to 2.50 Ga (Appendix 2) formed by orthogneisses, orthoderived migmatites, metamafic and metaultramafic rocks, paragneisses, quartzites, marbles, metavolcanic rocks and iron formations grouped in the Serra do Ingá Unit and in the Amarante, Campo Grande, Granjeiro and Saquinho complexes (Silva et al. 1997; Cavalcante et al. 2018; Dantas et al. 2019; Ruiz et al. 2019; Santos et al. 2020; Ferreira et al. 2020b; Freimann 2014; Ancelmi 2016; Gomes et al. 2021).

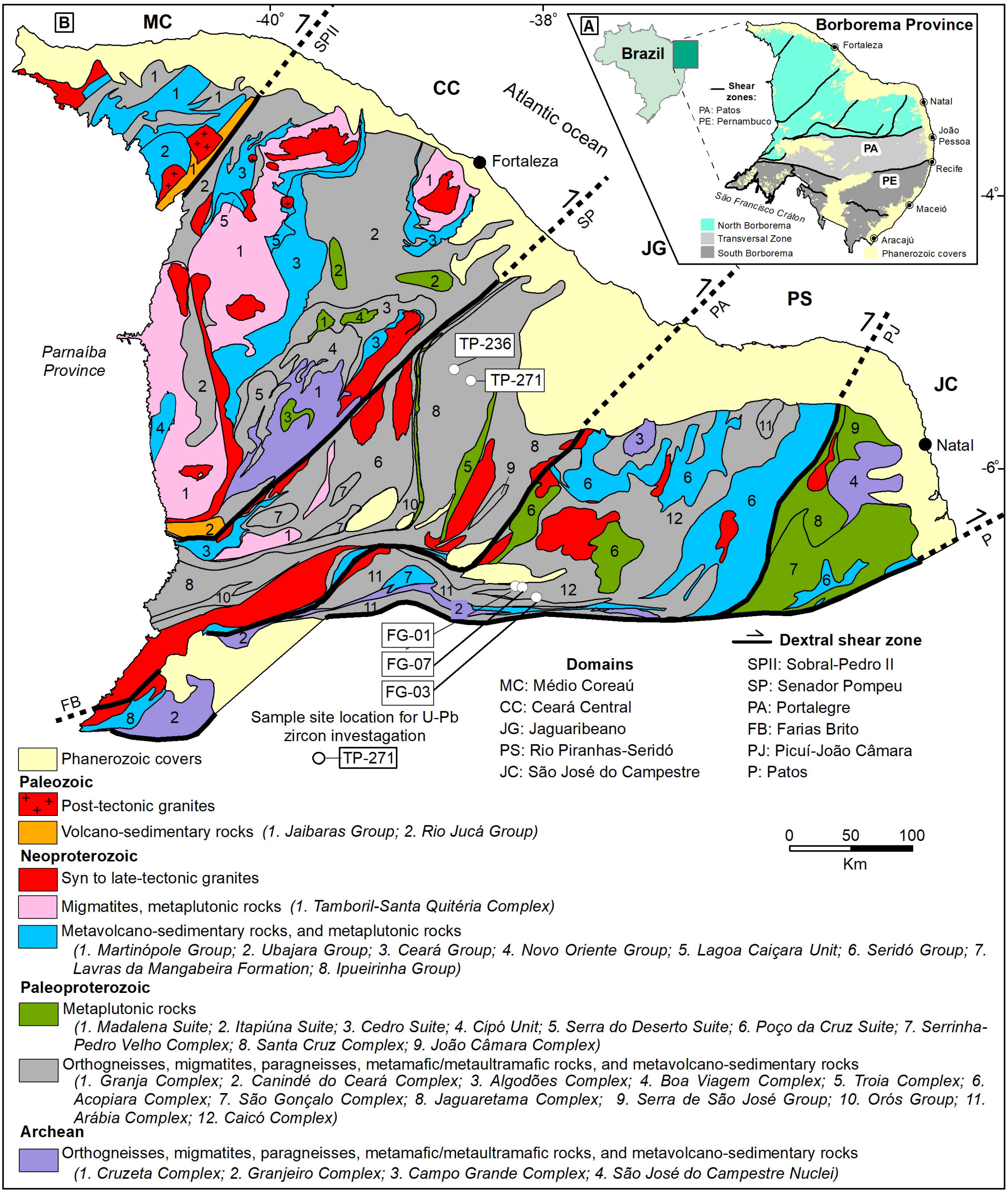

FIGURA 1. (A) Location of the Borborema Province in the northeast of Brazil and its tectonic subdivision. (B) Main litho-stratigraphic units and shear zones of the North Borborema Province.

The Paleoproterozoic basement of the domain (Fig. 1B) comprises Siderian metaplutonic and metavolcano-sedimentary rocks of the Arábia Complex (2.48 to 2.33 Ga; Appendix 2; Dantas et al. 2008; Ancelmi 2016; Costa and Dantas 2018; Gomes et al. 2021) and the Rhyacian Caicó Complex (2.27 to 2.11 Ga; Appendix 2; Jardim de Sá 1994; Souza et al. 2007, 2016). Geological units consisting only of metaplutonic rocks correspond to the Serra da Formiga and Poço da Cruz suites, of Rhyacian and Orosirian-Statherian ages, respectively (Appendix 2; Jardim de Sá 1994; Medeiros et al. 2012a; Costa and Dantas 2018). Metavolcano-sedimentary rocks of Neoproterozoic age (Fig. 1B; Appendix 2) comprise the Lavras da Mangabeira Formation and the Seridó and Ipueirinha groups (Jardim de Sá 1994; Silva et al. 1997; Van Schmus et al. 2003; Hollanda et al. 2015; Basto et al. 2019; Medeiros et al. 2021).

2.5. São José do Campestre Domain

The Archean nucleus of the São José do Campestre Domain (Fig. 1B) consists of orthogneisses, migmatites, granulite gneisses, metamafic and metaultramafic rocks, paragneisses, marbles and calc–silicate rocks, grouped into distinct units, aged between 3.41 and 2.65 Ga (Appendix 2): Presidente Juscelino, Brejinho, Senador Elói de Souza, Riacho das Telhas, Serra Caiada complexes and Bom Jesus Metatonalite, Teixeira Gneiss, and São José do Campestre Granitoid (Dantas 1997; Dantas et al. 2013; Jesus 2011; Souza et al. 2016).

The Paleoproterozoic rocks, with ages ranging between 2.23 and 2.07 Ga (Appendix 2) correspond to migmatites, granitic to tonalitic orthogneisses, augen gneisses and amphibolites, grouped in the João Camara, Serrinha-Pedro Velho, Santa Cruz complexes and Caiongo Unit (Dantas 1997; Guimarães et al. 2009; Dantas et al. 2013; Oliveira e Cunha 2018). The Neoproterozoic supracrustal rocks crop out in the extreme northeast and south portions of the São José do Campestre Domain, being represented by the metavolcano-sedimentary rocks of the Seridó Group.

2.6. Neoproterozoic and Paleozoic magmatism

The syn- to late-orogenic Neoproterozoic magmatism is one of the most striking features in the Borborema Province (Fig. 1B), being represented by several batholiths, stocks, plutons and dikes, composed of syenites, leucogranites, granites, monzonites, granodiorites, tonalites, gabbros and diorites, and grouped in the Banabuiú, São João do Sabugi, Itaporanga, Catingueira and Alcalina Caxexa suites (Angelim et al. 2006; Nascimento et al. 2015). They are Ediacaran rocks, with crystallization ages between 620 and 545 Ma (Appendix 2).

The post-orogenic Paleozoic magmatism is represented by syenite, granite, monzonite, granodiorite and diorites of Cambrian and Ordovician age (Appendix 2), included in the Meruoca and Taperuaba suites (Castro 2004; Archanjo et al. 2009; Garcia et al. 2018), wich crop out in the Médio Coreaú and Ceará Central domains (Fig. 1B). In the Rio Piranhas-Seridó Domain, several pegmatite bodies occur, with crystallization ages ranging between 549 and 491 Ma (Appendix 2; Hollanda et al. 2017; Degen et al. 2019).

3. Zircon U-Pb geochronology (LA-ICP-MS, SHRIMP)

Five samples were selected for zircon U-Pb geochronological analysis. The analytical procedures are described in Appendix 1.

3.1. Migmatitic schist of the Jaguaretama Complex (TP-236)

The paraderived migmatitic schist of the Jaguaretama Complex (Fig. 1B) is composed of plagioclase, quartz, biotite and garnet, has grano-lepidoblastic texture. The leucosome is lenticular, and composed of quartz and potassium feldspar (Fig. 2A). For the provenance study, the zircon analyzed was extracted from the metatexite. The crystals consist of medium to large euhedral prisms (100-500 μm) with some rounding features, few fractures and inclusions. Backscattered electron images show a varied internal structure, with predominance of oscillatory zoning, but truncated zonations, irregular spots and presence of homogeneous rims can be observed (Fig. 2B).

For this sample, 62 points were analyzed in 61 crystals. Among the data obtained, one was discarded by the high analytical error and other 13 were not used in the frequency diagram because they presented discordant $^{207}Pb/^{206}Pb$ apparent ages above 10% (Table 1). The data that passed through this filter have mostly Rhyacian apparent ages ranging between 2102 and 2308 Ma. The Th/U ratios of these points are varied and it was not possible to make a direct correlation between younger ages and low Th/U ratios (below 0.05), which are commonly associated with recrystallization under metamorphic conditions. The dominant population has a range of ages between 2187 and 2138 Ma, with four peaks of $^{207}Pb/^{206}Pb$ apparent ages at 2144, 2156, 2172 and 2178 Ma, which indicates the age range of the main sources of detritus from the original sediments (Fig. 2C). Although two younger apparent ages (2102 and 2113 Ma) were identified, they were not considered statistically representative. Thus, the peak of 2144 Ma generated with 15 points is considered to be indicative of the maximum deposition age of the protolith of the migmatitic schist (Fig. 2C and D).

3.2. Migmatitic orthogneiss of Jaguaretama Complex (TP-271)

The migmatitic orthogneiss from Jaguaretama Complex (Fig. 1B) is gray, fine-grained and granoblastic, composed of plagioclase, potassium feldspar, quartz, biotite and hornblende (Fig. 3A). Zircon crystals are usually prismatic (type 3:1 to 4:1) with bipyramidal terminations, ranging from 100 to 500 μm and have some fractures and inclusions. In backscattered electron image the oscillatory zoning predominates (Fig. 3B). Forty-eight points were analyzed in 40 crystals, and the results showed some dispersion and varying degrees of discordance between the apparent ages (Table 2). In the main group, data from 21 points located in the cores were used in regression, which indicated upper intercept at 2186 ± 10 Ma, interpreted as the crystallization age of the igneous protolith (Fig. 3C).

3.3. Migmatitic orthogneiss of the Rio Piranhas-Seridó Domain (FG-01, FG-03, FG-07)

Migmatitic orthogneiss samples obtained in different outcrops in the Rio Piranhas-Seridó Domain (Fig. 1B) and previously classified as Arábia Complex (Siderian) or Caicó Complex (Rhyacian) were analyzed by the U-Pb SHRIMP method, with the initial objective of determining its correct stratigraphic positioning.

The FG-01 sample is a granodioritic migmatitic orthogneiss, composed of plagioclase, K-feldspar, quartz, biotite and hornblende (Fig. 4A). The zircon crystals of the FG-01 sample have a size of 100 to 800 μm. They are usually subhedral, occurring as fragments and prisms with poorly defined pyramidal terminations. They are colorless, clear with few inclusions and rare fractures. In the cathodoluminescence (CL) imaging there is strong oscillatory zonation, besides sector zoning (Fig. 4B). The U-Pb isotopic data of these crystals are concordant (Table 3), and yielded a concordia

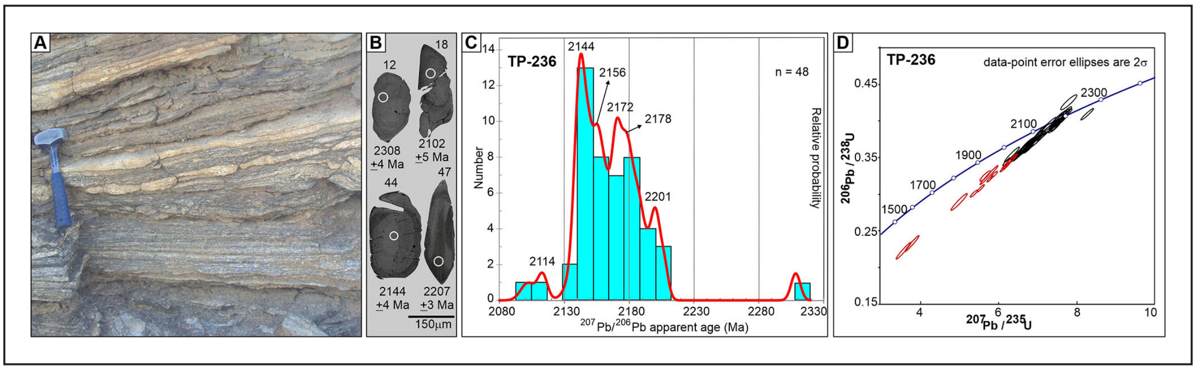

FIGURA 2. A) Macroscopic aspects of the migmatitic schist of the Jaguaretama Complex, from which the TP-236 sample was collected; B) selected image of backscattered electrons for the zircon crystals analyzed; C) frequency histogram of the concordant $^{207}Pb/^{206}Pb$ ages (±10%); D) Concordia diagram of the sample TP-236.

TABLE 1. U-Pb isotopic data in detrital zircons for the TP-236 sample (migmatitic schist, -5°16'8'', -38°38'47'').

grain. spot	f206 (%)	RATIOS								Coef. corr	AGES (Ma)						Conc. (%)
		Th/U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	err (%) 1sigma	$^{207}Pb/^{235}U$	err (%) 1sigma	$^{206}Pb/^{238}U$	err(%) 1sigma		$^{207}Pb/^{206}Pb$	err (%)	$^{207}Pb/^{235}U$	err (%)	$^{206}Pb/^{238}U$	err (%)	
017-Z12	0.00	0.15	418479	0.146753	0.21	8.284	0.80	0.409394	0.78	0.96	2308	4	2263	7	2212	15	95.83
064-Z47	0.00	0.25	452495	0.138392	0.19	7.468	0.69	0.391377	0.66	0.95	2207	3	2169	6	2129	12	96.47
063-Z46	0.01	0.26	293265	0.137983	0.23	7.623	0.66	0.400707	0.62	0.92	2202	4	2188	6	2172	11	98.65
076-Z57	0.01	0.24	279301	0.137835	0.18	7.666	0.55	0.403381	0.51	0.92	2200	3	2193	5	2185	10	99.29
080-Z60	0.01	0.26	214628	0.137798	0.22	7.427	0.76	0.390903	0.73	0.95	2200	4	2164	7	2127	13	96.69
026-Z19	0.01	0.21	132349	0.137344	0.27	7.575	1.05	0.400032	1.02	0.96	2194	5	2182	9	2169	19	98.87
028-Z21	0.01	0.31	282487	0.137244	0.23	7.744	0.77	0.409228	0.73	0.95	2193	4	2202	7	2211	14	100.85
038-Z28	0.00	0.11	320489	0.136891	0.20	7.443	0.78	0.394344	0.76	0.96	2188	3	2166	7	2143	14	97.93
077-Z58	0.00	0.16	304055	0.136692	0.22	7.339	0.69	0.389377	0.65	0.94	2186	4	2154	6	2120	12	96.99
068-Z51	0.01	0.15	109376	0.136563	0.35	7.616	1.28	0.404488	1.23	0.96	2184	6	2187	11	2190	23	100.26
020-Z15	0.00	0.17	299657	0.136562	0.21	7.486	0.75	0.397600	0.72	0.95	2184	4	2171	7	2158	13	98.81
078-Z59	0.01	0.21	138477	0.136194	0.22	7.027	0.90	0.374180	0.87	0.97	2179	4	2115	8	2049	15	94.02
010-Z07	0.00	0.12	494136	0.136180	0.20	7.768	0.60	0.413692	0.57	0.92	2179	3	2204	5	2232	11	102.41
023-Z16	0.01	0.13	251007	0.136109	0.29	7.331	0.89	0.390634	0.84	0.94	2178	5	2153	8	2126	15	97.59
036-Z26	0.01	0.09	204526	0.135998	0.21	7.496	0.96	0.399734	0.93	0.97	2177	4	2172	9	2168	17	99.59
058-Z43	0.01	0.13	110848	0.135980	0.30	7.024	1.18	0.374618	1.15	0.97	2177	5	2114	10	2051	20	94.23
066-Z49	0.03	0.26	58237	0.135791	0.37	7.181	1.16	0.383557	1.10	0.95	2174	6	2134	10	2093	20	96.26
030-Z23	0.01	0.14	203689	0.135593	0.26	7.539	0.79	0.403232	0.74	0.93	2172	5	2178	7	2184	14	100.56
074-Z55	0.01	0.11	145985	0.135585	0.24	6.769	0.70	0.362099	0.66	0.93	2172	4	2082	6	1992	11	91.74
019-Z14	0.01	0.16	164139	0.135469	0.30	7.576	0.97	0.405598	0.93	0.95	2170	5	2182	9	2195	17	101.14
044-Z32	0.00	0.13	317614	0.135446	0.20	6.789	0.64	0.363509	0.61	0.94	2170	4	2084	6	1999	10	92.12
049-Z37	0.01	0.13	274461	0.135440	0.20	6.786	0.62	0.363371	0.58	0.93	2170	4	2084	5	1998	10	92.09
034-Z24	0.01	0.15	165262	0.135399	0.20	7.053	0.66	0.377779	0.63	0.94	2169	4	2118	6	2066	11	95.24
040-Z30	0.01	0.09	198558	0.134927	0.21	6.790	1.20	0.365006	1.18	0.98	2163	4	2084	11	2006	20	92.73
065-Z48	0.01	0.12	198041	0.134916	0.19	6.969	0.91	0.374648	0.89	0.977	2162	3	2107	8	2051	16	94.84
004-Z02B	0.00	0.09	699062	0.134651	0.19	6.690	0.77	0.360365	0.74	0.97	2159	3	2071	7	1984	13	91.87
069-Z52	0.01	0.14	240183	0.134592	0.22	6.864	1.08	0.369889	1.06	0.98	2159	4	2094	10	2029	18	93.98
075-Z56	0.00	0.08	445071	0.134406	0.23	6.920	0.55	0.373422	0.50	0.87	2156	4	2101	5	2045	9	94.86
054-Z39	0.01	0.15	140006	0.134394	0.21	6.743	0.78	0.363886	0.75	0.96	2156	4	2078	7	2001	13	92.78

TABLE 1. U-Pb isotopic data in detrital zircons for the TP-236 sample (migmatitic schist, -5°16'8'', -38°38'47'') (continued)

grain. spot	f206 (%)	RATIOS								Coef. corr	AGES (Ma)						Conc. (%)
		Th/U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	err (%) 1sigma	$^{207}Pb/^{235}U$	err (%) 1sigma	$^{206}Pb/^{238}U$	err(%) 1sigma		$^{207}Pb/^{206}Pb$	err (%)	$^{207}Pb/^{235}U$	err (%)	$^{206}Pb/^{238}U$	err (%)	
009-Z06	0.00	0.13	564005	0.134292	0.18	6.519	0.81	0.352067	0.79	0.97	2155	3	2048	7	1944	13	90.24
037-Z27	0.01	0.14	244247	0.134235	0.18	7.027	0.71	0.379656	0.69	0.96	2154	3	2115	6	2075	12	96.31
060-Z45	0.02	0.12	94044	0.134034	0.30	7.301	1.08	0.395078	1.04	0.96	2151	5	2149	10	2146	19	99.76
005-Z02N	0.01	0.15	252625	0.133904	0.15	6.786	0.69	0.367537	0.67	0.97	2150	3	2084	6	2018	12	93.86
056-Z41	0.01	0.08	129938	0.133726	0.19	6.849	0.85	0.371470	0.83	0.97	2147	3	2092	8	2036	14	94.82
039-Z29	0.01	0.11	210635	0.133624	0.23	6.490	0.80	0.352251	0.77	0.95	2146	4	2045	7	1945	13	90.64
008-Z05	0.00	0.17	377116	0.133570	0.21	6.919	0.73	0.375687	0.70	0.95	2145	4	2101	6	2056	12	95.84
067-Z50	0.01	0.14	101769	0.133559	0.35	6.755	0.99	0.366797	0.92	0.93	2145	6	2080	9	2014	16	93.89
043-Z31	0.03	0.22	49025	0.133537	0.47	6.577	1.45	0.357202	1.37	0.94	2145	8	2056	13	1969	23	91.79
059-Z44	0.00	0.06	713259	0.133497	0.22	7.035	0.68	0.382196	0.64	0.93	2144	4	2116	6	2087	11	97.30
007-Z04	0.00	0.25	412484	0.133368	0.18	6.748	1.00	0.366971	0.98	0.98	2143	3	2079	9	2015	17	94.04
006-Z03	0.00	0.17	583633	0.133351	0.16	6.417	0.57	0.349031	0.55	0.95	2143	3	2035	5	1930	9	90.08
048-Z36	0.03	0.22	48965	0.133321	0.41	6.770	1.10	0.368302	1.02	0.92	2142	7	2082	10	2021	18	94.36
015-Z10	0.00	0.08	468435	0.133202	0.18	6.651	0.66	0.362117	0.63	0.95	2141	3	2066	6	1992	11	93.07
079-Z60	0.01	0.14	189744	0.133169	0.23	6.566	0.71	0.357609	0.67	0.93	2140	4	2055	6	1971	11	92.09
027-Z20	0.01	0.13	197845	0.133067	0.41	7.806	1.08	0.425438	1.00	0.92	2139	7	2209	10	2285	19	106.84
003-Z01	0.01	0.07	227673	0.133062	0.16	7.115	0.79	0.387821	0.77	0.98	2139	3	2126	7	2113	14	98.78
035-Z25	0.00	0.04	387501	0.131145	0.21	6.228	0.68	0.344397	0.65	0.94	2113	4	2008	6	1908	11	90.27
025-Z18	0.00	0.09	4036448	0.130303	0.31	6.365	1.21	0.354257	1.17	0.96	2102	5	2027	11	1955	20	93.00
Zircons not included in age calculations																	
073-Z54	0.01	0.11	201413	0.130032	0.25	5.397	0.69	0.301027	0.65	0.92	2098	4	1884	6	1696	10	80.84
070-Z53	0.01	0.16	118157	0.132788	0.28	6.344	1.01	0.346509	0.97	0.96	2135	5	2025	9	1918	16	89.83
057-Z42	0.02	0.12	68722	0.132654	0.28	6.262	1.02	0.342350	0.98	0.96	2133	5	2013	9	1898	16	88.96
055-Z40	0.01	0.13	235706	0.131146	0.25	5.905	0.63	0.326570	0.58	0.89	2113	4	1962	5	1822	9	86.20
050-Z38	0.00	0.04	510041	0.133250	0.23	6.194	0.85	0.337148	0.82	0.96	2141	4	2004	7	1873	13	87.47
047-Z35	0.04	0.14	40894	0.125702	0.46	5.017	1.70	0.289472	1.64	0.96	2039	8	1822	14	1639	24	80.39
046-Z34	0.03	0.06	53029	0.118916	0.44	3.815	1.92	0.232677	1.87	0.97	1940	8	1596	15	1349	23	69.51
045-Z33	0.67	0.41	2669	0.130880	0.26	1.332	16.66	0.073830	16.65	1.00	2110	5	860	92	459	73	21.76
029-Z22	0.00	0.04	369982	0.128493	0.28	5.777	1.65	0.326072	1.63	0.99	2077	5	1943	14	1819	26	87.57
024-Z17	0.02	0.14	67511	0.117069	0.52	3.603	2.16	0.223211	2.10	0.97	1912	9	1550	17	1299	25	67.93
018-Z13	0.01	0.21	112390	0.126917	0.40	5.685	0.96	0.324896	0.88	0.90	2056	7	1929	8	1814	14	88.22
016-Z11	0.00	0.16	728375	0.131212	0.17	5.807	0.57	0.320980	0.54	0.94	2114	3	1947	5	1795	8	84.88
014-Z09	0.01	0.18	291743	0.131065	0.21	5.563	0.69	0.307827	0.66	0.94	2112	4	1910	6	1730	10	81.90
013-Z08	0.00	0.16	529123	0.132728	0.26	6.333	0.78	0.346047	0.73	0.93	2134	5	2023	7	1916	12	89.75

age of 561 ± 2 Ma, interpreted as the crystallization age of the protolith (Fig. 4C).

The FG-03 sample is a gray medium-grained monzonite orthogneiss composed of plagioclase, K-feldspar, quartz and biotite (Fig. 4D). Zircon crystals are 150 to 400 μm long, prismatic with little expressive pyramidal terminations, colorless and clear, with translucent areas, rich in inclusions and fractures. The CL image reveals internal structure with oscillatory zoning (Fig. 4E). In this sample, 17 spot analyzes were performed in zircon crystals (Table 4). The isotopic ratios are concentrated in two sets: the data of two cores (1.1 and 8.1) with Rhyacian $^{207}Pb/^{206}Pb$ apparent ages and the other data with Neoproterozoic ages (Table 4). Among the Neoproterozoic results, five analytical points have $f^{206}Pb\%$ above 5% and had their data discarded from age calculations. The valid Neoproterozoic data were used in the calculation of concordia

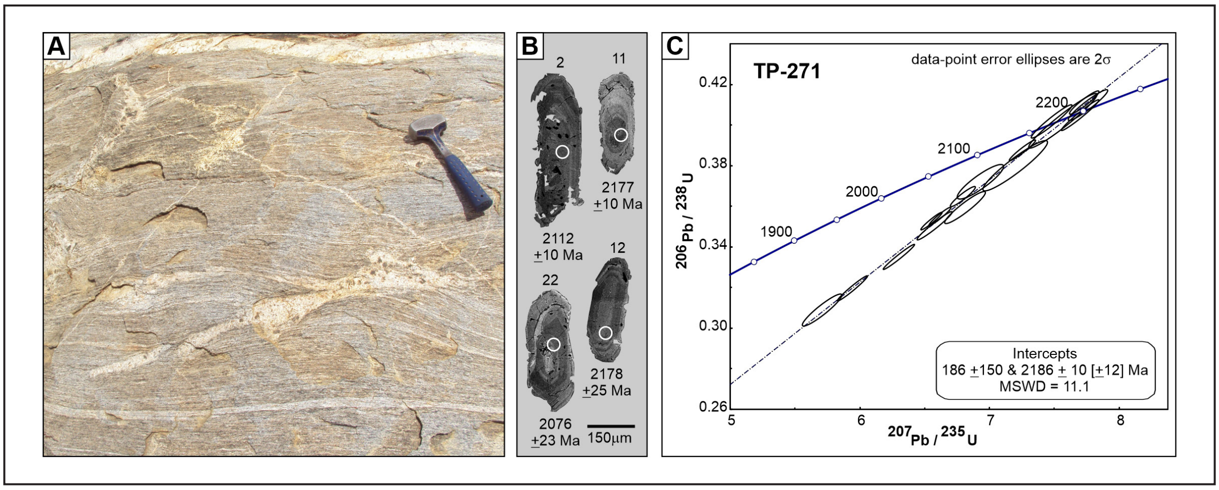

FIGURA 3. A) Macroscopic aspects of the migmatitic orthogneiss of the Jaguaretama Complex, from which the TP-271 sample was collected; B) selected image of bakcscattered electrons of analyzed zircon crystals; C) Concordia diagram of the TP-271 sample.

TABLE 2. Zircons U-Pb isotopic data for TP-271 sample (migmatitic orthogneiss, -5º21'5'', -38º31'34'').

grain. spot	f206(%)	RATIOS								Coef. corr	AGES (Ma)						Conc. (%)
		Th/U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	err (%) 1sigma	$^{207}Pb/^{235}U$	err (%) 1sigma	$^{206}Pb/^{238}U$	err (%) sigma		$^{207}Pb/^{206}Pb$	err (%)	$^{207}Pb/^{235}U$	err (%)	$^{206}Pb/^{238}U$	err (%)	
007-Z3B*	0.00	0.09	311353.5	0.134	0.117	6.462	0.947	0.349	0.940	0.992	2157	2	2041	8	1928	16	94
009-Z4B*	0.05	0.08	29503.3	0.134	0.122	6.202	0.644	0.336	0.633	0.979	2149	2	2005	6	1868	10	93
018-Z8B*	0.00	0.07	587531.0	0.133	0.169	5.882	0.790	0.321	0.772	0.974	2136	3	1959	7	1796	12	92
020-Z10*	0.01	0.18	119445.1	0.135	0.250	6.449	0.782	0.347	0.741	0.939	2161	4	2039	7	1920	12	94
026-Z13B*	0.00	0.06	315400.8	0.133	0.129	6.651	0.510	0.362	0.493	0.952	2140	2	2066	4	1993	8	96
027-Z14B*	0.00	0.12	606893.8	0.134	0.120	6.498	0.514	0.351	0.500	0.961	2152	2	2046	5	1942	8	95
028-Z15B*	0.00	0.08	574950.8	0.133	0.133	6.349	0.537	0.345	0.521	0.957	2142	2	2025	5	1912	9	94
030-Z17*	0.01	0.15	196773.5	0.134	0.142	6.521	0.661	0.352	0.646	0.972	2157	2	2049	6	1943	11	95
050-Z31B*	0.01	0.19	197487.4	0.133	0.150	5.900	0.730	0.321	0.714	0.976	2141	3	1961	6	1795	11	92
034-Z18**	0.01	0.16	210801.9	0.135	0.169	5.944	0.807	0.319	0.789	0.975	2164	3	1968	7	1787	12	91
013-Z5B**	0.14	0.15	11239.6	0.137	0.150	6.303	0.776	0.335	0.762	0.979	2183	3	2019	7	1862	12	92
010-Z5N**	0.01	0.15	156206.0	0.134	0.393	5.709	1.104	0.309	1.032	0.929	2152	7	1933	10	1735	16	90
019-Z9**	0.01	0.15	106460.2	0.136	0.200	6.579	0.839	0.350	0.815	0.968	2179	3	2056	7	1937	14	94
044-Z25**	0.02	0.39	65701.7	0.138	0.316	6.815	0.939	0.359	0.884	0.935	2197	5	2088	8	1979	15	95
016-Z7B**	0.00	0.08	851169.5	0.135	0.117	6.553	0.519	0.353	0.505	0.964	2161	2	2053	5	1947	8	95
015-Z7N**	0.00	0.15	772995.9	0.135	0.126	6.618	0.528	0.355	0.513	0.960	2166	2	2062	5	1959	9	95
025-Z13N**	0.00	0.13	368592.1	0.135	0.176	6.795	0.578	0.365	0.551	0.936	2166	3	2085	5	2004	9	96
039-Z23**	0.02	0.18	64460.8	0.135	0.468	6.932	1.046	0.372	0.936	0.884	2166	8	2103	9	2038	16	97
038-Z22**	0.02	0.17	60454.0	0.137	0.485	7.201	1.408	0.380	1.322	0.936	2196	8	2137	13	2076	23	97
005-Z2**	0.01	0.21	269573.6	0.136	0.134	7.257	0.562	0.388	0.546	0.962	2174	2	2144	5	2112	10	99
004-Z1**	0.01	0.22	135843.6	0.138	0.162	7.702	0.780	0.405	0.764	0.976	2202	3	2197	7	2191	14	100
024-Z12**	0.01	0.22	208612.3	0.137	0.383	7.568	1.422	0.402	1.370	0.962	2184	7	2181	13	2178	25	100
023-Z11**	0.01	0.22	269230.2	0.135	0.220	7.480	0.860	0.402	0.832	0.963	2165	4	2171	8	2177	15	100
040-Z24**	0.01	0.29	143453.3	0.137	0.241	7.763	0.795	0.410	0.758	0.946	2194	4	2204	7	2214	14	100
029-Z16**	0.01	0.24	249045.7	0.136	0.176	7.733	0.591	0.411	0.564	0.940	2182	3	2200	5	2220	11	101

* Zircon rims, ** Zircon cores

age of 574 ± 6 Ma, associated with MSWD of 0.10 (Fig. 4F). This result is considered the crystallization age of the protolith of the gneiss and the two Rhyacian cores (Table 4) are interpreted as inheritance.

In order to complement the investigation regarding the age of magmatism, a sample (FG-07) of a gray coarse-grained migmatitic orthogneiss of tonalitic composition (Fig. 4G) was selected for zircon U-Pb analysis. In general, the zircon crystals are large (400-800 μm), occurring as subhedral fragments and prisms with pyramidal terminations. The crystals are colorless, clear with few inclusions and rare fractures. The predominant internal structure in CL image is the thick oscillatory zoning along with subordinate sector zoning. Insertions with irregular limits and homogeneous areas are locally common and features that suggest the presence of cores are identified in few grains (Fig. 4H). The

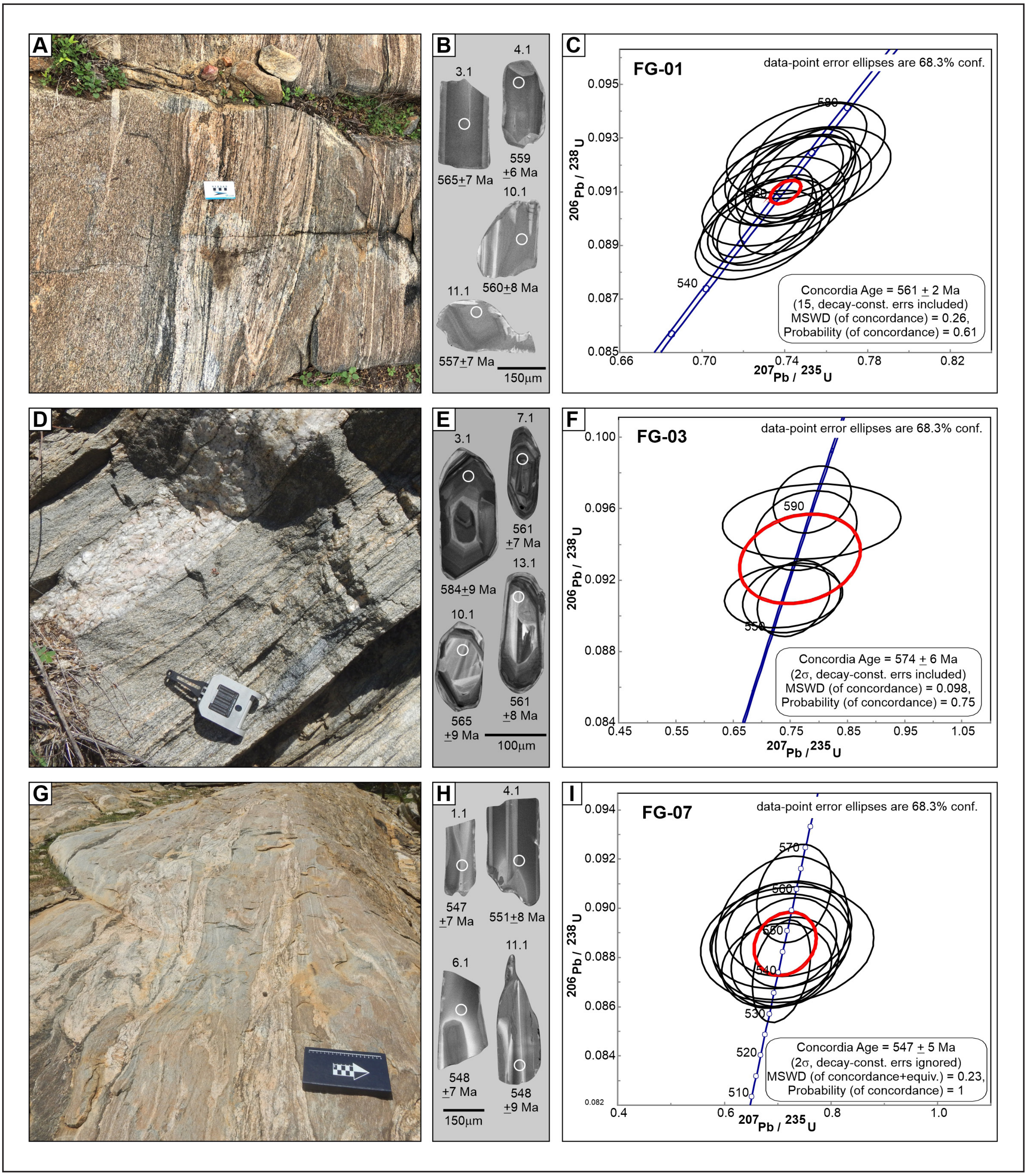

FIGURA 4. Macroscopic aspects of the migmatitic orthogneisses of points FG-01 (A), FG-03 (D) and FG-07 (D). Cathodoluminescence images of zircon crystals from FG-01 (B), FG-03 (E) and FG-07 (H) samples. Concordia diagrams of the sample FG-01 (C), FG-03 (F) and FG-07 (I)

TABLE 3. Zircons U-Pb isotopic data for FG-01 sample (migmatitic orthogneiss, -6º51'30'', -38º11'52'').

Spot	RATIO										$^{206}Pb_c$(%)	(ppm)		AGE (Ma)				Disc.	Obs.
	$^{204}Pb/^{206}Pb$	±%	$^{207}Pb/^{206}Pb$	±%	$^{208}Pb/^{206}Pb$	±%	$^{206}Pb/^{238}U$	±%	$^{232}Th/^{238}U$	±%		U	Th	$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$			
FG_01_1.1	0.000040	100	0.059676	1.62	0.086	5.84	0.300432	0.69	0.183	0.66	0.07	94	17	555	±7	570	±42	+2.8	1
FG_01_2.1	0.000085	71	0.060363	1.65	0.069	3.70	0.280211	0.70	0.108	0.85	0.15	93	10	564	±7	572	±49	+1.5	1
FG_01_3.1	---	100	0.059298	1.82	0.456	1.66	0.266794	0.76	1.428	0.32	0.00	82	114	565	±7	578	±40	+2.3	1
FG_01_4.1	0.000231	41	0.062148	1.55	0.508	1.37	0.248147	0.66	1.650	0.27	0.41	116	185	559	±6	559	±62	+0.0	1
FG_01_5.1	0.000114	50	0.060690	1.34	0.409	1.30	0.266313	0.57	1.302	0.45	0.20	144	181	566	±6	568	±43	+0.5	1
FG_01_6.1	0.000165	50	0.061805	2.50	0.574	1.35	0.254438	0.69	1.838	0.27	0.29	104	185	566	±7	582	±72	+2.9	1
FG_01_7.1	---	100	0.058795	3.13	0.148	2.69	0.275878	0.75	0.363	0.52	0.00	81	29	570	±7	559	±68	-2.0	1
FG_01_8.1	0.000090	71	0.060056	1.71	0.103	3.13	0.226137	0.70	0.194	0.62	0.16	105	20	539	±6	558	±52	+3.5	2
FG_01_9.1	0.000042	100	0.059609	2.98	0.080	5.57	0.242066	0.69	0.184	0.64	0.08	105	19	564	±7	567	±69	+0.6	1
FG_01_10.1	0.000079	71	0.060907	1.58	0.069	3.57	0.234708	0.66	0.131	0.71	0.14	115	15	560	±8	595	±46	+6.2	1
FG_01_11.1	---	100	0.058619	1.81	0.075	3.85	0.246061	0.75	0.131	0.80	0.00	87	11	557	±7	553	±40	-0.8	1
FG_01_12.1	0.000136	58	0.061060	1.72	0.083	3.49	0.278178	0.73	0.159	0.73	0.24	83	13	554	±7	570	±57	+2.9	1
FG_01_13.1	0.000096	71	0.060425	1.76	0.070	3.89	0.228698	0.72	0.127	0.79	0.17	97	12	552	±7	568	±54	+3.0	1
FG_01_14.1	0.000078	71	0.060024	1.59	0.062	3.77	0.251855	0.66	0.102	0.82	0.14	107	11	571	±7	563	±46	-1.4	1
FG_01_15.1	0.000081	71	0.059911	1.61	0.068	3.61	0.247865	0.67	0.107	0.80	0.14	105	11	564	±7	557	±47	-1.2	1
FG_01_16.1	0.000075	71	0.059896	1.56	0.088	3.05	0.225308	0.64	0.170	0.61	0.13	122	20	555	±6	560	±45	+0.9	1

Observation: 1 - Data used to calculate the age of 561. 2 Ma - Data not used in age calculation.

TABLE 4. Zircons U-Pb isotopic data for FG-03 sample (migmatitic orthogneiss, -6º56'26'', -38º27'23'').

Spot	RATIO										^{206}Pbc(%)	(ppm)		AGE (Ma)				Disc.	Obs.
	$^{204}Pb/^{206}Pb$	±%	$^{207}Pb/^{206}Pb$	±%	$^{208}Pb/^{206}Pb$	±%	$^{206}Pb/^{238}U$	±%	$^{232}Th/^{238}U$	±%		U	Th	$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$			
1.1	0.0003	19	0.139	1.1	0.29	2.2	1.03	0.47	1.04	0.32	1.11	160	161	2105	±27	2162	±23	3	1
2.1	0.0012	17	0.077	1.5	0.13	2.7	0.30	1.00	0.35	0.48	2.10	166	56	594	±7	578	±120	-3	2
3.1	0.0008	18	0.071	5.3	0.05	15.2	0.29	1.22	0.08	0.76	1.47	211	16	584	±9	587	±160	1	2
4.1	0.0015	24	0.081	5.5	0.10	10.2	0.17	0.90	0.12	0.96	2.71	109	13	550	±8	584	±251	6	3
5.1	0.0024	15	0.094	5.6	0.13	8.3	0.29	0.78	0.14	0.86	4.25	146	20	587	±8	603	±282	3	2
6.1	0.0013	19	0.077	5.1	0.07	13.2	0.18	1.33	0.12	2.01	2.30	214	25	562	±7	560	±199	0	2
7.1	0.0058	6	0.143	2.9	0.44	3.1	0.28	1.06	0.64	0.74	10.23	374	232	561	±7	580	±254	4	4
8.1	0.0005	20	0.152	1.8	0.18	1.6	1.22	0.75	0.61	0.59	2.63	64	38	2138	±27	2296	±37	8	1
8.2	0.0035	7	0.112	6.0	0.16	11.9	0.19	2.33	1.34	4.72	6.91	438	568	543	±10	667	±283	19	4
9.1	0.0027	18	0.099	10.8	0.13	21.4	0.29	1.84	0.16	0.96	5.22	131	20	522	±9	615	±483	16	4
10.1	0.0035	16	0.112	10.7	0.21	12.0	0.25	1.64	0.29	0.72	6.48	84	23	565	±9	655	±529	14	4
11.1	0.0021	18	0.091	6.0	0.33	4.0	0.23	0.88	0.84	0.44	4.01	98	80	541	±10	599	±296	10	3
12.1	0.0009	20	0.073	2.8	0.05	4.7	0.14	0.60	0.06	0.87	1.87	347	20	542	±6	595	±125	9	3
13.1	0.0009	21	0.073	2.3	0.05	8.7	0.16	0.63	0.08	1.44	1.76	317	25	561	±8	615	±116	9	2
14.1	0.0020	19	0.089	1.8	0.56	1.8	0.20	1.36	1.60	0.34	3.82	120	185	534	±7	611	±209	13	3
15.1	0.0031	14	0.105	6.7	0.16	6.0	0.31	0.85	0.14	0.94	5.64	103	14	564	±9	570	±372	1	4
16.1	0.0010	18	0.074	4.8	0.65	1.1	0.24	1.06	2.03	0.25	1.87	204	401	561	±8	605	±159	8	2

Observation: 1 - Inheritance?, 2 - Data used in the calculation of the 574 Ma Concordia Age, 3 - Data not used in age calculation,
4 - Data discarded due to high common lead concentration.

TABLE 5. Zircons U-Pb isotopic data for FG-07 sample (migmatitic orthogneiss, -6º51'57'', -38º8'49'').

Spot	RATIO										$^{206}Pb_c$(%)	(ppm)		AGE (Ma)				Disc.	Obs.
	$^{204}Pb/^{206}Pb$	±%	$^{207}Pb/^{206}Pb$	±%	$^{208}Pb/^{206}Pb$	±%	$^{206}Pb/^{238}U$	±%	$^{232}Th/^{238}U$	±%		U	Th	$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$			
1.1	0.0011	24	0.0746	3.77	0.389	4.1	0.21	0.82	1.04	0.37	1.91	92	92	547	±7	569	±177	+4	1
2.1	0.0004	33	0.0642	3.35	0.080	5.8	0.20	1.43	0.13	0.72	0.68	143	17	540	±8	555	±106	+3	1
3.1	0.0016	28	0.0822	6.66	0.600	4.2	0.21	1.14	1.65	0.45	2.87	53	85	547	±9	561	±323	+3	1
4.1	0.0011	26	0.0752	5.88	0.376	5.1	0.22	0.90	0.98	0.42	2.03	93	89	551	±8	554	±233	+1	1
5.1	0.0007	21	0.0690	4.06	0.731	1.1	0.24	0.59	2.37	0.23	1.29	166	381	559	±8	550	±134	-2	1
6.1	0.0012	27	0.0745	7.03	0.584	1.9	0.19	0.94	1.72	0.36	2.06	93	155	548	±8	520	±268	-6	1
7.1	0.0011	24	0.0756	4.82	0.157	6.3	0.20	0.82	0.25	1.46	2.04	118	28	543	±7	567	±201	+5	1
9.1	0.0011	22	0.0735	5.78	0.087	10.6	0.21	1.25	0.11	0.84	1.92	143	16	542	±7	524	±211	-4	1
10.1	0.0013	23	0.0767	6.10	0.145	3.6	0.21	0.85	0.27	0.66	2.33	110	28	550	±12	521	±249	-6	1
11.1	0.0010	25	0.0731	7.72	0.635	1.6	0.20	0.83	2.00	0.32	1.87	113	220	548	±9	525	±263	-4	1
8.1	0.0022	22	0.0910	5.69	0.175	10.9	0.18	2.26	0.12	1.13	3.94	82	10	525	±8	565	±340	+7	2
12.1	0.0016	24	0.0806	6.93	0.224	3.0	0.18	0.94	0.50	0.54	2.80	99	48	527	±8	523	±303	-1	2

Observation: 1 - Data used in age calculation. 2 - Data not use in age calculation

group of data generated in the analysis of this sample is quite homogeneous and concordant (Table 5). The selection of the most concordant data (10 points) allowed the calculation of the concordia age of 547 ± 5 Ma (MSWD = 0.23), interpreted as the crystallization age of the protolith of the gneiss (Fig. 4I).

4. Discussion: Geodynamic evolution of the North Borborema Province

4.1. Archean Nuclei

The North Borborema Province has fragments of Archean crust (Figures 1B and 5) located in the São José do Campestre, Rio Piranhas-Seridó (Campo Grande and Granjeiro complexes) and Ceará Central domains (Cruzeta Complex).

The Archean orthognaisses of the São José do Campestre Domain have Paleo- to Neoarchean ages (Fig. 5A), with Nd isotopic signatures indicating the reworking of the oldest crust and the accretion of juvenile material (e.g., Dantas et al. 2004, 2013). In the Granjeiro Complex, the orthogneisses are also Paleo- to Neoarchean (Fig. 5B), being the Neoarchean ones of juvenile nature (Silva et al. 1997; Freimann 2014; Ancelmi 2016; Pitarello et al. 2019; Vieira 2019; Gomes et al. 2021). The Campo Grande Complex, has Meso- to Neoarchean rocks (Fig. 5B) with Nd TDM model ages ranging between 3.7 and 2.7 Ga and εNd values indicating Neoarchean juvenile source and locally older crust reworking (Ferreira et al. 2020b). The Cruzeta Complex is formed by Neoarchean orthogneisses (Fig. 5C) with Nd TDM ages and εNd values that indicate both a juvenile origin and reworking of older radiogenic crust (Fetter 1999; Ganade et al. 2017). Based on the data presented, it is suggested that the Paleoarchean units correspond to an initial protocrust derived from the mantle, in which juvenile Meso- to Neoarchean rocks from magmatic arcs were accreted (Fig. 7).

4.2. Paleoproterozoic Basement

Based on the information presented below, we understand that in the Paleoproterozoic there was an alternation between extensional and compressional events, with substantial crustal growth during the Rhyacian Orogeny. The Granja Complex, located in the Médio Coreaú Domain, is formed by Siderian rocks (Fig. 5D), with Nd isotopic signatures indicating juvenile accretion, probably in island arc setting (Fig. 7) (Fetter 1999; Santos 1999; Almeida 2019). Similarly, the orthogneisses of the Arábia Complex were also generated in the Siderian (Fig. 5B), probably by juvenile accretion (island arc developed around 2.48 Ga) around Archean nuclei (Fig. 7), as attested by Nd and Hf isotopic signatures (Vieira 2019; Costa et al. 2021a).

Possibly, the Archean and Siderian continental mass was fragmented into crustal blocks and, subsequently, agglutinated by the accretionary and collisional processes during the Rhyacian Orogeny in about 2.1 Ga (Brito Neves 2011). The orthoderived rocks of magmatic arcs, produced in this orogeny (Figs. 5 and 7), occur in all domains of the Northern Borborema Province. In the Central Ceará Domain, they correspond to the orthogneisses of the Algodões Complex (intraoceanic arc) and the Canindé do Ceará Complex and Madalena Suite (continental arc), as proposed by Costa et al. (2015).

In the Jaguaribeano Domain the orthogneisses of the Jaguaretama and São Gonçalo complexes are Rhyacian (Fig. 5E), with Nd TDM model ages ranging between 2.98 and 2.53 Ga and negative εNd values, indicating the incorporation of Archean crust (Fetter 1999; Sá et al. 2014; Gomes et al. 2021).

For the Rio Piranhas-Seridó Domain, Medeiros et al. (2021) suggest an evolution from the generation of oceanic arcs, with successive collisions and generation of the Caicó protocrust. The Paleoproterozoic litho-stratigraphic units that border the Archean nucleus of the São José do Campestre Domain evolved from the accretion of magmatic arcs in the Rhyacian Orogeny (Dantas et al. 2004, 2013).

Some sedimentary basins are associated with the Rhyacian Orogeny (Fig. 7), which is suggested by Rhyacian detrital zircons with Rhyacian-Orosirian metamorphic recrystallization rims (Costa and Palheta 2017; Calado et al. 2019; Muniz et al. 2022). For example, the metasedimentary rocks of the Canindé do Ceará Complex, have detrital zircons that point to Archean and Paleoproterozoic sources, with a maximum age of sedimentation around 2.13 to 2.0 Ga (Costa and Palheta 2017; Mendes et al. 2021; Muniz et al. 2022), while recrystallized zircons indicate high-grade metamorphism effect and minimum age for deposition around 2.10 to 2.0 Ga (Costa and Palheta 2017; Muniz et al. 2022) (Fig. 6A). For a schist sample of the Tróia Complex, Archean and Paleoproterozoic detrital zircons were found (Fig. 6A), with maximum sedimentation age at 2207 Ma (Souza 2016). Additionally, the Tróia metavolcano-sedimentary sequence is cut by metatonalites (Mirador Unit) with ages around 2.18 Ga (Costa et al. 2018), showing minimum age for deposition of this unit.

Based on the geochronological data of this work and compiled from Calado et al. (2019), the metasedimentary sequence of the Jaguaretama Complex is also Paleoproterozoic in age, with the maximum sedimentation age around 2.14 Ga (Fig. 6B). The main source of the sediments corresponds to the Rhyacian orthogneisses and subordinate Siderian detritus. According to Calado et al. (2019), the metamorphism age obtained by U-Pb analyzes on recrystallization rims of detrital zircon for the sample of the Jaguaretama Complex is estimated at of 2046 Ma, indicating the minimum age for the deposition of the studied sequence.

According to the Rhyacian-Orosirian ages of regional metamorphism obtained in rocks of the Ceará Central Domain (Gomes 2013; Garcia et al. 2014; Muniz et al. 2022) and the Jaguaribeano Domain (Calado et al. 2019), the Rhyacian continental collision must have occurred between 2.07 and 1.96 Ga, similarly to what is observed in other domains of the Borborema Province (Neves et al. 2006), in the São Francisco Craton (Teixeira et al. 2017) and worldwide (Zhao et al. 2002).

After the consolidation of the Rhyacian Orogeny, there was probably a global process of extension of continental masses in the Statherian, as interpreted by Brito Neves et al. (1995). In the North Borborema Province, the record of this event would correspond to the Orós and Serra de São José groups (Jaguaribeano Domain) and the Saquinho Unit (Médio Coreaú Domain), formed by metavolcano-sedimentary rocks of a rift setting, with crystallization ages ranging between 1.76 and 1.79 Ga (Fig. 5D) (Sá 1991; Cavalcante 1999; Santos 1999; Magini 2001; Benedetti 2012). The maximum sedimentation age of the Orós Group is around 1.70 Ga (Costa and Palheta 2017), with Archean and, predominantly, Paleoproterozoic sources (Fig. 6B).

Orthoderived and anorogenic augen gnaisses occur associated, and correspond to the Serra do Deserto and Poço da Cruz suites (located in the Jaguaribeano and Rio Piranhas-Seridó domains, respectively), both with U-Pb crystallization ages in zircon, between 1.80 and 1.74 Ga (Figs. 5E and B).

4.3. Mesoproterozoic and Neoproterozoic supracrustal and metaplutonic rocks

A Mesoproterozoic extensional event was defined based on the Forquilha retro-eclogites, in the Ceará Central Domain, whose age of crystallization of the mafic protolith is 1.57 to 1.52 Ga (zircon U-Pb), with age of metamorphism in ca. 614 Ma (Amaral et al. 2015; Ancelmi et al. 2015).

The rupture of the supercontinent formed in the Rhyacian Orogeny during a Tonian extensional event developed between about 900 to 800 Ma (Caxito et al. 2020, 2021) resulted in the NOBO-BENI (Northern Borborema/Benino-Nigeria) and AMCAPAY (Alto Pajeú-Alto Moxotó- Rio Capibaribe-Pernambuco-Alagoas/Adamawa-Yade) blocks.

The Brasiliano Orogeny generated extensive belts of supracrustal rocks, bordering a Paleoproterozoic and Archean basement, as well as several granitoids (Brito Neves et al. 2000; Arthaud et al. 2008; Caxito et al. 2020; Neves 2021). However, the understanding of this event in the context of the Borborema Province is still a subject of debate. Like some authors, we believe that the available data are indicative of the rupture of a Paleoproterozoic supercontinent, with oceanic crust formation, followed by oceanic subduction and continental collision (Van Schmus et al. 2008; Araujo et al. 2012; Caxito et al. 2021). However, there are other authors who believe in the development of an intracontinental orogen (Neves et al. 2009), or in the amalgamation of several exotic terrains in an accretionary orogen (Santos 1996; Brito Neves et al. 2000).

The associations of meta-volcano sedimentary rocks related to the Brasiliano Orogeny in the North Borborema Province correspond to the Ceará and Martinópole (Figs. 6A, B and C), Ipueirinha and Seridó (Figures 6D and E), Novo Oriente and Ubajara groups.

In the Médio Coreaú and Ceará Central domains, some authors propose that the continental rupture occurred around 770 Ma (Fetter 1999; Castro 2004; Arthaud et al. 2015), with generation of the Santa Quitéria Magmatic Arc (SQMA) between 640 to 610 Ma and collisional orogen between 610 and 590 Ma (Fetter 1999). Alternatively, Araujo et al. (2014) suggest the development of a juvenile magmatic arc between 880 and 800 Ma (Lagoa Caiçara Unit, Fig. 5C); the generation of continental magmatic arc between 660 and 630 Ma (Santa Quitéria Unit of the Tamboril-Santa Quitéria Complex, Fig. 5C); followed by a collisional event between 625 and 600 Ma (Tamboril Unit of the Tamboril-Santa Quitéria Complex, Fig. 5C) (Fig. 7). According to Amaral (2010) and Costa et al. (2013), most of SQMA's plutonic magmatism is probably the effect of a slab breakoff process. Additionally, Basto et al. (2019) propose that the Ipueirinha Group would correspond to a back-arc basin associated with the SQMA.

In the Rio Piranhas-Seridó and São José do Campestre domains, the Seridó Basin developed at the end of the Neoproterozoic period (Fig. 7), associated with the Brasiliano Orogeny. The basin formation begun as an Atlantic Margin type passive continental margin (Jucurutu and Equador formations), with subsequent increase of energy and deposition of turbidites of the Seridó Formation (Medeiros et al. 2021). Although we agree with the evolution proposed by Medeiros et al. (2021), we understand that there is an alternative model, of intracontinental nature, which corresponds to the generation of continental rift followed by the closure of a small oceanic basin (Van Schmus et al. 2003).

A common feature in the Borborema Province corresponds to batholiths and smaller bodies of magmatic rocks of Ediacaran, Cambrian and Ordovician age (Fig. 5). The structural characteristics of the granitoids show that the older ones, formed between 640-610 Ma, are usually syn-tectonic, with low-angle foliation, both in the North Borborema and in the Borborema Province as a whole (e.g., Costa et al. 2013).

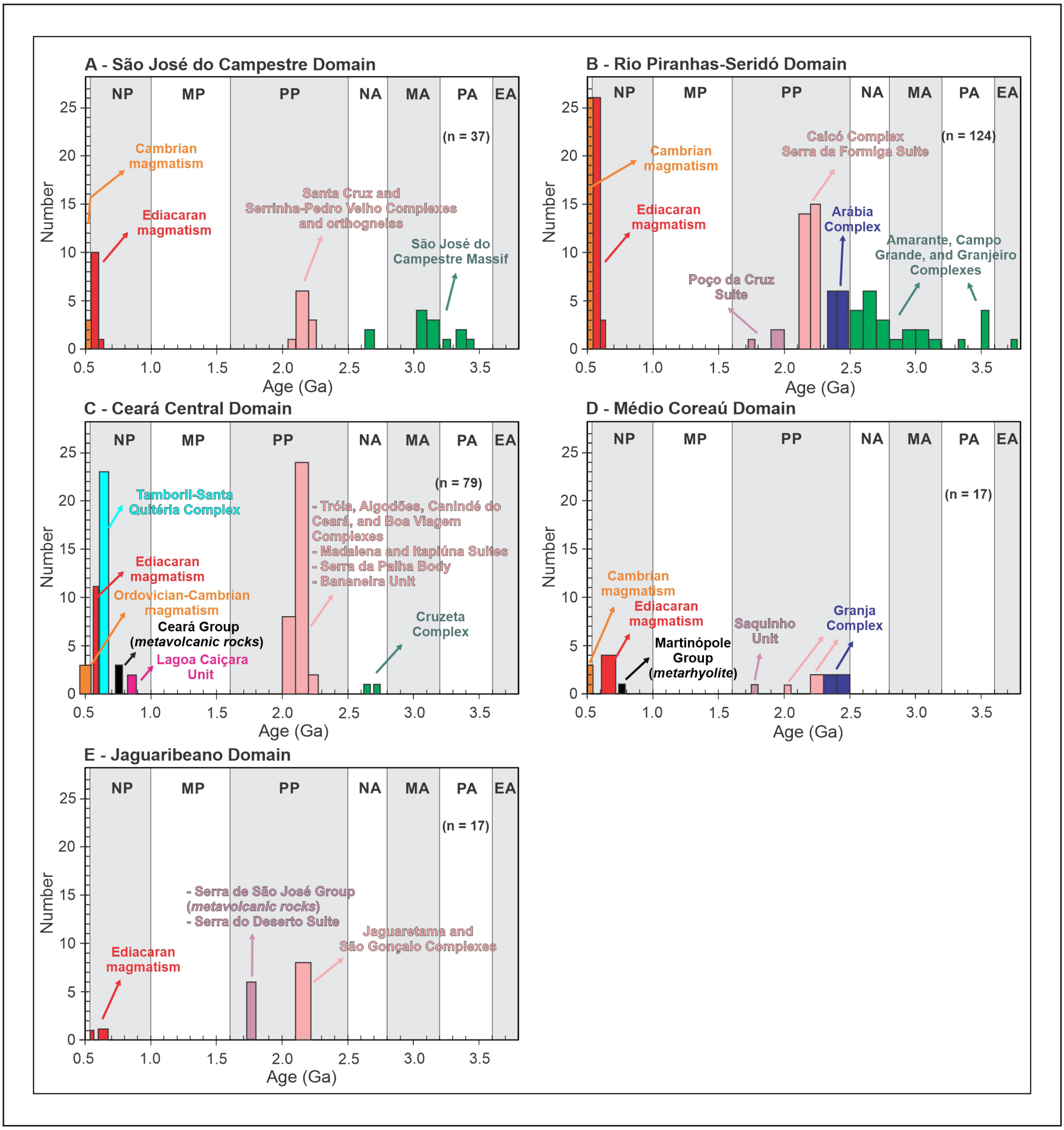

FIGURA 5. Histograms of U-Pb crystallization ages in orthogneisses zircon and granitoids of the Northern Borborema Province. NP: Neoproterozoic, MP: Mesoproterozoic, PP: Paleoproterozoic, NA: Neoarchean, MA: Mesoarchean, PA: Paleoarchean, EA: Eoarchean.

Whereas the 590-540 Ma granitoids are syn-tectonic in relation to high-angle shear zones (e.g., Quixadá and Quixeramobim batholiths). Younger batholiths (late- to post-tectonic) are less deformed to isotropic. The zircon U-Pb ages restrict the main granitic events to three main intervals; 650-620 Ma, 590-570 Ma and 545-520 Ma (Appendix 2). From the geotectonic point of view, in general, the oldest, Cryogenian-Ediacaran interval, is interpreted as a record of oceanic subduction (magmatic arc) (Fetter et al. 2003; Santos et al. 2009), similarly as proposed for other domains of the Borborema Province (e.g., Oliveira et al. 2010; Brito Neves et al. 2016). However, Neves (2015) argues against an accretionary process and oceanic subduction for the Neoproterozoic-Ediacaran evolution of the Borborema Province. This means that fold belts and granitic plutonism of this age were the product of the lithosphere extension without any oceanic crust formation, followed by compression due to far-field stresses (Neves 2015).

5. Conclusions

We presented in this work a chronostratigraphic review of the litho-stratigraphic units of the Northern Borborema

Province, which are formed by associations of rocks generated and submitted to various orogenic and extensional events. The specific considerations, based on the revision of the compiled data and the unpublished geochronological data, include the following.

In the Jaguaretama Complex, located in the Jaguaribeano Domain and consisting of an association of orthogneisses and migmatitic paragneisses, a zircon U-Pb age was obtained, of 2186 Ma for orthogneisses, interpreted with the crystallization age of the igneous protolith. The metasedimentary rocks are formed by detritus from predominantly Paleoproterozoic sources, with a maximum sedimentation age around 2144 Ma.

The Ceará Group, composed of Neoproterozoic supracrustal rocks, is distributed both in the Ceará Central and in the Jaguaribeano domains, according to lithological similarity and the same range of age of detrital zircon of quartzites of both domains. The Seridó Group, also composed of Neoproterozoic supracrustal rocks, is located in the Rio Piranhas-Seridó and São José do Campestre domains.

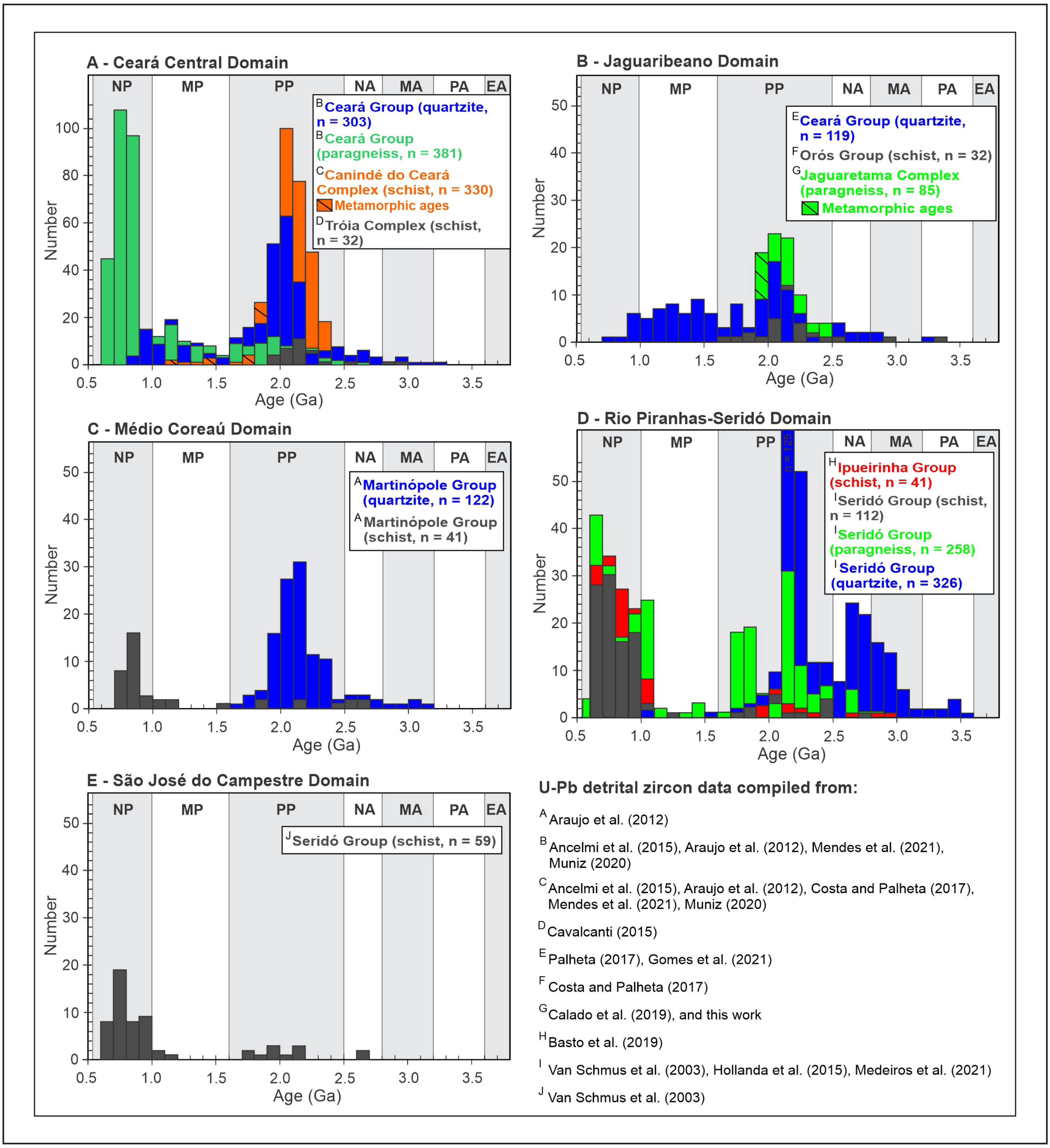

FIGURA 6. Histograms of U-Pb ages (apparent ages 207Pb/206Pb) in detrital zircon of paraderived schists, paragneisses and quartzites of the Northern Borborema Province. NP = Neoproterozoic, MP = Mesoproterozoic, PP = Paleoproterozoic, NA = Neoarchean, MA = Mesoarchean, PA = Paleoarchean, EA = Eoarchean.

Detrital zircon U-Pb data show that the maximum deposition age of the Ceará Group is around 600 Ma, therefore, from the Ediacaran period and thus contemporary to the Seridó and Ipueirinha groups. The great difference between the age of vulcanism (between about 770 and 650 Ma) and the maximum sedimentation of the Ceará Group, corroborates the evolutionary model proposed by Araujo et al. (2012), of a long-lived active continental margin. Thus, the Ceará, Ipueirinha and Seridó groups are coeval and may have been deposited in a pre-Ediacaran single crustal block and reworked during the Brasiliano Orogeny.

The three samples of ortho-derived rocks located in the central portion of the Rio Piranhas-Seridó Domain, which were analyzed by the zircon U-Pb method, have a penetrative

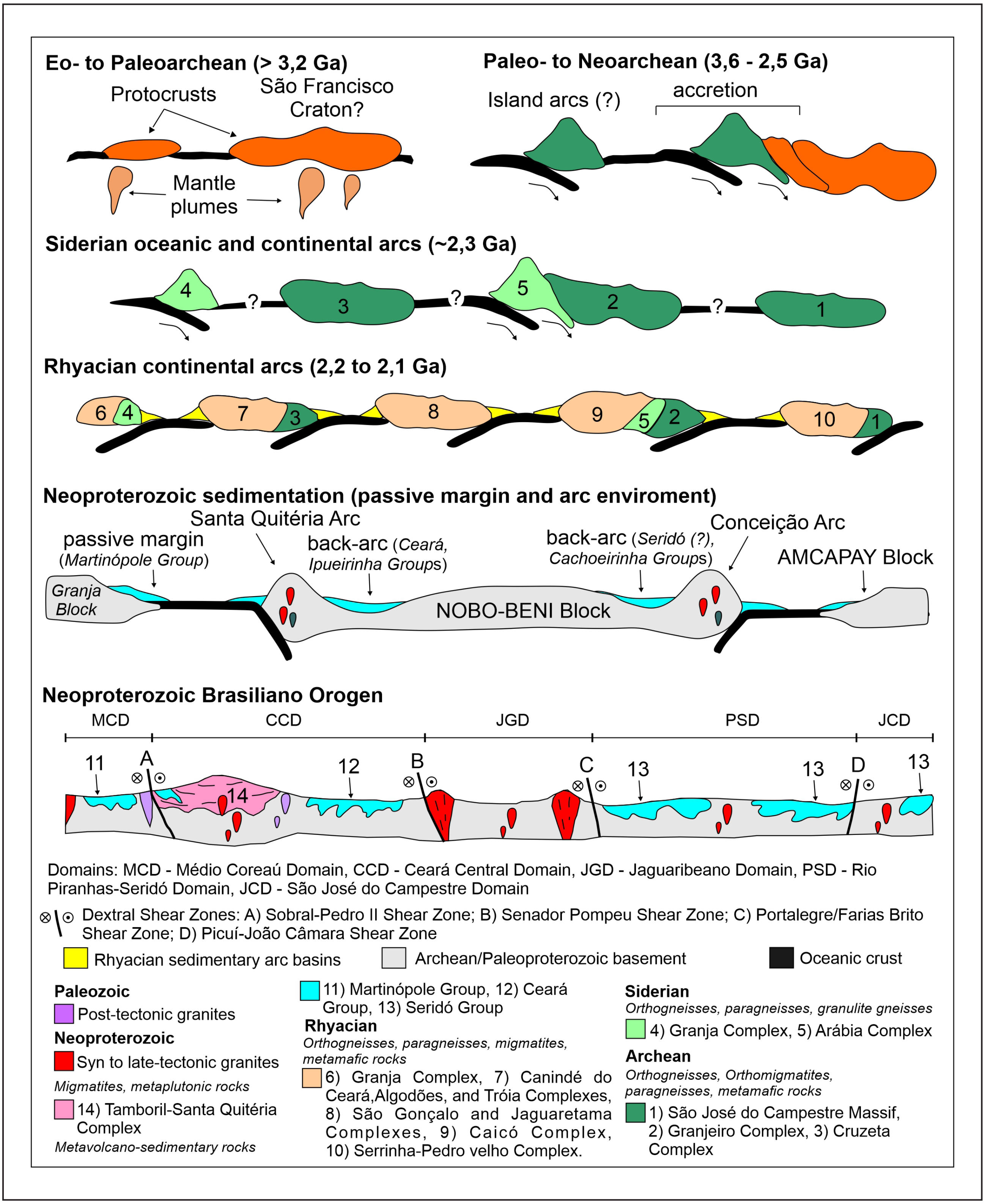

FIGURA 7. Model of geodynamic evolution proposed for the North Borborema Province.

deformation fabric, marked by compositional banding and migmatization structures, which makes them similar to poly-deformed rocks, constituent of the Paleoproterozoic litho-stratigraphic units. However, the ages obtained are all Ediacaran, between about 574 and 547 Ma, and interpreted as the crystallization age of the igneous protolith. Thus, the samples analyzed are related to the syn- to late-tectonic magmatism in relation to the Brasiliano Orogeny, whose deformation and migmatization should be due to the tectonic activity of extensive shear zones, which are adjacent to the analyzed orthogneisses.

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Appendix 1 (U-Pb geochronology methods)

Five samples were submitted to zircon U-Pb geochronological analysis. Two samples (TP-236, migmatitic schist and TP-271, migmatitic orthogneiss) were prepared in the laboratory of the Residence of Fortaleza (SGB/CPRM) and the other three (FG-01, FG-03 and FG-07, migmatic orthogneisses) were prepared in the laboratory of the Residence of Teresina (SGB/CPRM). The samples were crushed, sprayed and sifted, separating the fraction lower than 500 µm. The heavy minerals were concentrated by panning and the magnetic portion was separated by the Frantz isodynamic separator. From the non-magnetic fraction, the zircon grains were manually separated in binocular magnifying glass, embedded in epoxy resin, worn until the exposure of their internal area and polished in diamond paste of 0.25 µm.

The internal structures of the zircon crystals of the samples TP-236 (paraderived migmatitic schist) and TP-271 (migmatitic orthogneiss) were characterized by backscattered electron images (BSE) in the Scanning Electronic Microscope of the Laboratory of Geochronological, Geodynamic and Environmental Studies of the University of Brasilia (UnB, Brasilia, Brazil). The U and Pb isotopes in situ determinations were also performed at UnB, following the procedure presented by Bühn et al. (2009), using the high-resolution multi-collector mass spectrometer with Thermo-Finnigan Neptune plasma source coupled to a Nd-YAG (λ = 213 nm) laser ablation system of brand New Wave Research, USA. The ablation was performed with a spot of 30 µm, a frequency of 10 Hz and a fluence of 0.19-1.02 J/cm2. The ablated material was carried by the mixture of Air (~0.90 L/min) and He (~0.40 L/min) and its isotopic composition determined in analyzes of 40 cycles of 1s. The raw data were reduced using an Excel spreadsheet built in the laboratory itself, where corrections were applied to white, instrumental drift.

The zircons of the FG-01, FG-03 and FG-07 samples (migmatitic orthogneisses) were imaged by cathodoluminescence (CL) in the Scanning Electron Microscope of the Center for Geochronology and Isotopic Geochemistry Research of the University of São Paulo (CPGeo/USP, São Paulo, Brazil). The isotopic composition of the points was determined in the ion microprobe SHRIMP IIe, of CPGeo/USP. For normalization of U-Pb-TH concentration, the zircon international standard SL13 (238 ppm) was used and the bracketing of the ratio 206Pb/238U was performed using the natural standard TEMORA 2, of age 416.78 Ma (Black et al. 2004). The analysis conditions were: spot size = 24 µm, 6 scans, dead time = 25ηs and source slit = 80µm. For the data reduction the program Squid 1.06 was used. The age calculations of all samples analyzed, as well as the plot of the points were performed with the Isoplot 4.15 program (Ludwig 2012).

Appendix 2 (Digital supplement)

Tables with zircon U-Pb ages of orthoderived rocks and syn- to post-orogenic magmatic suites of the Northern Borborema Province, compiled from literature (references in the tables and in the digital supplement). Available at https://jgsb.cprm.gov.br/index.php/journal/issue/view/31

Authorship credits

Author	A	B	C	D	E	F
TRGP	■	■	■	■	■	■
FGC	■		■	■	■	
CFB			■	■	■	
JBR			■	■	■	
VCM	■	■	■	■	■	■
ESMP			■		■	
BOC			■		■	
RC				■	■	
RBM			■		■	
FGS	■	■	■		■	■
RGB				■		
ARD				■		
DMFM				■	■	
JSS		■			■	

A - Study design/ Conceptualization **B** - Investigation/ Data acquisition
C - Data Interpretation/ Validation **D** - Writing
E - Review/Editing **F** - Supervision/Project administration

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