https://rbgeomorfologia.org.br/
ISSN 2236-5664

Revista Brasileira de Geomorfologia

v. 25, nº 3 (2024)

http://dx.doi.org/10.20502/rbg.v25i3.2566

Research Article

Geomorphological Compartmentation of Pereiro Massif and its surroundings, in Northern Northeast of Brazil

Compartimentação Geomorfológica do Maciço do Pereiro e entorno, Nordeste Setentrional do Brasil

Diêgo Souza Albuquerque [1], Rafael Albuquerque Xavier [2] e Dirce Maria Antunes Suertegaray [3]

[1] Universidade Federal da Paraíba, Departamento de Geociências, João Pessoa, Paraíba, Brasil. diealbuquerque07@gmail.com.
ORCID: https://orcid.org/0000-0002-0504-4972

[2] Universidade Estadual da Paraíba, Departamento de Geografia, Campina Grande, Paraíba, Brasil. rafaelxavier@servidor.uepb.edu.br.
ORCID: https://orcid.org/0000-0002-1737-7547

[3] Universidade Federal da Paraíba, Departamento de Geociências, João Pessoa, Paraíba, Brasil. dircesuerte@gmail.com.
ORCID: https://orcid.org/0000-0002-3513-6376

Received: 10/04/2024; Accepted: 04/07/2024; Published: 19/08/2024

Abstract: The Pereiro Massif (PM), located between the states of Ceará, Rio Grande do Norte and Paraíba, is a granitoid body that occupies an area of approximately 2,200 km², and and has maximum altitudes of 861 meters. This work aimed to elaborate and discuss the geomorphological compartmentalization of the Pereiro Massif and its surroundings. To this end, the following procedures were followed: 1) bibliographic and cartographic review on the geology and relief of the study area; 2) creation of the geomorphological map in a GIS environment, through SRTM image processing; 3) field activities for mapping conference, obtaining information to characterize the shapes and photographic survey. Fifteen units were mapped and grouped into three dimensions that consider the resulting processes and forms: accumulation, flattening and erosion surfaces. The compartments are classified recognizing processes associated with continental denudation with erosion, transport and deposition of material, based on structural geomorphology. The mapping carried out enhances the scientific notoriety of the PM and is expected to serve for environmental planning actions, such as the creation of protected areas and environmental licensing procedures.

Keywords: Geomorphological Mapping; Crystalline Massif; Accumulation; Flattening; Erosion.

Resumo: O Maciço do Pereiro (MP), localizado entre os estados do Ceará, Rio Grande do Norte e Paraíba, é um corpo granitóide que ocupa área de, aproximadamente, 2.200 km², e tem altitudes máximas de 861 metros. Este trabalho teve o objetivo de elaborar a compartimentação geomorfológica do Maciço do Pereiro e entorno. Para tanto, seguiu-se com: 1) revisão bibliográfica e cartográfica sobre geologia e relevo da área de estudo; 2) confecção do mapa geomorfológico, através do processamento de imagens SRTM; 3) atividades de campo para conferência do mapeamento, obtenção de informações para caracterização das formas e levantamento fotográfico. Foram mapeadas quinze unidades, sendo elas agrupadas em três dimensões que consideram os processos e as formas resultantes: superfícies de acumulação, aplanamento e dissecação. Os compartimentos estão classificados reconhecendo processos associados à denudação continental e com base na geomorfologia estrutural. O mapeamento elaborado amplia a notoriedade científica do MP e espera-se que possa servir para ações de planejamento ambiental, como criação de áreas protegidas e procedimentos de licenciamento ambiental.

Palavras-chave: Mapeamento Geomorfológico; Maciço Cristalino; Acumulação; Aplanamento; Dissecação.

1. Introduction

The different forms of relief are syntheses resulting from the interaction between the lithostructural framework, tectonic events, and climatic actions (DINIZ, et al., 2017), and in some cases, anthropogenic action can be added. Knowledge of landforms is a tool of unquestionable relevance to the planning and use of the territory by societies.

In the Northeast of Brazil, there is a diverse mosaic of geomorphological compartments, including residual forms resulting from differential erosion on deformational structures in the Borborema Province (COSTA et al., 2020), constituting "[...] surface geomorphological expressions of processes associated with crustal deformation, metamorphism, plutonism and neotectonics" (COSTA et al., 2019, p. 186).

In this context, we can point to the crystalline massifs which, for the most part, in the Borborema Province, are associated with granitoids whose genesis is related to differential erosion processes (LIMA et al., 2020). This scenario includes the Pereiro Massif (PM), with features carved out of granitic and metamorphic lithotypes - ridges, escarpments, domed shapes, flat tops, and several valleys.

The Pereiro Massif, located in the central portion of northern northeastern Brazil, between the states of Ceará, Rio Grande do Norte and Paraíba (Figure 1), is elongated and strongly dissected, and is an important record of regional geomorphological evolution. It is a crystalline relief embedded in the countryside surface, which occupies an area of approximately 2,200 km², with accommodation oriented in a NE-SW direction, modeled dominantly on Neoproterozoic granitoids from the Brasiliano Magmatism (MAGINI and HACKSPACHER, 2008).

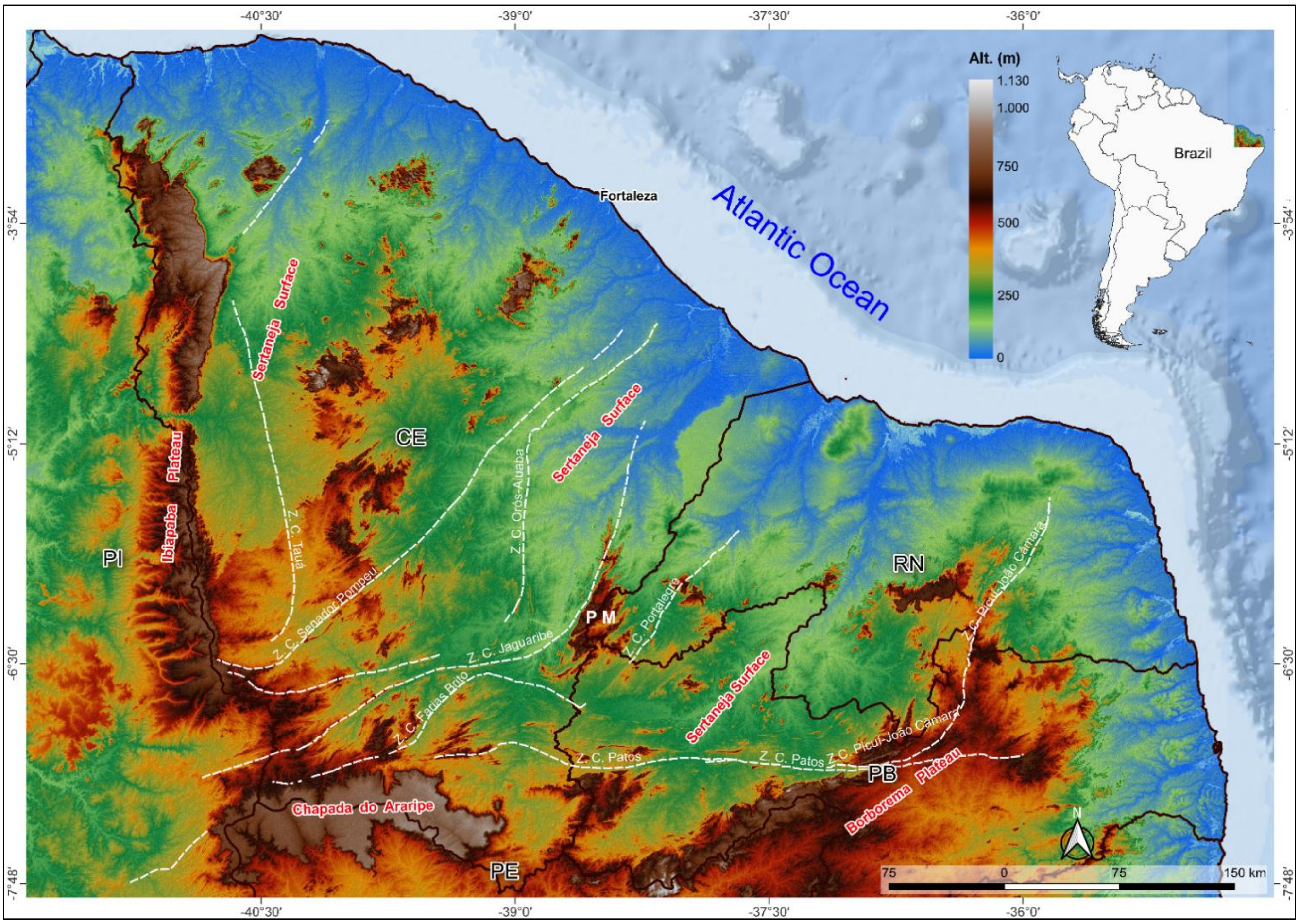

Figure 1. Location of the Pereiro Massif (PM), in north-eastern Brazil. Source: prepared by the authors, 2023, based on SRTM altimetry data (2011). Geographic Coordinate System/Datum SIRGAS 2000.

Considering the exuberance of the PM and its natural potential, coupled with the need for more horizontal and vertical studies on it, the purpose of this work was to draw up the geomorphological compartmentalization of the Pereiro Massif and its surroundings. To achieve this, it was necessary to review the literature on the origin and evolution of the PM - the first stage - in order to provide a basis for cartographic delimitation and understanding of its forms - the second stage.

There is no geomorphological mapping proposal for the PM prior to this one and considering its spatial expressiveness and the growing anthropogenic pressure on the PM environment caused by settlement, it is essential to have a satisfactory knowledge of the relief, especially for technical environmental planning actions and to support other academic studies. In this context, the mapping carried out will firstly increase the scientific reputation of the PM and secondly, it can be used for environmental planning actions, such as the creation of protected areas and environmental licensing procedures, supporting land use planning.

2. Geomorphological interpretations of the Pereiro Massif: a review

The Pereiro Massif was initially explained as the result of erosive processes from pediplanation, characterizing it as a residual form. This explanation is based on King (1956), who developed a model for classifying Flattening Surfaces in Brazil, based on the occurrence of post-Cretaceous epirogenesis, accompanied by phases of dissection and pediplanation, widely disseminated by Ab'Sáber (1969), Andrade and Lins (1965) and Bigarella (1994). In this model, morphogenetic processes in a dry climate erode the higher reliefs, mainly their escarpments, retreating the slopes and depositing the eroded material in the lower areas, forming stepped landscapes.

Based on this model, Souza (1988) drew up a classification for the morphostructural units of the state of Ceará, grouping the relief into three geological domains and establishing a geomorphological compartmentalization that considered the predominance of pediplanation processes in sculpting the relief. In this classification, the PM is included in the Domain of Ancient Shields and Massifs and is named Residual Plateau, giving it a predominance of dissected erosive forms.

According to Souza (1988), the land in this Domain is made up of lithologies dating back to the Precambrian period, so that the landforms within it show reflections of remote tectonic events and evidence of Cenozoic climatic fluctuations, which made severe dissection possible in the higher topographic compartments. In this explanation, the Residual Plateaus, including the PM, are the result of a complex morphogenetic evolution, subsidized by pediplanation, building stepped surfaces in the hinterlands of Ceará (SOUZA, 1988).

Following this conception, official compartmentalizations followed the residual rite. The IBGE (2006) classified the PM as belonging to the Residuals Sertanejos Plateaus, characterized as a set of spatially expressive forms, in flat and/or dissected patterns, at high altitudes, limited by lower surfaces, in which erosion rates are higher than sedimentation rates.

Later, the IBGE (2009a, 2019) removed the term "residual" from these forms, leaving only the nomenclature "Sertanejos Plateaus". This choice does not make the mistake of indicating only one process or the one most prevalent in the formation of these reliefs. This choice was possibly due to the growing research that considers more recent tectonic factors in the structuring of these areas and not only the erosive processes.

Despite its scientific relevance as a geomorphological explanation, the model of stepped surfaces, which establishes a correlation between altitude and the chronology of forms, has met with resistance to general application in the Northeast of Brazil. According to Maia and Bezerra (2011), when subjected to morphostratigraphic and morphotectonic criteria, this concept does not hold up. The authors show that the evolution of the Brazilian Northeast's relief took place in a more complex way than the pediplanation concept proposes, incorporating tectonic events. It was clear that King (1956) did not incorporate rifting mechanisms and history of the basins, nor post-rift reactivation data, when imagining the tectonic stability of the area, given its location on the eastern equatorial passive margin of South America.

In short, those who question the applicability of King's model (1956) point to intra-planar tectonic activity as an agent in the evolution of the relief in the Brazilian Northeast. In this vein, Maia, Bezerra and Sales (2010), based on structural geomorphology, state that that region has undergone the occurrence of various tectonic episodes, resulting in important geomorphological compartments, originating in the Brazilian Orogeny and the separation of Gondwana, when the final separation between South America and Africa occurred in the Cretaceous.

At the end of the 20th century and the beginning of the 21st, several studies have raised hypotheses about the structuring of the Brazilian Northeast's terrain in correlation with the events of the "dance of the continents" (SALES, 2016). It is not intended to review this theme, however, in the light of the literature, it is necessary to point out how the Pereiro Massif figures in this context.

According to Peulvast et al. (2006) and Sales (2002), the rise of the PM is linked to the division of Gondwana, a process that began at the threshold of the Jurassic period, around 200 and 180 Ma (MATOS, 2000). This division, which began with rifting, separated the continents of South America and Africa, with the process beginning in the northern portion and later in the southern direction of South America, establishing the Atlantic (BRITO NEVES, 1999).

Around 120 Ma, an important intra-continental rift system developed in the Borborema Province, with subordinate basaltic magmatism (BRITO NEVES, 1999), which was responsible for the formation of the 500 km long Cariri-Potiguar Rift Zone, reaching the terrains that comprise the Potiguar/Apodi Basin and the terrains located in the south of the state of Ceará, corresponding to the Araripe Basin, forming elevated terrains and a set of discontinuous NE-SW basins and half grabens (PEULVAST et al. , 2006; MARTINS and SALES, 2019).

The last area of South America to move away from Africa was the Northeast, around 100 Ma, through transform faults, generating the passive continental margin (MATOS, 2000). The stagnation of the rifting that divided these continents was probably interrupted due to the thickness of the continental crust in the Northeast, preventing its complete rupture and therefore inhibiting the formation of an ocean floor, as is common in the formation of rifts (MARTINS and SALES, 2019).

In this approach, the consideration of the occurrence of the Cariri-Potiguar rift explains that the PM is one of the shoulders of the rift, given its location in the center of the axis. As rifts usually have lateral areas formed by uplifted rocky terrain, the PM and the Borborema Plateau represent the shoulders of this Cretaceous rift (PEULVAST et al., 2006; MARTINS and SALES, 2019). In this sense, the PM would have its genesis in the Cretaceous stretching processes responsible for the separation of South America and Africa.

After this initial genesis, the PM rift shoulder went through phases of differential erosion and regression of its original shape, while the tectonic valleys were gradually filled in and sedimentary basins were formed (MARTINS and SALES, 2019), such as the Apodi Basin (RN/CE), Araripe (CE/PB/PI), Iguatu and Icó (CE) and Rio do Peixe (PB/CE), which are located on the Cariri-Potiguar structural axis.

In this context, the PM, like other massifs in the Borborema Province, underwent differential erosion after Cretaceous uplift, although it was not completely lowered, with the more resistant granitic rocks standing out. Thus, in this approach to Cretaceous tectonics, the Pereiro Massif has a genesis linked to the division of Pangea and Tertiary erosive activity (SALES, 2016), being a type of tectonic/structural and residual relief.

There was further uplift of the relief following the Cretaceous period, as indicated by various studies in the Brazilian Northeast. These structural reliefs are present in the trends of various shear zones and geological faults, which justifies the neotectonic pulses and reflections in the geomorphological compartments. The main initial interpretations of neotectonic activities in the structuring of the relief in the Brazilian Northeast came from Saadi (1993; 1998). Neotectonics, according to Saadi (2005), refers to movements in the earth's crust that were established from the Upper Tertiary onwards and were decisive for the current relief; another explanation is that they are considered to be new tectonic events that occurred after the final orogenesis, including those after the Cretaceous, up to the "instantaneous" seismic events.

Based on the assumption that the geomorphology of the Northeast of Brazil is influenced by the tectonic factor - and that this concept has long been disregarded in the interpretation of the regional relief - emphasizing exogenous geomorphological processes to explain the morphology, Gurgel (2012) prepared a study that suggests evidence of neotectonic activities in the PM. This research contested the explanations that the PM was just a residual form, indicating that Cenozoic neotectonic pulses raised the massif, thus constituting a more recent elevation than the Cretaceous, as proposed by the hypothesis listed above.

In short, Gurgel (2012) methodological procedures were based on dating of colluvium-alluvium and pedogenetic horizons, as well as geomorphological analysis in the field, identifying typical forms of neotectonics. According to Gurgel (2012) and Gurgel et al. (2013), the Jaguaribe and Portalegre faults were reactivated during the Tertiary period, delimiting the PM in a westerly and easterly direction, respectively, and were responsible for its uplift.

The neotectonic activities that followed the Quaternary were responsible for the formation of a Quaternary basin in the interior of the massif, located in the state of Rio Grande do Norte (GURGEL et al., 2013) (Figure 2). With this result, in addition to the Cretaceous basins located inside the PM - the Icozinho Basin and the Rio Nazaré Basin (CASTRO and CASTELO BRANCO, 1999), the Merejo Basin is revealed, dating from the Quaternary, elevated in relation to the other basins, with altitudes reaching 600 meters (GURGEL, et al., 2013). The morphotectonic features of the Merejo Graben are still poorly eroded and are bordered by a very steep horst system (GURGEL, 2012).

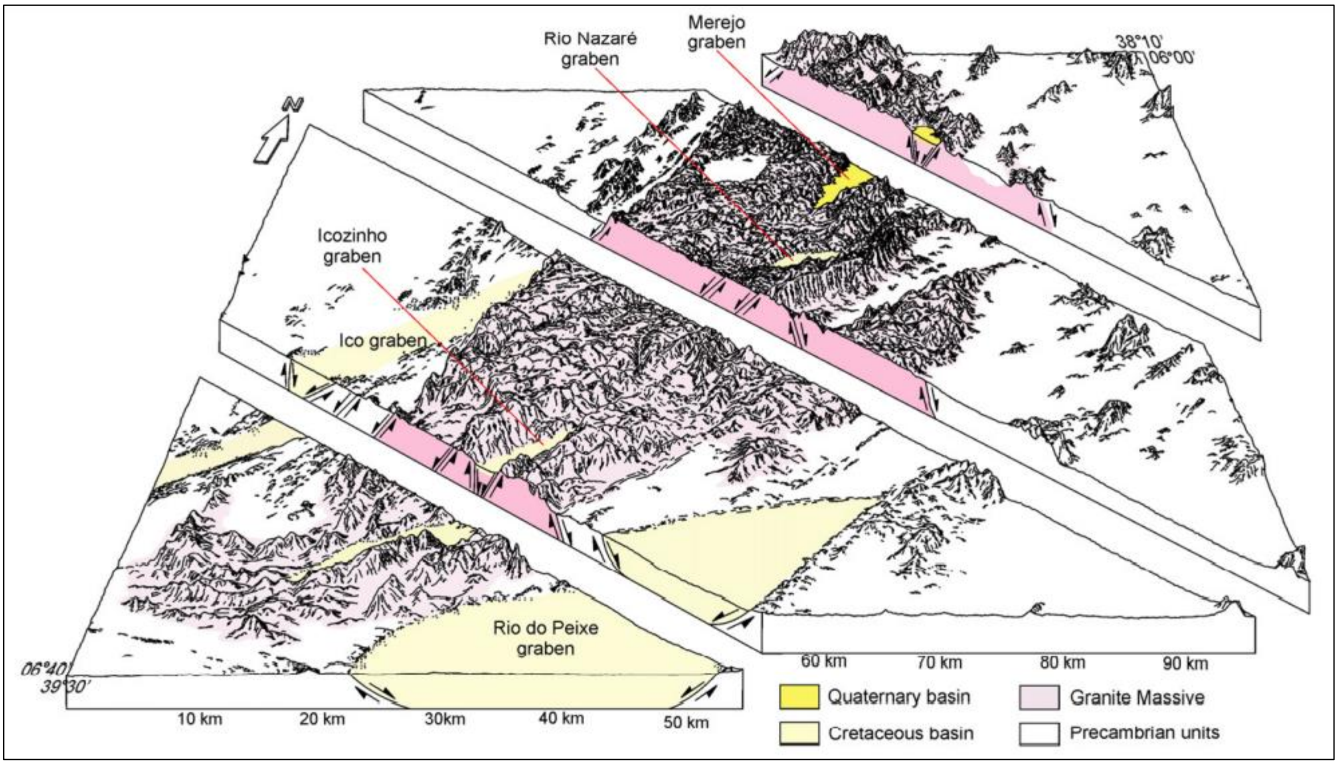

Figure 2. Representation of the Pereiro Massif, sedimentary basins and limiting faults. Source: Gurgel et al. (2013).

The discussions put forward by Gurgel et al. (2013) question and contradict only denudational explanations for PM. For the authors, the sloping topography, vigorous escarpments and flat tops that exist today could not have withstood 140 Ma of erosion. Therefore, if they were just Cretaceous forms, they wouldn't have the altitudes they have. Thus, fault reactivations have repeatedly rejuvenated the PM relief and the erosion of this relief has occurred mainly through the retreat of the scarp, rather than erosion of the upper surfaces, clarifying that weathering is concentrated above all along the area controlled by the PM fault scarps, the result of a climate similar to that of today (GURGEL et al., 2013). In the interim, the authors indicated a neotectonic origin for the scarps that support the PM, recognizing important morphologies that represent such evolution, such as recent and poorly eroded triangular facets and the Graben Merejo fault scarp.

The theoretical discussions put forward by various researchers and cited in this article point out the trajectory of nature and list geological history to explain the geomorphological features we see today. When it comes to the PM, the classic version of the Flattening Surface that explains it has proven to be flawed over time, once we realize the peculiarities of this form compared to the whole of the Brazilian Northeast. Therefore, the denudational model did not fully explain it.

In addition to the aforementioned model, others have been developed that consider new elements in the representation of the PM trajectory, namely: past tectonic events involving the "dance of the continents", in which the massif would be a feature inherited from the Cretaceous, being remodeled by Cenozoic erosive action (PEULVAST et al., 2006; SALES, 2016; MARTINS and SALES, 2019); and neotectonic uplift that occurred in the Tertiary, rejuvenating its morphology (GURGEL et al., 2013).

It must be pointed out that the last two models mentioned above do not exclude the completeness of the plateau for the PM, since they do not refute the fact that denudational processes contribute to the shaping of this compartment (SOUZA, 1988), through differential erosion, shaping the various existing features.

3. Materials and Methods

For the geomorphological mapping of the Pereiro Massif and its surroundings, the following order of procedures was followed: 1) bibliographic and cartographic review of the landforms of the study area, concerning the states of Ceará, Rio Grande do Norte and Paraíba and the northern Northeast of Brazil; 2) preparation of the geomorphological map in a GIS environment; 3) field activities to check the mapping and obtain information to characterize the landforms, as well as a photographic survey of the study area.

The literature review sought lines of interpretation of the regional relief and the Pereiro Massif (GURGEL et al., 2013; MAIA and BEZERRA, 2011; 2014; MAIA, BEZERRA and SALES, 2010; PEULVAST et al, 2006; PEULVAST and SALES, 2003; BRITO NEVES, 1999; SOUZA, 1988), while the cartographic review considered existing geological and geomorphological mappings to reinterpret their information (COSTA et al., 2020; DINIZ et al., 2017; CPRM, 2013; PEULVAST and SALES, 2003).

To prepare the geomorphological mapping, the altimetry data was acquired using Shuttle Radar Topography Mission (SRTM) images from the TOPODATA project, made available by the National Institute for Space Research (INPE) in GeoTiff format. The images, with a resolution of 30 meters, refer to squares 05s_39_ and 06s_39_. In Qgis Forenze 3.28, they were reprojected to the SIRGAS 2000 Datum and then mosaicked to form a single raster layer and cut out for the study area.

Subsequently, contour lines were obtained, the shaded relief was extracted, the hypsometry was drawn up and the slope classes in degrees (º) were extracted, as well as topographic profiles and three-dimensional relief models. All this information was essential for delimiting the geomorphological forms of the area.

Once this database had been generated, the information was superimposed on the geological mesh so that delimitation could begin, using the raster file of the SRTM image previously selected for interpretation, creating vector files of the delimited shapes. The indication of the existing compartments was also based on the theoretical and cartographic references that were consulted. The delimitation of the different units was based on modelling, which refers to the 4th taxon in the relief hierarchy proposed in the Geomorphology Technical Manual (IBGE, 2009b). The nomenclature of some units was based on previous work; for others, the shape and local elements such as altitude, location and drainage network were taken into account.

The color scheme used followed the recommendations of the IBGE (2009b), in which the orange and brown tones are used for the Neoproterozoic Mobile Belts, while those in green are for the Phanerozoic Sedimentary Basins and Covers, and the lighter tones are assigned to topographically lower units in relation to the nearby geomorphological units.

Field work was carried out to recognize and improve the geomorphological mapping, enabling the shapes to be described and analyzed, and the different compartments identified were photographed.

Although shapes were mapped at intermediate scales, the final map was on a scale of 1:400,000, due to the scope of the area, and its final layout was drawn up using the Qgis Forenze 3.28 software, with the Universal Transverse Mercator (UTM) map projection, zone 24 South.

4. Results

4.1 Geomorphological units of the Pereiro Massif and its surroundings

The PM has altimetry levels predominantly between 400 and 600 meters, and on the highest ridges it reaches a maximum of 861 meters, and its surroundings have altitudes that prevail between 100 and 400 meters (Figure 3).

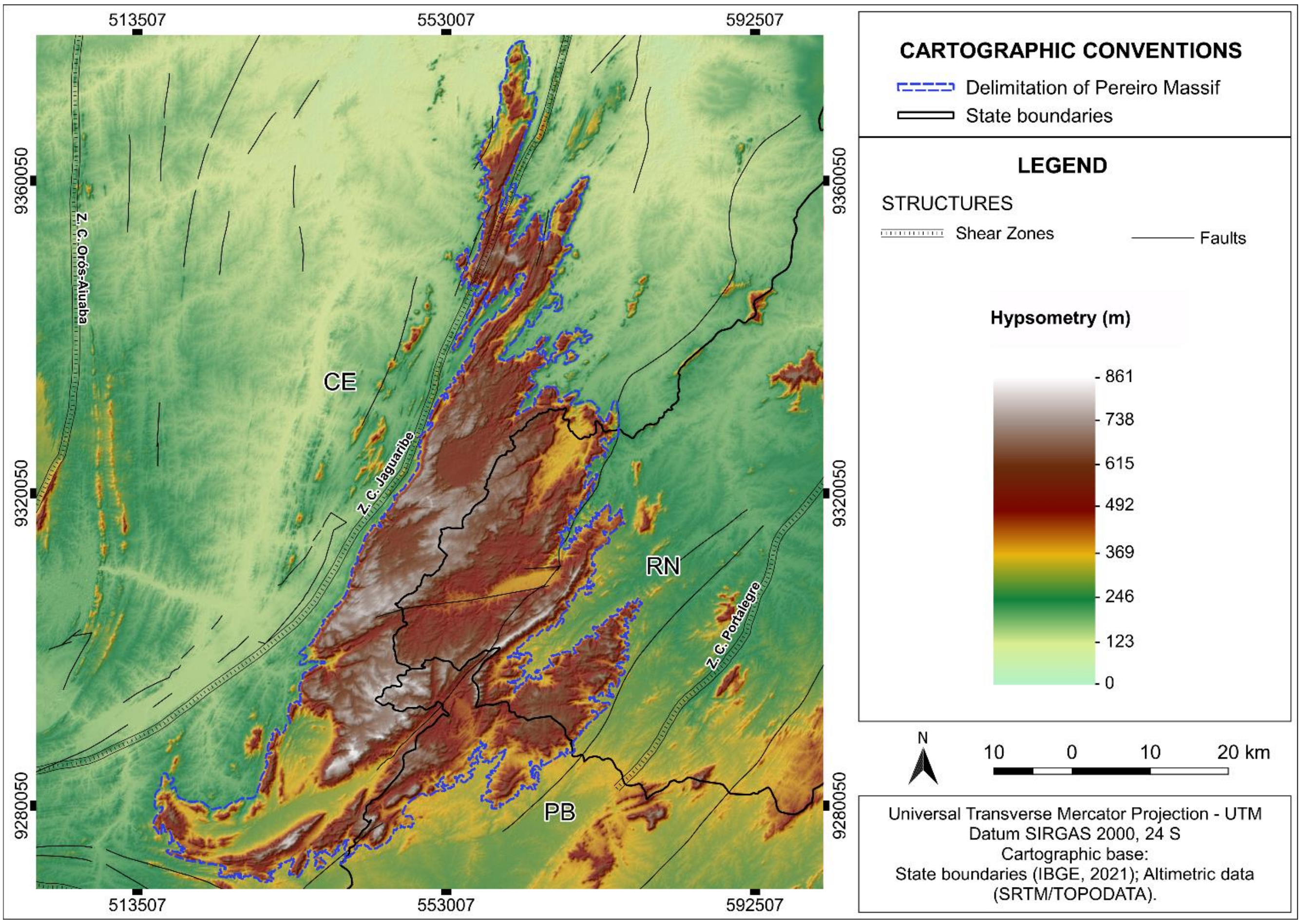

Figure 3. Hypsometry of the Pereiro Massif and its surroundings. Source: prepared by the authors, 2023.

In the context of the Borborema Province, the PM is located in the Jaguaribeano Domain and is bounded to the west by the Jaguaribe Shear Zone, to the east by the Portalegre Shear Zone and to the south by the Farias Brito Shear Zone.

Its lithostructural framework (Figure 4) is composed predominantly of the Itaporanga Intrusive Suite, with igneous rocks of granitic composition, centralized and elongated according to the direction of the massif; the Serra do Deserto Intrusive Suite, which has bands of supra-crustal rocks such as quartzites, diorites and tonalites and magmatic rocks such as augen granite orthognaths; and the Jaguaretama Complex, comprising granite orthognaths and orthomigmatites, granite, tonalite, paragnaths, amphibolites, quartzites and metaultramafic rocks (SANTOS, et al. 2021; CPRM, 2014). The last two units are also the main boundaries of the PM. Figure 5 shows the lithostratigraphic units of the Pereiro Massif and its surroundings.

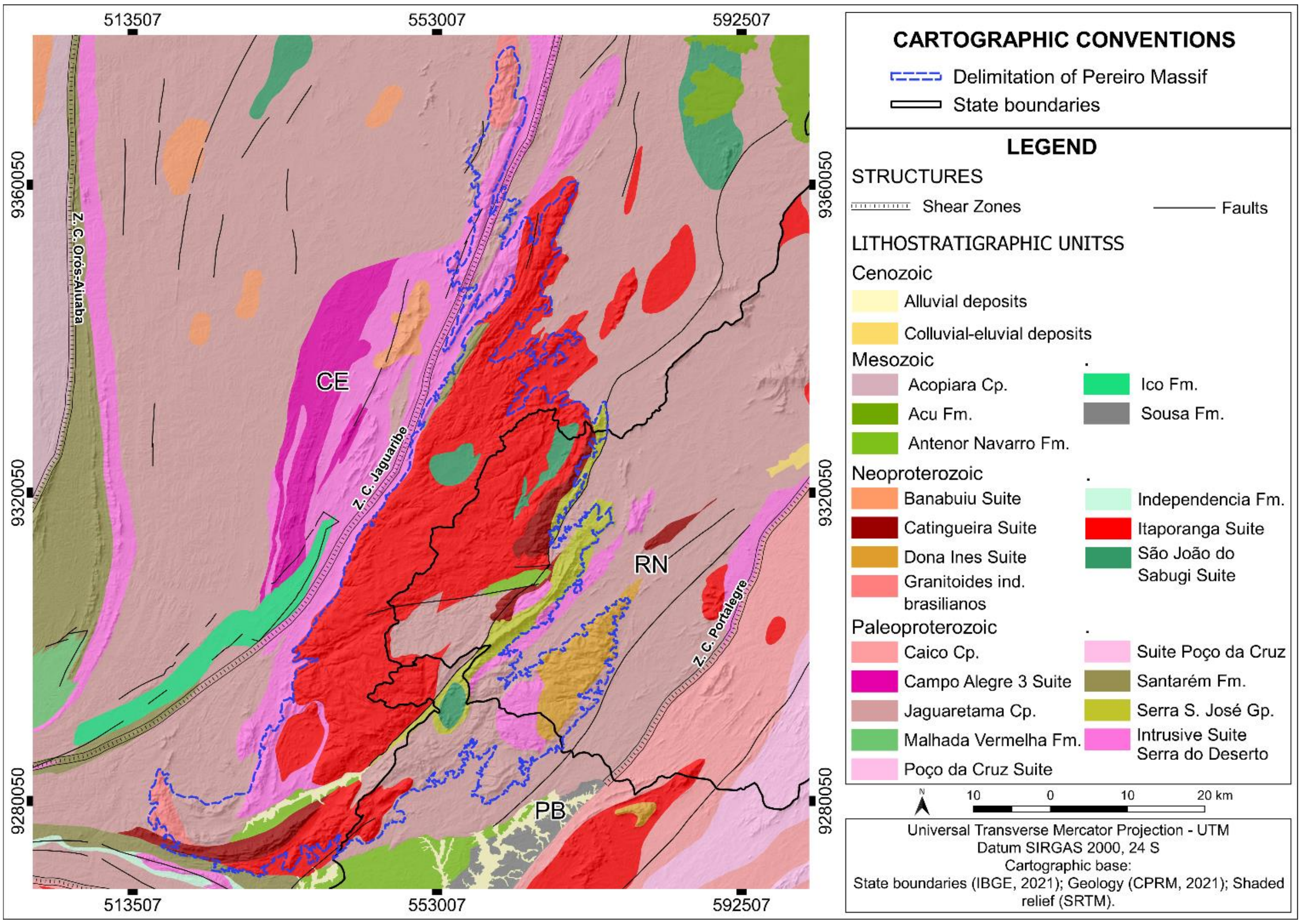

Figure 4. Lithostratigraphic units of the Pereiro Massif and its surroundings. Source: Prepared by the authors, 2023.

The Pereiro Massif and its surroundings geomorphological compartmentalization (Figure 6) was drawn up according to the characteristics of the relief modeling, by considering process and form. The mapped units were grouped into three dimensions, taking into account the processes and resulting forms: accumulation surfaces, flattening surfaces and erosion surfaces.

Accumulation forms include those formed by sedimentation processes, in which the process of deposition is superior to the process of erosion and material transportation. Flattening forms reflect the inverse process of the first dimension presented, in which geomorphological forms have undergone/are undergoing flattening imposed by erosive episodes subsequent to their creation. Differential erosion acts on these units and the existence of more or less flattened topographies depends on their geological foundation.

The forms classified as erosion in the field of study are higher than those belonging to the previous dimensions. The erosion geomorphological units are the result of the process of differential erosion on their geological components, presenting different features as a result of the wearing away of the material, providing forms with steep slopes on the slopes, busier surfaces, different forms of tops and the formation of valleys.

Figure 5 shows the Geomorphological Map of the area under study, and Figures 6 and 7 show topographic profiles representing the geomorphological compartmentalization and associated lithostratigraphy.

.

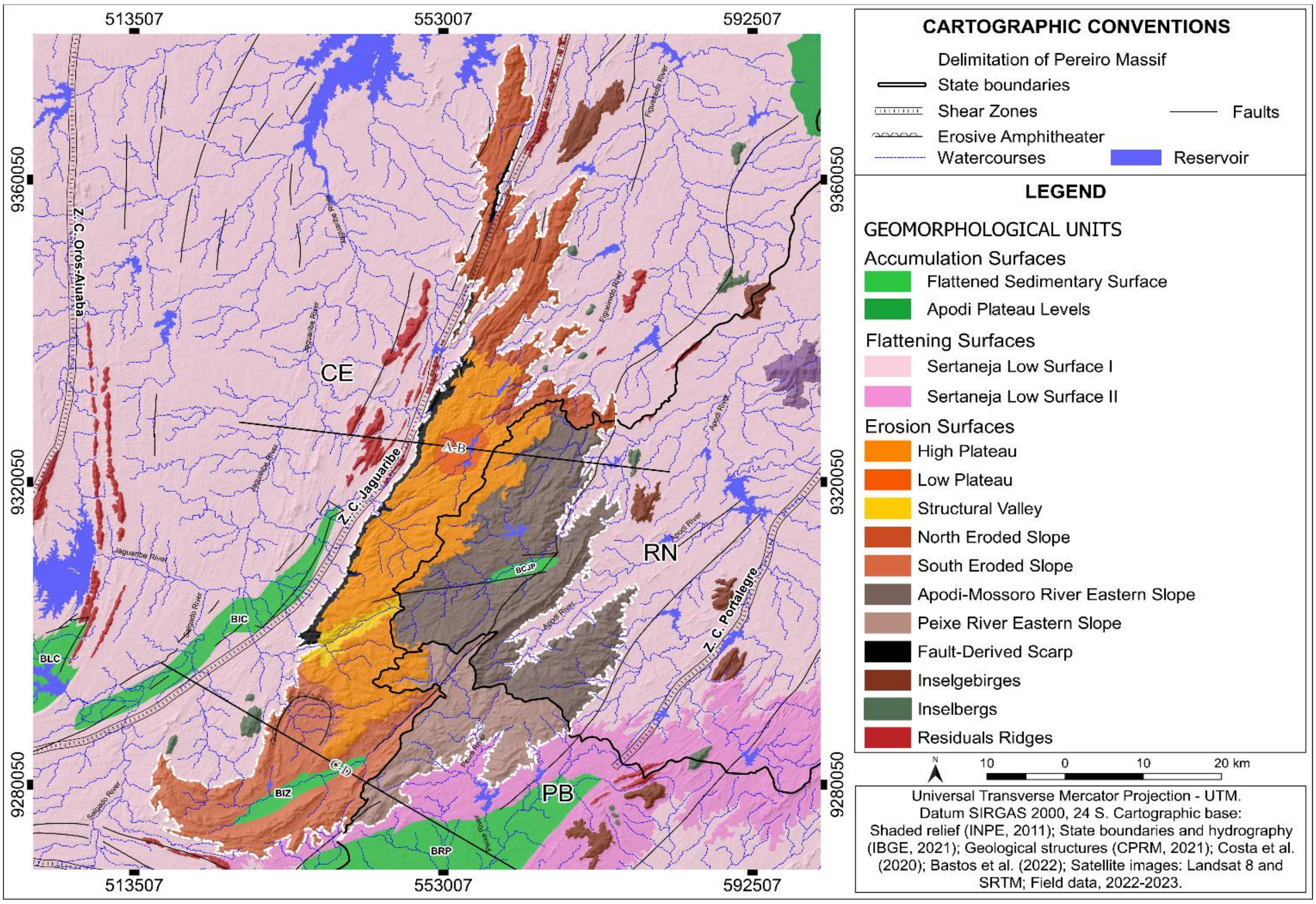

Figure 5. Geomorphological units of the Massif of Pereiro and its surroundings. Source: Prepared by the authors, 2023.

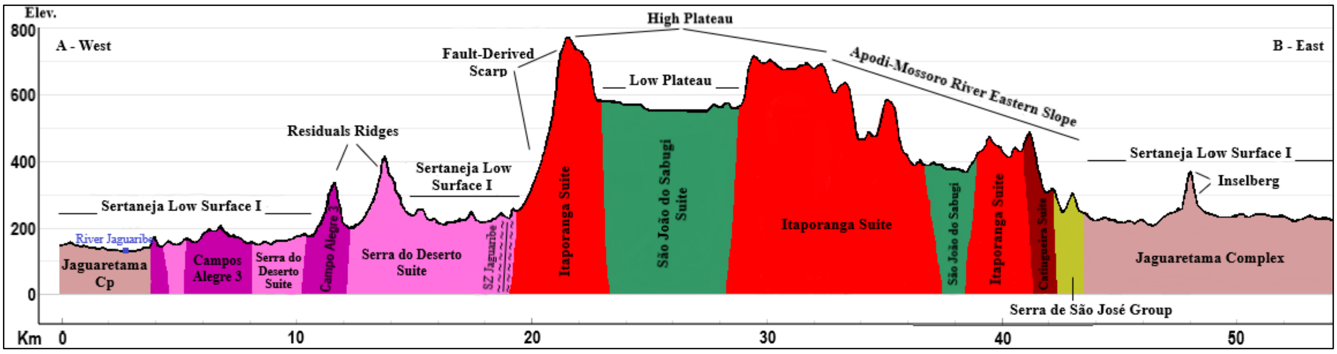

Figure 6. Topographic profile A-B (figure 5) highlighting relief units and correlated lithostratigraphy. Source: prepared from SRTM data. Abbreviations: Cp.: Complex; ZC: Shear Zone

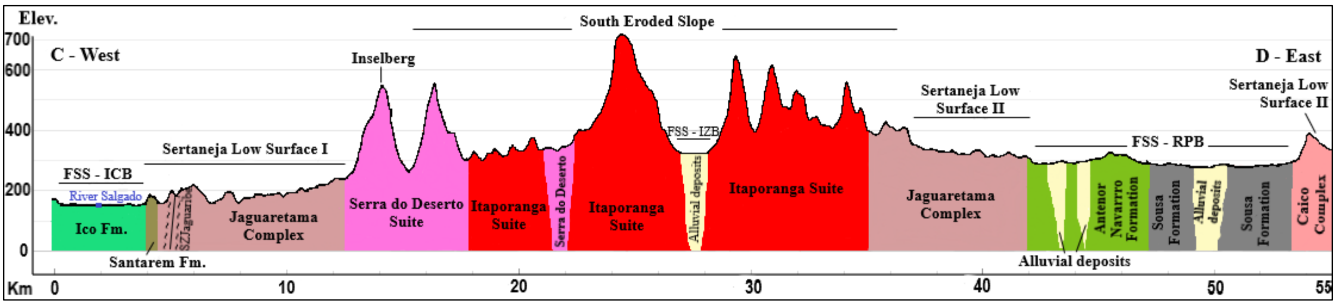

Figure 7. Topographic profile C-D (figure 5) highlighting relief units and correlated lithostratigraphy. Source: prepared from SRTM data. Abbreviations: Fm.: Formation; ZC: Shear Zone; FSS-ICB: Flattened Sedimentary Surface - Icó Basin; FSA-IZB: Flattened Sedimentary Surface - Icozinho Basin; FSA-RPB: Flattened Sedimentary Surface - Rio do Peixe Basin.

5. Discussions

5.1 Accumulation Surfaces

The Flattened Sedimentary Surfaces encompass flat and gently undulating features that developed over the sedimentary packages of Cretaceous tectonic basins. These basins were generated during the Cariri-Potiguar rifting, are known as the Cariri Valley Rift Basins (CASTRO and CASTELO BRANCO, 1999), and were formed in half-grabens, as a result of the extensional regime along Neoproterozoic fault lines, reactivated during the separation of the Gondwana Supercontinent in the Mesozoic period (SILVA et al., 2003).

These strike-slip intracratonic basins (SILVA et al., 2003) are indicated in the study area/map (Figure 5) as the Lima Campos Basin (LCB), the Icó Basin (ICB), the Rio do Peixe Basin (RPB), the Icozinho Basin (IZB) and the Coronel João Basin (CJB). As for the depth of the basement of these basins, Castro and Castelo Branco (1999) present some measures: the Rio do Peixe Basin reaches depths up to 1.900 m, the Lima Campos Basin reaches depths up to 650 m and the Ico Basin, which has thicknesses of less than 200 m. The filling of the basins by continental sediments has resulted in flat relief features and in altimetric levels lower than the adjacent geomorphological units (Figure 8).

Figure 8. Flattened Sedimentary Surface IZB in the middle, formed in a half-gradient and the horst in the background. Source: authors' collection, 2023.

The lands of the Icó Basin have a lower altitude, around 150 m, and, in the LCB area, there are altitudes of 250 m, and in the IZB and RPB terrain, they reach 300 m. Of the intracratonic basins, the CJPB has the highest altitude, since it developed over the Pereiro Massif, above 400 m.

The Apodi Plateau Levels unit was mapped based on Costa et al. (2020). It is part of the Potiguar Basin and appears in the northeastern part of the study area. The Potiguar Basin has a similar geological construction to the aforementioned basins, being part of the Cariri-Potiguar rifting, however, after receveing debris, it was slightly uplifted. The Apodi Plateau Levels mapped constitute the front of the Chapada Cuestiforme of Apodi, present predominantly in the state of Ceará, with an altitude up to 250 m. This front forms a ramp with a variable slope shaped in the sandstones of the Açu Formation, showing incipient dissection by 1st and 2nd order channels, towards the Sertaneja Surface of the Pre-Cambrian basement (COSTA et al., 2020).

5.2 Flattened Surfaces

The flattened surfaces are represented by the feature called Sertaneja Low Surface (Figure 9), which in this mapping has been sectored into two, as proposed by Costa et al. (2020).

The Sertaneja Low Surface I is predominantly associated with the Jaguaretama Complex of crystalline basement, composed especially of orthogneisses, migmatites, granite and quartzites. According to Maia and Bezerra (2014), the lithological complexity of this area makes it difficult to characterize it geologically. However, there is a predominance of a rocky mineralogical substrate resulting from the metamorphism that occurred in the Precambrian, and this characteristic controlled the differential erosion that occurred in the Cenozoic. Its terrain has a minimum elevation of 70 m and does not exceed 300 m in altitude. The predominant slopes range from flat to undulating, and there are still a few sectors where there is a strong undulation

The Sertaneja Low Surface II is located in the southeast of the study area. Its altimetric levels are higher than 300 m, exceeding 400 m at the PM base and the residual reliefs. This unit is supported by lithologies from the Jaguaretama Complex, Caicó Complex, Itaporanga Suite and Poço da Cruz. It encompasses more hills features, where interfluves are formed separating stretches of the Apodi-Mossoró (RN) and Rio do Peixe (PB) river basins (Figure 9). Its land has slopes that vary from flat to steeply undulating, the latter class being more present in this unit than in first Lowered Surface mentioned above.

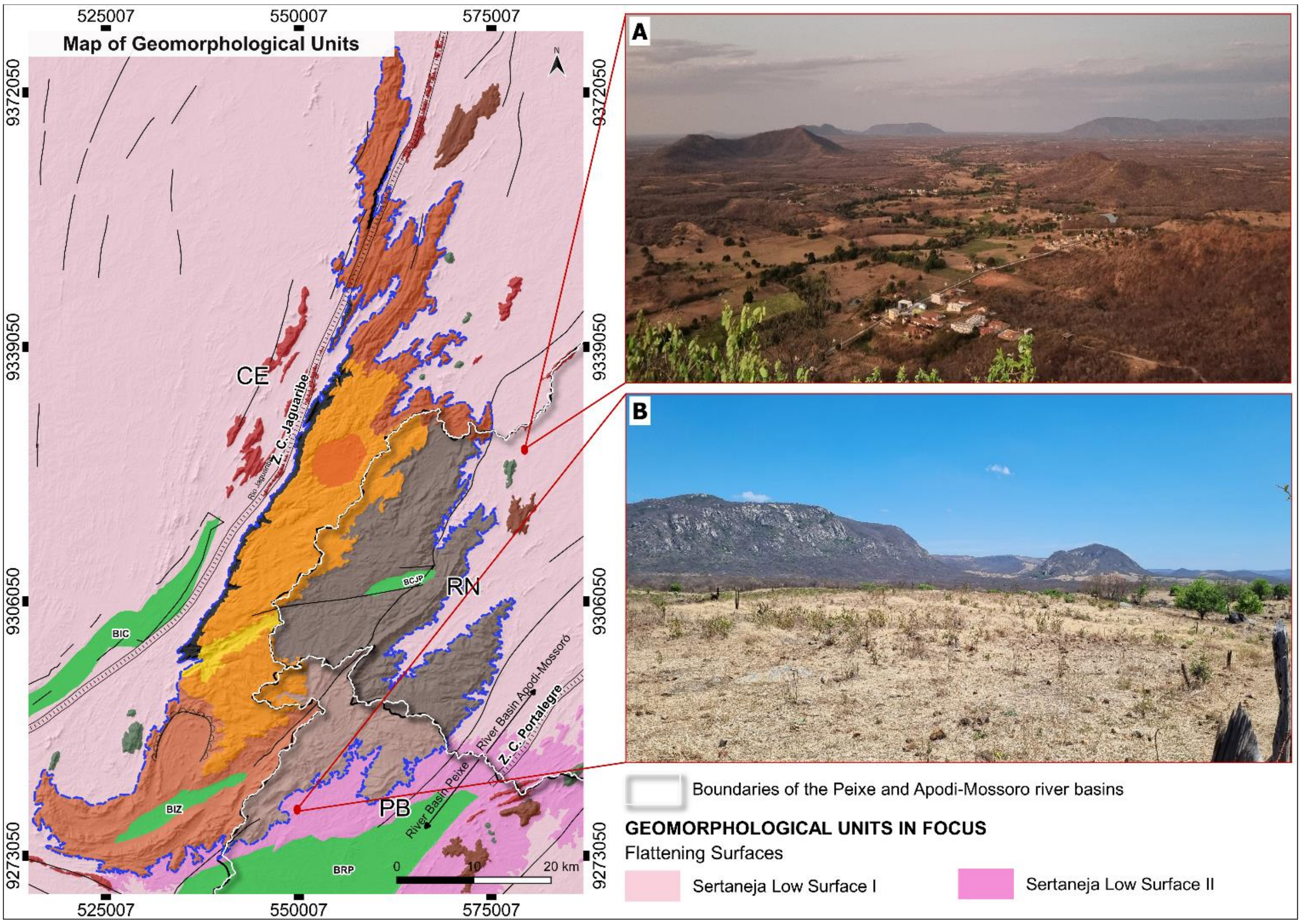

Figure 9. A – Sertaneja Low Surface I in which the altitude does not exceed 250 meters, dotted with residual reliefs, municipality of Encanto/RN; B – Sertaneja Low Surface II reaching 405 meters in altitude; in the background, following the Peixe River Eastern Slope, exposing granite outcrops, municipality of Triunfo/PB. Source: authors' collection, 2023.

In the two units of Flattening Surfaces, there are forms more resistant to erosion, presenting themselves as topographic prominences that stand out on the flattened surface. These are usually geologically associated with exhumed granitic cores (COSTA et al., 2020), forming features such as Inselgebirges, Inselbergs, and Residual Ridges.

5.3 Erosion Surfaces

In this classification, the Pereiro Massif was divided into nine geomorphological compartments that reflect the morphological characteristics of the eroded relief.

The High Plateau (Figure 10-A) encompass sectors located above an altitude of 600 m, supported entirely by the porphyritic granitoids of the Itaporanga Suite. Convex tops are common, forming a mamelon landscape, with hills in the shape of half-oranges. Other areas have sharp tops, where the highest altitudes can be seen. Predominantly, the slope of this unit varies from undulating to strongly undulating.

There are also smaller sectors that are flat and gently undulating. Based on this occurrence, the Low Plateau unit was mapped, which corresponds to an area of approximately 34.84 km², structured in the São João do Sabugi Suite, made up of diorites, quartz, granodiorites and gabbros (SANTOS et al., 2021). The Low Plateau has a rounded shape and a flat surface, which is unusual for this type of morphology in areas supported by crystalline rocks (MARTINS and SALES, 2019). Its altitude is around 550 m. When analyzing the areas that border it, there is a difference of more than 150 m between the neighboring tops of the High Plateau (above 700 m) and the lowered surface. The slopes of the High Plateau have very steep gradients, which allows us to infer that there has been no smoothing of the relief by weathering processes in the integration of one form into another. The only part of the lowered plateau that does not have a slope with higher altitudes surrounding it is in the northeast, where the Figueiredo River flows.

There are also several river valleys on the High Plateaus, which vary in shape, size and depth. A valley is a topographic form that encompasses a talvegue and two slopes with two converging slope systems (GUERRA and GUERRA, 2008). In the study area, one of these forms deserves to be highlighted, a feature called the Structural Valley (Figure 10-B). This feature refers to a longitudinal corridor more than 1,000 meters long, with an altitude of more than 500 m, giving it its suspended character.

Morphologically, it is a valley with a U-shaped profile, as the walls of the slopes are steeper (around 45º) in the upper part, and it becomes slightly smoother near the flatter and wider valley floor, with a slope that varies from flat to gently undulating. There is a clear difference in altitude between the top of the slopes and the bottom of the valley, which exceeds 100m. The Structural Valley is cut out by a geological sheet, which supports its indication of a structural nature, since this area may have suffered tectonic forces that were able to produce an incision from the fault, and was later reworked by fluvial dynamics, with excavation of the river bed and widening of the slopes.

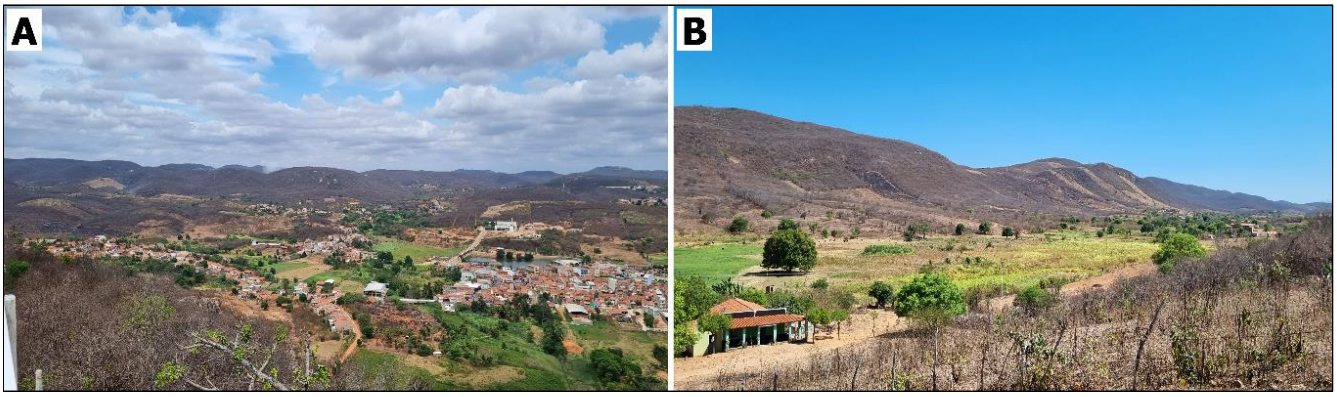

Figure 10. A - segment of the High Plateau where the municipal seat of Pereiro is located, with mamelon forms in the background; B - segment of the Structural Valley, Icó/CE, with perennial crops on the valley floor. Source: authors' collection, 2023.

The northern and southern portions of the MP were mapped in two units that have similarities in the constitution of their shapes: the North Eroded Slope and the South Eroded Slope, respectively. The first one shows an elongated profile that is not very extensive laterally compared to the rest of the massif. The influence of the Jaguaribe Shear Zone and geological faults on the morphology of this area is noticeable. The tops tend to follow the direction of these structures, with parallel gneissic and granitic ridges or elongated domes (PEULVAST et al., 2006). The separation between the generally sharp tops is due to the existence of several hanging valleys with a V profile, where the side slopes meet without a wide bottom separating them.

Most of the North Eroded Slope is made up of granitoids from the Itaporanga Suite and metamorphized rocks from the Serra do Deserto Intrusive Suite, such as augen granitic gneisses, quartzites and diorites, and in the final northern stage of the MP there are indiscriminate Brasilian granitoids (SANTOS et al., 2021). The occurrence of ridges and slopes bare of soil and vegetation is common, where rocky outcrops appear. The Serra da Micaela is located in the area of the indiscriminate granitoids, of Neoproterozoic age, with altimetric levels of 300 to 500 m, where the largest rocky outcrops can be seen on its leeward slopes and erosion processes forming hanging valleys.

The Serra da Micaela is part of the Castanhão Ecological Station-CE, being one of the fully protected Conservation Units in Ceará. The addendum about the area is important, as it is the only portion of the PM that has and/or is part of a Conservation Unit, even other areas have relevant natural characteristics, deserving adequate guarantees of protection.

The North Eroded Slope has elevation levels of 300 to 700 m (highest peak), presenting mountainous features with dissected, steep and slightly smoothed slopes, where slopes vary from 45º to > 75º. The tops have wavy and strongly corrugated surfaces.

The South Eroded Slope forms a concave direction west-east in the PM, in which it is clear that the lateral portions of this unit were dissected, and they've left, in its center, a lowered area. The features of this unit have a strong relationship with tectonic events that structure the massif. It is worth remembering that the Icozinho Basin is located in its center. On the right side of the Icozinho graben is a steep slope that exceeds 800 m in altitude, interpreted as a horst. In the northeast portion of the unit there is an oblique, extensive and deep valley, which gains altitude as it approaches the interfluves. In the northwestern portion of the unit, the existence of an erosive amphitheater was indicated, an oval-shaped portion of the land worked by erosion, sculpting the slopes of the High Plateaus and forming short, steep and suspended valleys.

The South Eroded Slope has different altitudes ranging from 300 m at the foot of the mountains to 800 m on the high peaks. This diversity of shapes implies terrain slopes that range from flat to steep. The separation between the elevated forms due to the existence of wide and deep valleys at the base level is noticeable on the land of this unit. Some mountains are smooth, with moderate slopes. From the characteristics listed, it can be seen that this area underwent a strong denudational process, responsible for the enculturation of the surface.

The next two geomorphological units were defined based on the interpretation of the work carried out by the drainage network in sculpting the morphology of the areas. For Maia and Bezerra (2011), rivers, as geomorphological agents, are mainly responsible for the Cenozoic denudations in emerged areas that occurred in the Brazilian Northeast.

The Apodi-Mossoro River Eastern Slope comprises the portion of the PM belonging to the upper course of the Apodi-Mossoró River basin. Most of this unit has lower elevations than the High plateaus unit, except in rare sectors of the interfluves and in an exuberant symmetrical ridge that cuts through this unit, close to the valley carved by the Apodi River, towards the east.

In this portion of the PM, there is a high drainage density, generally in dendritic patterns, related to the crystalline basement. The river dissection carried out a work of softening the relief, in which the altitude drops from the interfluves to the foot of the massif, when it meets the Rebased Sertaneja Surface I. Smoothing does not mean flattening of the forms. In almost the entire area, a busy relief can be seen, with predominantly convex tops (Figure 11).

Figure 11. Busy relief with convex tops on the Aposi-Mossoro River Eastern Slope, in São Miguel/RN, showing clear work by the drainage network in creating the forms. Source: authors' collection, 2023.

In this unit, in the Coronel João Pessoa Basin and close to the municipality of Doutor Severiano, the surface takes on flat and gently wavy shapes. In the rest, wavy and strongly wavy reliefs predominate. Highlight for the slopes, which despite being gentler than the Eroded Slopes units, also have restricted sectors with mountainous slopes, between 45º and 75º.

The Peixe River Eastern Slope is located in the upper reaches of the River Peixe sub-basin, which makes up the Piranhas-Açu River basin. Like the previous one, this geomorphological unit presents dissection produced by the River Peixe drainage network. Its morphology varies from wavy to strongly wavy, presenting a lowering in the central portion close to the seat of the municipality of Poço Dantas/PB, and smoothing out as it approaches the Sertaneja Low Surface II. There are also steeper slopes in the basin's interfluves. The elevation of this unit varies between 400 and more than 700 m. The municipal headquarters of Bernardino Batista/PB, for example, has elevations that exceed 700 m in altitude.

The Fault-Derived Scarp (Figures 12 and 13) is located on the western edge of the Pereiro Massif. It is a conspicuous scarp over more than 100 km related to a reactivated fault zone, the Jaguaribe Shear Zone (PEULVAST et al., 2006). For the most part, the southern portion, the escarpment has a straight granite wall, dissected at the top by only short, steep valleys. In the northern portion of the scarp, with metamorphosed lithologies, it appears as a residual fault scarp controlled by the intrusive contact parallel to the fault zone but it has suffered erosive retreat in relation to the development of steep pediments and alluvial fans (PEULVAST et al., 2006).

The presence of denudation, controlled by the drainage network, of smaller portions of the escarpment is clear, in which weathering and erosion have affected its walls, causing changes in its topography, losing much of its abrupt shape.

Figure 12. Segment of the Fault-Derived Scarp from the MP, Icó/CE, with exposure of granite walls and short, suspended valleys. Below, segment of the Sertaneja Low Surface I. Source: authors' collection, 2023.

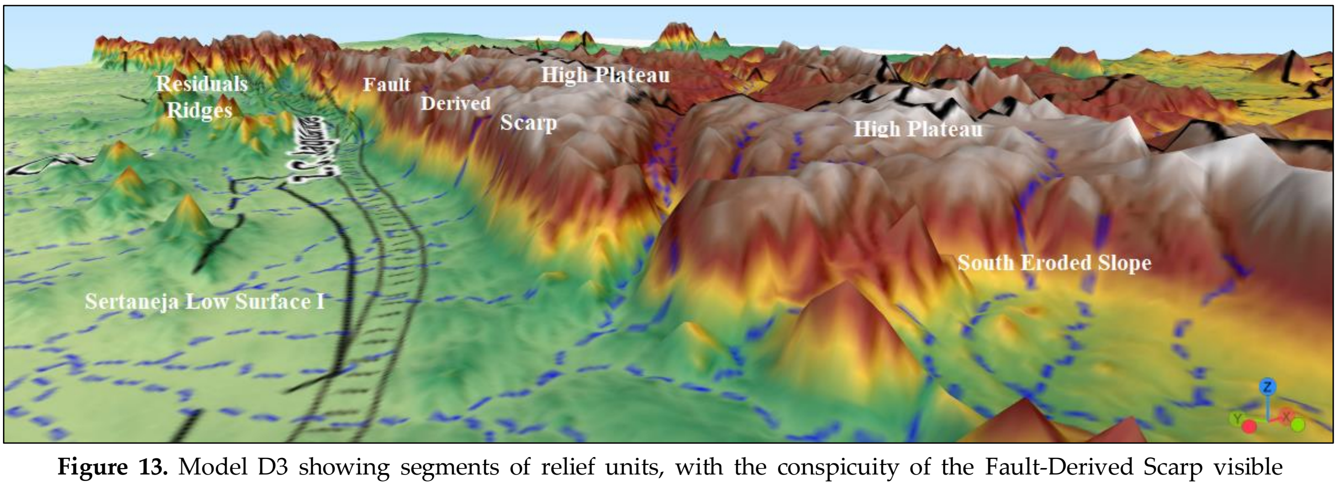

Figure 13. Model D3 showing segments of relief units, with the conspicuity of the Fault-Derived Scarp visible (following figure 12). Source: prepared from SRTM data.

The residual reliefs that appear on the lowered surfaces mentioned above were defined as Inselgebirges, Inselbergs and Residuals Ridges. The existence of these forms is related to granite cores and/or metamorphosed rocks that are more resistant than those in the lowered surroundings, managing to resist the regional exhumation process, emerging as elevated areas.

In the Brazilian Northeast, little has been written about the Inselgebirges form, which makes mapping difficult. However, Bigarella, Becker and Santos (2009) clarify that this term has German origin and comprises a topographic overhang that has a system of valleys and ridges and the amplitude of the massif. As a parameter for mapping these forms, was used the proposal for the hierarchy of residual reliefs by Bastos et al. (2022), which establish Inselbergs with dimensions smaller than 10 km², Inselgebirges with dimensions between 10 and 50 km² and massifs with dimensions above 50 km².

In this work, in addition to the dimension parameter by Bastos et al. (2022), morphological characteristics were essential to differentiate Inselgebirges from Inselbergs. The forms indicated as Inselgebirges (Figure 14) are located in the east-southeast portion of the study area, and they have elongated and grouped features, while the separations of the granite bodies are produced by the development of valleys. Elevation levels are around 600 m on the sharpest ridges and most slopes have mountainous slopes.

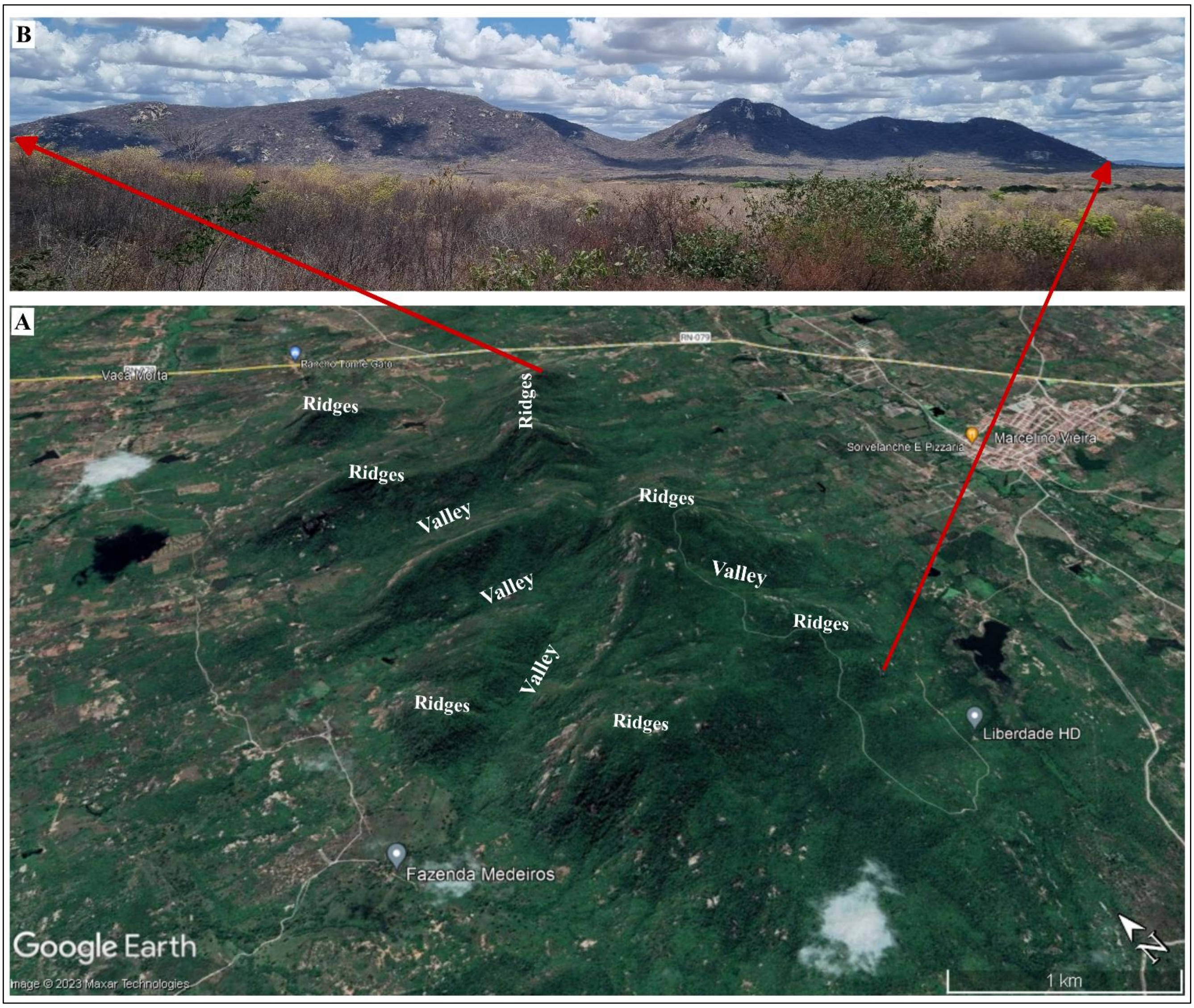

Figura 14. Inselgebirg in a granite core with a system of valleys and ridges developed over it, located in Marcelino Vieira/RN. A – Inselgebirg seen from Google Earth image (2023); B - photo of the eastern slope of the Inselgebirg seen from the RN-079 highway. Source: authors' collection, 2023.

Inselbergs have a more restricted occurrence in the area. They are characterized as isolated elevations made up of rocks of intrusive plutonic or metamorphosed plutonic origin (LIMA et al., 2009). Such forms are reflections of a structure of minerals that are more resistant to weathering and exhumation processes in the past, considered as testimonial reliefs (RIBEIRO, MARÇAL and CORREA, 2010). They've been interpreted as a source of valuable information about the geomorphological evolution of the areas in which they occur (MAIA et al., 2015). For the latter scholars, the greatest occurrence of Inselbergs, in the Brazilian Northeast, is related to granitoid cores with the lowest densities of fractures, enabling their maintenance as an outcrop.

The Inselbergs surrounding the Pereiro Massif do not exceed 7 km^2 in area, reach elevations of 400 m and have slopes of around 50°.

The Residuals Ridges are elevated forms around 400 m in altitude, which can exceed this value by 100 m, which appear in the middle of Sertaneja Low Surface. They are elongated structures that form a continuous line, sometimes separated by river valleys or mouthwaters. It is clear that most of the Residual Ridges in the area have structural control, as they are aligned according to the Shear Zone trends. This happens in those oriented near the Orós-Aiuaba Shear Zone, in the westernmost portion of the study area, and ridges that follow the direction of the Jaguaribe Shear Zone (Figure 15).

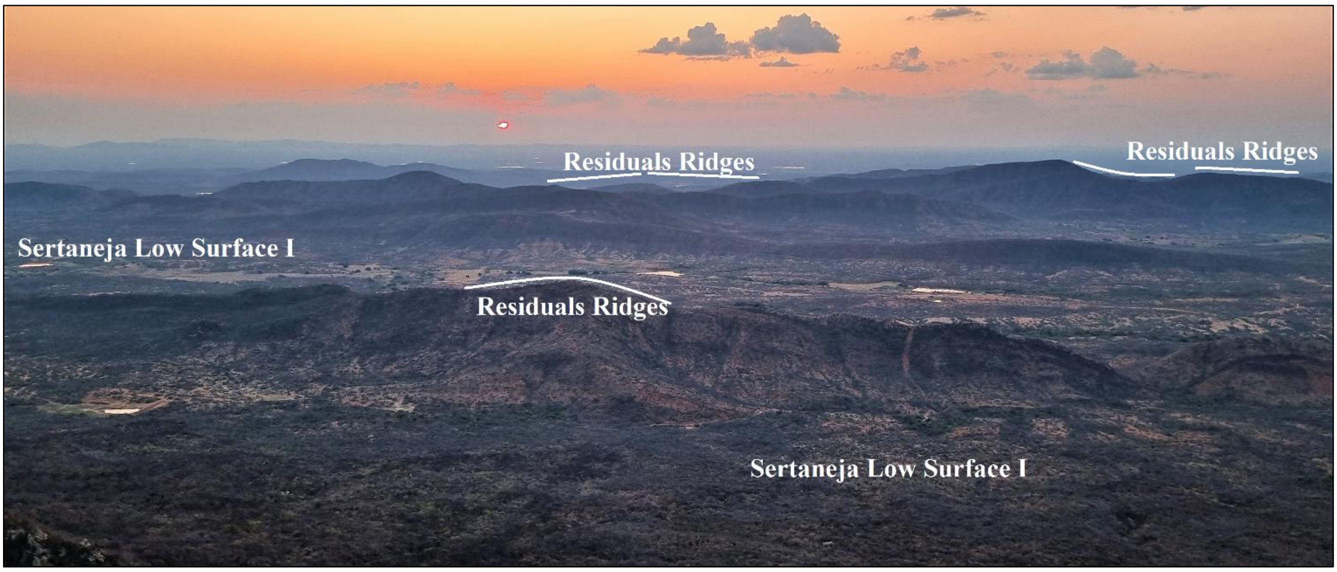

Figura 15. Residual Ridges supported by metamorphic rocks, Jaguaribe/CE. Source: authors' collection, 2023.

The ridges indicated in figure 15 above are supported by metamorphic rocks of the Serra do Deserto Intrusive Suite, predominantly, consisting of ortho-derived gneisses, of granitic and syenitic composition (SANTOS et al., 2021). Most of the mapped ridges are composed of metamorphic rocks from the Serra do Deserto Suite and Formation Santarém. The others are supported by granite rocks, mainly from the Itaporanga Suite.

Most of these geomorphological forms have convex and straight slopes with slopes ranging from 20 to 45º. These features also have convex and sharp tops, which define a strongly wavy pattern to the relief.

4. Conclusions

From the bibliographic and empirical study of the Pereiro Massif and its surroundings, it was possible to compress the characteristics and peculiarities of the geomorphology of the area, allowing the establishment of intrinsic lithological, climatic, tectonic event associations and the arrangement of relief models.

The integration between process and form was considered for mapping the relief units of the PM and its surroundings, with the relief distinguished into three dimensions: accumulation, flattening and erosion surfaces. In this way, the fifteen geomorphological compartments are classified recognizing processes associated with continental denudation with erosion, transport and deposition of material, as well as events with an emphasis on structural geomorphology, which helped in the architecture of observed forms.

The identification of the different compartments, through the final map of the geomorphological units of the Pereiro Massif and its surroundings, and its discussion, exposes the understanding of the relief configurations.

This result is a relevant tool that can assist in the investigation and understanding of the evolution of soils, vegetation cover, the uses of relief by societies and environmental changes. Furthermore, the mapping created offers support for environmental planning actions, such as the creation of protected areas and environmental licensing procedures, supporting territorial planning.

Contributions of the Authors: Diêgo S. Albuquerque: conception, research, methodology, software, validation, data preparation, investigation, analysis and writing of the article. Rafael A. Xavier: supervision, validation, methodology, visualization, analysis and writing of the article. Dirce M. A. Suertegaray: supervision, validation, visualization, analysis and writing of the article.

Funding: This research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), through a Doctoral scholarship awarded to the first author (Process number 88887.821279/2023-00).

Acknowledgments: We would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the scholarship awarded; the PPGG/UFPB; and the anonymous reviewers for their time spent on reading and valuable contributions.

Conflict of Interest: The authors declare there is no conflict of interest. The funders had no role in the study design.

References

1. AB´SABER, A. N. Participação das superfícies aplainadas nas paisagens do Nordeste Brasileiro. **Bol. Geomorfologia**, IGEOG-USP, n. 19, p. 1-38, 1969.
2. ANDRADE, G. O.; LINS, R. **Introdução à morfoclimatologia do Nordeste do Brasil**. Recife/PE: SUDENE, 1965.
3. BASTOS, F. H.; LIMA, D. L. S.; CORDEIRO, A. M. N.; MAIA, R. P. Relevos graníticos do Nordeste brasileiro: uma proposta taxonômica. In: CARVALHO JUNIOR, O. A. C. et al. (Ed.). **Revisões de literatura da Geomorfologia brasileira**. Brasília: Universidade de Brasília, 2022, p. 737-762.
4. BIGARELLA, J. J.; BECKER, R. D.; SANTOS, G. F. **Estrutura e origem das paisagens tropicais e subtropicais:** fundamentos geológico-geográficos, alteração química e física das rochas e relevo cárstico e dômico. Florianópolis: Editora UFSC, 2004.
5. BIGARELLA, J. J. **Estrutura e Origem das Paisagens Tropicais**. Florianópolis: Ed. UFSC, 1994.
6. BRITO NEVES, B. B. América do Sul: quatro fusões, quatro fissões e o processo acrescionário andino. **Revista Brasileira de Geociências**, Curitiba/PR, v. 29, n. 3, p. 379-392, set., 1999.
7. CASTRO, D. L.; CASTELO BRANCO, R. M. Caracterização da arquitetura interna das bacias do Vale do Cariri (NE do Brasil) com Base Em Modelagem Gravimétrica 3-D. **Revista Brasileira de Geofísica**, Rio de Janeiro, v. 17, n. 2 e 3, 1999.
8. CPRM. **Geodiversidade do estado do Ceará**. Fortaleza: CPRM, 2014.
9. CPRM. **Mapa Geodiversidade do Estado da Paraíba**. 2013. Escala 1: 500.000.
10. COSTA, L. R. F.; MAIA, R. P.; BARRETO, L. L.; SALES, V. C. C. Geomorfologia do Nordeste setentrional brasileiro: uma proposta de classificação. **Revista Brasileira de Geomorfologia**, São Paulo, v. 21, n. 1, jan./mar. p. 185-208, 2020. DOI: https://doi.org/10.20502/rbg.v21i1.1447.
11. DINIZ, M. T. M.; OLIVEIRA, G. P.; MAIA, R. P.; FERREIRA, B. Mapeamento Geomorfológico do Estado do Rio Grande do Norte. **Rev. Bra. Geomorfologia**. São Paulo, v. 18, n. 4, out./dez. p. 689-701, 2017. DOI: https://doi.org/10.20502/rbg.v18i4.1255.
12. GUERRA, A. T; GUERRA, A. J. T. **Novo Dicionário Geológico-Geomorfológico**. Rio de Janeiro: Bertrand Brasil, 2008.
13. GURGEL, S. P. P.; BEZERRA, F. H., CORRÊA, A. C. B., MARQUES, F. O., MAIA, R. P. Cenozoic Uplift and Erosion of Structural Landforms in NE Brazil. **Geomorphology**, Amsterdam, v. 186, p. 68-84, 2013.
14. GURGEL, S. P. P. **Evolução Morfotectônica do Maciço Estrutural Pereiro, Província Borborema**. Tese (Doutorado em Geociências), Departamento de Geologia, Universidade Federal do Rio Grande do Norte, Natal, 2012.
15. IBGE. **Compartimentos de Relevo do Brasil (1:250.000).** IBGE, 2019. Escala 1: 12.000.000.
16. IBGE. **Mapa de unidades de relevo do Brasil**. Rio de Janeiro: IBGE, 2009a. Escala 1: 24.000.000.
17. IBGE. **Manual Técnico de Geomorfologia**. 2. ed. Rio de Janeiro: IBGE, 2009b.
18. IBGE. **Mapa de unidades de relevo do Brasil**. Rio de Janeiro: IBGE, 2006. Escala 1: 5.000.000.
19. KING, L, C. A Geomorfologia do Brasil Oriental. **Revista Brasileira de Geografia**, v. XVIII, n. 2, 1956.
20. LIMA, D. L. S., BASTOS, F. H., CORDEIRO, A. M. N., MAIA, R. P. Geomorfologia granítica do Maciço de Uruburetama, Ceará, Brasil. **Revista Brasileira de Geomorfologia**, n. 20, v. 2, p. 373-395, 2019. DOI: https://doi.org/10.20502/rbg.v20i2.1401.
21. LIMA, G. M. P.; FARIAS, F. F.; BARBOSA, J. S. F.; GOMES, L. C. C. **Inselberge**: Ilhas Terrestres. Salvador: EDUFBA, 2009.

22. MAIA, R. P.; BEZERRA, F. H. R.; NASCIMENTO, M. A. L.; CASTRO, H. S.; MEIRELES, A. J. A.; ROTHIS, L. M. Geomorfologia do campo de Inselbergs de Quixadá-NE do Brasil. **Revista Brasileira de Geomorfologia**, São Paulo, v. 16, n. 2, p. 239-253, abr./jun., 2015. DOI: https://doi.org/10.20502/rbg.v16i2.651.
23. MAIA, R. P.; BEZERRA, F. H. R. Condicionamento Estrutural do Relevo no Nordeste Setentrional Brasileiro. **Mercator**, Fortaleza, v. 13, n. 1, p. 127-141, jan./abr. 2014. Disponível em: www.mercator.ufc.br. Acesso em: 08 jun. 2019.
24. MAIA, R. P.; BEZERRA, F. H. R. Neotectônica, geomorfologia e sistemas fluviais: uma análise preliminar do contexto nordestino. **Revista Brasileira de Geomorfologia**, v. 12, n. 3, p. 37-46, 2011. DOI: https://doi.org/10.20502/rbg.v12i0.257.
25. MAIA, R. P.; BEZERRA, F. H. R.; SALES, V. C. Geomorfologia do Nordeste: concepções clássicas e atuais acerca das superfícies de aplainamento nordestinas. **Revista de Geografia**, Recife, v. 27, n. 1. Esp, p. 6-19, 2010.
26. MAGINI, C.; HACKSPACHER, P. C. Geoquímica e ambiência tectônica do arco magmático de Pereiro, região NE da Província Borborema. **Revista Brasileira de Geociências**, v. 38, n. 2, p. 336-355, 2008.
27. MARTINS, J. G.; SALES, V. C. Paisagem geomorfológica e geografia ambiental do Maciço do Pereiro, estado do Ceará, nordeste do Brasil. **Revista Equador**, Teresina/PI, v. 8, n. 1, p. 1-25, 2019. DOI: https://doi.org/10.26694/equador.v8i1.8154.
28. MATOS, R. M. D. Tectonic evolution of the Equatorial South Atlantic. **Geophysical Monograph**, v. 115, p. 331-354, 2000.
29. PEULVAST, J. P.; SALES, V. C. Stepped surfaces and Paleoland forms in the Northern Brasilian: Constraintson models of morfotectonic evolution. **Geomorphology**, v. 62, v. 1, p. 89-122, 2003.
30. PEULVAST, J. P.; SALES, V. C.; BEZERRA, F. H. R.; BETAR, F. Landforms and Neotectonics in the Equatorial Passive Margin of Brazil. **Geodinamica Acta**, Paris, n. 19, v. 1, p. 51-71, 2006. DOI: https://doi.org/10.3166/ga.19.51-71
31. RIBEIRO, S. C.; MARÇAL, M. S.; CORREA, A. C. B. Geomorfologia de Áreas Semiáridas: uma contribuição ao estudo dos Sertões Nordestinos. **Revista de Geografia**, Recife, v. 27, n. 1, p. 120-137, jan./mar. 2010.
32. SAADI, A.; BEZERRA, F. H. R.; COSTA, R. D.; IGREJA, H. L. S.; FRANZINELLI, E. Neotectônica da plataforma brasileira. In: SOUZA, C. R. G. et. (Orgs.). **Quaternário do Brasil.** Ribeirão Preto: Holos, Editora, 2005, p. 211-230.
33. SAADI, A. Modelos morfogenéticos e tectônica global: reflexões conciliatórias. **Geonomos**, Belo Horizonte, n. 6, v. 2, p. 55-63, 1998.
34. SAADI, A. Neotectônica da plataforma brasileira: Esboço e interpretação preliminares. **Geonomos**, Belo Horizonte, v. 1, p. 1-15, 1993.
35. SALES, V. C. C. **Megageomorfologia do Estado do Ceará**: História da Paisagem Geomorfológica. Novas Edições Acadêmicas, 2016.
36. SALES, V. C. C. **Evolution géomorphologique de la zone cotière de l´Etat du Ceará, Brésil**: du long terme au court terme. 511p. Tese de Doutorado, Universidade Paris, France, 2002.
37. SANTOS, F. G.; PINÉO, T. R. G.; MEDEIROS, V. C.; S ANTANA, J. S.; MORAIS, D. M. F.; VALE, J. A. R.; WANDERLEY, A. A. **Mapa Geológico da Província Borborema**. Recife: SGB/CPRM, 2021. Escala 1: 1.000.000.
38. SILVA, A. J. P.; LOPES, R. C.; VASCONCELOS A. M.; BAHIA, R. B. C. Bacias sedimentares paleozóicas e meso-cenozóicas interiores. In: BIZZI, L. A. et al. (Eds.) **Geologia, Tectônica e Recursos Minerais do Brasil**. Brasília: CPRM, 2003, p. 55-85.
39. SOUZA, M. J. N. Contribuição ao estudo das unidades morfoestruturais do estado do Ceará. **Revista de Geologia**, n. 1, v. 1, 1988.