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PRE-CRETACIC REGIONAL STRUCTURING OF IBIAPABA, NORTHWEST OF THE STATE OF CEARÁ

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Abstract

Ibiapaba has gaps in its natural history and, therefore, there is a need for greater knowledge about its geomorphological evolution. An important gap is the knowledge of the structure of the geological substrates of the reliefs that compose it in the portion verified in the northwest region of *Ceará*. More than passive elements in the landscape, the lithological, tectonic and chronostratigraphic aspects, even old ones, influence and even condition the geomorphological arrangement on a regional scale, which occurs in *Ibiapaba*. Thus, the main objective of this work is to analyze the geological conditioning of the regional structure of pre-Cretaceous age in the geomorphology of *Ibiapaba* in its northern portion, northwestern *Ceará*. Methodologically, the theoretical assumptions of geomorphological science were used, with an emphasis on morphostructural analysis. In turn, the technical contingent of the research is divided into cabinet stages, with detailed bibliographic and cartographic surveys, field surveys and integrated analysis of all data in the laboratory stage, with an emphasis on thematic mappings *Ibiapaba* and region. The results achieved allow an analysis of the geological conditions of pre-Cretaceous age for the current geomorphological picture of *Ibiapaba*, a basic condition for the knowledge of the relief and its evolutionary aspects.

Keywords: Geomorphological evolution. Structural Geomorphology. Geomorphological Heritage.

ESTRUTURAÇÃO REGIONAL PRÉ-CRETÁCEA DA *IBIAPABA*, NOROESTE DO ESTADO DO *CEARÁ*

Resumo

A Ibiapaba apresenta lacunas em sua história natural e, por conseguinte, percebe-se a necessidade de um maior conhecimento sobre sua evolução geomorfológica. Uma lacuna importante passa pelo conhecimento da estruturação dos substratos geológicos dos relevos que a compõem na porção verificada na região noroeste do estado do Ceará. Mais do que elementos passivos na paisagem, os aspectos litológicos, tectônicos e cronoestratigráficos, mesmo antigos, influenciam e até condicionam o arranjo geomorfológico em escala regional, o que ocorre na Ibiapaba. Assim, o objetivo principal desse trabalho é analisar os condicionamentos geológicos da estruturação regional de idade pré-cretácea na geomorfologia da Ibiapaba em sua porção setentrional, região noroeste do Ceará. Metodologicamente foram utilizados os pressupostos teóricos da ciência geomorfológica, com ênfase na análise morfoestrutural. Por sua vez, o contingente técnico da pesquisa compartimenta-se em etapas de gabinete, com detalhados e criteriosos levantamentos bibliográfico e cartográfico, na realização de levantamentos de campo e na análise integrada de todos os dados na etapa de laboratório, com ênfase nos mapeamentos temáticos da Ibiapaba e região. Os resultados alcançados permitem fazer uma análise dos condicionantes geológicos de idade pré-cretácea para o atual quadro geomorfológico da Ibiapaba, condição básica para o conhecimento do relevo e seus aspectos evolutivos.

Palavras-chave: Evolução Geomorfológica. Geomorfologia Estrutural. Patrimônio Geomorfológico.

ESTRUCTURACIÓN REGIONAL PRE-CRETÁCEA DE *IBIAPABA*, NOROESTE DEL ESTADO DE *CEARÁ*

Resumen

Ibiapaba tiene lagunas en su historia natural y, por lo tanto, es necesario un mayor conocimiento sobre su evolución geomorfológica. Una brecha importante es el conocimiento de la estructura de los sustratos geológicos de los relieves que lo componen en la porción verificada en la región noroeste del *Ceará*. Más que elementos pasivos en el paisaje, los aspectos litológicos, tectónicos y cronoestratigráficos, incluso los antiguos, influyen e incluso condicionan la disposición geomorfológica a escala regional, que ocurre en *Ibiapaba*. Por lo tanto, el objetivo principal de este trabajo es analizar las condiciones geológicas de la estructura regional de la edad pre-Cretácica en la geomorfología de *Ibiapaba* en su porción norte, región noroeste de *Ceará*. Metodológicamente, se utilizaron los supuestos teóricos de la ciencia geomorfológica, con énfasis en el análisis morfoestructural. A su vez, el contingente técnico de la investigación se divide en etapas de gabinete, con encuestas bibliográficas y cartográficas detalladas y cuidadosas, encuestas de campo y análisis integrado de todos los datos en la etapa de laboratorio, con énfasis en mapeos temáticos de la *Ibiapaba* y región. Los resultados logrados permiten un análisis de las

condiciones geológicas de la edad pre-Cretácica para la imagen geomorfológica actual de *Ibiapaba*, una condición básica para el conocimiento del relieve y sus aspectos evolutivos.

Palabras-clave: Evolución geomorfológica. Geomorfología Estructural. Patrimonio Geomorfológico.

1. INTRODUCTION

Ibiapaba belongs to the group of humid mountains in the Northeastern semi-arid region, important geomorphological features for the state of *Ceará* and for the Northeast region of Brazil as a whole, an extensive and important relief that has gaps in its natural history. An important gap is related to the knowledge of the structure of the geological substrates of the reliefs that make up the landscape of *Ibiapaba* and its adjacent areas.

As is known, more than passive elements in the landscape, lithological, tectonic and chronostratigraphic aspects, even ancient ones, often influence and sometimes even condition the geomorphological arrangement on a regional scale, which occurs in *Ibiapaba* (MOURA-FÉ, 2015). Thus, the main objective here is to analyze the geological conditioning of the regional structure of pre-cretaceous age in the current geomorphology of *Ibiapaba* in its northern portion, in the northwest region of the state of *Ceará*.

The regional dimensions of *Ibiapaba* (extends for about 380 km along the western limit of *Ceará*) and the difficulty in working with all the models in the period of validity of the research, determined the choice of a fragment to carry out the study. The logistical elements were carefully considered and based on prior knowledge of the region, especially the most significant geographic and geomorphological characteristics, which could provide quicker and more satisfactory answers to the questions asked within the proposed objective.

Based on these criteria, a spatial cut of the model was performed (Figure 1), privileging the central-northern and northern sectors of *Ibiapaba*, as well as the respective northern and eastern surroundings, which make up the northwestern region of *Ceará*, fundamental to analyze , based on structural conditions, the morphological differentiation that was established between the northern and eastern sectors and for the evolutionary understanding of the region.

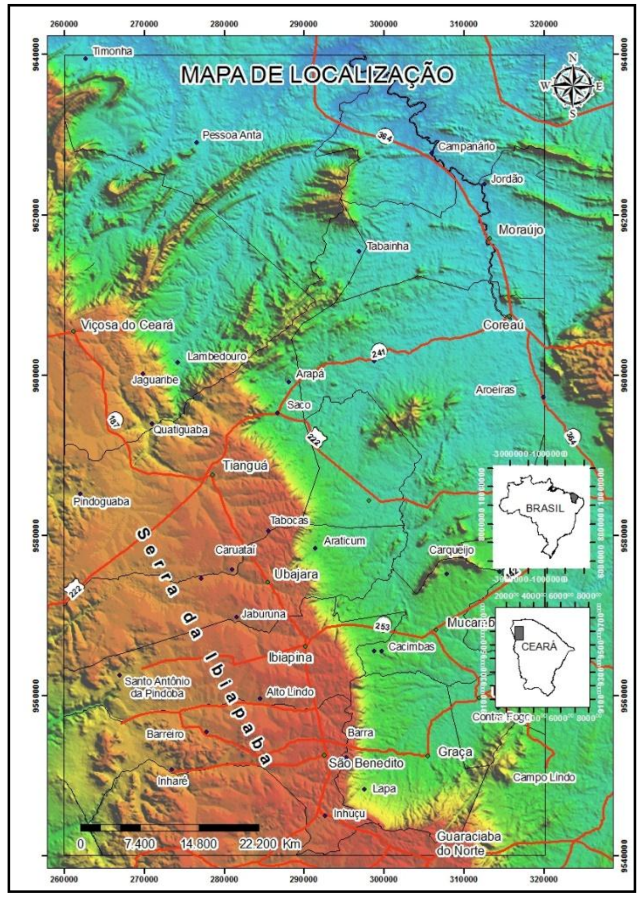

Figure 1 - Location map of northern Ibiapaba. Source: Moura-Fé (2015).

2. METHODOLOGY

The methodological script covered is divided into two lines: (1) on the theoretical basis, centered on the geomorphological morphostructural approach, which involves geological characterization in its structural and lithological aspects, and (2) the use of a technical contingent, divided into stages cabinet, field and laboratory.

A bibliographic survey was carried out in the office, which addressed the scientific production associated with the proposed research themes, which was done mainly through the journals portal of CAPES (Higher Education Personnel Improvement Coordination), aiming at the selection and download of elevant and current scientific articles.

Also in the office, the cartographic survey carried out selected thematic maps, satellite images, vector files and radar images, topographic maps and SRTM - Shuttle Radar Topography Mission, from the National Aeronautics and Space Administration (NASA) , scale 1:250,000 (1998), used in regional analyzes, but not presented in all materials prepared in the laboratory.

The field stages were carried out at different times of the research, carried out on consecutive days, with a predetermined route, dates and objectives. The surveys were concentrated in different segments of the region, aiming to speed up the performance of activities. In all of them, were made photographic records, topographic, morphometric, morphostructural and morphostratigraphic characteristics of the reliefs and their contacts, in addition to determining the UTM coordinates of the elements covered.

Finally, the laboratory activities consisted of detailed analyzes, both of printed and digital material from various maps: geological map of the state of *Ceará*, on the scale 1: 500,000; Morphostructural map of *Ceará* and adjacent areas of *Rio Grande do Norte* and *Paraíba* (CPRM, 2003), topographic maps of SUDENE (1977), scale of 1: 100,000, among others.

Analysis of satellite images available in the Google Earth software allowed the systematic interpretation of the area at different scales, in a 3-D model, in addition to allowing the elaboration of topographic profiles, which were also elaborated using Global Mapper software. All mapping was done using the ArcGIS / ArcMap software.

3. RESULTS AND DISCUSSION

3.1. Tectonic Context

On a wide scale, *Ibiapaba* is located in the tectonic context of the Parnaíba Province, having as its predominant substrate the lithologies concerning the Serra Grande group, in contrast to the lithostratigraphic diversity verified in its contacts to the east and to the north, corresponding to the other province, the Borborema Province (CPRM, 2003).

The study area, highlighted in Figure 2, presents the western predominance of the **Parnaíba Province (PP)**, which corresponds exactly to *Ibiapaba*, in a clear proximity between structure and relief. In practically the same spatial proportion, in the northern and eastern portions of the area, the **Borborema Province** emerges, more precisely, the Middle Coreaú subdomain (SDMC in portuguese), in a regional context topographically lower in relation to the PP.

Basically, the Middle Coreaú subdomain comprises a system of marginal folding of the Middle Coreaú and a system of parallel faults with NE-SW direction, structured in a succession of horsts and grabens, oriented according to this fault system, indicating a significant tectonic mobility from the region at the end of the pre-cambrian and in the lower Paleozoic, with secondary reactivations in more recent periods (COSTA et al., 1979; HASUI, 2012a; PIRES, 2003; SANTOS et al., 1984).

Delimited the SO by the Parnaíba basin and the SE by the *Sobral-Pedro* II shear zone (ZCS in portuguese), the SDMC is tectonically compartmentalized in 4 tectonic blocks, which correspond to an alternation of horsts and grabens (Figure 3): Horst of *Granja*, graben *Martinópole*, horst *Tucunduba* and graben *Ubajara-Jaibaras* (COSTA et al., 1979; PIRES, 2003), where all have direct contact with the northern and eastern slopes of *Ibiapaba*.

This broad tectonic framework is the first condition on the relief of the studied region, as it makes up its topographic macro-structuring, whereas, along the horsts we have the highest reliefs in the region of contact with *Ibiapaba*; and in the grabens we have lower altitudes and greater water intake in the hydrographic basins of the region and, therefore, the development of the largest watercourses.

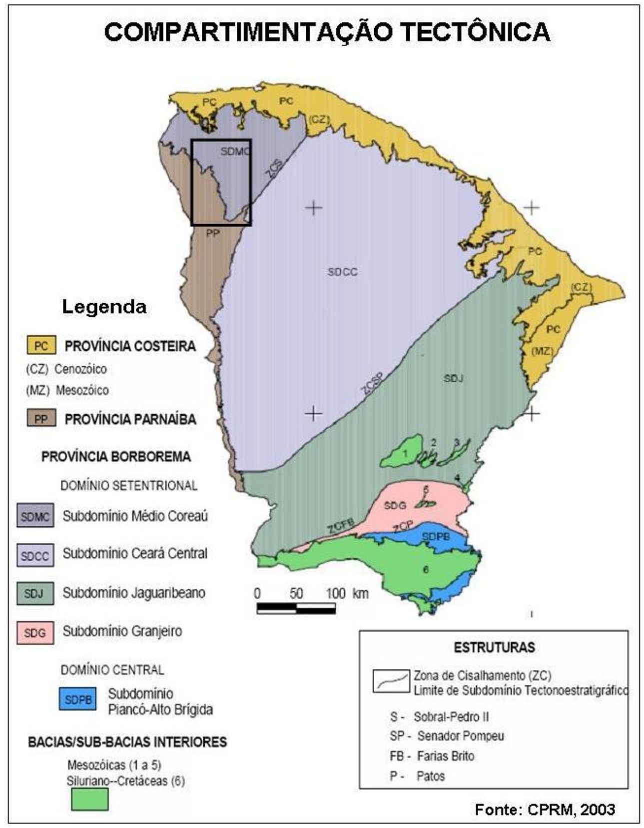

Figure 2 - Tectonic compartmentation in the state of Ceará. In highlight, the northern Ibiapaba. Source: CPRM (2003). Adap. Moura-Fé (2015).

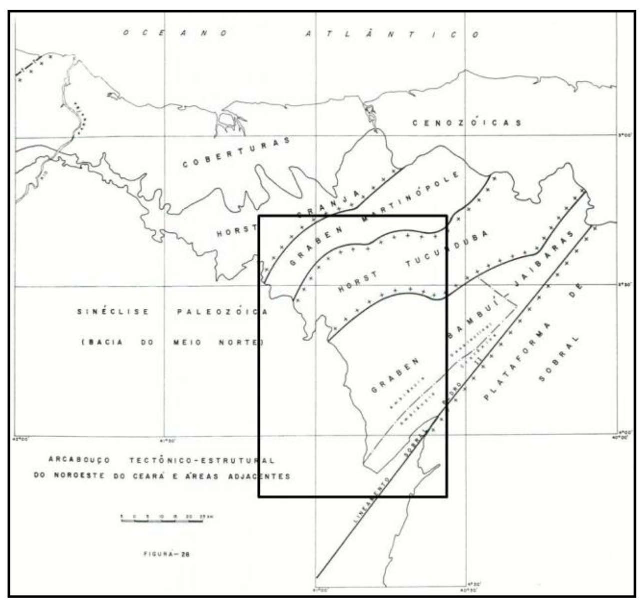

Figure 3 - Regional tectonic-structural compartmentation of the NO region of Ceará. Source: Costa et al. (1979). Adap. Moura-Fé (2015).

Associated with this current basic geomorphological macro-compartmentation, on these tectonic compartments there is a significant lithostratigraphic diversity (Figure 4), whose age is largely **pre-cretaceous**, which should be considered for geomorphological evolution by providing different patterns wheathering-erosives to the modeled ones of which they are substrate.

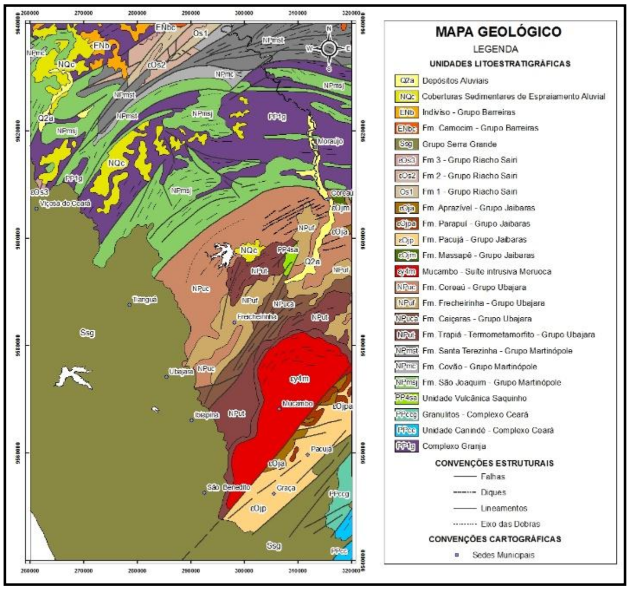

Figure 4 - Geological map of northern Ibiapaba. Source: Moura-Fé (2015).

3.2. Structuring of the Borborema Province

The pre-Cretaceous evolution, more precisely, of neoproterozoic age in the Borborema Province, outcropping in the eastern and northern segments of the study area, is characterized by the development of shear zones on a continental scale (VAUCHEZ et al., 1995), with the presence of granitic plutonism phases (BRITO NEVES et al., 2003), which are morphologically configured in the current landscape as inselbergs and small massifs, an interesting part of the morphostructural configuration of the current landscape of *Ibiapaba* and its surroundings (Figure 5), resulting , in large part, of the pre-cretaceous structuring of the region.

The SDMC comprises a Brasiliano belt formed during the agglutination of Gondwana (SANTOS et al., 2008), however, some of its lithologies were formed earlier, during the paleoproterozoic, like the gneisses of the **Granja complex**, possibly in its distensive stage (HASUI, 2012b). By correlation, the lithologies of the ***Ceará*** **complex** must also have their origins going back to the Transamazonian cycle.

The general organization of the Brasiliano / Pan-African belt, the Brasiliano cycle can be seen in Figure 6.

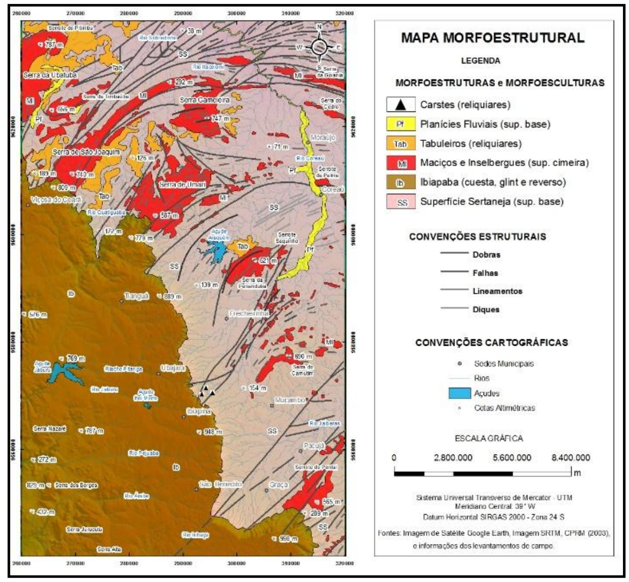

Figure 5 - Morphostructural map of northern Ibiapaba. Source: Moura-Fé (2015).

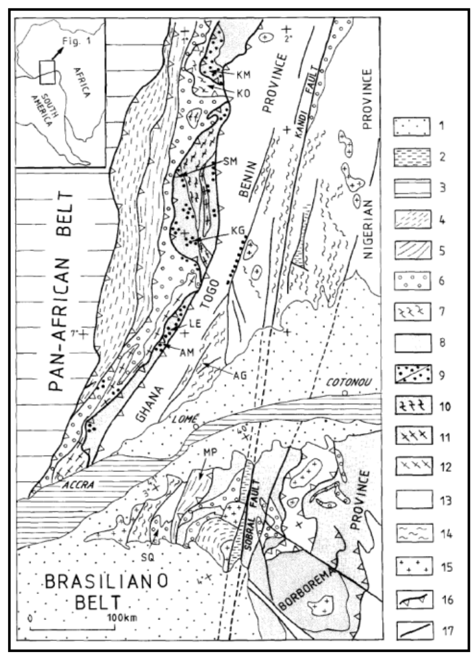

Figure 6 - Pan-African / Brasilian belt. Source: CASTAING et al. (1994). Neoproterozoic fit of the lithotectonic units of the Pan-African and Brasilian belts in Ghana-Togo-Benin and Northeast Brazil. Caption: Brasiliano Belt: 1-Mesozoic-Cenozoic; 2-Cambrian; 4-Ubajara group; 5-Phyllite of the Martinópole Group; 6-Methaquartzite; 8-Ceará monocyclic group; 13-Archean basement reworked; 14-Granulite; 15-Granite of Superior Brasiliano; 16-Thrust; 17-Transcurrent shear zone; MP = Phyllite Martinópole; SQ = São Joaquim Metaquartzite.

Since then, the Borborema Province has undergone other tectonic processes, resulting in its current configuration, endowed with several NE-SW shear zones (NOGUEIRA NETO et al., 1990), see figure 5. In general, the paleoproterozoic base it is composed of migmatitic gneisses and granulites, covered by late Paleoproterozoic and Neoproterozoic rocks, intruded by granites without post-tectonics (SANTOS et al., 2008).

Identifying the genesis of the other lithologies in the study area (see figure 4), going back to the post-Transamazonic cycle (still in the paleoproterozoic), **the Saquinho volcanic unit** marks a magmatism process associated with intracontinental rifting and constitutes a klippe over the **Ubajara group** (HASUI, 2012b).

The Rodínia fission (Lower Neoproterozoic) occurred in a well demarcated rift and drift process both in Brazil and in Africa. In the South American case, it occurred around 950 and 850 Ma, resulting in several descendants, whose large blocks developed wide neoproterozoic coverings in stable conditions and evolved to the later constitution of the Sin-Brasilian cratons, during the process of articulation of the Pannotia / Gondwana (BRITO NEVES, 1999). Also in the Neoproterozoic, the SDMC welcomed these neoproterozoic coverings, which would form the basis of the **Martinópole Group**'s metavolcanic package (780 Ma) and the **Ubajara Group**'s metasedimentary package, both in the marine environment, but which, in the second unit, went from marine to fluviomarinho (HASUI, 2012b), from the retreat of the Atlantic ocean, then in formation.

The development of the Brasilian cycle began at the beginning of the Neoproterozoic and was even more important for the structural evolution of these ancient lithologies (BRITO NEVES; CAMPOS NETO; FUCK, 1999) in the northwest region of *Ceará*. Around 650 Ma, the **Martinópole Group** metamorphosed medium grade, in the Goiabeira and São Joaquim formations, and from low to incipient in the other 2 formations (Covão and Santa Terezinha). In turn, the deformation of these formations occurred between 620-590 Ma (Upper Neoproterozoic), by tangential tectonics, generating a stack of NW convergence nappes, followed by a strong transcurrent tectonics, which originated the NW Shear Belt in *Ceará*, which sustains quartzitic massifs in northern contact with *Ibiapaba* (HASUI, 2012b).

Still in the late Proterozoic and early Paleozoic periods, the Granja complex was metamorphised to medium and high degrees, more or less migmatized and strongly deformed in the 560-550 Ma period, by the Brasilian cycle. Still in this cycle and under extensive regime, molassa basins (graben Ubajara-Jaibaras) and 530 Ma granitoid intrusions (**Meruoca Suite, Mucambo granitoid**) were installed, commonly connected in the Borborema System and associated with the ZCS (Transbrasiliana) to SE, and Café-Ipueiras to NO (HASUI, 2012b).

Specifically in relation to graben Jaibaras, this elongated NE-SO feature is the result of reactivations of crustal milonitic discontinuities belonging to the Transbrasiliano linearity, whose evolution was dominated by a strong magmatic activity (OLIVEIRA, 2001), right after the Brasiliano cycle in the Borborema province (OLIVEIRA et al., 2001), well registered in several regions of the state of *Ceará*.

The specific magmatic evolution of the graben Jaibaras basically comprises 4 events, separated temporally and spatially. The 1st phase involved the swarm of Coreaú dykes and represents the initial tectonic pulse of the opening of the rift. With the continuity of the rupture, the reactivation of deeper shear zones (2nd phase), originated the accommodation of the Mucambo pluton during the Lower Cambrian, prior to the main phase of filling the rift. The sedimentation of the basin (3rd phase) was accompanied by a large volume of volcanism, composed mainly of basalt floods, dikes and sills. The Meruoca pluton is the 4th and last igneous manifestation related to this basin, already in the Upper Cambrian (OLIVEIRA, 2000; 2001).

Regarding the **Mucambo granito**id from the **Meruoca Intrusive Suite**, its intrusion is associated with the 3rd interval of granitic magmatism occurring in the Borborema Province (545-520 Ma), whereas the first two were at the end of the Neoproterozoic (FERREIRA et al., 2004; MIZUSAKI et al., 2002).

The continuous convergence associated with the Brasilian cycle was responsible, in short, for the emergence of transcurrent zones (560 Ma), originating extensive NE-SW and E-W shear zones in the Borborema province and in the corresponding West African province. This significantly affected the entire hydrographic network in the region and, therefore, the regional drainage and dissection patterns of the modeled (SANTOS et al., 2008).

Related to the subsequent formation of the Parnaíba basin, the appearance of the Ubajara-Jaibaras graben occurred with the extensional event, associated with the reactivation processes along the Transbrasiliana shear zone, in a phase of intense fracturing, whose rigid breakable tectonic affected Massapê and Pacujá formations (basal formations of the Jaibaras group) are significant (ALMEIDA; ANDRADE FILHO, 1999; GORAYEB et al., 2011; OLIVEIRA; MOHRIAK, 2003).

The **Parapuí formation** marks the next event, in the form of a complex suite of volcanic rocks (predominantly basaltic), represented by lava flows, pyroclastic elements and sub-volcanic terms (COSTA et al., 1979; SANTOS et al., 1984). Belonging to the 1st magmatic stage representative of the province, its formation took place at the end of the Neoproterozoic and beginning of the Paleozoic, related to the rift phase of the Ubajara-Jaibaras gren (MIZUSAKI et al., 2002; NASCIMENTO; GORAYEB, 2004).

The rocks of the Parapuí formation are closely related to the Ubajara-Jaibaras graben, but this magmatism also manifested itself outside it (ALMEIDA; ANDRADE FILHO, 1999; COSTA et al., 1979). Although the continuity of these spills to the adjacent areas (horsts) has been largely eroded - probably in the course of the uplift of these structures, their records are kept in the sedimentary deposits of the Aprazível formation which cover, in erosive discord, the entire set of older rocks of the Ubajara group (NASCIMENTO; GORAYEB, 2004).

The end of the Precambric / Proterozoic and the beginning of the Phanerozoic / Paleozoic begins to characterize a period of post-orogenic Brasilian transition to a period of stabilization in the Borborema province (MABESSONE, 2002), where the processes of disaggregation predominated. In this way, the lithologies reported in this item were eroded and truncated indistinctly and are presented geomorphologically only as a wide topographically lowered surface, flat to gently undulating, the *sertaneja* surface, except for the contact with *Ibiapaba*, where its ancient rocks are uplifted, forming a glint contact (CLAUDINO-

SALES and PEULVAST, 2007; CLAUDINO-SALES and LIRA, 2011), as can be seen in the morphostructural profile in Figure 7.

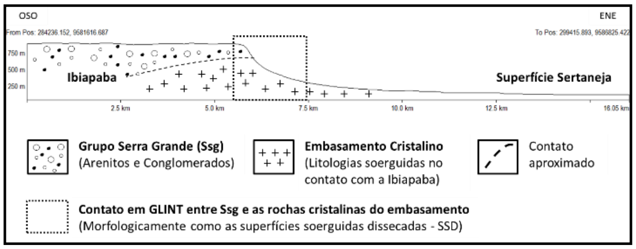

Figure 7 - Morphostructural profile Ibiapaba glint contact. Source: Moura-Fé (2015).

However, despite the trend towards tectonic stability, the last manifestations of the Brasilian cycle took place at the beginning of the Paleozoic, consisting of intrusions of diabase dikes, post-tectonic granitoids of up to 460 Ma and the implantation of molassa basins in both domains (ALMEIDA; BRITO NEVES; CARNEIRO, 2000; HASUI, 2012b). Thus, after these events, the structural pattern of the crystalline basement in the region is inherited mainly from the Brasilian cycle (FETTER et al., 1999; PEULVAST and CLAUDINO-SALES, 2003), with emphasis on the different shear zones NE-SW (NOGUEIRA NETO et al., 1990).

Table 1 presents a synthesis of the events and processes related to the proterozoic structural history of the crystalline basement, and their related geomorphological, tectonic and lithological reflexes.

EVOLUÇÃO ESTRUTURAL PROTEROZOICA DO SUBDOMÍNIO MÉDIO COREAÚ / PROVÍNCIA BORBOREMA (EMBASAMENTO CRISTALINO)					
Éon	**Era**	**Período**	**Idade (Ma)**	**Evento Tectônico**	**Reflexos Tectônicos / Litológicos e Geomorfológicos**
Proterozoico	Neoproterozoico	Ediacárico	635	Final do Ciclo Brasiliano Precoce (850-620 Ma)	- Movimentos orogênicos e desenvolvimento de zonas de cisalhamento NE-SO e L-O na região NO do Ceará (560-540 Ma); - Formação do graben Jaibaras. - Metamorfização, migmatização e deformação do Complexo Granja (560-550 Ma); - Deformação (620-590 Ma) e exumação do Grupo Martinópole.
		Cryogenico	850	Inicio do Ciclo Brasiliano Precoce (850-620 Ma)	- Deposição (780 Ma) e Metamorfismo (650 Ma) do Grupo Martinópole; - Preenchimento do gráben Martinópole.
		Tónico	1.000	Fissão do Rodínia (1,0-0,85 Ga)	- Erosão dos blocos descendentes dessa fissão e desenvolvimento de amplas coberturas neoproterozoicas, base dos pacotes sedimentares dos grupos Martinópole e Ubajara; - Abertura dos grabens Martinópole e Ubajara-Jaibaras. - Fases rifte e drifte bem demarcadas no Brasil (950-850 Ma);
				Fusão diacrônica do Rodínia. 2ª etapa (1-0,96 Ga)	- Sem influência estrutural na região Nordeste do Brasil. Permanência das condições estruturais derivadas do Ciclo Transamazônico.
	Meso proterozoico	Superior	1.600	Fusão diacrônica do supercontinente Rodínia – 1ª etapa (1,45-1,3 Ga)	
	Paleoproterozoico	Stathérico	1.800	Fissão do Atlântica / final do Ciclo Transamazônico	- Permanência das condições estruturais derivadas do Ciclo Transamazônico; - Ocorrência de magmatismo de pequena monta – Unidade Vulcânica Saquinho.
		Orosirico	2.050		
		Rhyácico	2.300		
		Sidérico	2.500	Fusão do supercontinente Atlântica / Início do Ciclo Transamazônico	- Estruturação do Complexo Granja, do embasamento de Senador Sá (NO do Ceará) – 2,35 Ga; dos maciços que formam o embasamento da Bacia do Parnaíba (Granja Norte, Granja Sul, Monte Alegre de Goiás e Parnaíba).

Table 1 - Synthesis of the proterozoic structural evolution. Source: Various authors. Org. Moura Fé (2015). Ages: IUGS (2013).

3.3. Pre-Cretaceous Parnaíba Province

In the South American platform, the stable continental portion of the South American plate, there is several evidences of extension processes, pure and, above all, simple (transtrational), resulting from the end of the Brasilian cycle (ALMEIDA et al., 1981; ALMEIDA; BRITO NEVES; CARNEIRO, 2000; BRITO NEVES, 1999; HASUI, 2012a; POPP, 2012) and distributed unevenly between 590 and 500 Ma in all structural provinces (locally entering into cratonic provinces), being responsible for the formation of tension-free basins over shear zones and allowing the formation of intracratonic basins (BRITO NEVES, 1999; SUGUIO, 2003).

Along the lower Paleozoic, on the basement of the NW region of *Ceará*, intracontinental rifts (SCHOBBENHAUS et al., 1984) were opened due to the fission of Pannotia (DANTAS et al., 1999), whose associated forces produced grabens, in which wide syneclises were developed where intracratonic basins originated (ALMEIDA; BRITO NEVES; CARNEIRO, 2000).

Thus, during the eocarbon (or eocarboniferous), the structural definition of the great Brazilian intracratonic basins occurred: Amazonas, Parnaíba, Paraná and Solimões (PEREIRA et al., 2012; PETRI and FÚLFARO, 1983), endowed with common characteristics, associated with both lack of intense structural deformations (THOMAZ-FILHO et al., 2000; THOMAZ-FILHO; MIZUSAKI; ANTONIOLI, 2008), regarding the intracratonic sedimentation phase marked by several depositional cycles (MOHRIAK, 2012), with sedimentation conditions very similar to along the Paleozoic (PIRES, 2003).

However, specifically, it is considered that the Parnaíba basin has already started in the silurian, developing on the Neoproterozoic base from the subsidence along the Transbrasiliano and Santa Inês lineaments, pre-Cambrian tectonic inheritances that are striking for all its evolution (ALMEIDA and CARNEIRO, 2004; CORDANI; BRITO NEVES; THOMAZ FILHO, 2009; CUNHA, 1993), while the most significant inherited fractures and failures controlled the directions of the depositional axes from the basin to the Eocarbon (VAZ et al., 2007).

Therefore, closely related to the Brasilian cycle, the initial formation of the Parnaíba basin is characterized by the opening of grabens and the accumulation of cambro-ordovician molassic facies, commonly associated with acid or intermediate volcanisms that make up the Jaibaras group (ALMEIDA; BRITO NEVES; CARNEIRO, 2000; CARNEIRO et al., 2012; CASTRO et al., 2014; SAADI; TORQUATO, 1992; SUGUIO, 2003) and the Parapuí formation (NASCIMENTO; GORAYEB, 2004).

According to Pires (2003), the evolution of the Parnaíba basin took place in two phases: (1) **Thalassocratic**: developed between Eosiluric and Eocarbonic (440-350 Ma), characterized by successive transgressions and marine regressions; and (2) **Geocratic**: between Neocarbon and Triassic (350-250 Ma), due to continental deposition and episodic marine inflows. Associated with this evolution, the succession of sedimentary and magmatic rocks in the Parnaíba basin is arranged in 5 supersequences: (1) Silurian, (2) Mesodevonian-Eocarboniferous, (3) Neocarboniferous-Eotriássica, (4) Jurassic and (5) Cretaceous, where eustasia was the primary factor in the control of transgressive-regressive cycles and, consequently, of the disagreements that extend throughout the basin and that define the limits of these supersequences (VAZ et al., 2007).

The 1st super-sequence is strictly related to the **Serra Grande group**, which marks the beginning of a marine entry. The coarse character of the sandstones and conglomerates of the **Ipu formation** (lower formation) indicates shallow and agitated water conditions, in a neritic environment, with rapid and continuous lowering of the sedimentation basin, covered by an extensive water depth, which only reached greater depths in the final group sedimentation phase, with more stable sedimentation of fine sandstones (COSTA et al., 1979).

The **Tianguá formation** (intermediate formation) represents the maximum flood surface and the layers of the **Jaicós formation** (higher formation), the regressive interval of this sequence, whose facies indicate deposition by fluvial, deltaic and platform systems, in continental, transitional and shallow marine environments (GÓES; FEIJÓ, 1994).

From the Ordovician / Silurian to the Mississipian (lower carbon) sedimentation was clastic, predominantly marine, marked by a marked subsidence on the eastern edge with the NE and NW direction (SANTOS; CARVALHO, 2009). From Pennsylvanian (Neocarbonic) to Jurassic (Middle Mesozoic), the depocenters moved to the central part of the Parnaíba basin, where the sedimentation started to have a concentric pattern and the external shape of the basin became oval, typical of a interior syneclysis (VAZ et al., 2007).

Table 2 presents a synthesis of the events and processes related to the paleozoic structural history of the Parnaíba basin, with a record of past events related to the Brasilian cycle, with its tectonic, lithostratigraphic and geomorphological reflections, above all.

EVOLUÇÃO ESTRUTURAL PALEOZOICA DA BACIA DO PARNAÍBA						
Éon	**Era**	**Período**	**Época**	**Idade (Ma)**	**Evento Tectônico**	**Reflexos Tectônicos, Litoestratigráficos e Geomorfológicos**
Fanerozoico	Paleozoico	Permico		298,9	Fusão do 4º megacontinente Pangeia (250 Ma)	- Sem influência estrutural na região Nordeste do Brasil. Permaneceram as condições estruturais derivadas do Ciclo Brasiliano.
					Formação da bacia / Fase evolutiva Geocrática (Neocarbônico-Triássico; 350-250 Ma)	- Continuidade da deposição do Grupo Balsas; - Sedimentação controlada por mecanismo tectono-estrutural que imprimiu centros deposicionais aleatoriamente distribuídos na porção setentrional da bacia.
		Carbônico	Neocarbônico/ Pennsylvanico	323,2		- Deposição da 3ª supersequência (Neocarbônica-Eotriássica – Grupo Balsas). - Deslocamento dos depocentros para a parte central da bacia entre o Pennsylvanico e o Jurássico.
			Eocarbônico/ Mississippico	358,9	Formação da Bacia do Parnaíba / fase evolutiva Talassocrática (Eosilúrico – Eocarbonico; 440-350 Ma)	- Deposição da 2ª supersequência (Mesodevonica-Eocarbônica – Grupo Canindé).
		Devônico		419,2		
		Silúrico		443,4		- Deposição das litologias basais (Grupo Serra Grande) recobrindo os terrenos antigos do embasamento, dobrados no Ciclo Brasiliano; - Controle estrutural das principais fraturas e falhas do embasamento na direção dos eixos deposicionais até o Eocarbonico; - Origem a partir da subsidência ao longo dos lineamentos Transbrasiliano e Santa Inês.
		Ordovicico		485,4	Fissão do Pannotia (? Ma) / Final do Ciclo Brasiliano (620-550 Ma)	- Intrusões de diques, granitoides e implantação de grabens/bacias molássicas de idade cambro-ordovícica no Grupo Jaibaras (2ª fase molássica) (início da sedimentação paleozoica). Etapas associadas ao vulcanismo do Grupo Jaibaras – Formação Parapuí; - Preenchimento por subsidência termomecânica dos grabens.
		Câmbrico		541,0		- Evolução das sinéclises para bacias intracratônicas (590-500 Ma) e origem ou subsidência inicial da Bacia do Parnaiba (cambro-ordovícica); - Formação de riftes intracratônicos, bacias transtensionais, grabens (Ubajara-Jaibaras) e posterior desenvolvimento de sinéclises; - Eventos relacionados às deformações e eventos térmicos fini e pós-orogênicos do Ciclo Brasiliano.
					Fusão do supercontinente Pannotia (545-515 Ma) Ciclo Brasiliano (620-550 Ma)	- Consolidação de rochas sedimentares no embasamento da bacia – Formação Riachão e Grupo Jaibaras. Grupo Sairi?; - Instalação de bacias de molassa (1ª fase molássica) e intrusões granitoides (530 Ma) – granitoide Mucambo, associadas com os lineamentos Transbrasiliano (SE) e Café-Ipueiras (NO); - Formação da Cadeia Brasiliana (500-400 Ma).

Table 2 - Synthesis of Paleozoic structural evolution. Source: Various authors. Org. Moura Fé (2015). Ages: IUGS (2013)

4. FINAL CONSIDERATIONS

The lithological, tectonic and chronostratigraphic aspects, even old ones, often influence and sometimes even condition the geomorphological arrangement on a regional scale, which occurs in *Ibiapaba* and its tectonic provinces: Parnaíba and Borborema, more precisely, its Middle Subdomain Coreaú (SDMC), in turn, structured in a succession of horsts and grabens. This macro tectonic framework is the first condition on the relief of the region, making up the topographic macro-structuring, while along the horsts we have the highest reliefs in the region of contact with *Ibiapaba*; and in the grábens we have lower altitudes and greater water intake in the hydrographic basins of the region and, therefore, the development of the largest watercourses.

The structuring of the Borborema province, characterized by the development of a network of shear zones, resulted in the presence of inselbergs and small massifs, associated with granitic plutonism; paleoroterozoic magmatism and 530 Ma granitoid intrusions. However, above all, the continuous convergence associated with the Brasilian cycle was responsible for extensive NE-SW and E-W shear zones, which significantly affected the entire hydrographic network in the region and, consequently, the drainage patterns and regional dissection of the modeled.

However, in general, the lithologies of that province were eroded and truncated indistinctly and are presented geomorphologically only as a large topographically lowered surface, flat to smoothly wavy, the *sertaneja* surface.

It is worth stressing that such events have their importance related only to the structure (faults and lineaments) and ancient lithologies and still present in the study area, considering that any part of the current basis is the result of cretaceous and later differential erosion, having no, therefore, influence on the most current reliefs.

In relation to the Parnaíba province, its origin dates back to the lower Paleozoic, where on the base of the region, rifles were opened due to the fission of Pannotia, producing grabs, in which wide syneclises were later developed where intracratonic basins, such as the basin of the Parnaíba, later raised over the cretaceous and giving rise to the macro morphostructuring of *Ibiapaba*.

5. REFERENCES

ALMEIDA, A. R.; ANDRADE FILHO, J. F. A Suíte magmática Parapuí – Sobral-CE: petrologia e posição estratigráfica. *Revista de Geologia*, v. 12, p. 5-28, 1999.

ALMEIDA, F. F. M.; BRITO NEVES, B.B.; CARNEIRO, C. D. R. The Origin and evolution of the South American platform**.** *Earth Science Reviews*, n. 50, p. 77-111, 2000.

ALMEIDA, F. F. M.; CARNEIRO, C. D. R. Inundações marinhas fanerozóicas no Brasil e recursos minerais associados. In: MANTESSO-NETO, V. et al. (Org). *Geologia do continente sul-americano*, p. 43-58. São Paulo: Beca, 2004.

ALMEIDA, F. F. M.; HASUI, Y.; BRITO NEVES, B. B.; FUCK, R. A. Brazilian structural provinces: an introduction. *Earth-Science Reviews*, v. 17, n. 1-2, p. 1-29, 1981.

BRITO NEVES, B. B. América do Sul: quatro fusões, quatro fissões e o processo acrescionário andino. *Revista Brasileira de Geociências*, v. 29, n. 3, p. 379-392, 1999.

BRITO NEVES, B. B.; CAMPOS NETO, M. C. e FUCK, R. A. From Rodinia to Western Gondwana: an approach to the Brasiliano-Pan African Cycle and orogenic collage. *Episodes*, v. 22, n. 3, p. 155-166, 1999.

BRITO NEVES, B. B.; PASSARELLI, C. R.; BASEI, M. A. S.; SANTOS, E. J. Idades U-Pb em zircão de alguns granitos clássicos da Província Borborema. *Revista do Instituto de Geociências*, v. 3, p. 25-38, 2003.

CARNEIRO, C. D. R.; ALMEIDA, F. F. M.; HASUI, Y.; ZALÁN, P. V.; TEIXEIRA, J. B. G. Estágios evolutivos do Brasil no Fanerozóico. In: HASUI, Y. et al. (Org). *Geologia do Brasil*. São Paulo: Beca, 2012.

CASTAING, C.; FEYBESSE, J. L.; THIÉBLEMONT, D.; TRIBOULET, C.; CHÈVREMONT, P. Palaeogeographical reconstructions of the Pan-African/Brasiliano orogen: closure of an oceanic domain or intracontinental convergence between major blocks? *Precambrian Research*, v. 69, p. 327-344, 1994.

CASTRO, D. L.; FUCK, R. A.; PHILLIPS, J. D.; VIDOTTI, R. M.; BEZERRA, F. H. R. e DANTAS, E. L. Crustal structure beneath the Paleozoic Parnaíba Basin revealed by airborne gravity and magnetic data, Brazil. *Tectonophysics*, v. 614, p. 128-145, 2014.

CLAUDINO-SALES, V. e LIRA, M. C. Megageomorfologia do Noroeste do estado do Ceará, Brasil. *Caminhos de Geografia*, v. 12, n 38, p. 200-209, 2011.

CLAUDINO-SALES, V. e PEULVAST, J-P. Evolução Morfoestrutural do Relevo da Margem Continental do Estado do Ceará, Nordeste do Brasil. *Caminhos de Geografia*, v. 7, n. 20, p. 1-21, 2007.

CORDANI, U. G.; BRITO NEVES, B. B. e THOMAZ FILHO, A. Estudo preliminar de integração do Pré-Cambriano com os eventos tectônicos das bacias sedimentares brasileiras. *Boletim de Geociências da Petrobrás*, v. 17, n. 1, p. 205-219, 2009.

COSTA, M. J.; FRANÇA, J. B.; LINS, C. A. C.; BACCHIEGGA, I. F.; HABEKOST, C. R.; CRUZ, W. B. *Geologia da Bacia Jaibaras:* Ceará Piauí e Maranhão. Projeto Jaibaras. MME / DNPM: Brasília, 1979.

CPRM. Serviço Geológico do Brasil. *Mapa Geológico do estado do Ceará.* Escala 1:500.000. CD-ROM. 2003.

CUNHA, F. M. B. Evolução paleozóica da bacia do Parnaíba e seu arcabouço tectônico. Resumo. *Anuário do Instituto de Geociências*, v. 16, p. 80-81, 1993.

DANTAS, E. L.; VAN SCHUMS, W. R.; HACKSPACHER, P. C.; FETTER, A. *Identification of multiple orogenic/metamorphic events in polycyclic terranes:* possibilities and limitations. Insights from the Borborema Province, NE Brazil. Bahia, International Symposium on Tectonics, p. 15-17, 1999.

HASUI, Y. Compartimentação Geológica do Brasil. In: HASUI, Y.; CARNEIRO, C. D. R.; ALMEIDA, F. F. M. e BARTORELLI, A. (Org). *Geologia do Brasil.* São Paulo: Beca, 2012a.

HASUI, Y. Sistema Orogênico Borborema. In: HASUI, Y. et al. (Org). *Geologia do Brasil.* São Paulo: Beca, 2012b.

FERREIRA, V. P.; SIAL, A. N.; PIMENTEL, M. M.; MOURA, C. A. V. Intermediate to acidic magmatism and crustal evolution in the transversal Zone, northeastern Brazil. In: MANTESSO-NETO, V. et al. (Org). *Geologia do continente sul-americano*, p. 188-201. São Paulo: Beca, 2004.

FETTER, A.; VAN SCHMUS, W. R.; SANTOS, T. J. S.; ARTHAUD, M.; NOGUEIRA NETO, J. *Geocronologia e estrutura do Estado do Ceará*: NW da Província Borborema, NE Brasil. XVII Simpósio de Geologia do Nordeste, Fortaleza (CE), Anais, p. 32-33. 1999.

GÓES, A. M. O. e FEIJÓ, F. J. Bacia do Parnaíba. *Boletim de Geociências da Petrobrás*, v. 08, n. 1, p. 57-67, 1994.

GORAYEB, P. S. S.; BARBOSA, R. C. O.; AUGUSTO, C.; MOURA, V.; LEMOS, R. L. Petrografia, geocronologia e significado tectônico do Nefelina Sienito Brejinho: extremo noroeste da Província Borborema. *Revista Brasileira de Geociências*, v. 41, n. 3, p. 390-407, 2011.

IUGS. International Commission of Stratigraphy. *Tabela cronoestratigráfica internacional.* 2013. Disponível em: http://www.stratigraphy.org/ICSchart/ChronostratChart2013-01Portuguese_PT.pdf Acesso em: 27 abr. 2019.

MABESSONE, J. M. História Geológica da Província Borborema (NE Brasil). *Revista de Geologia*, v. 15, p. 119-129, 2002.

MIZUSAKI, A. M. P.; THOMAZ-FILHO, A.; MILANI, E. J.; CÉSERO, P. Mesozoic and Cenozoic igneous activity and its tectonic control in northeastern Brazil**.** *Journal of South American Earth Sciences*, v. 15, n. 2, p. 183-198, 2002.

MOHRIAK, W. Bacias da margem continental divergente. In: HASUI, Y. et al. (Org). *Geologia do Brasil.* São Paulo: Beca, 2012.

MOURA-FÉ, M. M. *Evolução Geomorfológica da Ibiapaba setentrional*, *Ceará*: Gênese, Modelagem e Conservação. Tese de Doutorado (PPGG –UFC), Fortaleza-CE, 2015. 307 p.

NASCIMENTO, R. S.; GORAYEB, P. S. S. Basaltos da Suíte Parapuí, Gráben Jaibaras, Noroeste do Ceará: Caracterização, Petrografia, Geoquímica e Química Mineral. *Revista Brasileira de Geociências*, v. 34, n. 4, p. 459-468, 2004.

NOGUEIRA NETO, J. A.; TORQUATO, J. R.; MACAMBIRA, M. J. B.; ARTHAUD, M. H. Avaliação dos dados geocronológicos do Complexo Granja (CE). *Revista de Geologia*, v. 3, p. 5-18, 1990.

OLIVEIRA, D. C. Reavaliação da evolução tectono-magmática do Graben de Jaibaras (nordeste do Brasil). *Acta Geologica Hispanica*, v. 36, n 1-2, p. 53-95, 2001.

OLIVEIRA, D. C. Stratigraphic interplays between igneous and sedimentary events in the early palaeozoic Jaibaras Trough (Northeast Brazil). *Revista Brasileira Geociências*, v. 30, n. 3, p. 427-431, 2000.

OLIVEIRA, D. C.; MARTINS, G.; BRANCO, R. M. G. C.; CASTRO, D. L. Um modelo alternativo para a formação da Bacia do Jaibaras: implicações para a evolução final da Cadeia Brasiliana/pan-africana no noroeste da Província Borborema. *Revista de Geologia*, v. 14, p. 11-21, 2001.

OLIVEIRA, D. C.; MOHRIAK, W. U. Jaibaras trough: an important element in the early tectonic evolution of the Parnaiba interior sag basin, Northern Brazil. *Marine and Petroleum Geology*, v. 20, p. 351-383, 2003.

PEREIRA, E.; CARNEIRO, C. D. R.; BERGAMASCHI, S.; ALMEIDA, F. F. M. Evolução das sinéclises paleozóicas: Províncias Solimões, Amazonas, Parnaíba e Paraná. In: HASUI, Y. et al. (Org). *Geologia do Brasil.* São Paulo: Beca, 2012.

PETRI, S.; FÚLFARO, V. J. *Geologia do Brasil*. São Paulo: EDUSP, 1983.

PEULVAST, J. P. e CLAUDINO SALES, V. *Carta morfoestrutural do Ceará e áreas adjacentes do Rio Grande do Norte e Paraíba.* Nota Explicativa. In: CPRM. Atlas Digital de Geologia e Recursos Minerais do Ceará. CD-Rom, 73 p., 2003.

PIRES, F. R. M. Arcabouço geológico. In: CUNHA, S. B. e GUERRA, A. J. T. *Geomorfologia do Brasil*. 3 ed. Rio de Janeiro: Bertrand Brasil, 2003.

POPP, J. H. *Geologia geral*. 6 ed. Rio de Janeiro: LTC, 2012.

SAADI, A.; TORQUATO, J. R. Contribuição à neotectônica do estado do Ceará. *Revista de Geologia*, v. 5, p. 5-38, 1992.

SANTOS, E. J.; COUTINHO, M. G. N.; COSTA, M. P. A.; RAMALHO, R. A região de dobramentos nordeste e a bacia do Parnaíba, incluindo o Cráton de São Luís e as bacias marginais. In: SCHOBBENHAUS, C. (Coord.). *Geologia do Brasil.* Brasília: Departamento Nacional de Produção Mineral, 1984.

SANTOS, M. E. C. M.; CARVALHO, M. S. S. *Paleontologia das bacias do Parnaíba, Grajaú e São Luís*. Rio de Janeiro: CPRM, 2009.

SANTOS, T. J. S.; FETTER, A. H.; HACKSPACHER, P. C.; SCHMUS, W. R. V.; NOGUEIRA NETO, J. A. Neoproterozoic tectonic and magmatic episodes in the NW sector of Borborema Province, NE Brazil, during assembly of Western Gondwana. *Journal of South American Earth Sciences,* v. 25, p. 271–284, 2008.

SCHOBBENHAUS, C.; CAMPOS, D. A.; DERZE, G. R.; ASMUS, H. E. *Geologia do Brasil*. Escala 1:2.500.000. Brasília: DNPM, 1984.

SUGUIO, K. *Geologia Sedimentar*. São Paulo: Edgard Blucher, 2003.

THOMAZ-FILHO, A.; MIZUSAKI, A. M. P. e ANTONIOLI, L. Magmatismo nas bacias sedimentares brasileiras e sua influência na geologia do petróleo. *Revista Brasileira de Geociências*, v. 38, n. 2 – suplemento, p. 128-137, 2008.

THOMAZ-FILHO, A.; MIZUSAKI, A. M. P.; MILANI, E.J.; CESERO, P. Rifting and magmatism associated with the South America and Africa break up. *Revista Brasileira de Geociências*, v. 30, n. 1, p. 17-19. 2000.

VAUCHEZ, A.; NEVES, S.; CABY, R.; CORSINI, M., EGYDIO-SILVA, M; ARTHAUD, M.; AMARO, V. The Borborema shear zone system, NE Brazil. *Journal of South American Earth Sciences*, v. 8, n. 3-4, p. 247-266, 1995.

VAZ, P. T.; REZENDE, N. G. A. M.; WANDERLEY FILHO, J. R.; TRAVASSOS, W. A. S. Bacia do Parnaíba. *Boletim de Geociências da Petrobrás*, v. 15, n. 2, p. 253-263, 2007.

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