Mercator, Fortaleza, v. 24, e24028, 2025 ISSN:1984-2201

MORPHOMETRIC AND GEOMORPHOLOGICAL CHARACTERIZATION IN THE MUNICIPALITY OF VIÇOSA DO CEARÁ, CEARÁ, BRAZIL

https://doi.org/10.4215/rm2025.e24028

Silva, J.B. [a]* - Falcão Sobrinho, J. [b] - Rodrigues, S.C. [c] - Diniz, S.F. [d]

(a) Master's Student in Geography
ORCID: https://orcid.org/0000-0002-9935-8285. **LATTES:** http://lattes.cnpq.br/5460829127729532.
(b) PhD in Development and Environment
ORCID: https://orcid.org/0000-0002-7399-6502. **LATTES:** http://lattes.cnpq.br/1116969589809299.
(c) PhD in Geography
ORCID: https://orcid.org/0000-0002-5376-1773. **LATTES:** http://lattes.cnpq.br/0563872406702918.
(d) PhD in Geosciences and Environment
ORCID: https://orcid.org/0000-0001-6127-9883. **LATTES:** http://lattes.cnpq.br/9288376463276634.

Article history:
Received 30 August, 2025
Accepted 16 November, 2025
Published 10 December, 2025

(*) CORRESPONDING AUTHOR
Address: Av. Eurípedes Ferreira Gomes, nº 646 apt. 2, Pedrinhas, Zip Code 62040-750, Sobral (CE), Brazil. Phone: (+55 88) 996628805
E-mail: joao.bandeira.silva05@gmail.com

Abstract

Geomorphological science aims to study landforms on the Earth's surface and explain their formation and genesis. Cartography, in this case, geomorphological mapping, is used to represent geomorphological features. The method for hierarchizing the relief was based on Ross (1992); for morphometric characterization, the ALOS PALSAR Digital Elevation Model (DEM) with a spatial resolution of 12 meters was used for hypsometry, slope, and the Relief Dissection Index (RDI) maps; and for vertical curvature, the TOPODATA project used the DEM from the SRTM mission. The classification and systematization of morphological units was based on the work of Dantas, Lacerda, and Maia (2023). The municipality of Viçosa do Ceará presents morphostructures of the Parnaíba Sedimentary Basin and the Ancient Shield and Massif Domains; The Ibiapaba Cuesta, the Sertaneja Surface, and the Crystalline Residual Plateaus are considered morphosculptures, and each morphosculpture represents a distinct morphological unit. Given these assumptions, this work contributes to exploratory research that serves as a basis for future scientific investigations on geomorphological mapping. The objective was to characterize three taxonomic and morphometric levels of the municipality of Viçosa do Ceará, Ceará.

Keywords: Morphology; Relief Taxonomy; Morphometric Indices.

Resumo / Resumen

CARACTERIZAÇÃO MORFOMÉTRICA E GEOMORFOLÓGICA NO MUNICÍPIO DE VIÇOSA DO CEARÁ, CEARÁ, BRASIL

A ciência geomorfológica objetiva estudar as formas de relevo na superfície terrestre e explicar a formação e a sua gênese. Para poder representar as feições geomorfológicas é a cartografia, no caso o mapeamento geomorfológico. Como método de hierarquização do relevo teve como base Ross (1992); para caracterização morfométrica usou-se o Modelo Digital de Elevação (MDE) do ALOS PALSAR com resolução espacial de 12 metros para os mapas de hipsometria, declividade e o Índice de Dissecação do Relevo (IDR), e para a Curvatura Vertical o projeto do TOPODATA que usou o MDE da missão SRTM. Na classificação e sistematização das unidades morfológicas teve base o trabalho de Dantas, Lacerda e Maia (2023). O município de Viçosa do Ceará apresenta morfoestruturas da Bacia Sedimentar do Parnaíba e os Domínios dos Escudos e Maciços Antigos; como morfoesculturas a Cuesta da Ibiapaba, a Superfície Sertaneja e os Planaltos Residuais Cristalinos; e como unidades morfológicas distintas em cada morfoesculturas. Diante destes pressupostos o presente trabalho colabora com uma pesquisa de cunho exploratório que serve como base para futuras investigações científicas na temática do mapeamento geomorfológico. O objetivo foi caracterizar três níveis taxonômicos do relevo e morfométrico do município de Viçosa do Ceará, Ceará.

Palavras-chave: Morfologia; Taxonomia do Relevo; Índices Morfométricos

CARACTERIZACIÓN MORFOMÉTRICA Y GEOMORFOLÓGICA EM EL MUNICIPIO DE VIÇOSA DO CEARÁ, CEARÁ, BRASIL

La ciencia geomorfológica tiene como objetivo estudiar las formas del relieve en la superficie terrestre y explicar su formación y génesis. Para representar las formas geomorfológicas se utiliza la cartografía, en este caso, el mapeo geomorfológico. Como método de jerarquización del relieve se tomó como base a Ross (1992); para la caracterización morfométrica se empleó el Modelo Digital de Elevación (MDE) del ALOS PALSAR con resolución espacial de 12 metros para los mapas de hipsometría, pendiente y el Índice de Disecación del Relieve (IDR), y para la Curvatura Vertical se utilizó el proyecto TOPODATA que empleó el MDE de la misión SRTM. Para la clasificación y sistematización de las unidades morfológicas se tomó como referencia el trabajo de Dantas, Lacerda y Maia (2023). El municipio de Viçosa do Ceará presenta morfoestructuras de la Cuenca Sedimentaria del Parnaíba y los Dominios de Escudos y Macizos Antiguos; como morfoesculturas, la Cuesta de Ibiapaba, la Superficie Sertaneja y los Altiplanos Residuales Cristalinos; y unidades morfológicas distintas en cada morfoescultura. Bajo estos supuestos, el presente trabajo contribuye a una investigación de carácter exploratorio que sirve como base para futuros estudios científicos en la temática del mapeo geomorfológico. El objetivo fue caracterizar tres niveles taxonómicos del relieve y morfométricos del municipio de Viçosa do Ceará, Ceará.

Palabras-clave: Morfología; Taxonomía del Relieve; Índices Morfométricos

INTRODUCTION

Geomorphology is a field within geographic science that studies landforms, seeking to understand, explain, and predict the formation and genesis of Earth's surface features and their evolution over time. The guiding element of this research will be landforms. According to Falcão Sobrinho (2007), landforms represent a category of abstraction, materialized as the foundation of human activities, whether in engineering, agriculture, or urban planning. One of the specialized approaches is geomorphological mapping.

Rodrigues (2010) emphasizes that the cartographic product results from field surveys and observations, cartographic representation techniques, document analysis, visual language, and ultimately the interpretation, publication, and final printing of the map. For this purpose, it is necessary to understand the genesis, the different scales of landforms, and their chronology (Ross, 1992). In this context, the present research aims to characterize the taxonomic levels of relief and the morphometry of the municipality of Viçosa do Ceará, Ceará, Brazil.

MATERIALS AND METHODS

In this section, the study area and the methodological procedures of the present research are addressed and presented.

STUDY AREA

The municipality of Viçosa do Ceará covers an area of approximately 1,310.91 km². Located in the northern part of the Ibiapaba Plateau, it encompasses the backslope, the plateau, and the front (scarp), and finally the sertaneja surface (Figure 1).

Since part of the area is located to the west, within the Northern Ibiapaba Plateau, with average altitudes ranging from 750 to 800 meters, it forms part of the border of the Parnaíba Sedimentary Basin (Souza, 2006) to the west, and to the east the Sertaneja Depression (or Sertaneja Surface) along with other geomorphological components such as ridges, hillocks, and residual massifs (Souza; Lima; Paiva, 1979).

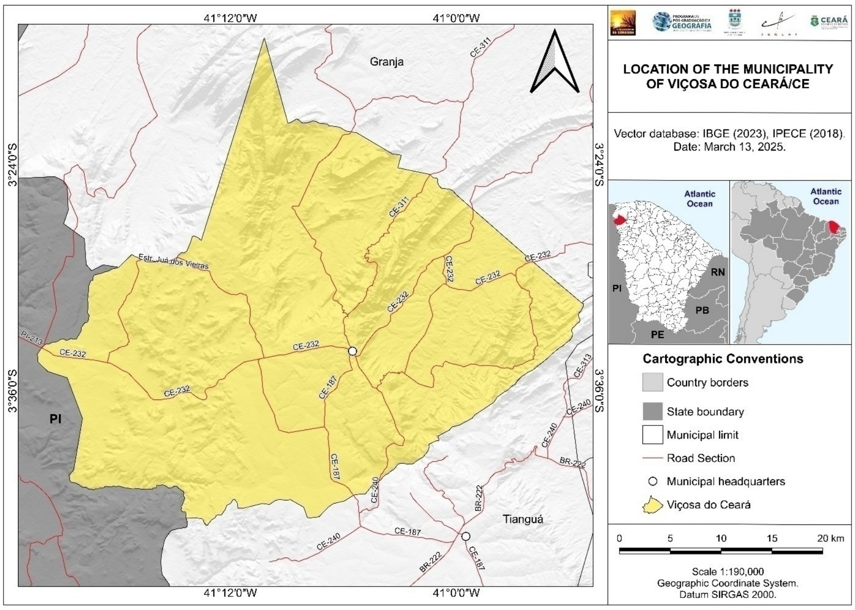

Figure 1 - Location of the study area. Source: Organized by the authors based on the continuous bases of Brazil (IBGE, 2023) and the municipal seats (IPECE, 2018), produced using the GIS software QGIS® Desktop 3.34.9.

It is important to emphasize that natural elements are in a continuous process of evolution based on their dynamics, and relief is no exception to this interaction. Each geomorphological unit presents particularities in its formation and degradation over time. In addition to mechanical erosive processes on the sertaneja surface and the backslope, and chemical processes on the front and the plateau, other erosional processes may also be observed.

METHODOLOGICAL PROCEDURES

The present study is based on the hierarchy of landforms proposed by Ross (1992). For morphometric indices such as relief dissection, the method of Guimarães et al. (2017) was applied; for vertical curvature, data from the TOPODATA project of the National Institute for Space Research (INPE, 2011) were used, along with the Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM). To characterize the morphological units, the approach of Dantas, Lacerda, and Maia (2023) was adopted.

The research has an exploratory character, in which the problem was addressed through the following stages: first, a bibliographic review, including monographs, dissertations, theses, books, and journals related to the central theme of the research; second, fieldwork, which identified the study area as well as the application of the taxonomic methodology, followed by office-based analysis; and third, the technical treatment of the research, carried out in the office, which consisted of the methodological procedures for organizing the geomorphological and topographic maps, with the support of software tools, to be cross-checked with the fieldwork (Figure 2).

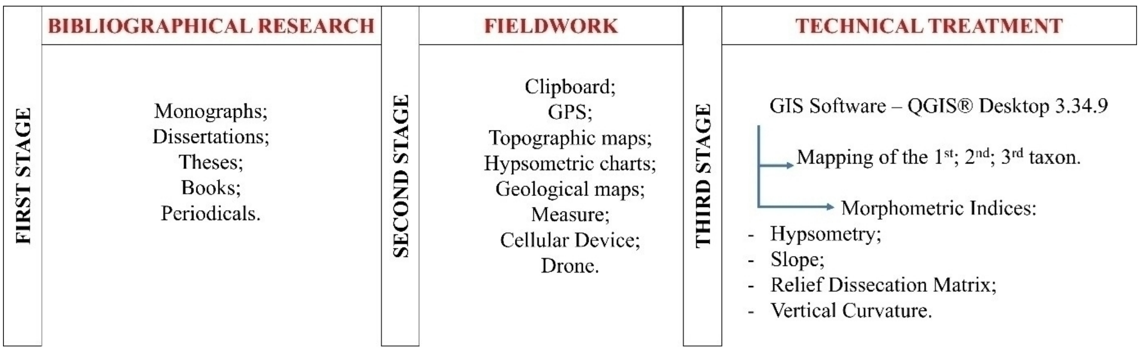

Figure 2 - Flowchart of the research stages. Source: Organized by the authors (2025).

The method used for the hierarchy of landforms was the Relief Taxonomy proposed by Ross (1992), in which:

•The 1st taxon corresponds to the Morphostructural Units, a broader taxon defined by structural characteristics and a specific pattern of major landforms.

•The 2nd taxon refers to the Morphosculptural Units, a smaller taxon resulting from climatic action over geological time within the morphostructure.

•The 3rd taxon corresponds to the Morphological Units or Patterns of Similar Forms, in which current morphoclimatic processes become more easily observed.

For cartographic purposes, the morphological units identified are those presented in Table 1. The working scales used for the mapping were 1:200,000, applied to landform units from the 1st to the 3rd taxon.

Relief units pattern	Predominant amplitudes (m)	Predominant slopes
Escarpment	> 300 m	58-100%. Walls >100%
Plateau	0 a 20m	0-5%
Dissected Plateau	20 a 200m	3-9%
Low Plateau	0 a 20 m	3-9%
Subtop (Step)	10 a 50m	5-18%
Incised Valley	> 50 m	36-100%. Walls >100%
Conserved Sertaneja Surface	0 a 10m	0-9%
Tabuleiro	20 a 50 m	9-47%
Fluvial Terrace	2 a 20m	0-5%
Fluvial Plain	0	0-5%
Residual Massifs	> 300 m	36-100%. Walls >100%
Ridges	100 a 300m	36-100%. Walls >100%
Inselberg	40 a 100m	18-58%

Tabela 1 - Morphometric Criteria for Mapping the 3rd Taxon. Source: Adapted from Dantas, Lacerda, and Maia (2023).

RESULTS AND DISCUSSION

This section presents the results of the morphometric characterization proposed in the methodological procedures and the taxonomic mapping of the landforms of the municipality of Viçosa do Ceará – CE, achieved in line with the research objectives.

MORFHOMETRIC CHARACTERIZATION OF MUNICIPALITY OF VIÇOSA DO CEARÁ – CE

This section presents the morphometric indices that were characterized and developed for the study area, including hypsometry, slope, the Relief Dissection Index (RDI), and vertical curvature. These morphometric indices were necessary as one of the criteria for classifying the taxonomic units of the study area, in addition to providing quantitative information on the shape and dynamics of the terrain. Figure 3, the hypsometric map, shows that the municipality has an altimetric range of approximately 700 meters.

Areas of lower altitude, between 100 and 300 meters, are found on the Sertaneja Surface. Among the Crystalline Residual Massifs, inselbergs, ridges, and the Espigão (Serra de São Joaquim), altitudes vary from 300 to 800 meters. In the Ibiapaba Sedimentary Plateau, the escarpment sectors range from 300 to 600 meters, while the subtop and top reach elevations between 600 meters and above 800 meters. However, altimetry decreases from 700 meters to 300 meters in altitude toward the Homoclinal Depression of the Sedimentary Plateau.

Slope (Figure 4), in turn, is shown as very gentle to gentle in the flatter areas of the municipality, particularly on the Sertaneja Surface and in the vicinity of the Ibiapaba Sedimentary Plateau. Average slopes are observed on the tops of certain landforms, such as the Crystalline Residual Massif Serra de Umari and the Homoclinal Depression of the Ibiapaba. Steep and very steep slopes are found on the escarpments of the Ibiapaba Sedimentary Plateau, as well as on the Crystalline Residual Massifs, inselbergs, ridges, and the Espigão Serra de São Joaquim.

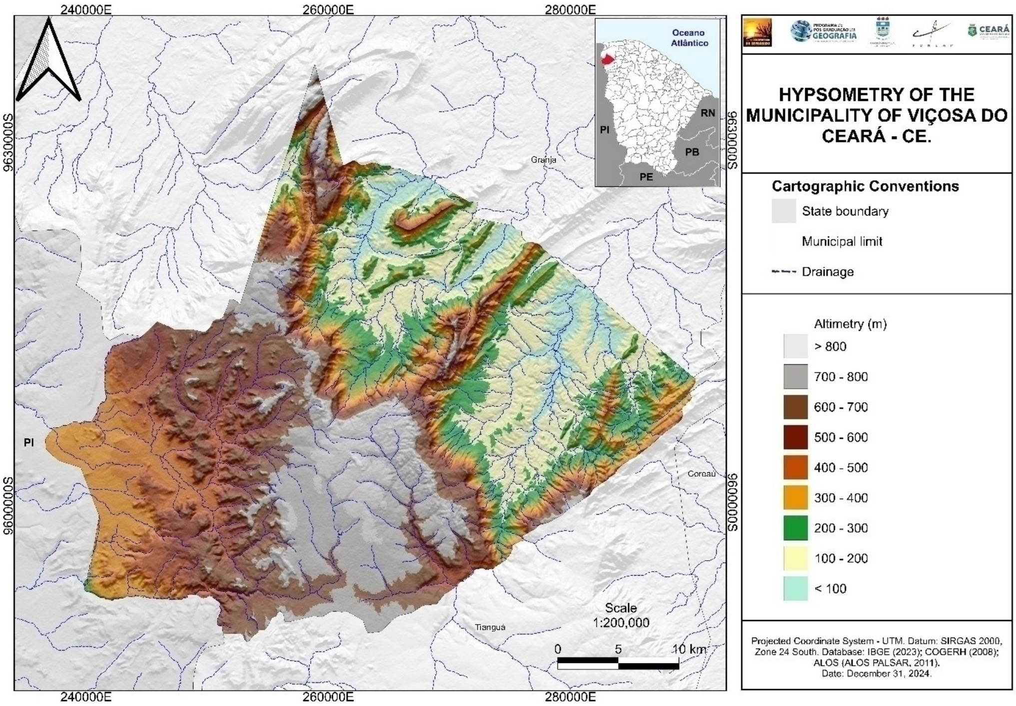

Figure 3 - Hypsometric map of the study area. Source: Organized by the authors based on the continuous databases of Brazil (IBGE, 2023) and the 12-meter ALOS Digital Elevation Model (ALOS PALSAR, 2011), produced using the GIS software QGIS® Desktop 3.34.9.

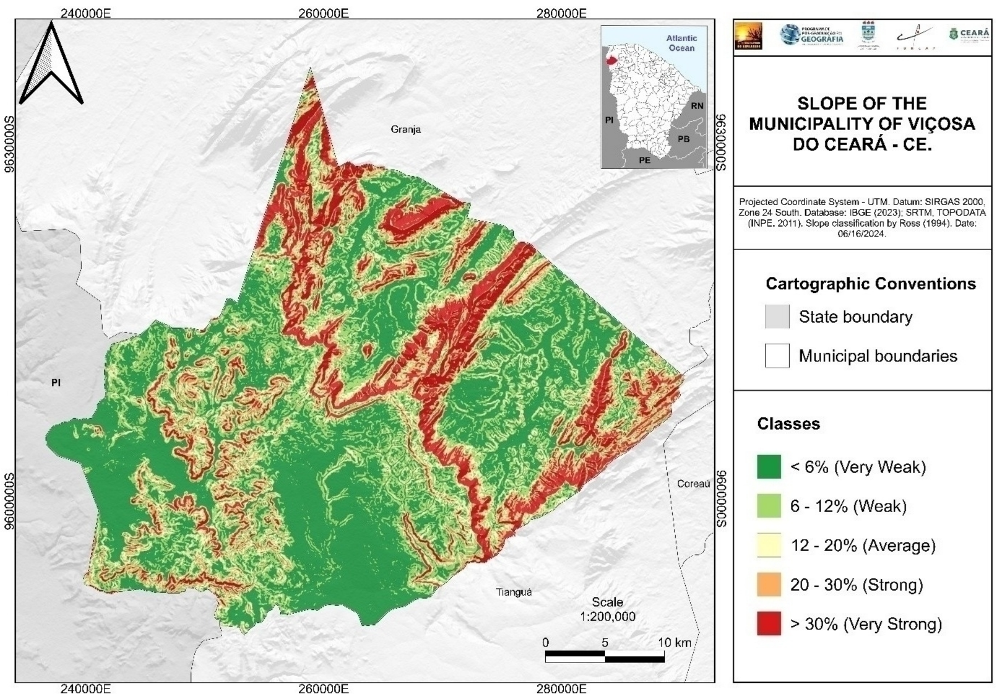

Figure 4 - Slope map of the study area. Source: Organized by the authors based on the continuous databases of Brazil (IBGE, 2023) and the 12-meter ALOS Digital Elevation Model (ALOS PALSAR, 2011). Slope classes were defined according to the method proposed by Ross (1994), produced using the GIS software QGIS® Desktop 3.34.9.

Figure 5 presents the Vertical Curvature, a variable that refers to the convex/concave nature of the terrain. It is related to the processes of water and sediment transport and accumulation across the soil surface, driven by gravity. It can be observed that convex tops and slopes have divergent drainage flow, where water moves in opposite directions from the central point.

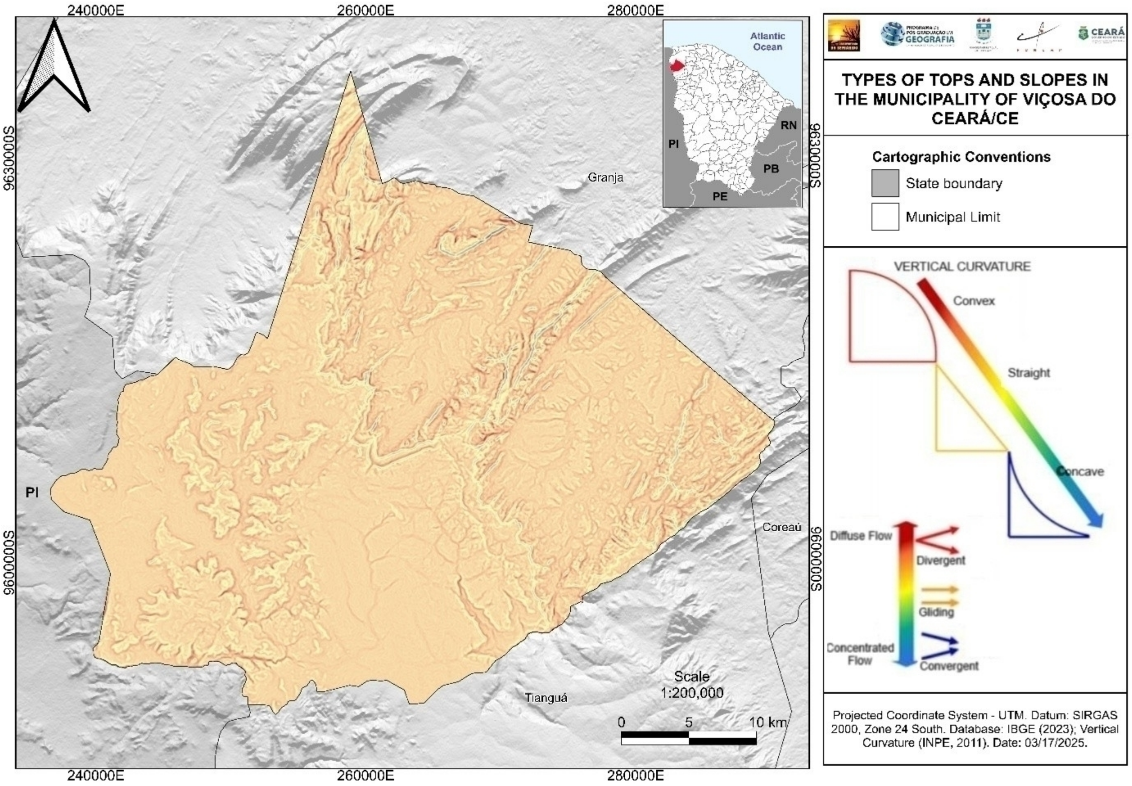

Figure 5 - Vertical curvature map of the study area. Source: Organized by the authors based on the continuous databases of Brazil (IBGE, 2023) and the Vertical Curvature digital model (INPE, 2011). Produced using the GIS software QGIS® Desktop 3.34.9.

Straight tops and slopes exhibit a planar flow, where water moves in a general direction without following a defined channel. Water spreads out rather than concentrating at a single point. In contrast, concave tops and slopes have concentrated drainage flow, where watercourses converge toward a central point, similar to a funnel.

This map was used as a basis for identifying types of tops and slopes. Vertical curvature was overlaid onto the Relief Dissection Matrix to define each vertical typology.

Figure 6 presents the Relief Dissection Index (RDI), which was calculated from the sum of the degree of vertical incision (Vertical Dissection) and the average interfluve dimension (Horizontal Dissection). In addition to overlaying vertical curvature to identify typologies of tops and slopes—convex (renamed as "sharp"), concave, and straight (renamed as "tabular")—it was necessary to overlay the map of morphological units to identify denudational and aggradational forms. This procedure allowed for the identification of the fluvial plain (fp) and the fluvial terrace (ft).

Some considerations regarding the creation of the RDI map are as follows. Even though the ALOS PALSAR Digital Elevation Model with a 12-meter spatial resolution was used, during the process of filling the drainage flow within the QGIS® GIS software, the final product consisted of sub-basins that presented errors, or "holes." When Vertical Dissection and Horizontal Dissection were calculated, the lowest Relief Dissection value obtained was 14. However, a value of 14 is still considered very high compared to the flatter areas of the study area, as shown in Figure 7.

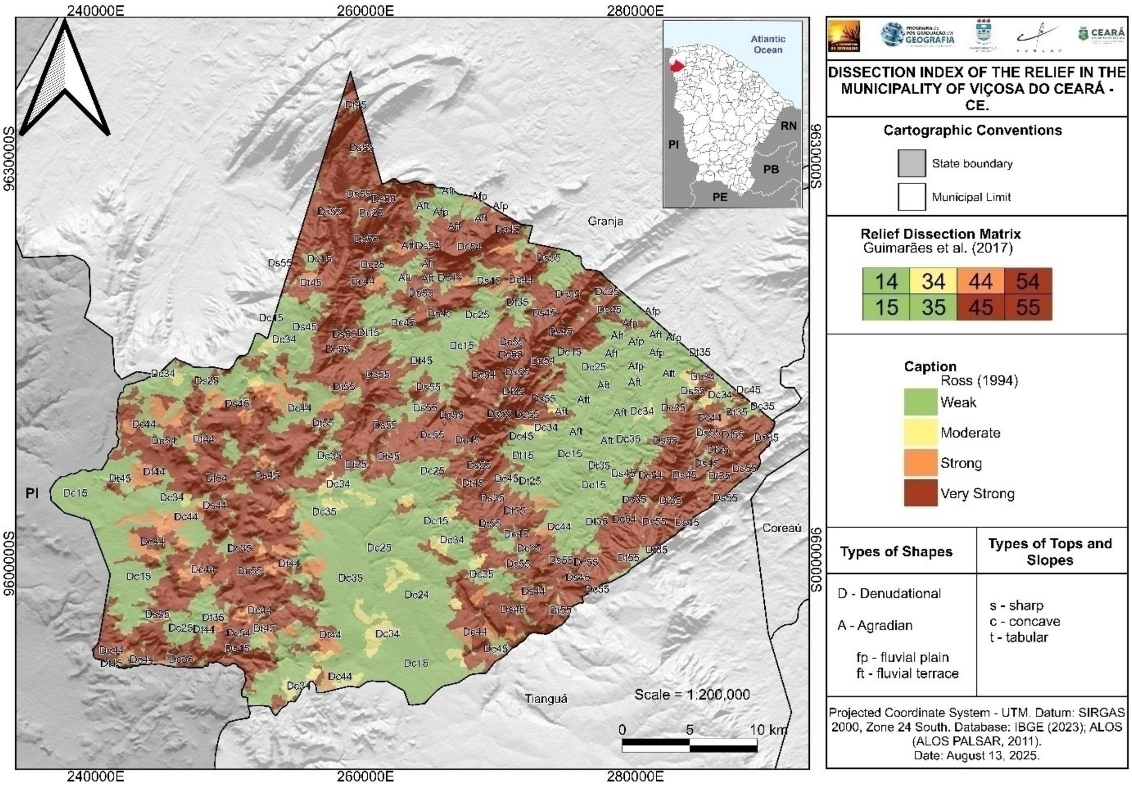

Figure 6 - Relief Dissection Index (RDI) map of the study area. Source: Organized by the authors based on the continuous databases of Brazil (IBGE, 2023), the 12-meter ALOS Digital Elevation Model (PALSAR, 2011), and adaptation of the method by Guimarães et al. (2017). Produced using the GIS software QGIS® Desktop 3.34.9.

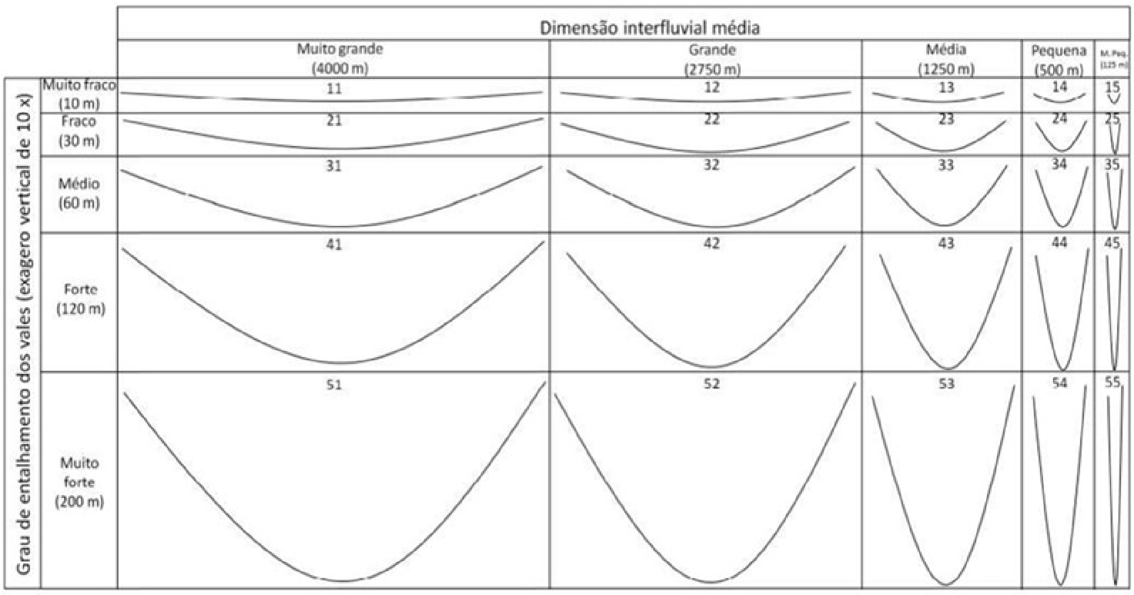

Figure 7 - RDI variables. Source: Adapted from Guimarães et al. (2017).

MORFHOSCTRUCTURAL, MORFHOSCULPTURAL AND MORPHOLOGICAL UNITS OF THE MUNICIPALITY OF VIÇOSA DO CEARÁ – CE

The municipality is composed of two Morphostructural Units (Figure 8): the Parnaíba Sedimentary Basin and the Domain of Ancient Shields and Massifs. The Parnaíba Sedimentary Basin is located to the west, with its boundary with the other morphostructure oriented SE-NW. It is part of a syncline that formed during pre-Silurian times (Brazil, 1981).

As previously mentioned, the area experienced post-Cretaceous epirogenesis due to the strong regional geological structure, and the centripetal drainage networks remained isolated (Ab'Saber, 1998; 2003). This led to the formation of two typical structural reliefs: the Cuesta with backslope, and the structural escarpments along the edges of the Sedimentary Basin, which were uplifted and subjected to complex circumdenudation processes, giving rise to a network of peripheral depressions.

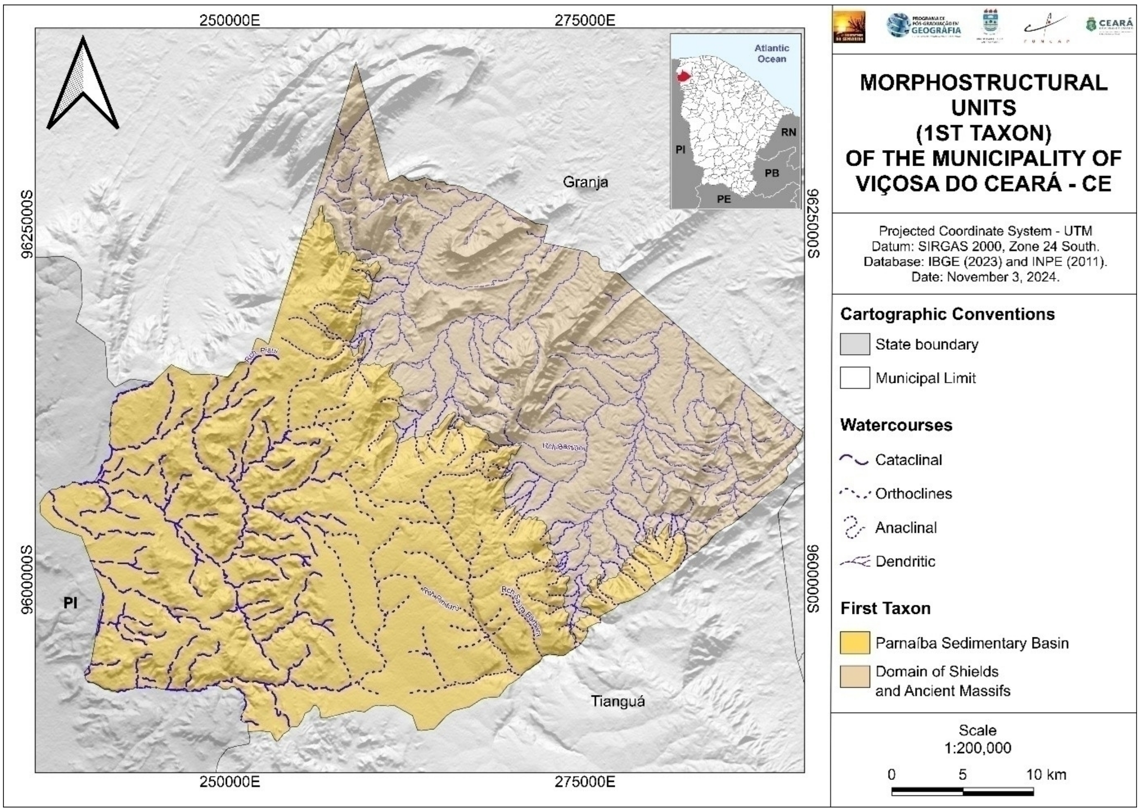

Figure 8 - Morphostructural Units of Viçosa do Ceará – CE. Source: Organized by the authors based on geospatial data from the Continuous Databases of Brazil (IBGE, 2023) and the Shaded Relief from TOPODATA (INPE, 2011). Produced using the GIS software QGIS® Desktop 3.34.9.

Therefore, it is characterized as a Concordant Inclined Structure, monocline or homoclinal, since its layers are superimposed with a slight inclination in a constant direction. Its edges produce sub-tabular and asymmetrical reliefs, the Cuestas (Penteado, 1983). This form will be further discussed under the morphosculptural units. The basal formation belongs to the Serra Grande Group (Brazil, 1981; Souza, 1988; Moura-Fé, 2015; Bastos et al., 2024), with the study area concentrating the Jaicós (Ssgj) and Tianguá (Ssgt) Formations.

According to Bastos et al. (2024), this sedimentary plateau divides hydrographic basins that drain different morphostructural contexts. In this case, the municipality of Viçosa do Ceará drains rivers and streams to the Parnaíba Basin on the backslope, and to the Coreaú Basin toward the erosive escarpment.

The next Morphostructural Unit is the Domain of Ancient Shields and Massifs, which comprises forms with lithologies dated to the Precambrian. These were products of the effects of remote tectonic events and reflect the relationship between morphology, lithological factors, and evidence of Cenozoic climatic fluctuations (Souza, 1988). According to Cavalcanti and Cavalcante (2014), this domain is part of the Middle Coreaú geological domain in the northwest of Ceará state, west of the Sobral-Pedro II Shear Zone.

Also known as the Transbrasiliano Lineament, it represents the junction of the São Luís-West African craton and a succession of terrains between the Central Hoggar and Central Ceará–Jaguaribe regions (Brito Neves, 1999; Matos, 2000). It corresponds to the denudational forms of the crystalline basement and will be addressed in the morphosculptural taxa.

Thus, the Morphosculptural Units (Figure 9) in the municipality's territory are arranged into three units: the Ibiapaba Cuesta, the Sertaneja Surface, and the Crystalline Residual Plateaus.

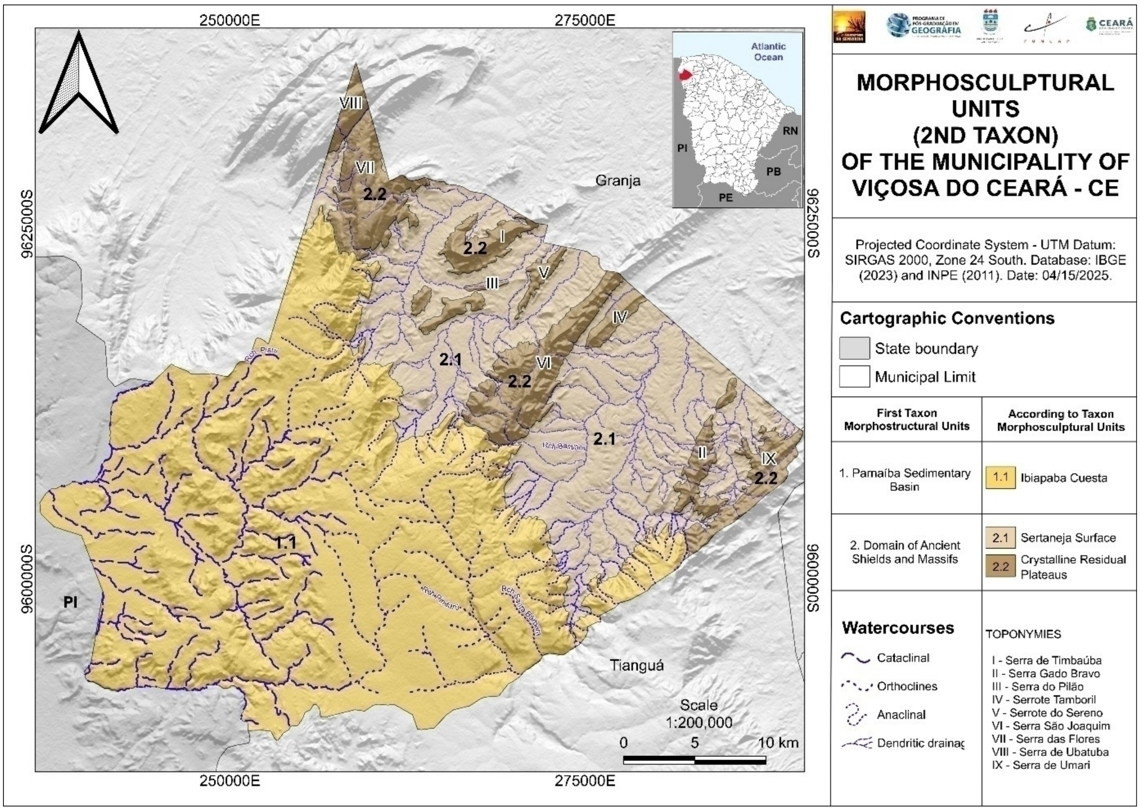

Figure 9 - Morphosculptural Units of Viçosa do Ceará – CE. Source: Organized by the authors based on geospatial data from the Continuous Databases of Brazil (IBGE, 2023) and the Shaded Relief from TOPODATA (INPE, 2011). Produced using the GIS software QGIS® Desktop 3.34.9.

Since the concept of a plateau is a general term for structures with sedimentary and crystalline elevations, the eastern edge of the Parnaíba Sedimentary Basin morphosculptural unit, as previously mentioned, is referred to as a Cuesta. This is because it is an asymmetrical form: to the east, there is a festooned escarpment or front with indentations and protrusions, as well as ridge forms; to the west, the backslope is asymmetrical toward the state of Piauí, sculpted over geological time through climatic variations.

It is noteworthy that the drainage channels in the municipality of Viçosa do Ceará correspond to four types: Anaclinal, Cataclinal, Dendritic, and Orthoclinal. On the Cuesta front, the pattern is Anaclinal (Obsequent), forming a dense and branched network, deepened by the regressive erosion of the plateau escarpment; elements such as the cornice and talus are observed. On the Cuesta top, the pattern is Orthoclinal (Subsequent), with drainage running parallel to the bedding direction and perpendicular to the dip. The backslope is composed of Cataclinal (Consequent) drainage, following the inclination of the asymmetrical bedding, cutting into resistant layers and forming gorges that may evolve into canyons (Penteado, 1988; Guerra & Guerra, 2008; Moura-Fé, 2015). On the Sertaneja Surface, drainage is Dendritic, with watercourses branching over the crystalline terrain (Guerra & Guerra, 2008).

Current morphoclimatic processes are perceptible in the Morphological Units, which are part of the third taxon. Among the morphological units present in the municipality of Viçosa do Ceará (Figure 10), the following are notable: the Escarpment, Plateau, Subtop (Step), Dissected Plateau, Low Plateau, and Incised Valley within the morphosculptural unit of the Ibiapaba Cuesta; the Conserved Sertaneja Surface, Tabuleiro, Fluvial Terrace, and Fluvial Plain in the morphosculptural unit of the Sertaneja Surface; and the Residual Massifs, Ridges, Inselbergs, and Colluvial Deposits in the morphosculptural unit of the Crystalline Residual Plateaus.

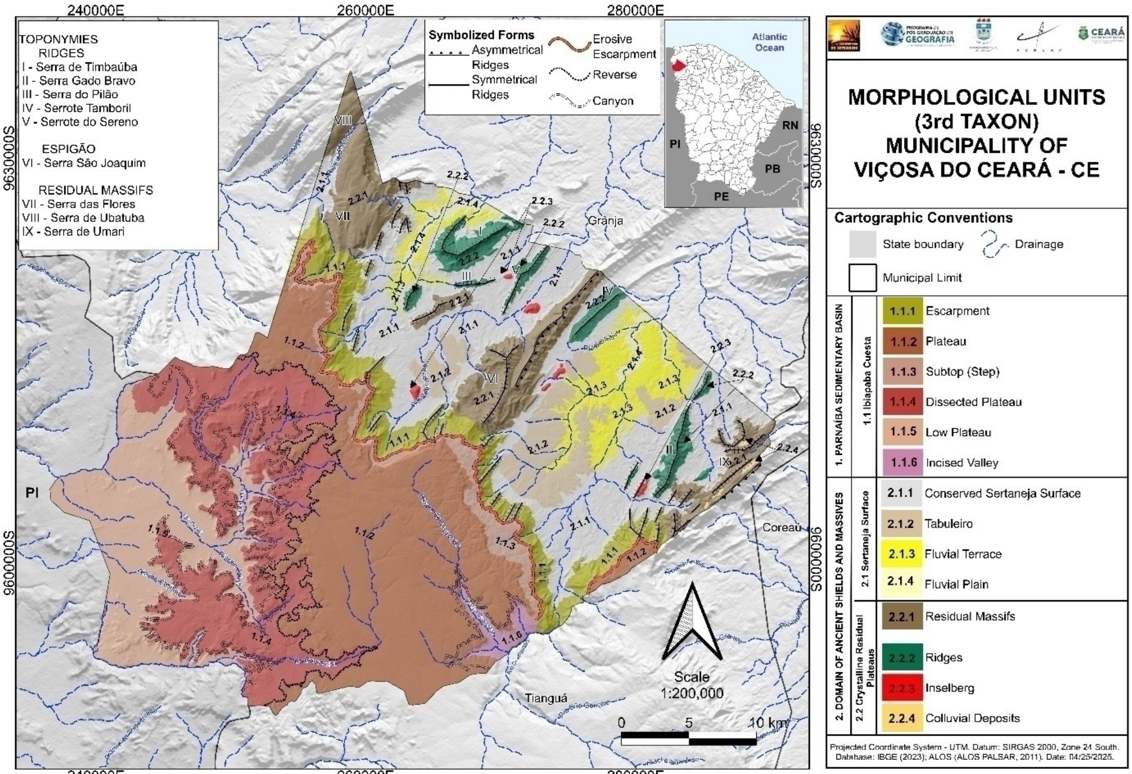

Figure 10 - Morphological Units of Viçosa do Ceará – CE. Source: Organized by the authors based on geospatial data from the Continuous Databases of Brazil (IBGE, 2023) and the Shaded Relief from TOPODATA (INPE, 2011). Produced using the GIS software QGIS® Desktop 3.34.9.

The Ibiapaba Cuesta (Figure 11), in addition to the previously mentioned forms, also contains forms that cannot be delineated as lines in geomorphological mapping products. These include the backslope, which is a homoclinal depression with a slight dip toward the state of Piauí, west of the Ibiapaba Plateau; the canyons present in the cataclinal rivers of the backslope and in the fluvial valley of the Boqueirão stream in the orthoclinal rivers on the plateau; and the erosive escarpment.

Figure 11 - Panoramic view of the Ibiapaba Cuesta at the municipal seat of Viçosa do Ceará – CE. Source: Authors’ collection (2024).

The Step feature is located on the subtop of the Cuesta, as it represents a terrace between the escarpment and the next Plateau feature, shaped like a table extending toward the indentations and the Ibiapaba Protuberance in Viçosa do Ceará. On the step, Yellow Latosol was observed (Figure 12).

Figure 12 - Yellow Latosol on the steps of the Church of Heaven in Viçosa do Ceará – CE. Source: Authors’ collection (2024).

Next, asymmetrically in relation to the backslope, there is the Dissected Plateau, shaped by the erosive action of rivers and streams, which can form canyon features due to the cataclinal drainage mentioned earlier. There is also a Low Plateau area with a terrace, featuring a flattened top different from the Dissected Plateau. It is also worth noting, within the morphosculpture of the Ibiapaba Cuesta, the erosive action of the Cataclinal rivers such as the Gameleira and Piranji Rivers, the Jabuti and Brejinho streams, as well as the Boqueirão stream on the plateau, which gave rise to the canyons (Figure 13).

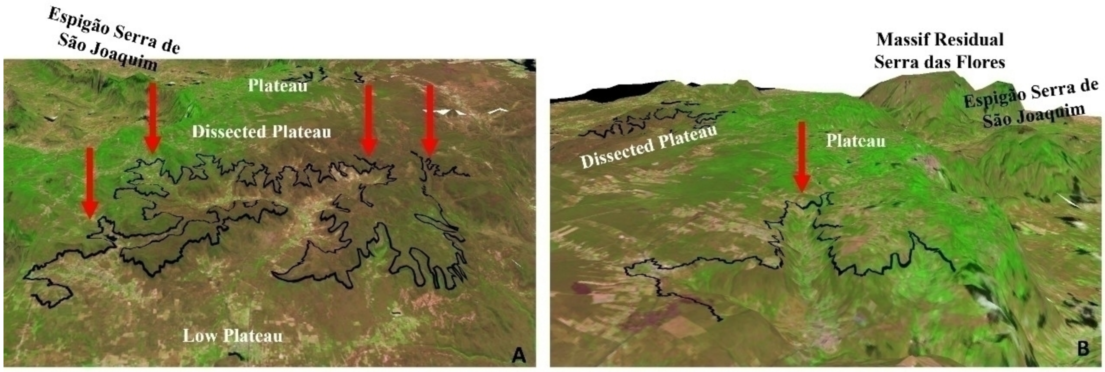

Figure 13 - Three-Dimensional Model of the Canyons of Viçosa do Ceará: Canyons of the Homoclinal Depression (A) and the Boqueirão Stream Canyon (B). Source: Organized and produced by the authors (2025) using the GIS software QGIS® Desktop 3.34.9, via the Qgis2threejs plugin, with radar images from the ALOS satellite (PALSAR, 2011) at 10-meter spatial resolution and Landsat 8 images (2024) at 30-meter spatial resolution.

A canyon is a deep or incised valley that exhibits typical features when cutting through sedimentary structures with little horizontal displacement (Guerra & Guerra, 2008). This Incised Valley is perceptible between the Plateau and Step units through the tributary streams of the Boqueirão stream. It is a large gorge with a marked difference between the thalweg and the top of the sedimentary plateau; the slopes are steep, and vertical erosion predominates.

The Ibiapaba Cuesta ends toward the homoclinal depression (backslope) from east to west. To the east lies the escarpment, which may include cornices and talus (Penteado, 1988). Cornices were observed at several points in the field, including a road connecting the municipal districts to the municipal seat, located on the Step (Subtop), locally known as Pedra do Itagurussu (Figure 14).

Pedra do Itagurussu (A) is part of the cornice, and its lithology belongs to the Jaicós Formation. Chemical weathering is evident (C), with water acting as a solvent on the sandstone, and biological weathering is observed through lichens and mosses decomposing the rock.

The very steep slope of the Cuesta escarpment prevents human appropriation of the relief, which contrasts with other landforms where slope allows occupation and use. At Pedra do Itagurussu, the sandstone serves as a stopping point for drivers, observed in the field, who use the water retained and overflowing from the rock to wash vehicles. The vegetation is no longer typical dry forest (Mata Seca) but Pluvio-Nebular Forest (B), featuring a dense canopy and tall arboreal species characteristic of dry forest and caatinga.

On the Sertaneja Surface (Figure 15), the Conserved Sertaneja Surface is observed, comprising a diverse complex of igneous-metamorphic rocks, as previously mentioned, covered by caatinga vegetation. It consists of dissected pediplains crossed by a dendritic drainage network, with Fluvial Terraces and Plains, and pediments located near the peripheral depression of the Ibiapaba Cuesta, referred to as Tabuleiros. The basal lithology belongs to the Granja Complex of the Paleoproterozoic and the Covão, Santa Terezinha, and São Joaquim Formations (Martinópole Group) of the Neoproterozoic.

Figure 14 - Pedra do Itagurussu (A), cornice of the Jaicós Formation; Pluvio-Nebular Forest (B); geochemical dissolution processes by water and biological weathering by mosses and lichens (C); measuring tape as scale, 91 cm (D). Source: Authors' collection (2024).

Figure 15 - Conserved Sertaneja Surface. Source: Authors' collection (2024).

Terraces are horizontal surfaces with a slight slope, composed of fluvial sediments (alluvial deposits), and are interrupted by a continuous incline when located near Fluvial Plains, where aggradational processes prevail over degradation. These features can be observed along the Timonha and Quatiguaba Rivers; they are marshy areas with limited access during the rainy season, but small-scale cultivation of sugarcane and carnauba palms occurs there (Figure 15).

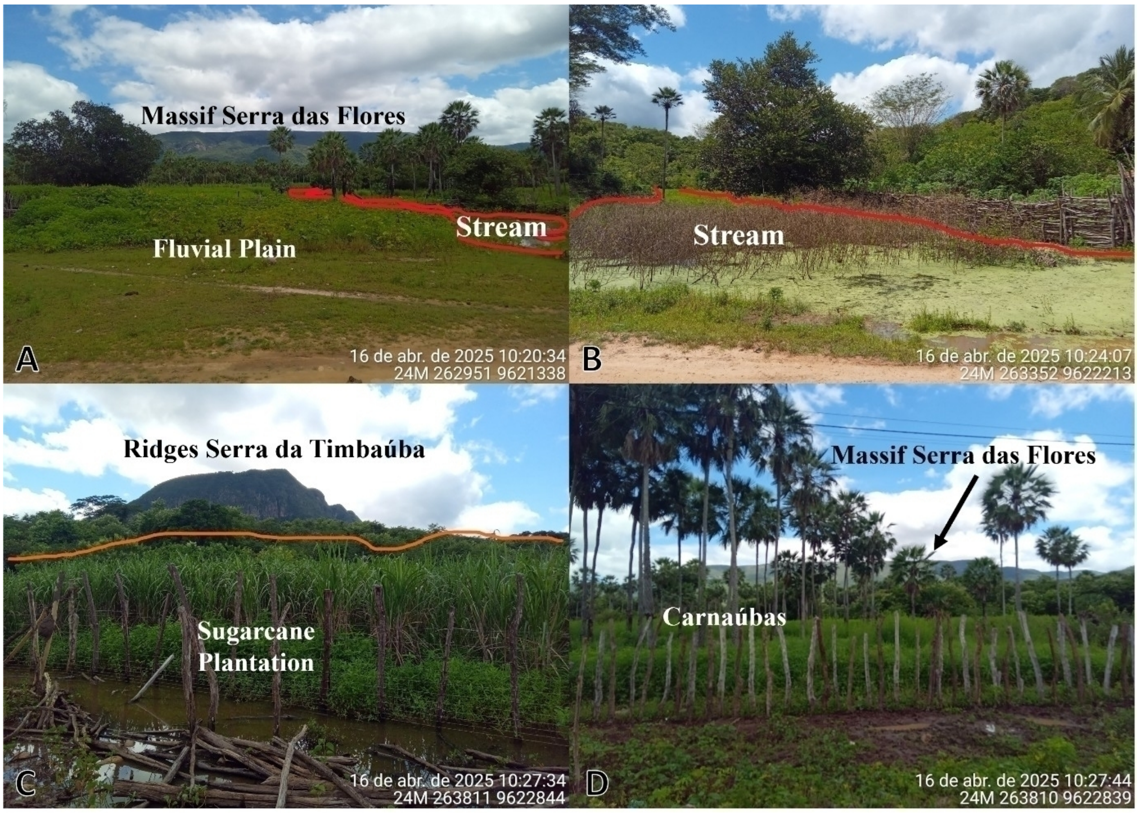

Figure 16 - Fluvial Plain (A); Tributary of the Boqueirão River (B); Small Sugarcane Plantation (C); Carnauba Palms (D). Source: Authors' collection (2025).

The Tabuleiros are associated with the plateau tops, exhibiting a typical mesa-like shape. According to Moura-Fé (2015), they are composed of the lithological substrate of sedimentary alluvial-spread cover and sediments from the Barreiras Group. They are isolated from each other by linear erosion from the dendritic drainage and have low altimetric variation.

The geomorphological features of the Residual Massifs include the Serras das Flores, Ubatuba, and Umari—where colluvial areas occur, referred to as Colluvial Deposits; the Ridges include the Serras da Timbaúba, Gado Bravo, Pilão, Tamboril, and do Sereno; and the São Joaquim Ridge (Figure 17).

As previously mentioned in the topographic profiles, the lithological base of these features belongs to the São Joaquim Formation of the Martinópole Group (Neoproterozoic), which also forms the basal part of the Ibiapaba Cuesta, while the structure is referred to as a Glint, but as a landform, it is a cuesta. Additionally, some areas of the São Joaquim Ridge exhibit lithologies of the Granja Complex (Paleoproterozoic).

The Residual Massif Serra das Flores is located northeast of the municipal seat of Viçosa do Ceará. The Residual Massif Serra de Ubatuba is situated behind Serra das Flores, with the municipal boundary cutting across only a small triangular area.

The Residual Massif Serra de Umari is located to the southeast, along the boundary between Viçosa do Ceará and Tianguá. It was reshaped during Cenozoic climatic fluctuations as a result of erosive and dissection processes. Symbolized forms are observed on the tops of symmetrical ridges, created by erosive work over geological time, influenced by the hardness and softness of the rocks.

Figure 17 - Panoramic aerial photographs of the Ibiapaba Sedimentary Plateau (A; B), the São Joaquim Ridge (C), and CE 311. Source: Authors' collection (2024; 2025).

Due to this characteristic, Serra de Umari features V-shaped fluvial valleys, reflecting the erosive action of the upper course of the Carnaubinha stream, which has intermittent drainage. In addition, colluvial areas are present on some parts of the ridge top, referred to as the Colluvial Deposits morphological unit, incised into valleys with sediment deposits between them.

The Gado Bravo Ridge is located northeast of the Residual Massif Serra de Umari and also exhibits a symmetrical ridge, an elongated relief with steep slopes that intersect to form a continuous line. The same feature is observed in other ridges, such as Serra de Timbaúba, Serra do Sereno, and Serra do Pilão, located north of the São Joaquim Ridge.

The São Joaquim Ridge is a dorsal morphology of the mountain range, with cliffed edges along the ridge. It extends to the municipality of Granja, totaling approximately 29 km from the base of the cuesta to its end in Granja. At the top, there are two ridge forms: a symmetrical one to the east, and an asymmetrical one to the west near the Ibiapaba Cuesta, which is more elongated and steep, with a distinct escarpment forming a ridge bundle. Erosive processes are also noticeable on the rocks in different areas (Figure 18).

Mechanical, biological, and chemical erosive processes occur in some areas of the ridge due to differences in elevation and climatic factors. Mechanical processes (A) occur along the ascent of CE 311, which runs over the São Joaquim Ridge. This happens because the rock is fractured by physical weathering, breaking in vertical, horizontal, and transverse directions; in this area, the climate is drier. Chemical erosive processes (B) are related to the exposure of rocks to water, which dissolves minerals, weakens the rocks, and facilitates erosion.

The origin of the morphological units within the morphosculpture of the Sertaneja Surface and the Crystalline Residual Plateaus is influenced by two factors. The first is differential erosion, where lithologies more resistant to erosion form topographic prominences. The second factor is control by the reactivation of shear zones, which caused subsidence and uplift along the Brasiliano deformation planes, giving rise to a landscape noticeably influenced by structural lineament trends (Maia & Bezerra, 2014).

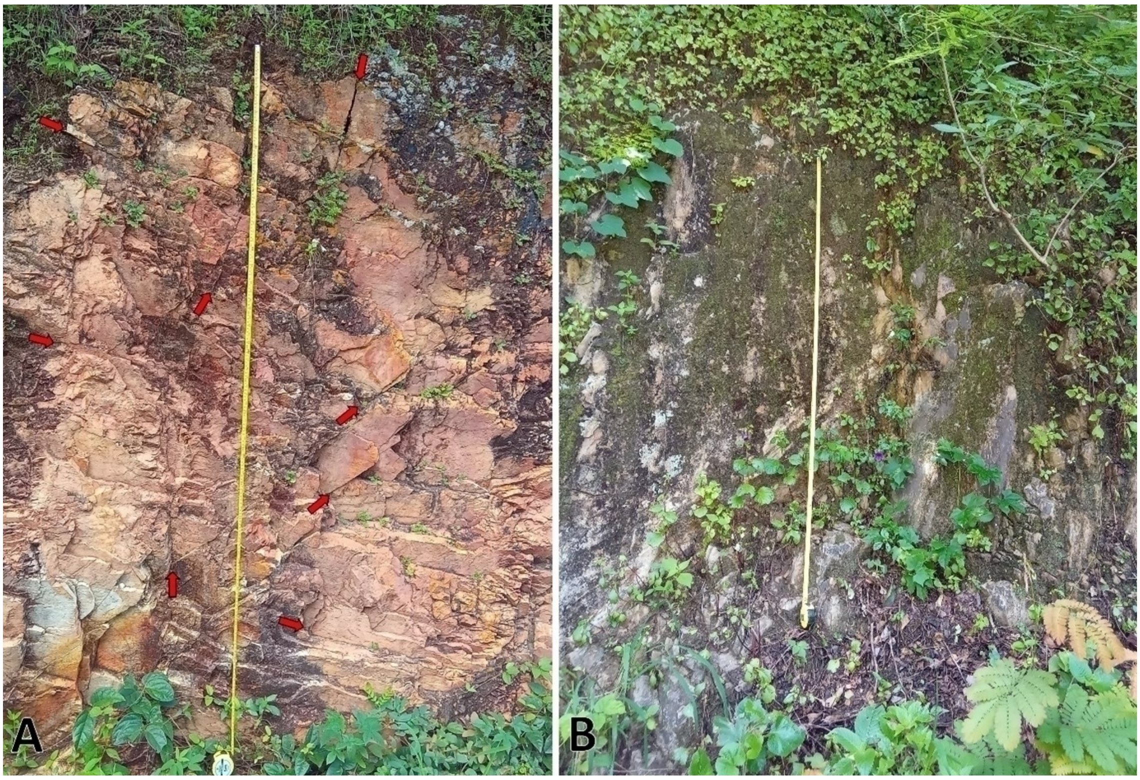

Figure 18 - Mechanical (A) and chemical (B) erosive processes on the São Joaquim Ridge. Source: Authors' collection (2024).

CONCLUSION

The municipality of Viçosa do Ceará – CE presents morphostructures of the Parnaíba Sedimentary Basin and the Domains of Shields and Ancient Massifs; morphosculptures include the Ibiapaba Cuesta, the Sertaneja Surface, and the Crystalline Residual Plateaus; and morphological units are as follows: in the Ibiapaba Cuesta, Escarpment, Plateau, Step (Subtop), Dissected Plateau, Low Plateau, and Incised Valley; in the Sertaneja Surface, Conserved Sertaneja Surface, Tabuleiros, Fluvial Terraces, and Fluvial Plains; and in the Crystalline Residual Plateaus, Residual Massifs, Ridges, Inselbergs, and Colluvial Deposits.

These features represent a diverse landscape from a geomorphological point of view within the municipality. Morphometric characteristics are also highlighted, such as an altimetric range of approximately 700 meters; slopes range from very gentle and gentle in the flatter areas of the municipality, especially on the Sertaneja Surface and near the Ibiapaba Sedimentary Plateau, and medium in other geomorphological features; vertical curvature allowed the observation of diffused, concentrated, and planar flows on the types of summits and slopes; and the Dissection Index (IDR) presented methodological challenges.

Even when using the ALOS PALSAR DEM with a spatial resolution of 12 meters, during the drainage flow filling process in the GIS software, the final product contained half-basins with gaps, or "holes." When vertical and horizontal dissection were calculated, the lowest relief dissection value was 14. However, 14 is still a very high dissection compared to the flatter areas of the study area. This demonstrates the need to improve the criteria for drainage flow procedures using a new tool or plugin in QGIS®. Based on these premises, the present study contributes to exploratory research and provides a foundation for future scientific investigations on the topic of geomorphological mapping.

ACKNOWLEDGMENTS

The authors acknowledge the Cearense Foundation for Scientific and Technological Development Support (FUNCAP) for the master's scholarship that enabled the research

DATA AVAILABILITY

Not applicable.

REFERENCES

AB'SABER, A. N. Os domínios de natureza no Brasil: potencialidades paisagísticas. São Paulo: Ateliê Editorial, 2003.

AB'SABER, A. N. Megageomorfologia do Território Brasileiro. In: CUNHA, S. B.; GUERRA, A. J. T. (Org.) Geomorfologia do Brasil. Rio de Janeiro: Bertrand Brasil, 1998.

BASTOS, F. de H.; SIAME, L.; LIMA, D. L. de S.; CORDEIRO, A. M. N. Lithostructural control of the relief in the eastern sector of the Parnaíba sedimentary basin (Ibiapaba Plateau), Northeast Brazil. Revista Brasileira de Geomorfologia, [S. l.], v. 25, n. 4, 2024. DOI: 10.20502/rbgeomorfologia.v25i4.2589. Disponível em: https://rbgeomorfologia.org.br/rbg/article/view/2589. Acesso em: 17 fev. 2025.

BRASIL. Folha SA.24 Fortaleza: geologia, geomorfologia, pedologia, vegetação e uso potencial da terra. Rio de Janeiro: Projeto RADAMBRASIL, 1981.

BRITO NEVES, B. B. AMERICA DO SUL: QUATRO FUSÕES, QUATRO FISSÕES E O PROCESSO ACRESCIONÁRIO ANDINO. Revista Brasileira de Geociências, n. 29, p. 379-392, 1999.

CAVALCANTI, J. A. D.; CAVALCANTE, J. C. Evolução Geológica. In: BRANDÃO, R. L.; FREITAS, L. C. B. (Org.) Geodiversidade do estado do Ceará. Fortaleza: CPRM, 2014.

DANTAS, M. E.; LACERDA, A.; MAIA, M. A. M. Guia de procedimentos técnicos do Departamento de Gestão Territorial: elaboração de cartas de padrão de relevo multiescala. Brasília: Serviço Geológico do Brasil – CPRM, v. 7, 2023.

GUERRA, A. T.; GUERRA, A. J. T. Novo Dicionário geológico-geomorfológico. Rio de Janeiro: Bertrand Brasil, ed. 6, 2008.

FALCÃO SOBRINHO, J. Relevo e paisagem: proposta metodológica. Sobral: Sobral Gráfica, 2007.

GUIMARÃES, F. S.; CORDEIRO, C. M.; BUENO, G. T.; CARVALHO, V. L. M.; NERO, M. A. Uma proposta para automatização do Índice de Dissecação do Relevo. Revista Brasileira de Geomorfologia, [S. l.], v. 18, n. 1, 2017. DOI: 10.20502/rbg.v18i1.1163. Disponível em: https://rbgeomorfologia.org.br/rbg/article/view/1163. Acesso em: 8 abr. 2024.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE. Bases Contínuas Cartográficas do Brasil (escala 1:250.000) [shapefile]. Rio de Janeiro: IBGE, 2023. Acesso em: 04 de jul. 2024. Disponível em: https://www.ibge.gov.br/geociencias/cartas-e-mapas/bases-cartograficas-continuas/15759-brasil.html?=&t=downloads.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS – INPE. Curvatura Vertical da Folha 03S42 [imagem matricial]. São José dos Campos: INPE, 2011. Acesso em: 04 de jul. 2024. Disponível em: http://www.dsr.inpe.br/topodata/acesso.php.

INSTITUTO DE PESQUISA E ESTRATÉGIA ECONÔMICA DO CEARÁ – IPECE. Sedes municipais (escala 1:600.000) [shapefile]. Fortaleza: IPECE, 2018. Acesso em: 01 de jul. 2024. Disponível em:

http://mapas.ipece.ce.gov.br/i3geo/ogc/index.php.

LANDSAT. Imagem de Satélite Landsat 8 do município de Viçosa do Ceará [imagem matricial]. Virgínia: USGS, 2024. Acesso em: 04 de fev. 2025. Disponível em: https://earthexplorer.usgs.gov/.

MAIA, R. P.; BEZERRA, H. H. R. CONDICIONAMENTO ESTRUTURAL DO RELEVO NO NORDESTE SETENTRIONAL BRASILEIRO. Mercator, Fortaleza, v. 1, pág. 127 a 141, abr. 2014. ISSN 1984-2201. Disponível em: . Data de acesso: 10 maio 2025.

MATOS, R. M. D. Tectonic evolution of the Equatorial South Atlantic, in W. Mohriak and M. Talwani, editors, Atlantic Rift on Continental Margins. AGU Geophysical Monograph, 115, p. 331-354, 2000.

MOURA-FÉ, M. M. Evolução Geomorfológica da Ibiapaba Setentrional, Ceará: Gênese, Modelagem e Conservação. 2015, p. 307. Tese (Doutorado) – Universidade Federal do Ceará, Centro de Ciências, Departamento de Geografia, Programa de Pós-Graduação em Geografia, Fortaleza, 2015.

PENTEADO, M. M. Fundamentos de Geomorfologia. Rio de Janeiro: IBGE, 3 ed., 1983.

RODRIGUES, S. C. CARTOGRAFIA E SIMBOLOGIA GEOMORFOLÓGICA: EVOLUINDO DA CARTOGRAFIA TRADICIONAL PARA O USO DE SIMBOLOGIA DIGITAL. Revista Brasileira de Geomorfologia, [S. l.], v. 11, n. 1, 2010. DOI: 10.20502/rbg.v11i1.136. Disponível em: https://rbgeomorfologia.org.br/rbg/article/view/136. Acesso em: 16 maio 2025.

ROSS, J. L. S. Análise empírica da fragilidade dos ambientes naturais e antropizados. Revista do Departamento de Geografia, n. 8, p. 63-74, 1994. DOI: https://doi.org/10.7154/RDG.1994.0008.0006. Disponível em: https://revistas.usp.br/rdg/article/view/47327. Acesso em: 18 ago. 2024.

ROSS, J. L. S. O REGISTRO CARTOGRÁFICO DOS FATOS GEOMORFOLÓGICOS E A QUESTÃO DA TAXONOMIA DO RELEVO. Revista do Departamento de Geografia, São Paulo, Brasil, v. 6, p. 17–29, 1992. DOI: 10.7154/RDG.1992.0006.0002. Disponível em: https://www.revistas.usp.br/rdg/article/view/47108. Acesso em: 18 ago. 2024.

SOUZA, M. J. N. Contexto Geoambiental do Semi-Árido Cearense: Problemas Perspectiva. In: FALCÃO SOBRINHO, J.; COSTA FALCÃO, C. L. (Org.). Semi-Árido: Diversidades, Fragilidades e Potencialidades. Sobral: Sobral Gráfica, 1 ed., 2006.

SOUZA, M. J. N.; LIMA, F. A. M.; PAIVA, J. B. COMPARTIMENTAÇÃO TOPOGRÁFICA DO ESTADO DO CEARÁ. Revista Ciência Agronômica, n. 9, p. 77-86, 1979.

Author's Affiliation

Silva, J.B. - Vale do Acaraú State University, Sobral (CE), Brazil
Falcão Sobrinho, J. - Professor at Vale do Acaraú State University, Sobral (CE), Brazil
Rodrigues, S.C. - Professor at Federal University of Uberlândia, Uberlândia (MG), Brazil
Diniz, S.F. - Professor at Vale do Acaraú State University, Sobral (CE), Brazil

Authors' Contribution

Silva, J.B. - The author contributed to the elaboration, realization and manipulation of the data and writing
Falcão Sobrinho, J. - The author contributed to the elaboration, realization and manipulation of the data and writing
Rodrigues, S.C. - The author contributed to the elaboration, realization and manipulation of the data and writing
Diniz, S.F. - The author contributed to the elaboration, realization and manipulation of the data and writing

Editors in Charge

Alexandra Maria Oliveira
Alexandre Queiroz Pereira