Geologia Série Científica USP

DOI: 10.5327/Z1519-874X201400030007

Revista do Instituto de Geociências - USP
Geol. USP, Sér. cient., São Paulo, v. 14, n. 3, p. 97-110, Setembro 2014

U-Pb and Sm-Nd data of the Rhyacian and Statherian Orthogneisses from Rio Piranhas-Seridó and Jaguaribeano Terranes, Borborema Province, Northeast of Brazil

U-Pb e Sm-Nd em Ortognaisses Riacianos e Estaterianos nos Terrenos Rio Piranhas-Seridó e Jaguaribeano, Província Borborema, Brasil

Jaziel Martins Sá[1], Laécio Cunha de Sousa[1], Jean Michel Legrand[1], Antonio Carlos Galindo[1,2], Heitor Neves Maia[1], Rafael Rabelo Fillippi[2]

[1]Departamento de Geologia, Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte - UFRN, Avenida Senador Salgado Filho s/n, Caixa Postal 1596, Campus Universitário, CEP 59078-970, Natal, RN, BR (jaziel@ccet.ufrn.br; laecio@geologia.ufrn.br; legrand@geologia.ufrn.br; galindo@geologia.ufrn.br; heitor@geologia.ufrn.br)

[2]Pós-graduação em Geodinâmica e Geofísica, Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte - UFRN, Natal, RN, BR (rafaelrfillippi@yahoo.com.br)

Received on January 20th, 2014; accepted on August 4th, 2014

Abstract

The Portalegre shear zone separates the Rio Piranhas-Seridó and the Jaguaribeano geological terranes in the Northern Domain of the Borborema Province. Banded gneisses of the Caicó and the Jaguaretama Complexes represent the basements of these terranes. U-Pb analyses yielded ages of 2,193 ± 16 Ma for the Jaguaretama Complex, which is similar to those obtained for the Caicó Complex. T_{DM} Sm-Nd ages for these basement complexes showed Neoarchean values (*ca*. 2.5 Ga), with $\varepsilon_{Nd(t)}$ values close to the CHUR composition. Elongated bodies were found intruding into the rocks of the Jaguaretama Complex. These foliated bodies with elongated phenocrysts are described as augen gneisses of the Serra do Deserto Suite. These gneisses yielded crystallization ages of 1,777 ± 8 Ma, confirming an extensional period during the Statherian, which is well represented in the Jaguaribeano Terrane by A-type plutonic rocks. Augen gneisses with similar textures, the so called Poço da Cruz Suite, are found intruding the Caicó Complex in the Rio Piranhas-Seridó terrane; however, the ages found throughout the domain are predominantly Rhyacian (*ca*. 2.2 Ga) and present calc-alkaline affinities. These findings indicate that the augen gneisses, which are widely distributed in these two terranes, have different signatures and are temporally well separated. Furthermore, in agreement with previous geophysical data suggesting a division of terranes marked by the Portalegre Shear Zone, it also demonstrates that even though the Caicó and the Jaguaretama Complexes have similar ages, similar structural evolution and metamorphism under similar pressure and temperature conditions, they exhibit marked differences in composition.

Keywords: Borborema Province; Jaguaribeano terrane; Rio Piranhas-Serido terrane; Serra do Deserto Suite; Poço da Cruz Suite; Portalegre shear zone.

Resumo

A zona de cisalhamento Portalegre separa os terrenos geológicos Rio Piranhas-Seridó e Jaguaribeano do Domínio Setentrional da Província Borborema, com gnaisses bandados dos Complexos Caicó e Jaguaretama representando os respectivos embasamentos destes terrenos. Análises U-Pb forneceram idades de 2.193 ± 16 Ma para os ortognaisses do Complexo Jaguaretama, resultados muito similares às determinadas para o Complexo Caicó. Idades T_{DM} Sm-Nd nesses Complexos forneceram valores neoarqueanos (ca. 2,5 Ga), com $\varepsilon_{Nd(t)}$ muito próximos ao CHUR. Intrudindo as rochas do Complexo Jaguaretama, destacam-se corpos alongados, foliados e com pórfiros estirados, denominados de Suíte Serra do Deserto. Estes forneceram idades de cristalização a 1.777 ± 8 Ma, ratificando um período extensional que ocorreu no Estateriano, bem representado no terreno Jaguaribeano por sequências vulcanos-sedimentares e plutônicas Tipo-A. Augen gnaisses com texturas similares, denominados de Suíte Poço da Cruz, são encontrados intrudindo o Complexo Caicó no terreno Rio Piranhas-Seridó, porém, as idades registradas por todo este domínio são predominantemente Riacianas (*ca.* 2,2 Ga) e de afinidades cálcio-alcalinas, indicando que estes augen gnaisses possuem diferentes assinaturas e estão bem separados no tempo. Além disso, além dos dados geofísicos prévios que sugerem esta divisão de Terrenos marcada pela Zona de Cisalhamento Portalegre, os Complexos Caicó e Jaguaretama exibem diferenças composicionais marcantes. Corpos de anfibolitos alongados e concordantes a subconcordantes com o bandamento do Complexo Caicó e importante contribuição sedimentar na constituição do Complexo Jaguaretama com importantes intercalações de mármores são algumas destas diferenças.

Palavras-chave: Província Borborema; Terreno Jaguaribeano; Terreno Rio Piranhas-Seridó; Suíte Serra do Deserto; Suíte Poço da Cruz; Zona de cisalhamento Portalegre.

INTRODUCTION

The characterization and subdivision of the Borborema Province into subprovinces or distinct geotectonic domains was first completed by Almeida et al. (1977, 1981) and it has since been reviewed by other authors, including Santos et al. (1984), Brito Neves et al. (1995), Van Schmus et al. (1995), Santos (1996, 1999), Santos and Medeiros (1999) and Medeiros et al. (2011). The first characterization uses the large E-W shear zones, called the Pernambuco and Patos Lineaments, to separate the large geotectonic domains, such as the Northern Subdomain, which consists of the geological terranes located to the north of the Patos shear zone (Figure 1), where the study area is located. Various folded belts or geological terranes have been characterized within these subdomains, and the following terranes are described within this Northern subdomain (Figure 1), from west to east:

(i) Médio Coreaú or NW Ceará;
(ii) Central Ceará;
(iii) Jaguaribeano;
(iv) Rio Piranhas-Seridó.

These terranes are oriented in the NE-SW direction, with a predominantly Rhyacian basement (2.25 – 2.05 Ga) and an Archean block called São José de Campestre Block or Massif (Dantas 1996; Dantas et al., 1998, 2004), located in the eastern portion.

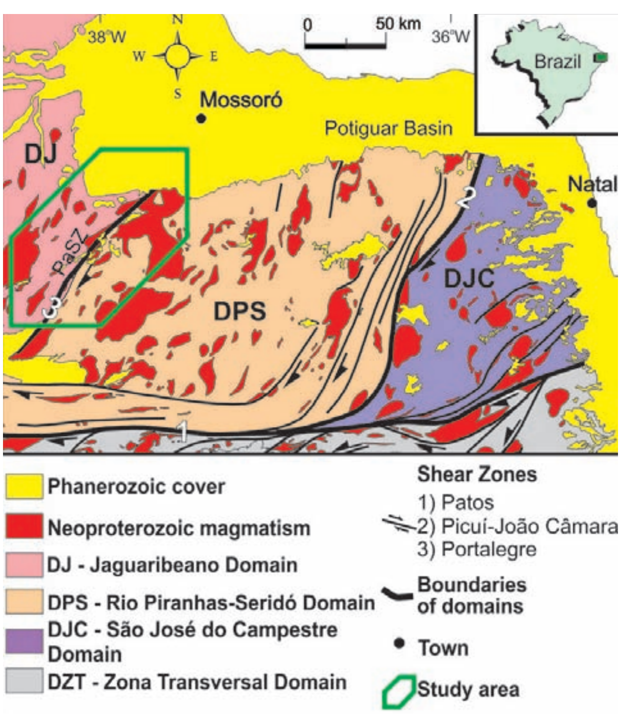

Figure 1. General geologic map of the Northern Domain of the Borborema Province showing the main Geological terranes and study area, highlighting the Portalegre shear zone (PaSZ).

These terranes have characteristic evolutions and distinct geophysic signatures (Cavalcante et al., 1998; Cavalcante, 1999; Campelo, 1999; Oliveira, 2008). They are limited by extensive shear zones, generally trending in the NE-SW direction, including the Sobral-Pedro II (Transbrasiliano Lineament), Senador Pompeu, Portalegre and Picuí-João Câmara shear zones.

In the far west region of the State of Rio Grande do Norte, there is a significant geological lineament in the NNE-SSW direction that is hundreds of kilometers long. It extends from the Patos shear zone in the south to the edges of the Potiguar Basin in the North (Figure 2), called the Portalegre shear zone (PaSZ). This shear zone mainly developed/reactivated during the Brasiliano Cycle. It had reactivations in the Phanerozoic times during the rifting and formation of the Potiguar Basin (Hackspacher and Oliveira, 1984; Hackspacher and Legrand, 1989; Nóbrega et al., 2005). This structure is known as an important marker of the division of geological terranes, outlining the Rio Piranhas-Seridó Terrane, in the east and the Jaguaribeano terrane, in the west. This terrane boundary is marked by contrasting ages that surround it and by geophysical anomalies, thereby juxtaposing geological terranes with different geophysical signatures (Cavalcante et al., 1998; Cavalcante, 1999; Campelo, 1999; Fuck et al., 2013). Here, we present geochronological data on the east and west regions of the Portalegre shear zone extending into the State of Ceará with the objective of highlighting regional similarities and differences (Figure 2).

GEOLOGICAL FRAMEWORK

In the Northern domain of the Borborema Province, located to the north of the Patos Lineament, the crystalline basement of mobile belts or supracrustal sequences is predominantly characterized by banded gneisses and orthogneisses of granitic to tonalitic composition (often migmatized), and belts of metasedimentary rock. The basement of the Jaguaribeano Terrane, called the Jaguaretama Complex, exhibits marble intercalations (mainly in the regions of Riacho de Santana and Poço Dantas) as well as intercalations of aluminous metasedimentary rocks (Souza et al., 2011). In turn, the basement of the Rio Piranhas-Seridó terrane, called the Caicó Complex, lacks marble intercalations and has frequent lenticular and elongated amphibolite bodies, which are much less common in the Jaguaretama Complex.

Previous dating has characterized the Jaguaretama and Caicó Complexes as being from Paleoproterozoic ages; specifically, the U-Pb dating indicated the Rhyacian (2.05 – 2.25 Ga) as the most significant period of the formation of these complexes (Hackspacher et al., 1990; Fetter et al., 2000; Legrand et al. 1991; Van Schmus et al., 1995; Souza et al., 2007). A petrogenetic model visualizing the formation and evolution of orthogneisses in the Caicó Complex involves the partial melting of the metasomatized mantle to generate basic magma. The magma underwent a subsequently fractional crystallization and an orogenic environment for the formation of these rocks, dated to the Rhyacian period, as suggested by Souza et al. (2007).

Gneisses of the Caicó and Jaguaretama complexes commonly exhibit complex and polyphasic structures with the development of isoclinal to tight folds and interfolial folds with limb transposition and marked apical thickening, displaying types 1 and 3 interference patterns of Ramsay (1967). They indicate a superposition of folding phases (Jardim de Sá, 1984; Hackspacher et al., 1980; Minnigh and Hackspacher, 1979; Sá, 1991; Sá et al., 1995). Migmatization processes producing neosomes with the crystallization of microcline, plagioclase and quartz during such deformations attest to high-temperature upper amphibolite facies metamorphic conditions.

These basement complexes are overlain by metasedimentary and metavolcanosedimentary sequences belonging to the São José, Orós and Peixe Gordo groups, to the west, and the Seridó Group, to the east of the Portalegre shear zone (PaSZ). These sequences cover large areas in the region representing ancient basins established over the basement complexes, which were previously deformed. These sequences were deposited during the Statherian period (1.8 – 1.7 Ga) in the case of sequences to the west of this shear zone (São José, Orós and Peixe Gordo groups) or during the Neoproterozoic era in the case of the Seridó group. This set of supracrustal rocks was solely affected by the Brasiliano orogenic cycle (Sá, 1991; Sá et al., 1995;

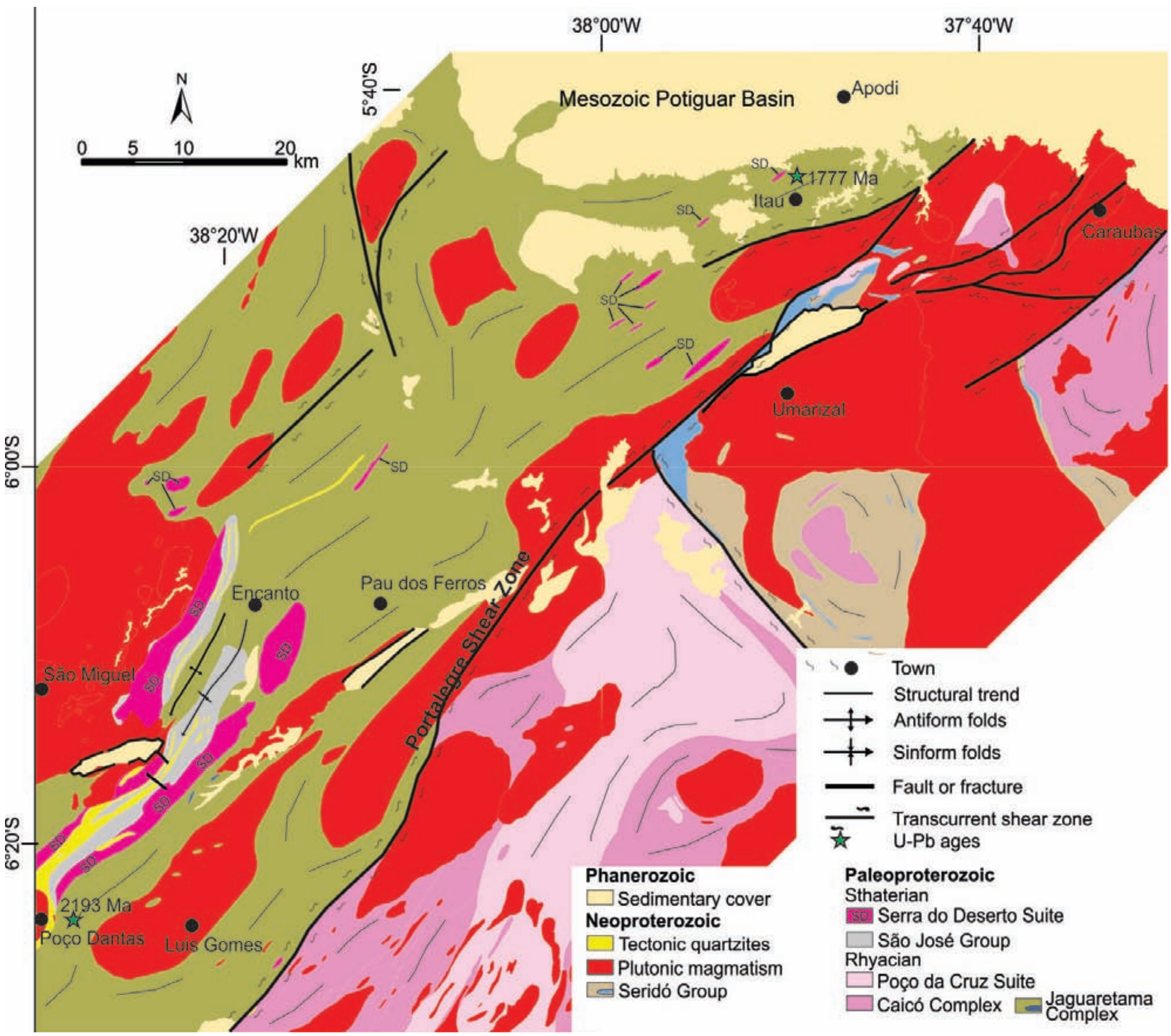

Figure 2. Geological framework of the adjacent areas to the Portalegre shear zone, with a stratigraphic column and localization of the U-Pb dated samples.

Cavalcante, 1998; Magini, 2001; Van Schmus et al., 2003), which formed transposed and isoclinal folds, tangential and transcurrent shear zones and extensive zones of mylonites, such as the PaSZ. The regional metamorphism associated with all of these supracrustal rocks varies regionally and occurred under PT (pressure and temperature) conditions corresponding to low-greenschist (chlorite – sericite) to amphibolite (staurolite – garnet – cordierite – sillimanite) facies and predominantly under low-pressure zone conditions (Sá and Legrand 1983; Sá, 1995; Lima, 1987, 1992; Souza et al., 1998).

The presence of tabular bodies of augen gneisses with generally subhorizontal prominent foliation deserves special mention in the geodynamic evolution of these terranes. These bodies are referred by Jardim de Sá et al. (1981, 1995) as G_2 augen gneisses; they are from the Paleoproterozoic age. These orthogneisses intrude into the basement units or occur in the interface of basement-metasupracrustal rocks. The fact of whether many of these tabular bodies of augen gneisses belong to basement units affected by the Transamazonian Cycle or if they represent intrusions subsequently to Paleoproterozoic deformation continues to be debated.

Macedo et al. (1984) perform whole-rock Rb-Sr isotopic dating of these augen gneisses from the Rio Piranhas-Seridó domain. They have obtained ages of *ca.* 2.0 Ga, which were interpreted as syntectonic intrusions. More recently, Hollanda et al. (2011) dated these "G_2" augen gneisses obtaining U-Pb zircon ages of approximately 2.2 Ga at various sites, with a single body in the Serra Negra region, yielding a 1.74 Ga age. Based on these results, these authors consider that these augen gneisses should belong to the magmatism inherent to the Caicó complex, an event that extended from the Rhyacian (2.24 Ga) to the Statherian period (1.75 Ga), thereby extending these conclusions to the Jaguaribeano terrane. However, all analyses were performed exclusively on the Rio Piranhas-Seridó terrane. In the east region, near to PaSZ, these Rhyacian augen gneisses (G_2) have been mapped as the Poço da Cruz Suite (Souza et al., 2011; Galindo et al., 2011).

On the western side of PaSZ, nearly 100 km west to the study zone, but within the Jaguaribeano terrane, Sá (1991) and Sá et al. (1995, 1997) dated well-foliated augen gneisses in the Orós-Jaguaribe belt. These rocks provided consistent ages of *ca*. 1.70 Ga, and were classified as intraplate granites. In the studied area, similar rocks occur in the Poço Dantas – Encanto – Pau dos Ferros – Itaú region, as various elongated bodies, displaying similar textures and structures; these bodies intrude into the Jaguaretama basement, and they were mapped by Souza et al. (2011) and Galindo et al. (2011) as Serra do Deserto Suite (Figure 2). The following sections present a petrostructural characterization of these units.

LITHOSTRATIGRAPHY

Jaguaretama Complex

This basement unit, which is homogeneously distributed in the study area, has a smoothly undulating and monotonous relief, and it is predominantly composed of orthoderived plutonic rocks, which vary from granitic to tonalitic in composition, in addition to banded biotite gneisses. Migmatitic features and neosomes (i.e., gneisses with centimetric- to decametric-scale gneissic banding progressing to stromatic and nebulitic migmatites) (Figure 3), are accompanied by the development of isoclinal to transposed folds. These structures were developed under PT conditions of upper amphibolite facies. In many outcrops,

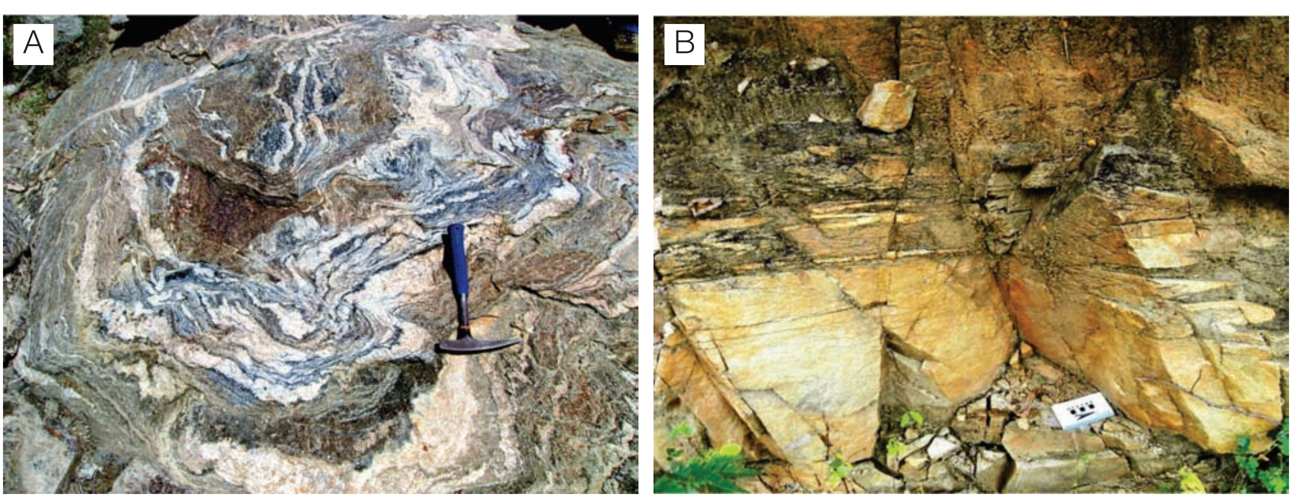

Figure 3. (A) Features of the stromatic migmatite and strongly deformed Jaguaretama complex; (B) banded gneiss of the Jaguaretama complex with interdigitation of lithological bands and intrafolial folds.

dike or vein injections of isotropic granites or granites with discrete foliation cut through the foliation and banding of these banded gneisses of the Jaguaretama complex. Concerning texture, the Jaguaretama complex exhibits intense variation from phaneritic rocks with fine granulation (equigranular, homogeneous) to porphyritic rocks with microcline phenocrysts measuring up to 3 cm, often called augen gneisses. A sample for isotopic U-Pb analysis was collected from one of these subunits, which contains smaller porphyries (predominantly millimetric with inequigranular texture) outcropping in a boudinaged body; this body is continuous for hundreds of meters and is up to several meters wide. This subunit, compositionally classified as syenogranite orthogneiss, exhibits strong gneissic foliation highlighted by the prominent orientation of amphiboles and biotites, predominantly consisting of microcline (40%), quartz (35%), plagioclase (18%), hornblende (5%) and biotite (2%) in addition to accessory titanite, allanite, apatite and zircon.

Caicó Complex

In the study area, the Caicó Complex occurs exclusively to the east of the PaSZ and in a limited area, west of the Caraúbas town, in the core of an antiformal structure and bordering the Catolé do Rocha granitic pluton. The rocks of this complex exhibit textures and structures that are similar to those of the Jaguaretama complex, with some specificities, such as enclaves and elongated amphibolite bodies, and they include distinguishable subunits, such as the Amphibolite Caicó complex, Banded Caicó complex or Undivided Caicó complex. Detailed description of the subunits of this complex in Rio Grande do Norte domain were performed by Souza et al. (2007, 2011).

The amphibolites are recurring, lenticular, elongated, sometimes boudinaged, and concordant to subconcordant with regard to the gneissic structure; these mainly consist of hornblende and plagioclase, and they include strongly deformed quartz-feldspar veins with tight and intrafolial folds (Figure 4).

Poço da Cruz Suite

To the north of the city of Umarizal, this unit occurs as small bodies and borders an antiformal structure at the contact with the Quixaba Neoproterozoic granitoid. To the west of Alexandria, this unit occurs as a larger body elongated in the NE-SW direction intruding into the gneisses and migmatites of the Caicó complex.

These units are mainly represented by the granodioritic to syenogranitic augen gneisses, which are consistently foliated, light gray to light brownish, with foliated microcline phenocrysts of different sizes, reaching 5.0 – 6.0 cm. Biotite and hornblende are the dominant ferromagnesian phases, although the latter may be absent. The outcrops of this suite are strongly elongated, forming L and L-S tectonites, and may locally exhibit decametric- to metric-scale mylonitic bands. Light gray biotite-orthogneiss having a medium to coarse granulometry also occurs subordinately (Figure 5), as well as lenses or small bodies of dioritic orthogneisses close to the Alexandria region.

Serra do Deserto Suite

The intrusive Serra do Deserto Suite is prominent in the Jaguaribeano domain and is represented by leucogneisses and syenogranitic to monzogranitic augen orthogneisses with biotite and amphibole. Elongated bodies hundreds of

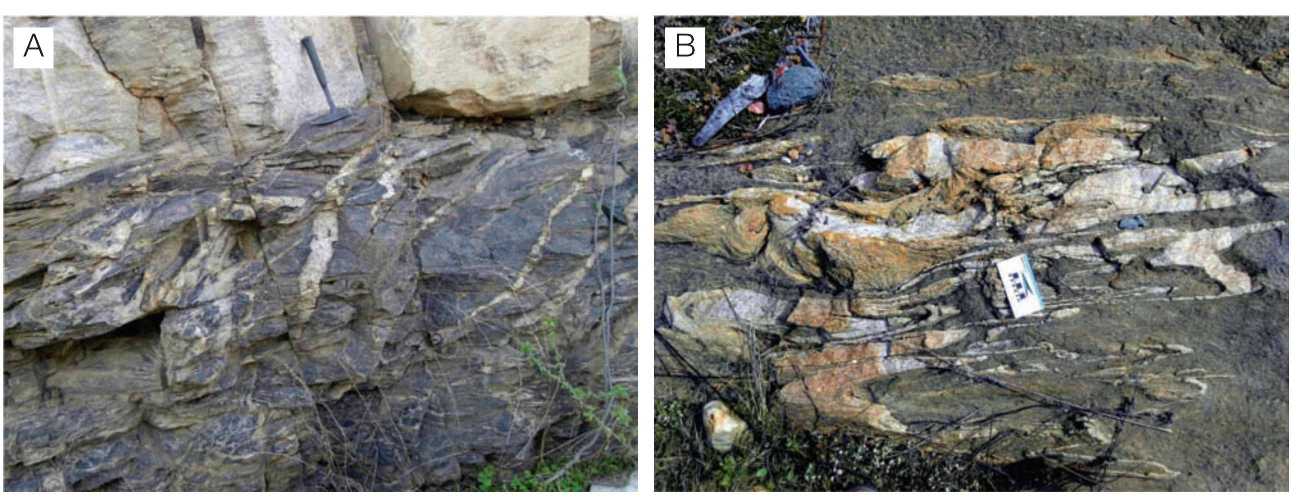

Figure 4. (A) Amphibolite lenses in orthogneisses of the Caicó complex, both with penetrative and concordant foliation; (B) aspect of the Caicó complex with amphibolite lenses and quartz-feldspar veins, which exhibit tight folds and limb transposition.

meters wide extend from the vicinity of Poço Dantas in the southeast to near the city of Encanto. This suite also occurs as lenticular and narrow bodies in the NE-SW direction, and further to the north, near the city of Itaú, it is always intruding into the rocks of the Jaguaretama complex or bordering Ediacaran Neoproterozoic granites. It displays continuous lineaments, a moderate to high relief that forms the east-facing of the São José and Das Almas hills, and it stands out topographically with respect to the rocks of the Jaguaretama Complex.

The Serra do Deserto Suite often features shear zones that imprint a heterogeneous deformation, exhibiting variations of moderately deformed zones and different degrees of comminution of its crystals from a coarse porphyritic texture to a medium-to-fine grained texture, progresses into mylonites rocks. The U-Pb isotopic analyses were performed in an outcrop in the region of Melancias, northeast of the city of Itau (Figure 2).

The syenogranitic orthogneisses are often leucocratic and occasionally mesocratic. They are pink in color, with black and greenish spots of mafic minerals. They have a medium-to-coarse granulation and often include porphyroblasts with well-developed augen features marked by stretched feldspar (Figure 6). They exhibit penetrative gneissic foliation indicated by the orientation of mafic minerals and quartz-feldspar aggregates. In zones of greater deformation, they acquire protomylonitic to mylonitic features in addition to S-C structures and quartz ribbons. Mylonitization produces mylonitic bands, which progress to mylonitic quartzites and ultramylonites.

These rocks are mainly composed of microcline (28 – 40%), plagioclase (22 – 30%), quartz (20 – 30%) and colored minerals represented by biotites (1 – 5%), hastingsite (0 – 4%) and epidote (2 – 3%). They occasionally contain secondary muscovites, opaque minerals, titanite, allanite and zircon as accessory minerals.

ISOTOPIC DATA

Isotopic U-Pb analyses of zircons and whole-rock Sm-Nd measurements were obtained in samples from augen orthogneisses and banded gneisses from Jaguaretama and Caicó basements. The samples were crushed and milled at the Department of Geology of the Federal University of Rio Grande do Norte (UFRN). The analyses were performed at the Laboratory of Isotopic Geology, at the University of Brasília, following the procedures described by Bühn et al. (2009) for U-Pb and Gioia (2000), and those mentioned by Pimentel (2000) for the Sm-Nd analyses. The ISOPLOT, version 3.0 software, was used to calculate the ages according to Ludwig (2003). The zircon analyses were obtained by laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS). Textural observations of zircons were performed using a stereomicroscope and a Scanning Electronic Microscope (SEM) at UFRN.

U-Pb of the Jaguaretama Complex

Zircons were extracted from a foliated orthogneiss with thin banding and elongated microcline phenocrysts (< 2.0 mm). The sample was collected east of the city of Poço Dantas

Figure 5. Textural aspect of the augen gneiss of Poço da Cruz Suite with a mylonitic structure and elongated microcline phenocrysts.

Figure 6. Textural and structural aspect of the Serra do Deserto augen gneiss with thin mylonitic bands highlighting the intense stretching of the feldspars.

Geol. USP, Sér. cient., São Paulo, v. 14, n. 3, p. 97-110, Setembro 2014

(see sample location in Figure 2). The orthogneiss is a very well preserved rock with limpid minerals and amphibole and biotite as the main mafic minerals.

The zircons are generally elongated and bipyramidal idiomorphic prisms. In the SEM images, zircons display cores with nice igneous oscillatory zoning and well developed rims (darker in SEM images). Some of these rims also have an oscillatory zoning, which may indicate contrasting chemistry in the crystallizing magma or latter magmatic resorbing. A metamorphic origin cannot be discarded (Figure 7). The analysis points were generally located in limpid sites to avoid complex and diffuse textures, although we did not find significant differences when analyses were performed at the core and rim of the crystals. The results are shown in Table 1. These data plot very near or on the concordia curve, dated from 2,193 ± 16 Ma (Figure 8), indicate a reliable result which is representative of the Rhyacian age of the Jaguaretama basement in this region. Similar ages of 2,191 ± 9 Ma (Pb-Pb in zircons) and 2,170 ± 9 Ma (U-Pb) were obtained by Cavalcante (1999) for biotite orthogneisses in the region of Limoeiro do Norte, and by Fetter et al. (2000) in tonalitic orthogneisses, respectively. Both analyses were performed in rocks belonging to the Jaguaretama complex, in the State of Ceará, much further to the west of the mapped area.

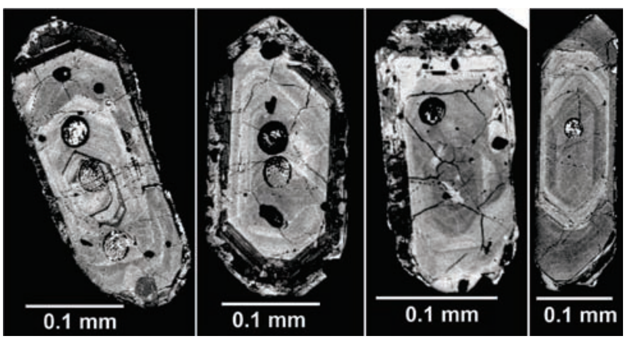

Figure 7. Scanning electronic microscopy images of idiomorphic to hypidiomorphic prismatic zircons from the Jaguaretama complex, exhibiting growth zoning and corroded edges.

U-Pb of the Serra do Deserto Suite

In the study region, this suite is represented by elongated bodies, which are kilometers long and hundreds of meters wide, or narrow lenses that ranges from dozens to hundreds of meters long. Zircons were separated from a tabular body intrusive and concordant with banded gneisses of the Jaguaretama complex, located to the north of Itaú along the BR-405 highway, in the village of Melancia (see sample location in Figure 2). The body has a coarse texture with elongated microclines up to 5 cm long. It exhibits prominent foliation and shows the development of a narrow shear zone accompanied by decreasing grain size (Figure 6). Gray granite dikes

Table 1. U-Pb zircon data for augen gneisses from the Jaguaretama complex (TFM-13, UTM coordinates: 557858E, 9292910 N).

	Ratio										Ages						
Zircon	f(206)%	Th/U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	1 s(%)	$^{207}Pb/^{235}U$	1s (%)	$^{206}Pb/^{238}U$	1s (%)	Rho	$^{207}Pb/^{206}Pb$ Ma	1s(%)	$^{207}Pb/^{235}U$ Ma	1s (%)	$^{206}Pb/^{238}U$ Ma	1s (%)	Conc. (%)
016 Z08	0.03	0.15	70466	0,13565	0.4	6,5927	1.4	0,35250	1.4	0.96	2172,3	6.8	2058,4	12.7	1946,5	23.3	89.60
024 Z14	0.08	0.34	19005	0,13817	0.7	6,8504	1.2	0,35960	1.0	0.90	2204,3	12.9	2092,3	10.8	1980,3	16.5	89.83
030 Z18	0.67	0.33	2259	0,13737	1.2	6,9056	2.0	0,36459	1.6	0.92	2194,3	21.3	2099,4	17.5	2003,9	26.9	91.32
027 Z15	0.08	0.20	19399	0,14134	0.4	6,9643	1.2	0,35736	1.1	0.95	2243,7	6.3	2106,9	10.3	1969,6	18.8	87.78
011 Z05	0.10	0.18	15856	0,13947	0.3	6,9692	1.1	0,36240	1.1	0.96	2220,7	5.2	2107,5	9.9	1993,6	18.5	89.77
028 Z16	0.59	0.20	1934	0,13598	0.4	6,9748	1.0	0,37201	0.9	0.91	2176,6	6.8	2108,2	8.8	2038,9	16.0	93.67
048 Z28	0.02	0.21	83740	0,13725	0.5	6,9963	1.4	0,36970	1.2	0.96	2192,8	9.1	2111,0	11.9	2028,0	21.7	92.48
047 Z27	0.12	0.37	12320	0,13895	0.6	7,0680	1.4	0,36891	1.2	0.90	2214,2	9.9	2120,0	12.0	2024,3	21.4	91.42
040 Z22	0.14	0.33	21275	0,13478	0.6	7,1311	1.3	0,38373	1.1	0.88	2161,2	10.2	2127,9	11.4	2093,7	20.5	96.88
042 Z24	0.03	0.34	49407	0,13543	0.8	7,2304	1.1	0,38721	0.7	0.81	2169,6	13.5	2140,3	9.5	2109,9	13.1	97.25
017 Z09	0.08	0.14	18530	0,13779	0.7	7,2649	1.5	0,38238	1.4	0.89	2199,7	11.5	2144,5	13.4	2087,4	24.2	94.90
022 Z12	0.02	0.19	55590	0,13524	0.5	7,3490	1.7	0,39412	1.6	0.95	2167,1	9.0	2154,8	14.9	2141,9	29.1	98.84
029 Z17	0.03	0.41	44273	0,13810	0.3	7,3803	1.4	0,38759	1.4	0.97	2203,5	5.8	2158,6	12.5	2111,6	24.5	95.83
023 Z13	0.02	0.36	66667	0,13641	0.4	7,5791	1.1	0,40296	1.0	0.91	2182,2	7.4	2182,4	9.5	2182,6	18.1	100.02
018 Z10	0.03	0.40	57682	0,13678	0.7	7,7296	1.3	0,40986	1.0	0.88	2186,8	13.0	2200,0	11.5	2214,3	19.3	101.26
015 Z07	0.02	0.30	66596	0,13882	0.4	7,9324	1.5	0,41444	1.4	0.95	2212,5	7.7	2223,4	13.4	2235,2	26.8	101.02
045 Z25	0.01	0.40	106545	0,13805	0.4	7,9571	1.0	0,41803	0.9	0.90	2202,9	7.2	2226,2	8.9	2251,5	17.0	102.21

truncate the foliation of this orthogneiss. The collected sample has well-preserved crystals and a monzogranitic composition consisting of microcline (35%), plagioclase (20%), quartz (30%) and mafic minerals, represented by biotite (6%), hastingsite (5%), metamorphic garnet (3%) and epidote (1%), as well as opaque minerals, titanite, allanite and zircon.

The zircons form a texturally homogenous group with elongated and bipyramidal prisms and very well preserved, rectilinear surfaces. They are shorter than 0.5 mm. They are limpid, rarely showing growth zones, except for the one to the right of Figure 9, which has a nice developed rim. They commonly exhibit tortuous microfractures filled with lighter material (Figure 9). Crystals exhibiting more complex structures, such as thin and discontinuous overgrowth edges, are rare. In some more elongated crystals, analyses were performed at the center and at the edge, with no clear difference among the 18 analyzed points (Table 2). These analyses yielded an age of 1,777 ± 8 Ma with almost all points plotted on concordia (Figure 10).

These data, which are interpreted as crystallization ages, confirm the existence of significant magmatic activity in the Statherian, especially in the Jaguaribeano terrane. Similar ages were previously reported in this region (Pb-Pb method; 1,778 ± 7 Ma; Cavalcante, 1999) and in the Orós belt (U-Pb; 1,673 ± 23 Ma; Sá et al., 1995) located further to the west. In addition to this Statherian plutonism, similar ages for lavas and volcanic tuffs in the São Jose (Cavalcante, 1999; Magini, 2001) and Orós - Jaguaribe (Sá et al., 1995) groups, as well as the metarhyolites of the Peixe Gordo sequence (Cavalcante, 1999), were found in the Jaguaribeano terrane. All of these data reliably indicate intense volcanic activity associated with the formation of volcanosedimentary sequences and intense plutonism in these areas. These ages, corresponding to the end of the Paleoproterozoic (Statherian) in the Northern portion of the province, are rare in the Rio Piranhas-Seridó terrane, and only one age has been reported in the plutonic body of Serra Negra do Norte (Hollanda et al., 2011).

Sm-Nd Data

The Sm-Nd analyses, obtained from whole rock samples, were performed on Serra do Deserto augen gneisses and the orthogneisses of the Jaguaretama and Caicó complexes, all of which are adjacent to the Portalegre shear zone. The geographic coordinates and obtained data are reported in Table 3 and Figure 11. Values of 2.19 Ga for the crystallization age of the basement complex units and 1.78 Ga for the augen gneisses of the Serra do Deserto Suite were used to calculate $\varepsilon_{Nd(t)}$.

We found that regardless of the lithological unit, the T_{DM} model ages yielded values near 2.5 Ga, with a single T_{DM} age of 2.98 Ga for the Jaguaretama. The results could suggest Archean sources (or crustal contamination of Paleoproterozoic sources) for these units, although no Archean source rocks have been found within these terranes. We are only aware of the São José do Campestre Massif, located hundreds of kilometers away from this region and to the east of the Rio Piranhas-Seridó Terrane.

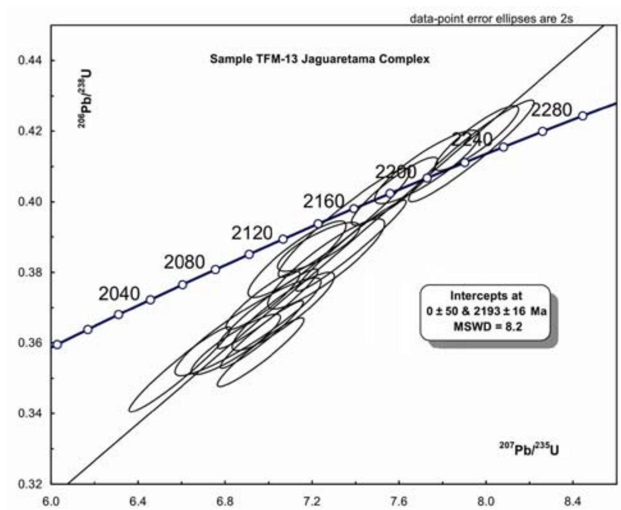

Figure 8. Concordia U-Pb diagram for zircons from orthogneisses of the Jaguaretama complex, east of Poço Dantas. See Figure 2 for location.

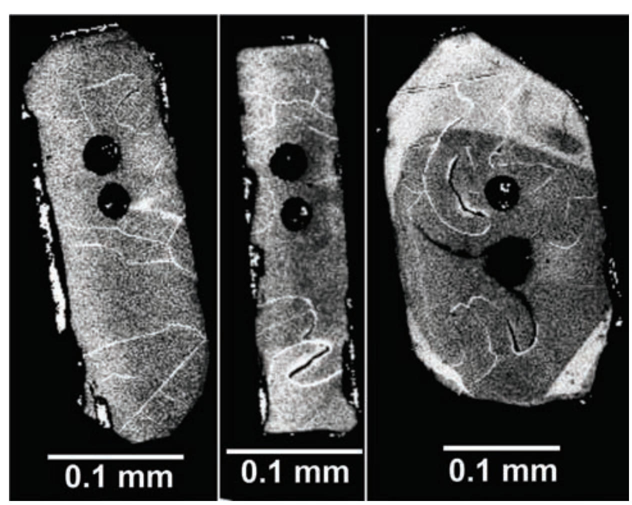

Figure 9. Scanning electronic microscopy images displaying elongated prismatic zircons from the Serra do Deserto Suite, featuring tortuous microfractures filled with lighter material. In the shortest crystal (on the right), a possible metamorphic overgrowth edge can be observed. Backscattered Electron Images.

Table 2. U-Pb zircon data for augen gneisses from Serra do Deserto orthogneisses (FA-67, UTM coordinates: 9365278N, 628300E).

			Ratio								Ages						
Zircon	f(206)%	Th/U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	1s (%)	$^{207}Pb/^{235}U$	1s (%)	$^{206}Pb/^{238}U$	1s (%)	Rho	$^{207}Pb/^{206}Pb$ Ma	1s (%)	$^{207}Pb/^{235}U$ Ma	1s (%)	$^{206}Pb/^{238}U$ Ma	1s (%)	Conc (%)
035 Z21	0.04	0.36	44210	0,10736	0.5	4,5120	1.0	0,30480	0.8	0.86	1755,1	8.5	1733,2	7.9	1715,1	12.6	97.72
005 Z03	0.03	0.29	48242	0,10863	0.4	4,5451	1.3	0,30345	1.2	0.95	1776,6	6.9	1739,3	10.6	1708,4	18.2	96.16
021 Z12	0.02	0.34	69702	0,10906	0.3	4,6406	0.8	0,30860	0.8	0.89	1783,8	6.4	1756,6	6.9	1733,8	11.5	97.19
027 Z16	0.01	0.30	163890	0,10802	0.3	4,6580	0.8	0,31276	0.7	0.91	1766,2	5.6	1759,7	6.6	1754,3	11.2	99.32
022 Z13	0.04	0.29	39435	0,11030	0.4	4,7038	1.1	0,30930	1.1	0.93	1804,3	7.2	1767,9	9.5	1737,3	16.2	96.29
023 Z14	0.05	0.29	34765	0,11040	0.4	4,7168	1.4	0,30988	1.3	0.95	1805,9	7.6	1770,2	11.3	1740,1	19.7	96.36
016 Z09	0.01	0.26	417402	0,11100	0.5	4,8034	1.1	0,31385	1.0	0.91	1815,9	8.2	1785,5	9.4	1759,6	15.8	96.90
034 Z20	0.01	0.34	65144	0,10950	0.4	4,8077	1.2	0,31842	1.1	0.95	1791,2	6.5	1786,2	9.7	1782,0	17.2	99.49
024 Z15	0.02	0.21	100057	0,10927	0.6	4,8443	1.1	0,32154	0.9	0.92	1787,2	11.2	1792,6	9.1	1797,3	14.0	100.56
018 Z11	0.01	0.31	169034	0,10806	0.4	4,8753	1.0	0,32721	0.9	0.96	1767,0	8.0	1798,0	8.6	1824,9	14.7	103.28
040 Z24	0.07	0.40	13375	0,11067	0.7	4,8969	1.5	0,32091	1.4	0.89	1810,5	12.6	1801,7	12.8	1794,2	21.3	99.10
036 Z22	0.02	0.41	69394	0,10895	0.7	4,9106	1.0	0,32689	0.8	0.88	1782,0	12.6	1804,1	8.8	1823,3	12.4	102.32
012 Z08	0.03	0.36	48511	0,10981	0.9	4,9374	1.6	0,32610	1.3	0.93	1796,3	17.1	1808,7	13.3	1819,4	20.0	101.29
030 Z19	0.02	0.24	84379	0,10833	0.7	4,9395	1.1	0,33068	0.8	0.87	1771,6	13.4	1809,0	9.1	1841,7	12.7	103.96
009 Z05	0.02	0.37	82918	0,10961	0.4	4,9916	0.9	0,33028	0.8	0.86	1793,0	7.5	1817,9	7.4	1839,7	12.3	102.61
028 Z17	0.03	0.26	47603	0,10983	0.4	5,0051	1.0	0,33050	0.9	0.88	1796,6	7.8	1820,2	8.2	1840,8	14.0	102.46
029 Z18	0.01	0.41	178580	0,10738	0.3	5,0427	0.8	0,34059	0.8	0.91	1755,4	5.8	1826,5	6.9	1889,5	12.4	107.64
011 Z07	0.01	0.37	154129	0,10779	0.2	5,1267	0.7	0,34496	0.7	0.92	1762,3	4.5	1840,5	5.9	1910,5	10.8	108.41

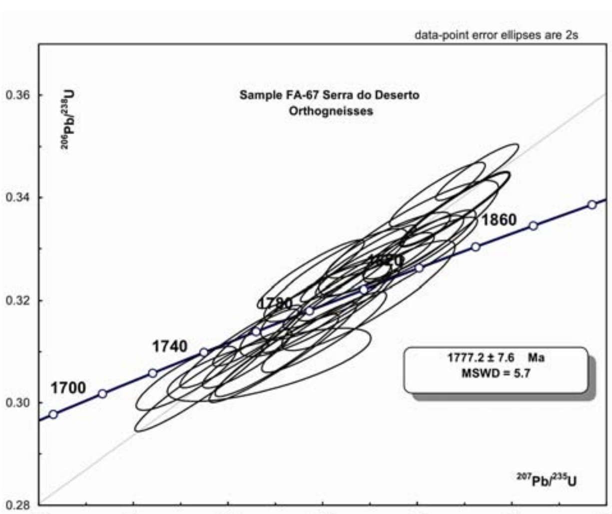

Figure 10. Concordia U-Pb diagram for zircons from augen gneiss of the Serra do Deserto Suite, north of the city of Itaú. See Figure 2 for location.

Other information extracted from these data includes the ε_{Nd} calculated for the time of crystallization of these rocks. These values are consistently negative and low (-1.0 to -2.0), suggesting mantle sources composition very similar to the chondritic uniform reservoir (CHUR), or with low crustal contamination, except for the Serra do Deserto Suite, which displays slightly higher values. Magini (2001) also obtained very similar values for these Jaguaretama basement rocks. Despite the varying composition, they have almost always indicated recurring $\varepsilon_{Nd(t)}$ from 0 to slightly negative values, and T_{DM} between 2.5 and 2.7 Ga. Souza et al. (2007) reported similar data, between +0.3 and -1.0, for tonalitic orthogneisses of the Caicó complex. Additionally, after petrogenetic modelling, they have also considered that these rocks derived from a mantle source.

DISCUSSION AND GEODYNAMIC EVOLUTION

The area in the far western region of the State of Rio Grande do Norte is geologically relevant because it exhibits contiguous Paleoproterozoic geological terranes, the Jaguaribeano and the Rio Piranhas-Seridó Terranes, with distinct geodynamic characteristics. These terranes are juxtaposed and separated by a major structural lineament, i.e., the Portalegre shear zone (PaSZ).

The basement complexes of these terranes have a similar structural evolution and metamorphism under similar PT conditions, i.e., upper amphibolite facies reaching anatexis with intense migmatization developed under low-pressure conditions. Lithologically, the Jaguaretama and the Caicó complexes are predominantly represented by granitic to tonalitic orthogneisses and subordinately dioritic. However,

Table 3. Sm-Nd (WR) isotopic data and related parameters for orthogneisses from Caico and Jaguaretama basements and Serra do Deserto Suite.

	Sample	Sm(ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ (± 2S)	$e_{Nd\ (0)}$	$e_{Nd\ (t)}$	T_{DM} (Ga)	U-Pb Age (Ga)	UTM Coordinates
Serra do Deserto augen gnaisse	FA 67	49.839	273.682	0.1101	0.511315±1	-25.80	-6.05	2.53	1.78	9365278N 0628300E
Jaguaretama Complex	CPM 67	5.546	32.397	0.1035	0.511211±2	-27.84	-1.62	2.53	(2.19)	9223300N 0585236E
Jaguaretama Complex	FA 63	14.122	78.682	0.1085	0.510989±7	-32.17	-7.39	2.98	(2.19)	9364920N 0634612E
Caico Complex	FA 99	7.033	43.382	0.0980	0.511141±1	-29.20	-1.44	2.50	(2.19)	9340754N 0656381E
Caico Complex	FA 94	6.482	42.588	0.0920	0.511060±2	-30.78	-1.33	2.47	(2.19)	9338864N 0656131E

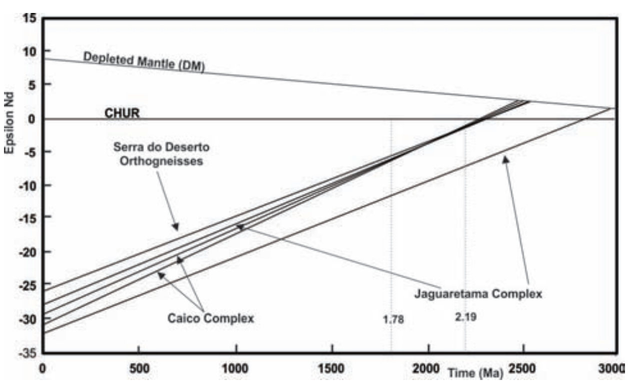

Figure 11. Nd evolution diagram for metaplutonic rocks from the Jaguaretama and Caicó complexes and for Serra do Deserto augen gneisses.

several significant differences between these units were identified. In this context, it was possible to identify important (meta) sedimentary sequences found at several locations in the Jaguaretama complex domain. In addition, we identified marble intercalations that have not yet been found in the Caicó complex. In contrast, the Caicó complex contains recurring elongated amphibolite bodies, concordant to subconcordant, with the gneissic structure, allowing for the characterization of areas called the amphibolite Caicó complex.

Both complexes were predominantly formed during the Rhyacian period, with multiple U-Pb zircon ages of approximately 2.2 Ga. The ages identified in this study and in other areas of these terranes are considered to be the crystallization age of these rocks. Although slightly older ages have been found at a small number of sites, these are also Paleoproterozoic ages and might represent nucleous or vestiges of sequences preceding the Caicó complex.

The Sm-Nd isotopic data reported here and in previous publications showed no significant differences between these complexes, consistently suggesting Neoarchean sources and ε_{Nd} parameters for these orthogneisses with near to zero or slightly negative values for these orthogneisses. These data indicate sources of composition that are very similar to CHUR, and they were possibly derived from the mantle. Based on isotopic signatures, it was not possible to distinguish between the Rhyacian Jaguaretama and the Caicó complexes. It should be noted that based on geochemical data from various regions of the Caicó complex, petrogenetic studies and modeling performed by Souza et al. (2007), the orthogneisses from this complex have calc-alkaline affinities and suggest an orogenic environment, of magmatic arc, for the generation and emplacement of these meta-plutonic rocks. Currently, existing geochemical data are not sufficient to support such conclusions for the Jaguaretama complex; however, the Sm-Nd data suggest mantle sources similar to the composition of CHUR.

Considering that the two geological terranes, to the east and west of the Portalegre shear zone, have different histories, a strong migmatization was observed in both the Caicó and the Jaguaretama basement complexes. This migmatization precedes Statherian intrusions of Serra do Deserto Suite. Some studies consider that migmatization is a Paleoproterozoic high grade metamorphism (Souza et al., 2007, and references therein). Based on the geochemical signature of the Caicó complex, indicative of having been generated and crystallized in an arc environment, it is reasonable to assume that such an orogenesis corresponds to the Transamazonian Cycle. The Rhyacian ages, unanimously considered as the age of crystallization, suggest that the oldest tectonic fabrics in these units are also from the Transamazonian or at least a regional tectonic event that occurred in the Rhyacian period.

The "G_2" augen gneisses of Jardim de Sá (1981, 1995), here called the Poço da Cruz Suite (Ferreira, 1998), have similar ages to those obtained in the Caicó complex, although they are intrusive in this unit. Additionally, the rocks of this complex exhibit frequent migmatization, and such a feature is absent in these orthogneisses. A Rhyacian age (U-Pb: 2,172 ± 24 Ma) was obtained by Hollanda et al. (2011) in an area slightly to the east of this study region, in the city of Antonio Martins. Ages *ca.* 2.2 Ga were also obtained by Hollanda et al. (2011) and Medeiros et al. (2012) at several other sites in the Rio Piranhas-Seridó terrane. In addition to the similar crystallization ages, the reported T_{DM} values were also of the Neoarchean, and the calculated ε_{Nd} values were only slightly more negative (between -2 and -4) than the data provided here and those by Souza et al. (2007) in the region further east to the Caicó complex. Therefore, Hollanda et al. (2011) considered the Poço da Cruz Suite and the Caicó complex to be isotopically indistinguishable. Geochemical data from the Poço da Cruz Suite, and consequently, from the "G_2" augen gneisses, remain scarce to define their formation environments. However, recent analyses have indicated a set of high-K rocks with calc-alkaline affinities. They suggest a collisional environment (Medeiros et al., 2012). The field relationships indicate that many of these G_2 augen gneiss bodies are intrusive in the banded gneisses of the Caicó complex, and the high quality of the U-Pb dates indicate a significant crustal accretion during the Rhyacian period, represented by the Poço da Cruz Suite, immediately after the consolidation of the Caicó plutonic rocks.

The Poço da Cruz unit does not occur in the Jaguaribeano terrane, and the Serra do Deserto Suite is prominent in this complex. This difference rests on the Statherian U-Pb ages of 1.7 – 1.8 Ga, which have been consistently obtained for this unit, and clearly differentiates them from the augen gneisses of Poço da Cruz Suite. Moreover, geochemical analyses of the Serra do Deserto Suite (Sá et al., 1995; Cavalcante, 1999) indicate signatures that are similar to those of anorogenic A-type granites, with even more negative $\varepsilon_{Nd(t)}$ values than the metaplutonics of Poço da Cruz Suite. In terms of age, the only body of granites/metaplutonics of the Statherian age in the Rio Piranhas-Seridó terrane is the Serra Negra do Norte pluton (Hollanda et al., 2011), with an age of 1.74 Ga, making it the first possible temporal correlate of the Serra do Deserto Suite. It is clear that the augen gneisses of these two terranes occurred at two temporally separate events, with the Serra do Deserto Suite being associated with an extensional period that occurred during the Statherian, best represented by the Jaguaribeano terrane and its volcanosedimentary sequences and A-type plutonic rocks. Any record of this event in the Rio Piranhas-Seridó terrane is, however, restricted to the Serra Negra do Norte body.

Extensions during this period are recorded to the south of the Patos Lineament in the so-called Transversal Zone, with various basic and acid volcanosedimentary and plutonic sequences formed from the Calymmian to the Statherian (1.52 – 1.75 Ga), as reported by Accioly (2001), Sá et al. (2002), Accioly et al. (2010) and others. These records draw attention to the fact that, at the end of the Paleoproterozoic and the beginning of the Mesoproterozoic, there was a significant magmatism and crustal extension throughout the entire Borborema Province.

ACKNOWLEDGEMENTS

This study was financed by the Research Company of Mineral Resources (CPRM-Brazilian Geological Survey), according to agreement CPRM 059/PR/2008-UFRN. We would like to thank the geologist Vladimir Cruz (CPRM), for the valuable and fruitful discussions, and Carlos Ganade de Araújo and an anonymous reviewer who provided many useful corrections, positive criticism and comments which significantly improved this work. We also thank the geologists Elton Dantas and Lindaray Sousa da Costa for their assistance at acquiring isotopic data.

REFERENCES

Accioly, A. C. A. (2001). *Geologia, geoquímica e significado tectônico do Complexo metaanortosítico de Passira – Província Borborema – Nordeste Brasileiro*. Tese (Doutorado). São Paulo: Instituto de Geociências – USP.

Accioly, A. C. A., Santos, C. A., Santos, E. J., Brito Neves, B. B., Rodrigues, J. B., McReath, I. (2010). Geochronology and geochemistry of the metavolcanic rocks from Riacho do Tigre Complex, Borborema Province, Northeastern Brazil. *Annals of the VII South American Symposium on Isotope Geology*. Brasília: SSAGI. CD-ROM.

Brito Neves, B. B., Van Schmus, W. R., Santos, E. J., Campos Neto, M. C., Kozuch, M. (1995). O evento Cariris Velhos na Província Borborema. *Revista Brasileira de Geociências*, 25(4), 279-296.

Bühn, B., Pimentel, M. M., Matteini, M., Dantas, E. (2009). High spatial resolution analysis of Pb and U isotopes for geochronology by laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS). *Anais da Academia Brasileira de Ciências*, 81(1), 99-114.

Campelo, R. C. (1999). *Análise de terrenos na porção setentrional da Província Borborema, NE do Brasil: integração de dados geológicos e gravimétricos*. Dissertação (Mestrado). Natal: Programa de Pós-graduação em Geodinâmica e Geofísica – UFRN.

Cavalcante, J. C. (1999). *Limites e evolução geodinâmica do Sistema Jaguaribeano, Província Borborema, Nordeste do Brasil*. Dissertação (Mestrado): Natal: Programa de Pós-Graduação em Geodinâmica e Geofísica – UFRN.

Cavalcante, J. C., Medeiros, W. E., Castro, D. L., Sá, J. M. (1998). A Faixa Jaguaribeana: integração geológico-gravimétrica. *XL Congresso Brasileiro de Geologia*, 1, 13-13, Belo Horizonte.

Dantas, E. L. (1996). *Geocronologia U-Pb e Sm-Nd de terrenos arqueanos e paleoproterozóicos do Maciço Caldas Brandão, NE do Brasil*. Tese (Doutorado). Rio Claro: Instituto de Geociências e Ciências Exatas – UNESP.

Dantas, E. L., Van Schmus, W. R., Hackspacher, P. C., Brito Neves, B. B. (1998). Archean accretion in the São José Campestre Massif, Borborema Province, NE of Brazil. *Revista Brasileira de Geociências*, 28(2), 221-228.

Dantas, E. L., Van Schmus, W. R., Hackspacher, P. C., Fetter, A. H., Brito Neves, B. B., Cordani, U., Nutman, A. P., Williams, I. S. (2004). The 3.4 e 3.5 Ga São José de Campestre massif, NE Brazil: remnants of the oldest crust in South America. *Precambrian Research*, 130(1-4), 113-137.

Ferreira, C. A. (1998). *Programa Levantamentos Geológicos Básicos do Brasil (PGB)*. Caicó, Folha SB.24-Z-B (Escala 1:250.000). Estados do Rio Grande do Norte e da Paraíba. Brasília: CPRM-Serviço Geológico do Brasil.

Fetter, A. H., Van Schmus, W. R., Santos, T. J. S., Arthaud, M., Nogueira Neto, J. A. (2000). U-Pb and Sm-Nd geochronological constraints on the crustal evolution and basement architecture of Ceará State, NW Borborema Province, NE Brazil: implications for the existence of the Paleoproterozoic supercontinent Atlantica. *Revista Brasileira de Geociências*, 30(1), 102-106.

Fuck, R. A., Soares, J. E. O., Lima, M. V. A. G. (2013). Seismic characteristics of the Borborema Province lithosphere. *XXV Simpósio de Geologia do Nordeste*, 495-496, Gravatá.

Galindo, A. C., Srivastava, N. K., Souza, L. C., Maia, H. N., Sá, J. M. (2011). *Nota Explicativa da Folha Apodi*. Brasília: CPRM-Serviço Geológico do Brasil.

Gioia, S. M. C. L., Pimentel, M. M. (2000). The Sm-Nd isotopic method in the Geochronology Laboratory of the University of Brasília. *Anais da Academia Brasileira de Ciências*, 72(2), 219-245.

Hackspacher, P. C., Jardim de Sá, E. F., Legrand, J. M. (1980). Organização Estrutural e Evolução Policíclica na Região Sudeste da Serra do Feiticeiro, Lages-RN. *Atas XXXI Congresso Brasileiro de Geologia*, 2616. Camboriú: SBG.

Hackspacher, P. C., Legrand, J. M. (1989). Microstructural and metamorphic evolution of the Portalegre shear zone, northern Brazil. *Revista Brasileira de Geociências*, 19(1), 63-75.

Hackspacher, P. C., Oliveira, D. C. (1984). A evolução estrutural das zonas de cisalhamento Portalegre e Santa Mônica (RN). *Anais XXXIII Congresso Brasileiro de Geologia*, 4,1679-1692. Rio de Janeiro: SBG.

Hackspacher, P. C., Van Schmus, W. R., Dantas, E. L. (1990). Um embasamento Transamazônico na província Borborema. *Anais XXXVI Congresso Brasileiro de Geologia*, 6, 2683-2696. Natal: SBG.

Hollanda, M. H. B. M., Archanjo, C. J., Souza, L. C., Liu, D., Armstrong, R. (2011). Long-lived Paleoproterozoic granitic magmatism in the Seridó-Jaguaribe domain, Borborema Province–NE Brazil. *Journal of South American Earth Sciences*, 32(4), 287-300.

Jardim de Sá, E. F. (1984). A evolução proterozoica da Província Borborema. *Atas XI Simpósio de Geologia do Nordeste*, 297-316. Rio de Janeiro: SBG.

Jardim de Sá, E. F., Fuck, R. A., Macedo, M. H. F., Peucat, J. J., Kawashita, K., Souza, Z. S., Bertrand, J. M. (1995). Pre-brasiliano orogenic evolution in the Seridó belt, NE Brazil: Conflicting geochronological and structural data. *Revista Brasileira de Geociências*, 25(4), 307-314.

Jardim de Sá, E. F., Legrand, J. M., McReath, I. (1981). Estratigrafia de rochas granitóides na região do Seridó (RN-PB), com base em critérios estruturais. *Revista Brasileira de Geociências*, 11(1), 50-57.

Legrand, J. M., Liegeois, J. P., Deutsch, S. (1991). Datação U-Pb e Rb-Sr de Rochas Precambrianas da Região de Caicó. Reavaliação da Definição de um Embasamento Arqueano. *Atas XIV Simpósio de Geologia do Nordeste*, 276-279. Recife: SBG.

Lima, E. S. (1987). Evolução termobarométrica das rochas metapelíticas do Grupo Seridó, Nordeste Brasileiro. *Revista Brasileira de Geociências*, 17, 315-323.

Lima, E. S. (1992). Metamorphic conditions in the Serido region of Northeastern Brazil during the Brasiliano cycle. *Journal of South American Earth Sciences*, 5(3), 265-273.

Ludwig, R. R. (2003). *Isoplot 3.0*: A geochronological toolkit for microsoft excel (revised version), v. 4. Berkeley: Berkeley Geochronological Center.

Macedo, M. H. F., Jardim de Sá, E. F., Sá, J. M. (1984). Datações Rb-Sr em ortognaisses e a idade do Grupo Seridó. *Atas XI Simpósio de Geologia do Nordeste*, 253-262. Natal: SBG.

Magini, C. 2001. *Evolução pré-cambriana da Província Borborema: o extremo oeste Potiguar*. Tese (Doutorado). Rio Claro: Instituto de Geociências e Ciências Exatas – UNESP.

Medeiros, V. C., Medeiros, W. E., Jardim de Sá, E. F. (2011). Utilização de imagens aerogamaespectrométricas, Landsat 7ETM+ e aeromagnéticas no estudo do arcabouço crustal da porção central do domínio da Zona Transversal, Província Borborema, NE do Brasil. *Revista Brasileira de Geofísica*, 29(10), 83-97.

Medeiros, V. C., Nascimento, M. A. L., Galindo, A. C., Dantas, E. L. (2012). Augen gnaisses riacianos no Domínio Rio Piranhas-Seridó, Província Borborema, Nordeste do Brasil. *Geologia-USP. Série Científica*, 12(2), 3-14.

Minnigh, L., Hackspacher, P. C. (1979). Preliminary Results of a Study on Structures in Schists of the Seridó Formation near Cruzeta-RN. *Atas IX Simpósio de Geologia do Nordeste*, 44-51. Natal: SBG.

Nóbrega, M. A., Sá, J. M., Bezerra, F. H. R., Hadler Neto, J. C., Iunes, P. J. (2005). The use of apatite fission track thermochronology to constrain fault movements and sedimentary basin evolution in northeastern Brazil. *Radiation Measurements*, 39(6), 627-633.

Oliveira, R. G. (2008). *Arcabouço geofísico, isostasia e causas do magmatismo cenozóico da Província Borborema e de sua margem continental (Nordeste do Brasil)*. Tese (Doutorado). Natal: Programa de Pós-Graduação em Geodinâmica e Geofísica – UFRN.

Ramsay, J.G. (1967). *Folding and fracturing of rocks*. New York: McGraw-Hill.

Sá, J. M. (1991). *Evolution Geodynamique de la Ceinture Proterozoique d'Orós, Province Borborema, Nord-Est du Brésil*. Tese (Doutorado). Nancy, France: Faculté de Sciences – Université de Nancy I.

Sá, J. M., Bertrand, J. M., Leterrier, J. (2002). Geochemistry and geochronology of Pre-Brasiliano rocks from the Transversal Zone, Borborema Province, Northeast Brazil. *Journal of South American Earth Sciences*, 14(8), 855-866.

Sá, J. M., Legrand, J. M. (1983). Superposição de Eventos Metamórficos na Região da Serra do Chico, Lages, RN. *Revista Ciências da Terra*, 7,12-15.

Sá, J. M., Leterrier, J., Bertrand, J. M. (1997). Augen Gnaisses vs Augen Gnaisses da Faixa Jaguaribeana, NE do Brasil: Estratigrafia, Geoquímica e Idades U-Pb. *Atas do XVII Simpósio de Geologia do Nordeste*, 1, 113-117.

Sá, J. M., McReath, I., Leterrier, J. (1995). Petrology, Geochemistry and Geodynamic Setting of Proterozoic Igneous Suites of the Orós fold Belt, Borborema Province, Northeast Brazil. *Journal of South American Earth Sciences*, 8(3), 299-314.

Santos, E. J. (1996). Ensaio preliminar sobre terrenos e tectonica acrescionária na Província Borborema. *Proceedings of the 39th Brazilian Geological Congress,* 6, 47-50. Salvador: SBG.

Santos, E. J. (1999). *Belém do São Francisco, folha SC.24-X-A*: estados de Pernambuco, Alagoas e Bahia. Programa de Levantamentos Geológicos do Brasil. Braília: CPRM. CD-ROM.

Santos, E. J., Medeiros, V. C. (1999). Constraints from granitic plutonism on Proterozopic crustal growth of the Transverse Zone, Borborema Province, NE Brazil. *Revista Brasileira de Geociências*, 29(1), 73-84.

Souza, L. C., Verkaeren, J., Legrand, J. M. (1998). O sincronismo entre o magmatismo e metamorfismo hidrotermal controlado pela condução/convecção em escala regional: caso dos micaxistos Seridó em torno do maciço granítico de Acari-RN. *Atas XL Congresso Brasileiro de Geologia*, 1, 517-517. Belo Horizonte: SBG.

Souza, Z. S., Martin, H., Peucat, J. J., Sá, E. F. J., Macedo, M. H. F. (2007). Calc-alkaline magmatism at the Archean–Proterozoic transition: the Caicó Complex Basement (NE Brazil). *Journal of Petrology*, 48(11), 2149-2185.

Souza, L. C., Sá, J. M., Legrand, J. M., Maia, H. N. (2011). *Mapa geológico da Folha Pau dos Ferros*. Escala 1:100.000. Brasília: CPRM-Serviço Geológico do Brasil.

Van Schmus, W. R., Brito Neves, B. B., Hackspacher, P. C., Babinski, M. (1995). U-Pb and Sm-Nd geochronological studies of the Eastern Borborema Province, Northeastern Brazil, initial conclusions. *Journal of South American Earth Sciences*, 8(3-4), 267-288.

Van Schmus, W. R., Brito Neves, B. B., Williams, I. S., Hackspacher, P. C., Fetter, A. H., Dantas, E. L., Babinski, M. (2003). The Serido Group of NE Brazil, a late Neoproterozoic pre- to syn-collisional basin in West Gondwana: insights from SHRIMP U-Pb detrital zircon ages and Sm-Nd crustal residence (TDM) ages. *Precambrian Research*, 127(4), 287-327.