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ORIGINAL ARTICLE

MORPHOSTRUCTURAL EVOLUTION AND GEOMORPHOLOGICAL MAPPING IN CRYSTALLINE MASSIF IN NORTHEASTERN OF BRAZIL

Evolução morfoestrutural e mapeamento geomorfológico em maciço cristalino do Nordeste brasileiro

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Abstract
This work addresses the morphostructural evolution of the Crystalline Massif in northeastern Brazil. Highlights as a test area the northwest of the State of Ceará, evaluating the Massif of Meruoca, as a result of the intrusion of post-tectonic granitoid from the orogenic collapse of Brazilians in the Middle Domain area Coreaú/Província Borborema. In addition, the reactivations of the Café-Ipueiras Fault and the Transbrazilian Lineament promoted morphotectonic events during the Cretaceous and Cenozoic, conditioning the elevation or exhumation of the relief. The operational procedures were divided into four stages: 1) Literature review; 2) Interpretation of SRTM images; 3) Elaboration of thematic mapping; 4) Fieldwork. The geomorphological mapping of the Meruoca Massif provided the identification of morphosculptural units classified in the 3rd taxon according to the Ross methodology (1991), denouncing the work of differential erosion on the morphing structure in the preparation of relief compartments that are individualised in the larger set of the geomorphological landscape.

Keywords: Crystalline Massifs, Morphostructures, Morphosculptures, Differential Erosion and Meruoca Massif.

Resumo
O presente trabalho aborda aspectos vinculados a evolução morfoestrutural do Maciço da Meruoca, situado no setor Noroeste do Ceará, como resultante da intrusão de granitoídes pós-tectônicos oriundos do colapso dos orógenos brasilianos na área do Domínio Médio Coreaú/Província Borborema. Além disso, as reativações da Falha Café-Ipueiras e do Lineamento Transbrasiliano promoveram eventos morfotectônicos durante o Cretáceo e no Cenozóico condicionando o alçamento e/ou exumação do relevo. Os procedimentos operacionais foram divididos em quatro etapas: 1) Revisão de literatura; 2) Interpretação de imagens SRTM; 3) Elaboração do mapeamento temático; 4) Trabalho de campo. A par dessas questões, o mapeamento geomorfológico do Maciço da Meruoca proporcionou a identificação de unidades morfoesculturais classificadas no 3º taxón conforme a metodologia desenvolvida por Ross (1991), denunciando o trabalho da erosão diferencial sobre a morfoestrutura na elaboração de compartimentos de relevo que se individualizam no conjunto maior da paisagem geomorfológica.

Palavras–chave: Maciços Cristalinos. Morfoestruturas. Morfoesculturas. Erosão Diferencial. Maciço Meruoca.

1. INTRODUÇÃO

The geomorphological evolution of the Northern Northeast of Brazil is controlled by Proterozoic shear zones (reactivated during the Cretaceous) (CLAUDINO-SALES, 2016), leading to a progressive exhumation of crystalline massifs that, through differential erosion, enable the formation of trends of geomorphological lineaments with the occurrence of symmetrical crests and crystalline masses. Examples of this context are the northwest sector of Ceará, which corresponds to the Transbrazilian domain (MAIA; BEZERRA, 2014).

The existence of a tectonic corridor formed by parallel ductile shear zones suggests that the Brazilian faults were generated from a continental orogeny as a result of deformation on the margins of ancient cratons. It indicates that the Transbrazilian Lineament began to form when the ancient continental masses collided during the Brazilian Orogenesis. (ARTHAUD *et al.*, 2013).

The Brazilian collision zone is well demarcated in the foundations of the South American Platform and the Northwest of the Borborema Province through an expressive shear zone in the SW-NE direction. The Transbrazilian Lineament is one of the main suture zones that registers the Western Gondwana amalgamation process (665-550 Ma). It covers the Northwest of the Borborema Province, and its continental margin extensions have continuity in the crust of West Africa through the *Kandi shear* zones between the *Dahomey belt* and the Transaharan Shield (BRITO NEVES; CORDANI, 1991; BRITO NEVES,1999, CORDANI *et al.*, 2013).

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In the evolutionary sequence, the Proterozoic morpho-structures were reworked along the Northern Northeast of Brazil by tectonic episodes (opening of the Potiguar rift, mid-Cenozoic uplifts), magmatic (neogenous volcanism), erosive (associated with dry climates and climate change, and variations of the Quaternary sea level) and sedimentological, (accumulation of sediments that formed the colluvial covers, river plains, and coastal deposits) (CLAUDINO-SALES, 2016).

The Meruoca Massif (Figure 1) is located in the northwest of the Borborema Province (Middle Coreaú Domain) as a geomorphological expression of the Meruoca Suite, bordering on the southeast with the Jaibaras basin through escarpments inherited from the Café-Ipueiras fault. The Jaibaras basin is delimited to SW by the Transbrazilian Lineament, which delimits the basin's contact with the supracrustral sequences of the Ceará Central Domain, which represent the regional floor of the lowland planing surfaces.

The Brasiliana orogeny defined the Transbrasiliano Lineament and the NW-SE, NE-SW and E-W shear zones controlling the installation of the late Brasiliano granitoids of the Meruoca Suite. After this event, the Cretaceous division of Pangea produced the uplift of the regional surface and the exhumation of the Brasiliano and late Brasiliano granites, exposing the granitoids to differential erosion (SANTOS; NASCIMENTO; CLAUDINO-SALES, 2020).

The Meruoca Massif is an expressive relief compartment in Northwest Ceará that dates back to the events of the end of the Brasiliano Cycle and the Meso-Cenozoic reactivations, covering an area equivalent to 438.35 km². Thus, the morphostructures were re-uplifted by tectonics, configuring themselves as sectors of greater lithological resistance against the selective work of differential erosion during the Cenozoic.

The present work addresses aspects relevant to the genesis and evolution of relief compartments, focusing on the geomorphological mapping of the Meruoca Massif guided by the Ross methodology (1991). This methodology is grounded on the concepts of morpho-structure and morpho-sculpture as a result of the contributions of Gerasimov (1946), Gerasimov and Meschericov (1968), and Meschericov (1968), outlining criteria for geomorphological cartography based on the spatial dimensioning of the genetic categories of topographical relief.

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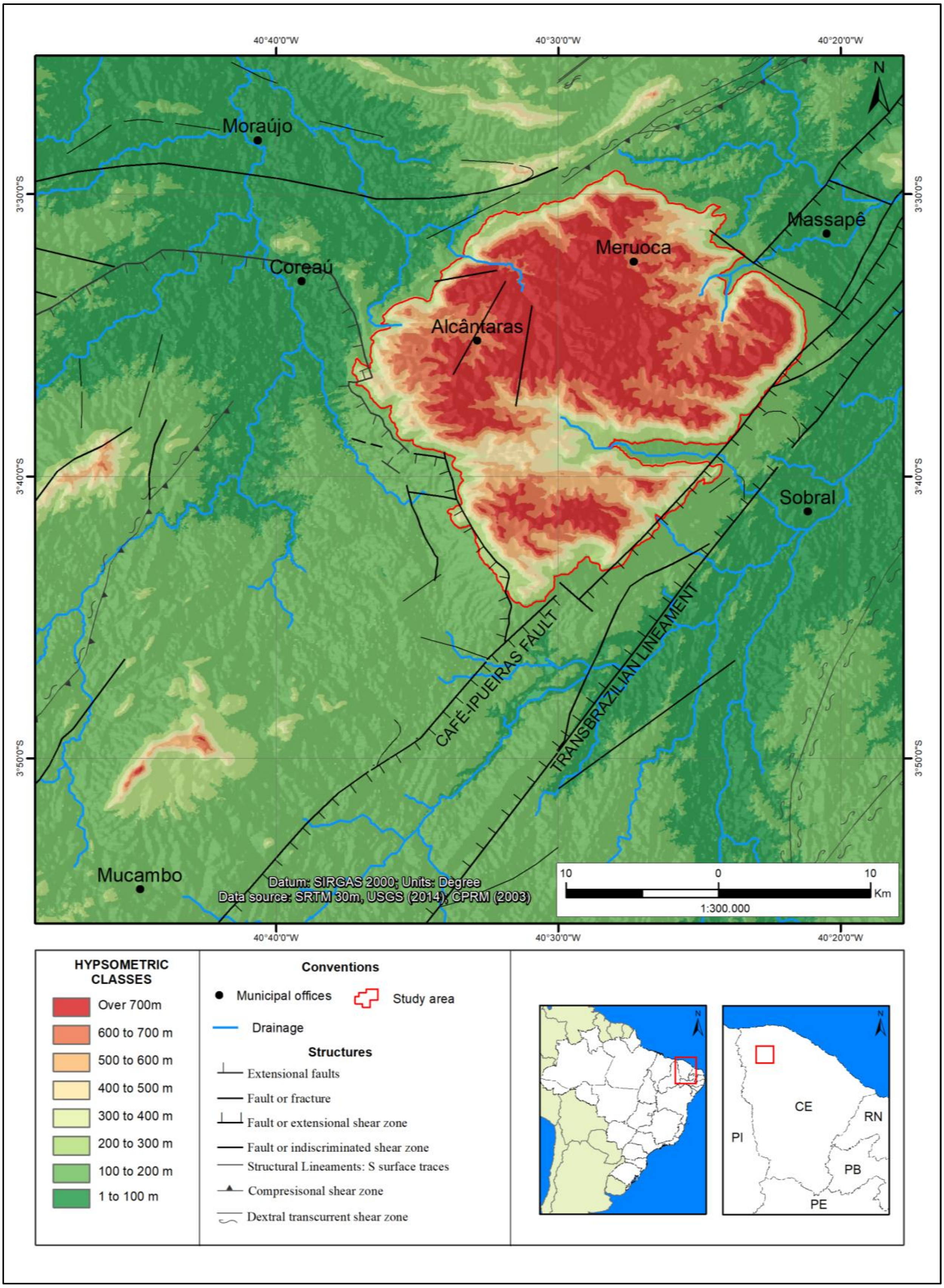

Figure 1 – Location of the Meruoca Massif in NW of Ceará.
Source: Cavalcante *et al.* (2003) and SRTM (2018). Elaborated by the authors (2022).

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2. MATERIALS AND METHODS

Thematic maps (Hypsometric/Location/Geology and Slope) were prepared in QGIS 3.18 software from the SRTM raster database (SHUTTLE RADAR TOPOGRAPHY MISSION) with a spatial resolution of 30 m. The SRTM image was superimposed on the CPRM cartographic base (CAVALCANTE *et al.*, 2003) to extract the main shear zones with the identification of fault kinematics (Transbrazilian Lineament and Café-Ipueiras Fault) and to guide manual delimitation of the brittle lineament traces in 1/50,000 compatible scale.

The extraction of the brittle structural lineaments was performed manually in the QGIS 3.18 software at a scale of 1/50,000 from an SRTM image with a spatial resolution of 30 m, according to the methodology applied in the works by Jardim de Sá *et al.* (1993), Amaro (1998), Camarão Júnior (2001), Silva (2014), Lima (2017), where the identification of faults, fractures, joints or river channels is a criterion for marking brittle traces. In remote sensing interpretations of geological structures, Jardim de Sá *et al.* (1993) define these brittle structures as photo lineations".

The geological map through the cartographic base of Pinéo *et al.* (2020) synthetically represents the organisation of chrono-lithostratigraphic data in the composition of a self-explanatory legend related to tectonic-structural- depositional events:

The geomorphological units are delimited in QGIS 3.18. The shading of the relief from the digital elevation model is performed. The SRTM image (SHUTTLE RADAR TOPOGRAPHY MISSION) with a spatial resolution of 30 m enabled the mapping of relief compartments. For the processing of this image, the SPRING 5.2.6 software is used. Ross's methodology (1991) results from the contributions of Demek (1967) and Mescherikov (1968) and in the technical work developed by the RADAMBRASIL Project (1981). Thus, geomorphological cartography expresses the dynamics of the earth's surface at the levels of the hierarchy below:

1st Taxon – Morphostructural Units – Correspond to macrostructures, such as the large structures related to the Pre-Cambrian Sedimentary Basins and Geological Provinces.

2nd Taxon – Morphosculptural Units – Correspond to relief compartments belonging to a specific morpho-structure and positioned at different topographic levels.

3rd Taxon – Modeled – Corresponds to the groups of forms of aggradation and denudation.

The geomorphological map was prepared at a working scale of 1/50,000, detailing up to the order of the 3rd taxon using GIS QGIS 3.18 from an SRTM (Shuttle Radar Topography Mission) images with a spatial resolution of 30 m.

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Block schematic diagrams represent the area's geomorphology from digital elevation models in 3D and topographic profiles in the Global Mapper 1.9 software, derived from SRTM. In addition, the construction of self-explanatory legends and geomorphological drawings was performed in Corel Draw 2020.

Fieldwork was essential for the recognition of the terrestrial reality. The GARMIN E TEX 10 GPS was used at this stage, with support from the CPRM Geological Map of the Northwest of Ceará (2015; 1/250,000 scale). Data were tabulated in the office to prepare the thematic mapping. Such information is validated from the analysis of the SRTM image to guide the interpretation of relief features expressed on the surface resulting from morphostructural and morphosculptural processes.

3. REGIONAL GEOLOGY AND MORPHOGENESIS

The simplified geology map (Figure 2) below results from the grouping of chrono-correlated geological units analogously linked to tectonic-structural-depositional events. In this way, the units follow the following orders with possible groupings: Granja Complex; Saquinho Volcanic Unit; Supracrustal Sequences and Metamorphic Basement (Canindé of Ceará Complex, Ceará Complex, Martinópole Group and Ubajara Group); Brasiliano Granites; Meruoca Granite, Mucambo Granite, Hornfels Mucambo; Jaibara Basin and Cenozoic Sedimentary Deposits (Colluvial-Eluvial Deposits and Alluvial Deposits). These units support the Meruoca Massif and the adjacent reliefs that comprise the lowland planing surfaces, massifs, inselbergs, and residual ridges. In this way, the evolution of morpho-structures results from the succession of the following events:

1) The Paleoproterozoic Basament refers to the Atlantida Orogenesis with the formation of the Granja Complex, constituted by intrusive syn-metamorphic rocks such as gneisses of different compositions of migmatites, granulites, and amphibolites. Data from Fetter *et al.* (2000) point U-Pb age in tonalitic orthogneisses to granodiorites from 2.357 to 2.271 Ga (SANTOS *et al.*, 2001). The age of the Granja Complex, according to data by Nogueira Neto (2000), by the U-Pb method in zircon minerals, is 2.426 Ga. The oldest supracrustal units correspond to the Canindé do Ceará Complex (Domain Ceará Central) rocks. U-Pb dating data from Castro (2004) and Amaral *et al.* (2012) suggest ages for the orthogneisses between 2.140-2.044 Ga (Riacian). Amaral *et al.* (2012) still obtained ages for the rocks of the Cariré Unit of 2.157 Ga and 613 Ma of crystallisation and metamorphism, respectively. They are metamorphic migmatites orthogneisses, paragneisses, schists, quartzites, amphibolites and marbles (AMARAL, 2010; TORRES *et al.*, 2010). In the post-

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orogenetic period, extensional events occurred, associated with the division of Atlantis/Columbia in the Paleoproterozoic foundations of the Middle Coreaú Domain, as part of the Saquinho volcanism (1.789 Ga U-Pb), responsible for an episode of intense magmatism and ensialic rifting (SANTOS *et al.*, 2002, 2008).

2) The West African-São Luís Shield Division provided the opening of an ocean basin with the deposition of supracrustal sequences of the Martinópole Group (quartzites, mica schists, marbles, and metarhyolites) (Middle Ceará Domain) and Independence Unit (high-grade metamorphosed rocks and commonly migmatized) (Domain Ceará Central). These units were deposited during the rifting of the Rodinia continent between 800-750 Ma. (FETTER *et al.*, 1997, 2003, ARTHAUD, 2007, HASUI, 2012).

3) Brazilian Orogenesis (665-550 Ma) with the formation of magmatic arcs inside the Brazilian Chain from the closure of small oceanic basins during the collage of Western Gondwana (Neoproterozoic). The deposition of the supracrustal sequences of the Ubajara Group occurs, presenting contraction and transcurrent structures with low-grade metamorphic rocks linked to the Brazilian Orogenesis (BRITO NEVES, 1999, FUCK *et al.*, 2013, ARTHAUD *et al.*, 2015, SOUZA, 2018).

4) The Brazilian Chain; Intrusion of late granites (Meruoca Suite) in the in-terval between 441 and 430 Ma (Meruoca and Mucambo granites), with contact metamorphism in the Mucambo Granite (Mucambo Hornfels). Formation of the Jaibaras Basin demarcates the Parnaíba Basin's rift phase (Neoproterozoic-Paleozoic). The Jaibaras Basin follows the trend of the Transbrazilian Lineament. Its NW border is delimited by the Café-Ipueiras Fault that separates the volcano-sedimentary filling from the Meruoca batholith. (SANTOS *et al.*, 2008, PEDROSA JR *et al.*, 2016, CLAUDINO-SALES, 2016, GARCIA *et al.*, 2018).

5) Opening of the Atlantic Equatorial Margin with the reactivation of the Brazilian shear zones (Café-Ipueiras Fault and Transbrazilian Lineament) with the exhumation of granitic plutons, expressed on the surface as structural massifs, such as the Meruoca Massif and Carnutim (MATOS, 2000 MAIA; BEZERRA, 2016). Flexural uplift of the interior of the continent, climatic variations with dismounting of relief volumes, correlative sedimentation of colluvial (Neogene-Quaternary) and alluvial (Quaternary) nature, elaboration of backland planing surfaces, under semi-arid conditions between the Miocene and the Pleistocene (PEULVAST; CLAUDINO-SALES, 2006, CLAUDINO-SALES, 2016).

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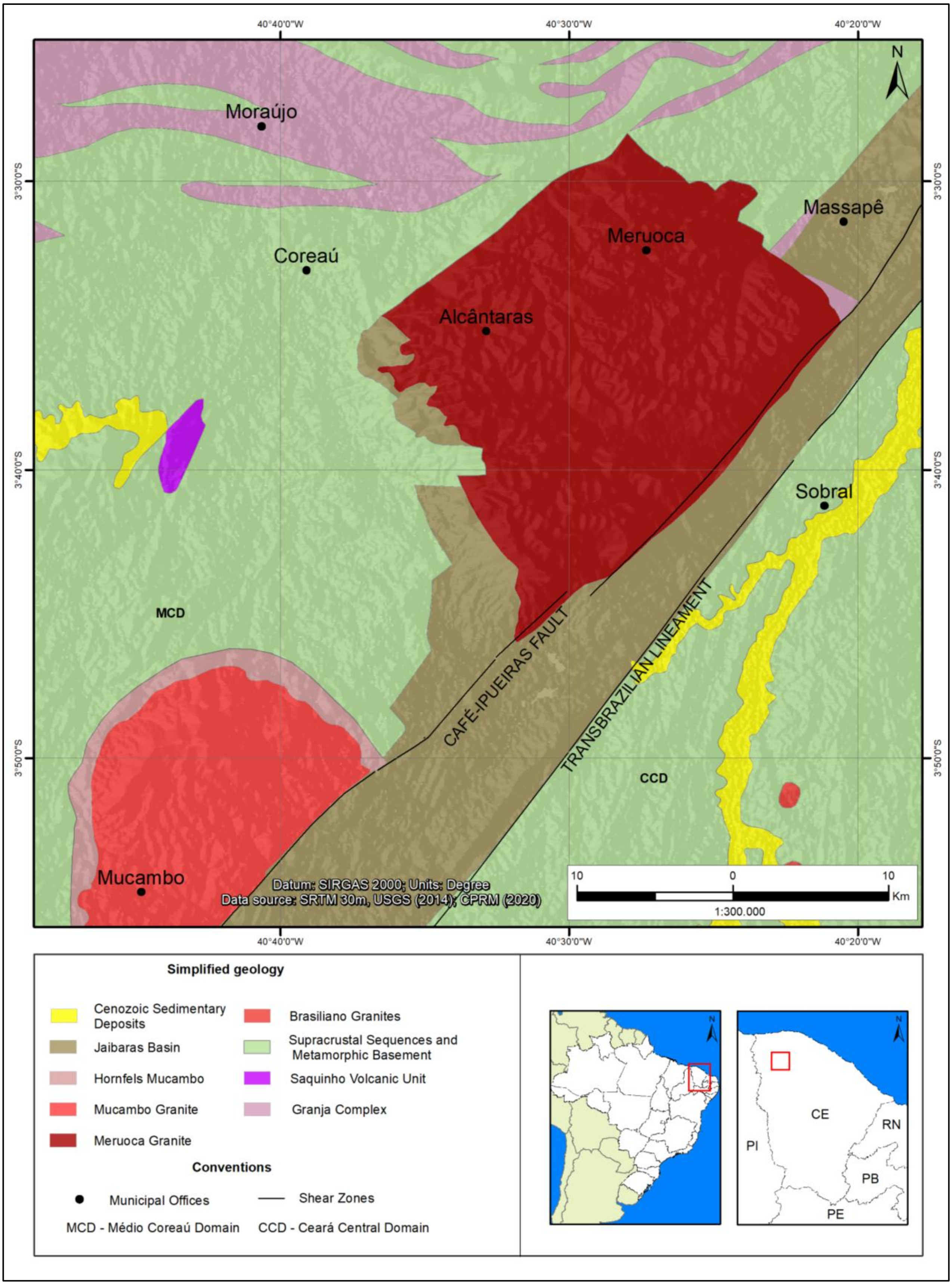

Figure 2 – Geological map of the Meruoca Suite and surrounding areas.
Source: Pinéo *et al.* (2020).
Elaborated by the authors (2022).

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4. MORPHOSTRUCTURAL EVOLUTION

The Meruoca Granite has a trapezoidal shape, presenting contacts with the Jaibaras Group of the magmatic and tectonic types. It is truncated to the southeast by the Café-Ipueiras fault and to the northeast by the Transbrazilian Lineament. Pluton comprises syenogranites, quartz syenites, and alkali feldspar granites with abundant graphic and granophyric elements (SIAL *et al.*, 1989, ARCHANJO *et al.*, 2009). Syenogranites occur in the central portions and gabbroic intrusions in the northern part with dark green aspects in colour. They have coarse to medium and thin to medium grain, respectively. (PEDROSA JR *et al.*, 2014).

Claudino-Sales (2016), based on Boillot's principles (1996), states that after the Brazilian Orogenesis, the Borborema Province went through a period of stabilisation, assuming an intraplate tectonic behaviour between Paleozoic and early Mesozoic, in the northern half, and even early from the Cretaceous, in the southern half. During the tectonic collapse of mountain ranges, extension and contraction processes coincide, resulting from the movements of the shear zones that produce tectonic denudation, that is, the outcropping of magmatic rocks formed at great depths. At the same time, heating and root fusion produce new magma, which ascends to the most superficial conditions generating late granites.

Later, transcurrent tectonics ensue at lower temperatures, and the ductile deformation gradually changes to brittle. Granitoids tend to lodge in transtension zones with different typologies. In rigidity and thick crust, post-tectonic intrusions occur in distensive regimes associated with the opening of the Jaibaras Rift. In Cambrian, there were post-Brazilian manifestations with the intrusion of the Granitoids Meruoca and Mucambo (FERREIRA *et al.*, 2004, HASUI, 2012). These granitoids are dated by Santos *et al.* (2013) and Santos *et al.* (2008), using the U-Pb method with ages obtained in zircons of 540.8 ± 5.1 and 532 ± 7 Ma, respectively.

Godoy (2010), from the analysis of fission tracks in zircon, demonstrates that the samples of the Meruoca and Mucambo granites were heated to 384 ± 48 Ma and 303 ± 35 Ma, respectively, lower than their crystallisation ages. Thus, the thermochronological data present a history of magmatic cooling for the granitic bodies, whose heat loss from the plutons occurred until the temperatures of the crustal level where they were placed, with a later cooling age by exhumation after heating that the area suffered above 240 °C, not linked to granitogenesis.

The tectonic reactivations linked to the rupture of Gondwana during the Cretaceous are responsible for the main lines of the relief of the Brazilian Northeast, controlling the

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denudational processes that come to express the evolution of the relief in the Cenozoic. Thus, the Pre-Cambrian ductile shear zone erosion led to a progressive exhumation of crystalline massifs. This exhumation made possible, through differential erosion, the formation of structural trends arranged in positive and negative linear forms associated with the Brazilian deformation planes (MAIA; BEZERRA, 2014).

The available apatite fission traces thermochronological data expose the exhumation ages of the surfaces around the Jaibaras Basin and Mucambo Granite. Godoy (2010) identifies ages of 86 ± 12, 115 ± 20, and 118 ± 17 Ma in the Mucambo Granite, Pacujá Formation and Aprazível Formation (Jaibaras Basin), respectively. These data demonstrate that the most recent cooling events occurred on a temporal scale analogous to the final breakdown of Gondwana at temperatures below 120 C° (apatite annealing), in which the rock was being exhumed between 3-0 km.

These thermochronological data attest that the reactivation of the Café-Ipueiras Fault during the Cretaceous promoted the uplift/exhumation of the Mucambo and Meruoca granitic rocks, forming the Carnutim and Meruoca massifs, respectively. Figure 3 shows a geological-geomorphological profile between the massifs of Meruoca (Meruoca Granite) and Carnutim (Mucambo Granite), pointing the former as the most expressive granitic massif in the northwestern segment of Ceará from escarpments that have slopes above 75% reaching an altitude of over 1,000 m.

From the Paleogene, the continent’s interior underwent flexural uplift in response to sediment overload on the shelf. Thus, it is likely that the Meruoca Massif underwent a smooth bending with shear stresses in normal faults in the NE-SW direction. (PEULVAST; CLAUDINO-SALES, 2006).

The Meruoca Granite does not present ductile deformation and represents post-orogenic plutonism registered in the Borborema Province (SANTOS *et al.*, 2008). Nevertheless, Figure 4 shows the direction of the brittle structural lineaments in the area as a function of tectonic reactivation events that occurred throughout the Cretaceous and Cenozoic:

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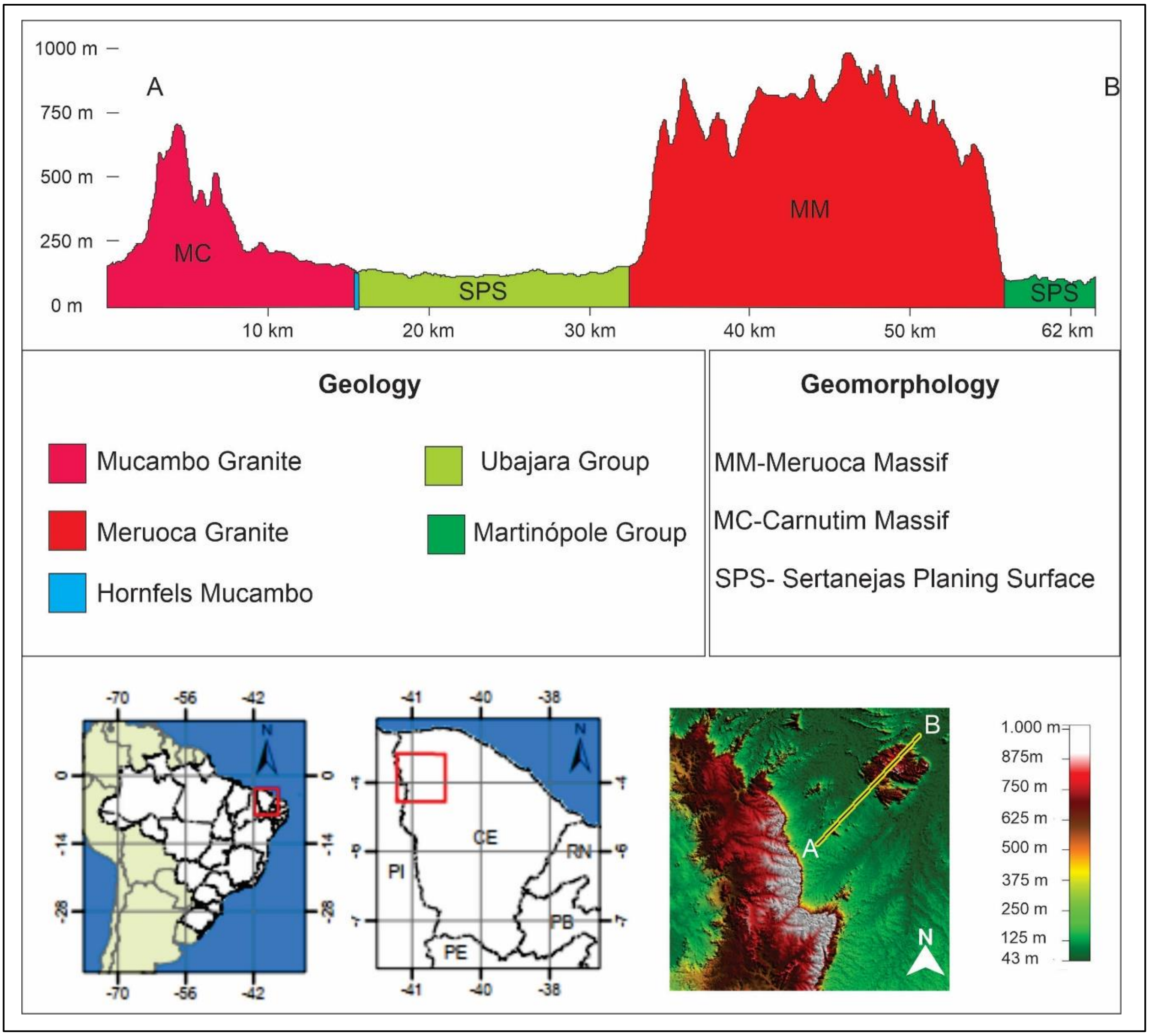

Figure 3 – Geological-Geomorphological profile between the Meruoca and Carnutim Massifs. Elaborated by the authors (2022).

During Gondwana Break-up in Northeast Brazil, tectonics was directed in the E-W and NW-SE sections, which reflect transpressive and distensive/transtension current environments. The E-W sections are directly related to the oceanic crust invoice zone nucleation in areas of lesser resistance of the continental crust, such as the Pre-Cambrian folded belts or on the boundary between two geological provinces. The NW-SE efforts reflect the oblique break-up of the old and tough Precambrian Shields during continental fragmentation. The main sedimentary basins present both E-W stretches of transpressional character, and the NW-SE stretches with transtensional and distensive deformation (ZALÁN, 2012).

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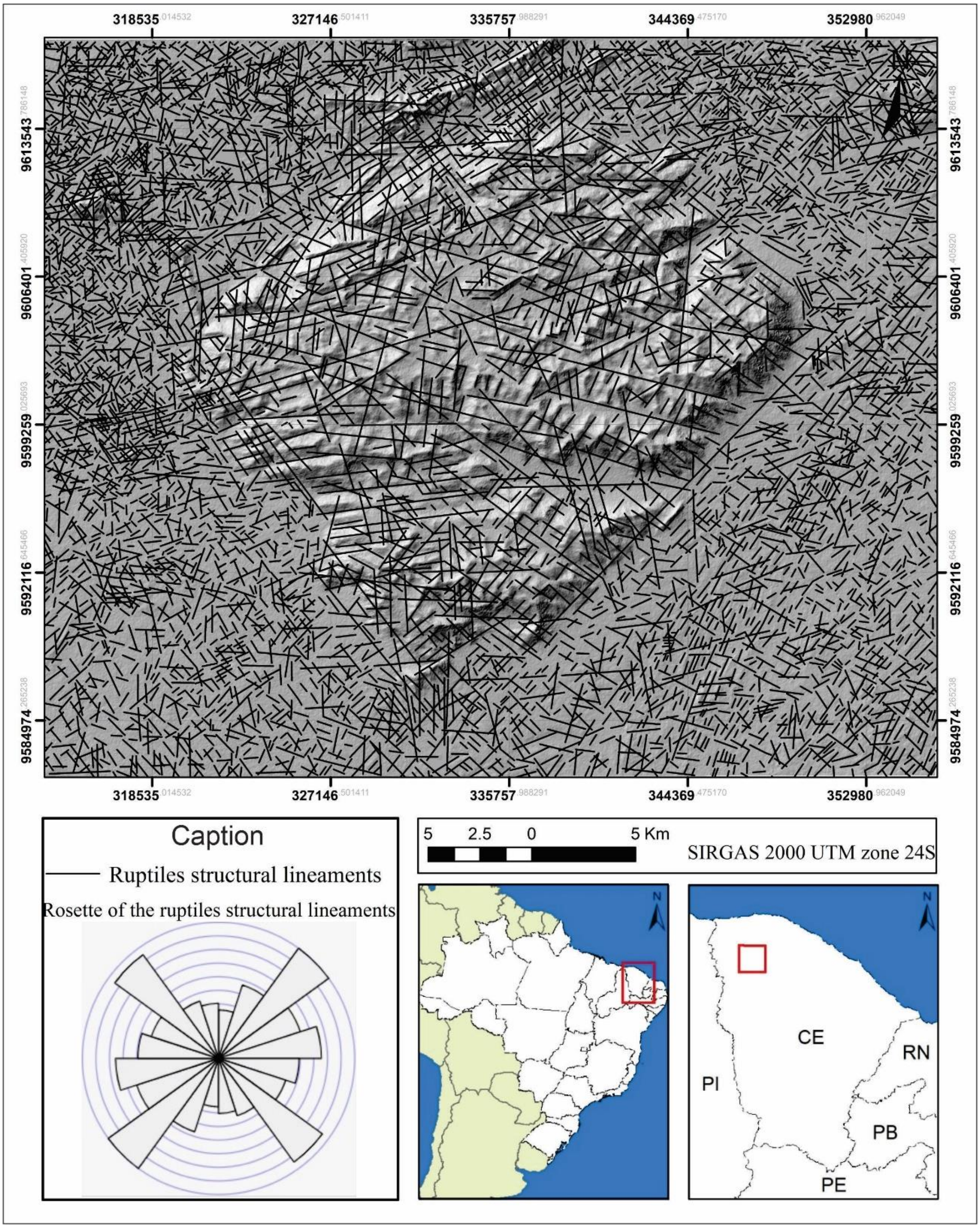

Figure 4 – Map of shearing structural lineaments of the Meruoca Massif and surroundings according to Pinéo *et al.* (2020). Elaborated by the authors (2022).

The NE-SW and NW-SE patterns predominate in the interior of the Meruoca Massif as a direct inheritance of the transcurrent shear system described by Zalán (2012) in the Borborema Province of Northeastern Brazil. Lineaments are expressed on the surface through crests (positive) and embedded valleys (negative).

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The structural disposition of the Meruoca Massif is controlled by the Transbrazilian Lineament and Café-Ipueiras Fault, which were reactivated according to the fission traces in apatites data of Godoy (2010) during the Cretaceous and Cenozoic, preferably following the NE-SW orientation as resulting from the transforming/current-voltage fields involved in the continental rupture of Gondwana.

According to Sial *et al.* (1981), there are large areas characterised by turbid brick-red feldspar and located in the south-central part of the pluton, indicating a high-level intrusion that suffered generalised late hydrothermal alteration. According to Moura (2010), the highest incidence of brittle traces coincides with the hydrothermal changes prevailing in the SE portion in contact with the Café-Ipueiras Fault.

Faults occur in the E-W direction, which according to Moura *et al.* (2014), depends on seismogenic faults related to fragile and fractured structures of Mesozoic basaltic dykes swarms that exist in the pluton, reactivated by seismicity.

The morphostructural evolution of the Meruoca Massif presents a sequence of events that goes back from post-Brazilian granitogenesis to Cretaceous and Cenozoic reactivations. Thus, the structural constraints expose the granitic batholith in the topographic startle as a sector of greater lithological resistance than the dynamic modelling of the relief under semi-arid conditions, whose geoform traces denote a typical residual massif amid the backland planing surfaces.

5. GEOMORPHOLOGICAL MAPPING

The Map in Figure 5 shows the geomorphological compartmentalisation of the Meruoca Massif based on Ross (1991). According to the mapping, the 1st taxon corresponds to the Granitic Massifs of the Borborema Province, integrating the Meruoca Massif in the hierarchical order of the 2nd taxon. The compartments: Northeastern slope; Central Plateau; South-Western Strand; Dissected Floors; and Rosário Mountain Range represent groupings of morphosculptural features of the 3rd taxon individualised as geomorphological units within the broader Meruoca Massif set.

Figure 6 shows the slope map of the area with topographic breaks that indicate the following classes: flat (0-3%); smooth wavy (3-8%); wavy (8-20%); strong wavy (20-45%); mountainous (45-75%) and rugged (> 75%):

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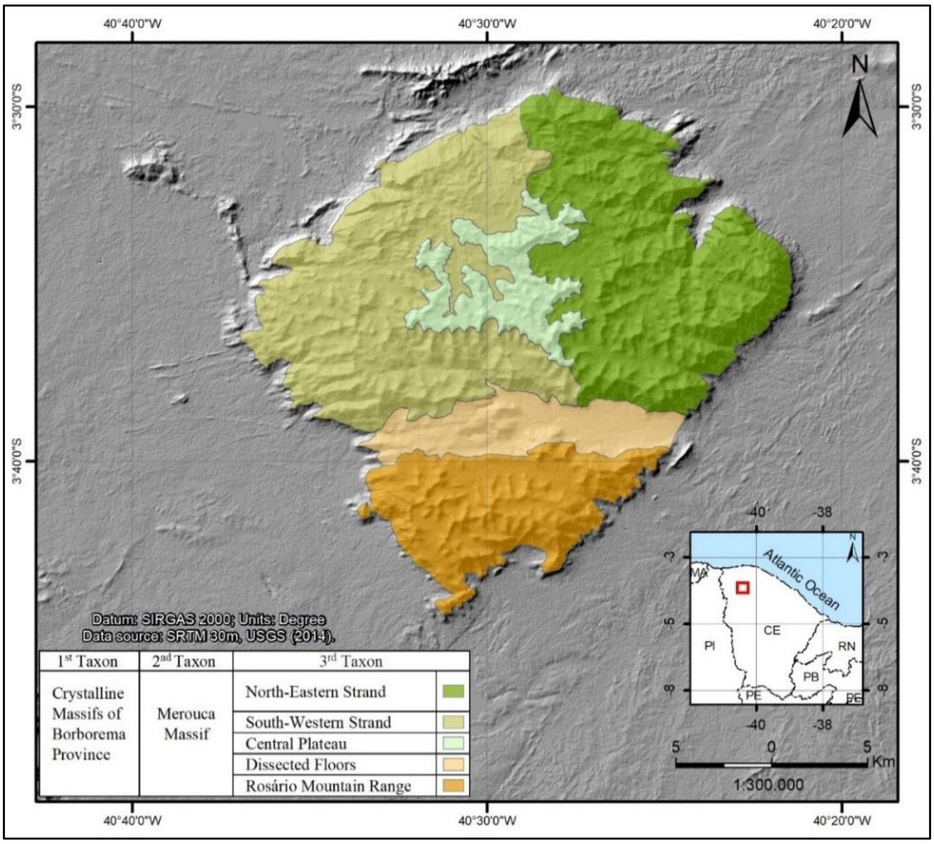

Figure 5 – Geomorphological map of the Meruoca Massif.
Elaborated by the authors (2022).

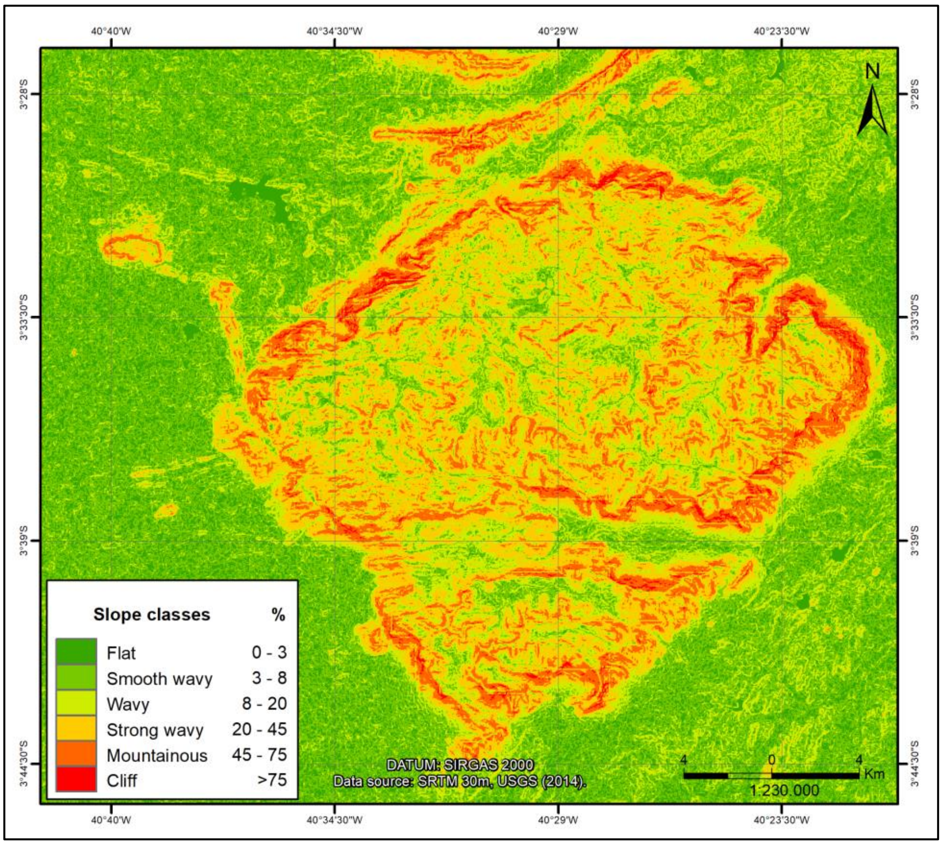

Figure 6 – Slope Map.
Source: SRTM (2020). Elaborated by the authors (2022).

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5.1. Northeastern Strand

The Northeastern slope presents steep slope ruptures (>75%) in a typical escarpment inherited from fault in horts in contact with the Café-Ipueiras Fault. This shear zone has a NE-SW orientation with extensional kinematics through normal faults positioned on the western limit of the Jaibaras graben, forming a rift basin bounded to the east by the Transbrazilian Lineament. It has an area equivalent to 139.98 km². The maximum altitude of this slope is around 1,000 m.

This sector is strongly dissected along orthogonal fault lines through suspended valleys and cliffs in contact between the granitoid and the clastic, volcaniclastic, and volcanic rocks that belong to the Jaibaras basin. This contact is demarcated by a short eroded corridor in a zone of strong cataclase and hydrothermal alteration. The Meruoca Massif has triangular facets resembling a recent fault escarpment, especially in its northeastern portion. This tectonic interpretation is also suggested by the low sinuosity of its contours and the presence of steep and short valleys between the facets (PEULVAST; BÉTARD; LAGEAT, 2009).

The occurrence of escarpments inherited from faults in the Northeastern Slope justifies the morphostructural conditioning of the Meruoca Massif in proximity to the space of accommodation of the granitic magmatism that allowed the pluton to be lodged. According to Claudino-Sales (2016), the arrangement of faults explains the quadrangular shape of the massif, controlling the smooth bending of the marginal flexure in the Cenozoic.

The drainage incision promotes the evolution of raised valleys in a V-shape, resulting in different levels of scallops from the prominence of terminal spurs and triangular facets between the indentations of the scarp line. These features are most expressive on the northeastern slope due to the structural predisposition of the faults, which, together with the greater notch power of the drainage in wetter conditions, allow the relief section by regressive erosion through strongly dissected valleys. The 3D model (Figure 7) illustrates the occurrence of festoons along the escarpments:

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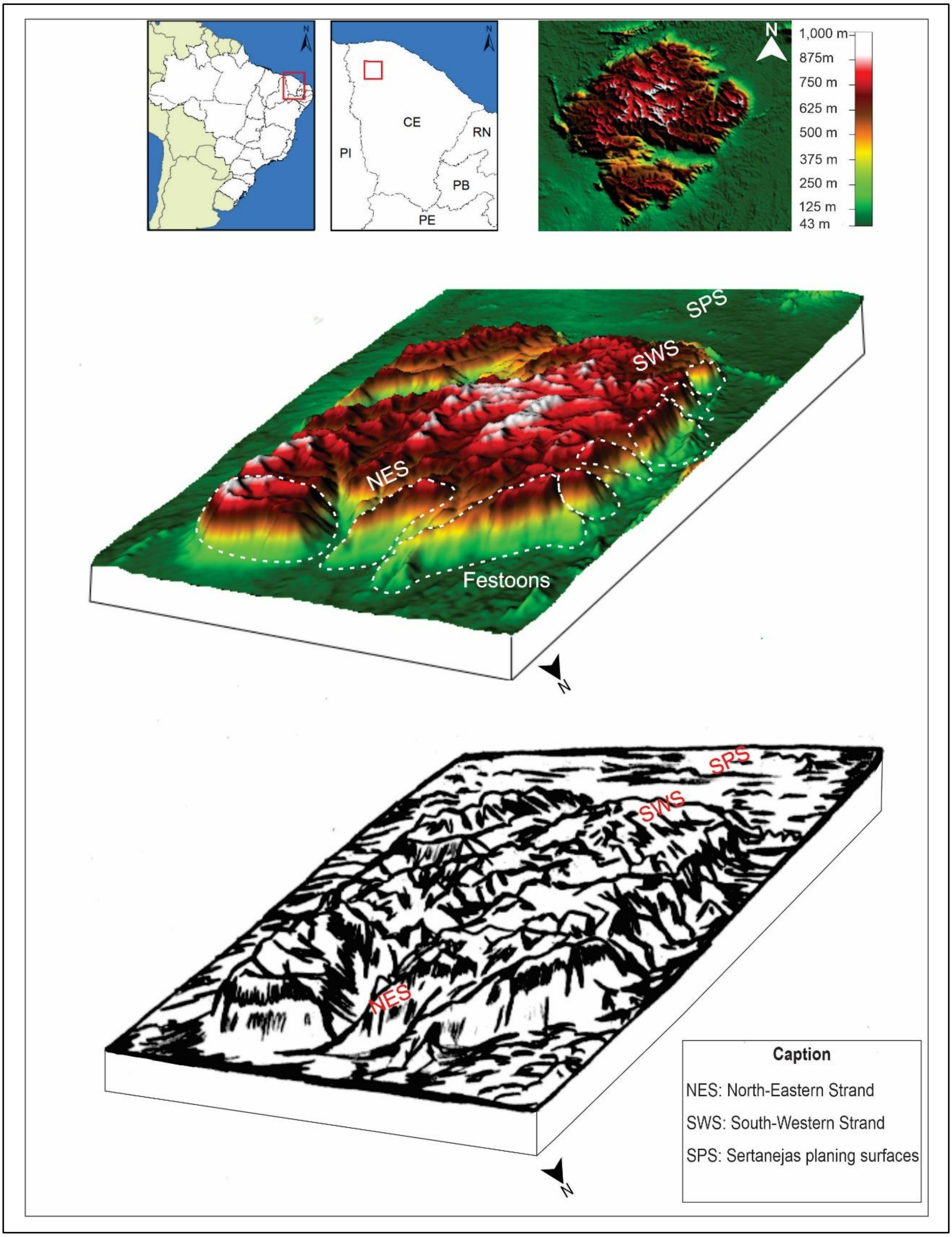

Figure 7 – Block Diagram and Geomorphological Drawing of the Massif of Meruoca with emphasis on the festoons of the Northeastern Side.
Source: SRTM (2020). Elaborated by the authors (2022).

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This morphology is due to the areolar processes that justify the modelling being strongly dissected convex and sharp tops. Small inlaid levels of alveolar plains are filled with alluvial and colluvial deposits. The Red-Yellow Ultisols covered by cloud-pluvial forest prevail (SOUZA, 2000).

5.2. Dissected Floors

The Dissected Floors represent an area equivalent to 39.73 km². The linear incision potential of the Boqueirão stream sectioned the structures of the Meruoca Granite through a system of embedded valleys according to the direction of the pre-existing and preferential invoicing zones for the drainage notch, which by a more powerful regressive erosion led to the elaboration of dissected plateaus. Fluvial dissection separates the tops of the interfluves draining towards the Acaraú hydrographic basin between the Northeastern Stream and Rosário Mountain Range.

The drainage network ramifies with dendritic and sub-dendritic patterns, whose fluvial spread forms small alveolar plains between the slopes. The slope in this sector configures from wavy (8-20%) to strong wavy (20-45%). The altitude reaches 534 m. There are sectors of topographic smoothing at around 125 m, close to the contact with the Café-Ipueiras Fault, with different levels of relief scaling, indistinctly truncating different paleosurfaces in the landscape evolution.

5.3. Rosário Mountain Range

It is a relief compartment located in the south/southeast segment of the Meruoca Massif, which was individualised in the larger group of the massif due to the river incision processes of the Riacho Boqueirão in the process of dissection and deepening of the valley. To the south, the granitic structures are elevated concerning the Jaibaras Basin, in the sector where the deposition of the Pacujá Formation overflowed the basin’s depocenter. The escarpments are controlled to the southeast by the Café-Ipueiras Fault and the south by normal faults perpendicular to the distensive system that integrates the Jaibaras Rift.

In Rosário Mountain Range, there is a progressive decrease in rainfall due to the position to the rear/leeward of the Northeastern slope of the Meruoca Massif. The caatinga vegetal covers Litholic Neosoils. The suspended pedimentation levels were partially dismantled, constituting a landscape dissected in ridges. At the base of the slopes, they form small intermontane depressions with characteristics similar to coalescing dendrite

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cones. The material covering them is heterogeneous in particle size, indicating a small selective capacity of torrential flow currents (SOUZA, 2000).

It is a relief compartment with an area of 71.98 km² and a maximum altitude of around 870 m. The slope displays steep characteristics (>75%), exposing granitic outcrops of chaotic blocks and boulders, attacked by mechanical weathering in response to the prevailing semi-arid conditions.

Figure 8 displays the topographical rupture between the granitic structures of Rosário Mountain Range and the lowland planing surfaces that surround the massif:

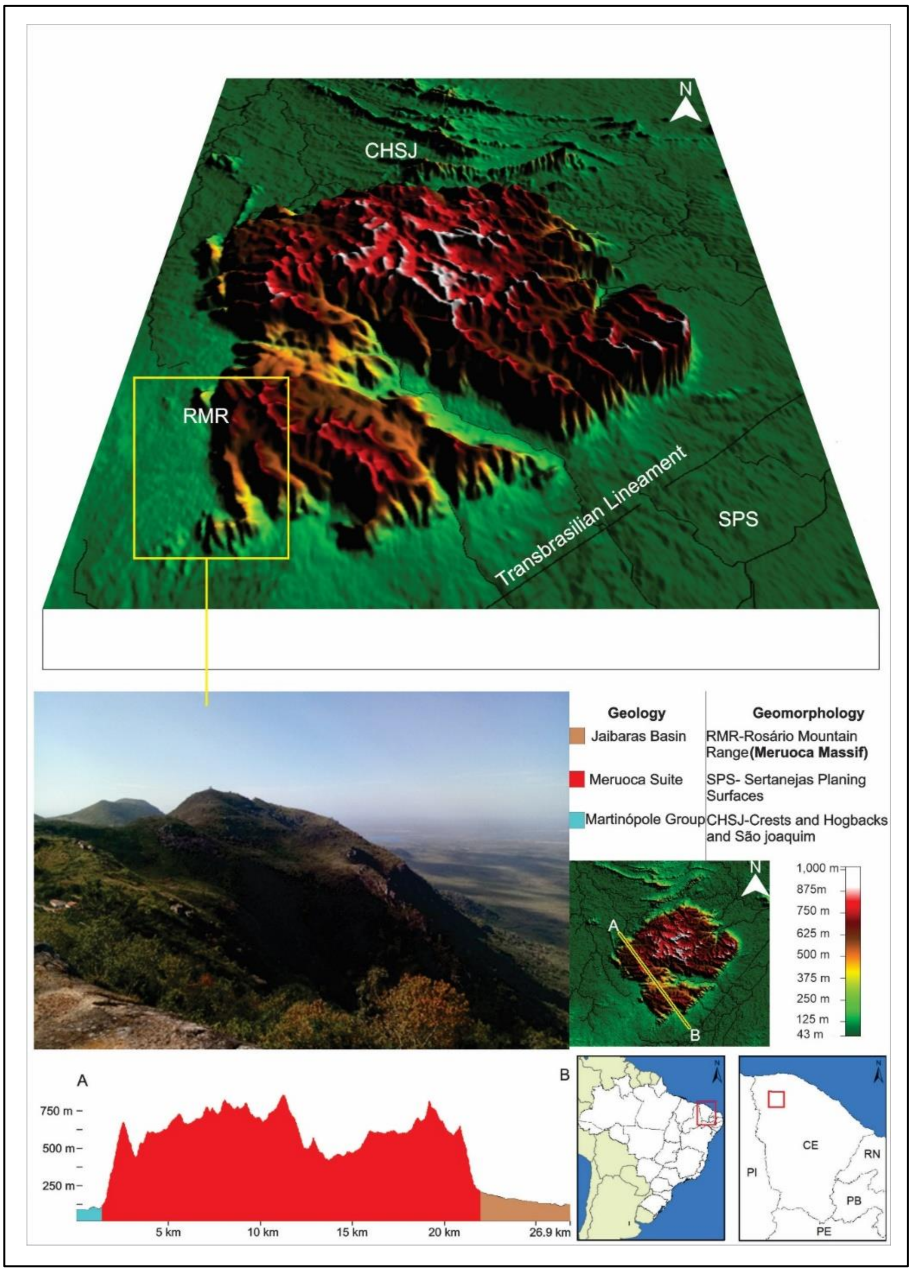

Figure 8 – Block Diagram and Geological-Geomorphological Profile of the Meruoca Massif, emphasising Rosário Mountain Range and surrounding reliefs. Elaborated by the authors (2022).

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5.4. Central Plateau

It corresponds to the summit surface of the Meruoca Massif between the Northeastern and South-Western slopes, varying from wavy (8-20%) to strong wavy (20-45%). Small topographic smoothing sectors (smoothly undulating surfaces 3-8%) spread alveolar plains between ridges and humps. Drainage is strongly branched with dendritic patterns. Thus, the interfluves separate valleys that drain into the Acaraú River Basin towards the Eastern North Slope and the Coreaú River Basin towards the South-Western Slope.

There is a higher incidence of pedogenetic processes that expose deeper Red-Yellow Ultisoils concerning the massif slopes. Moreover, rainfall averages reach indexes above 1200 mm, regularly distributed during the rainy season. Thus, favourable conditions stimulated the emergence of a typical summit swamp covered by cloud-pluvial forest, with high-size trees and accentuated density (SOUZA, 2000).

The central plateau occurs at the summit levels of the massif due to the coalescence of topographic smoothing sectors flattened between 900-1,000 m. It has an area equivalent to 36.67 km². The altitude in this sector reaches 1,020 m, demonstrating the peak of the Meruoca Massif. Figure 7 displays the relief compartments composing the Massif of Meruoca as a residual feature resulting from differential erosion on sectors of greater lithological resistance about the surrounding Lowland planing surfaces.

5.5. South-Western Strand

In this sector, the effects of orographic rains are minimised by the moisture loss from rainfall in the Northeastern Slope and the Central Plateau. Thus, the drainage does not have enough capacity to excavate deep valleys, producing pedimented surfaces in reflex to mechanical morphogenesis.

The soils show a tenuous pedogenetic evolution with the exposure of Litholic Neosols, rocky outcrops, and boulders, reflecting the low rainfall with the phytogeographic dispersion of arboreal-shrub Caatingas (SOUZA, 2000).

The South-Western Strand presents granitic towers (tors) and block chaos resulting from the performance of exogenous processes in the rock fracturing systems (LIMA, 2016). Block chaos results from the selective denudation of a weathering mantle with a higher density of *corestones* associated with rugged topographies susceptible to morphodynamic events. Tors are controlled by the density, orientation, and curvature of the fracture patterns made up of massive blocks of nearly equal size stacked. (MIGÓN, 2006, MAIA *et al.*, 2018).

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Maia and Nascimento (2018) discuss the occurrence of epigenic paleoenvironments on granitic rocks covered by the alteration mantle, submitted to meteoric systems derived from more humid tropical climates. Thus, in late-post tectonic granitoids, a set of erosional features forms relief patterns associated with differential weathering due to mineralogical, petrographic, or fracturing predisposition. They are dissolution basins, tafoni (tafone in the singular), flutes, saprolitized blocks in different degrees of development, slabs, boulders, granite balls (boulders), tors, and block chaos.

The elevated reliefs near the South-Western slope do not belong to the granite suite supporting the Meruoca Massif. They correspond to the exposure of quartzites from the São Joaquim Formation (Martinópole Group), which form crests and hogbacks in the E-W and SE-NW direction in the topographic rebound of differential erosion because of the higher resistance of this lithology to physical weathering. (Figure 9):

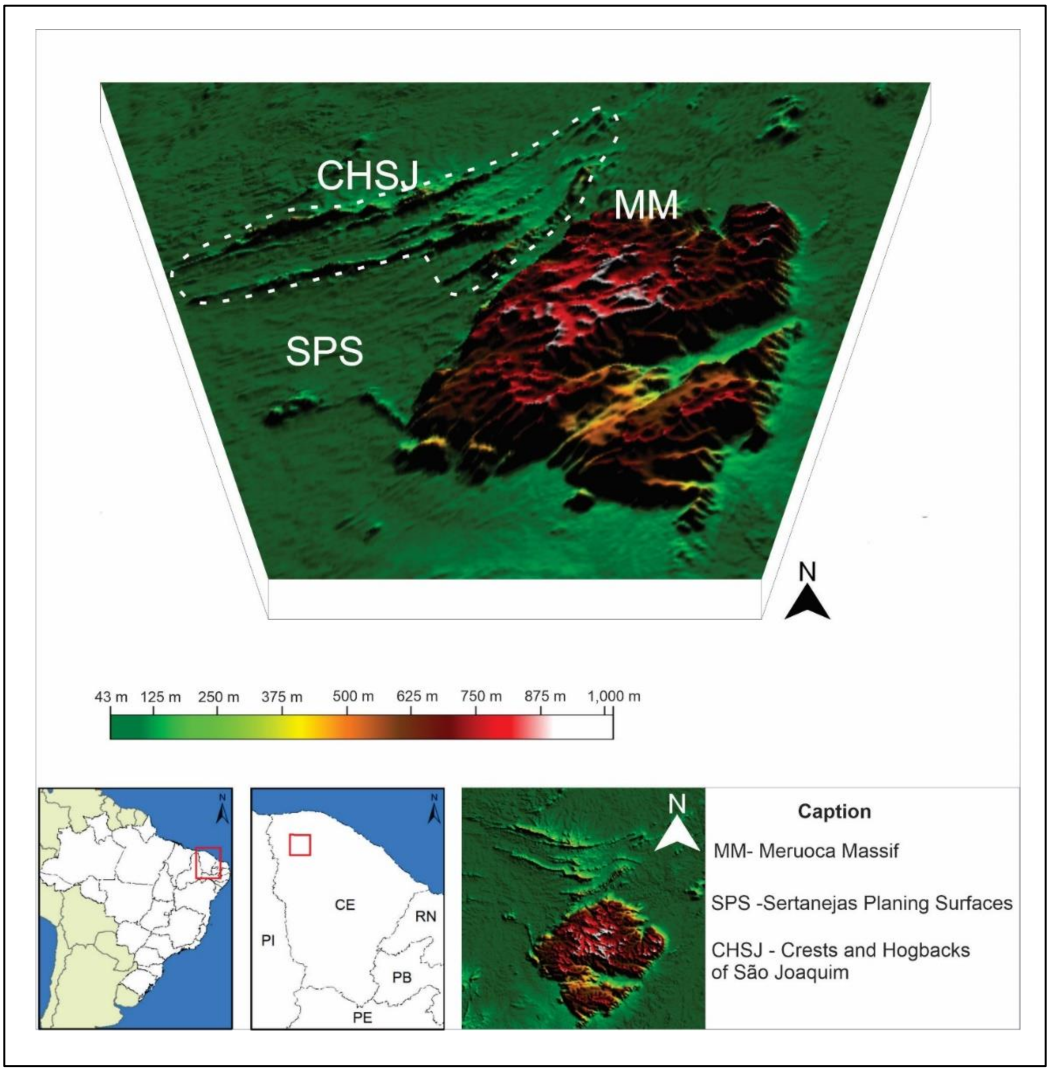

Figure 9 – Block Diagram of the Meruoca Massif and Surrounding Reliefs (Crests and Hogbacks of São Joaquim).
Source: SRTM (2020). Elaborated by the authors (2022).

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The slope along the slope ranges from mountainous (45-75%) to steep (>75%) and has a maximum altitude of around 920 m, covering an area equivalent to 149.99 km². An extension of the Arapá shear zone highlights the deposition of polymictic conglomerates of the Aprazível Formation, close to its source area, as deposits provided by the scarps are inherited from the fault. This normal fault system forms a tectonic arc that abruptly delimits the quartzites of the São Joaquim Formation and the rocks of the Ubajara Group and Jaibaras Basin concerning the contacts with the post-Brazilian granitoids that support the Meruoca Massif.

6. FINAL CONSIDERATIONS

The morphotectonic events that conditioned the uplift/exhumation of the Meruoca Massif resulted from the reactivation of the Café-Ipueiras Fault and the Transbrazilian Lineament are the main points to direct future field research in Structural Geomorphology in the area. First, however, it is necessary to date the crust's thermal history in correlation with the large-scale tectonic processes installed over the Borborema Province.

Thus, Fission Trace Thermochronology in Apatites can guide the preparation of more consistent data to prove morphotectonic phenomena, such as reactivations and flexural uplift of fault scarps, in addition to exhumation events of granitic structures during the Cretaceous and Cenozoic.

However, geomorphological mapping is vital for interpreting the dynamic modeling of the Meruoca Massif's relief compartments. Therefore, this research raises essential questions about the conditioning of the morpho-structure against the action of differential erosion in slopes inherited from faults, elucidating aspects about the structural predisposition of fractured sectors to dissection and the arrangement of triangular facets in contact with the Sertaneja planing surfaces.

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