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Nota técnica

Mapping relief units and geosites of Seridó UNESCO Global Geopark, Northeastern Brazil

Mapeamento de unidades de relevo e geossítios do Seridó Geoparque Mundial da UNESCO, Nordeste do Brasil

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Abstract: The Seridó UNESCO Global Geopark (SUGG) was approved in 2022. In all, the Geopark has 21 geosites, the main interest of which is geomorphological. Despite the importance of the geomorphological heritage in the SUGG territory, the area had not yet been mapped on a scale suitable for geoconservation actions by the SUGG technical staff and its scientific committee. The present work aims to identify landforms up to the fourth taxon, corresponding to types of relief forms, according to Ross's (1992) methodological proposal for the geomorphological mapping of Brazil. Landform hierarchy was established following the morphological taxon typology proposed by the RadamBrasil Project and described by Ross (1992). The first three taxons correspond to those of Diniz et al. (2017) for the Rio Grande do Norte geomorphological map. However, for this study, the fourth taxon was added. This scale and taxonomic level were considered suitable for geoconservation actions. Maps are also presented at higher taxonomic levels, with less detail, which are more suitable for geoeducation activities with schoolchildren in the SUGG territory.

Keywords: Geodiversity; Geomorphological Mapping; Geoheritage.

Resumo: O Seridó Geoparque Mundial da UNESCO (SGMU) foi chancelado em 2022. Ao todo, o Geoparque conta com 21 geossítios, cujo principal interesse é geomorfológico. Apesar da importância do patrimônio geomorfológico no território do SGMU, a área ainda não havia sido mapeada em escala adequada para ações de geoconservação pela equipe técnica do SGMU e seu comitê científico. O presente trabalho tem como objetivo identificar formas de relevo até o quarto táxon, correspondentes a tipos de formas de relevo, conforme proposta metodológica de Ross (1992) para o mapeamento geomorfológico do Brasil. A hierarquia de formas de relevo foi estabelecida seguindo a tipologia de táxons morfológicos proposta pelo Projeto RadamBrasil e descrita por Ross (1992). Os três primeiros táxons correspondem aos de Diniz *et al.* (2017) para o mapa geomorfológico do Rio Grande do Norte. No entanto, para este estudo, o quarto táxon foi adicionado. Essa escala e nível taxonômico foram considerados adequados para ações de geoconservação. Os mapas também são apresentados em níveis taxonômicos mais altos, com menos detalhes, que são mais adequados para atividades de geoeducação com crianças em idade escolar no território do SUGG.

Palavras-chave: Geodiversidade; Mapeamento geomorfológico; Geopatrimônio.

1. Introduction

Landform mapping is crucial for understanding landscape dynamics and providing a basis for implementing more realistic conservation policies. Surveying relief forms in different scales leads to landscape representations that highlight the relationship between the geological structural framework and surface processes, thus providing a spatial platform for overlapping other landscape elements. Furthermore, the growing access to free high-resolution imagery resulted in more detailed hence more applicable geomorphological mapping products.

The landforms of Rio Grande do Norte, Northeast of Brazil, have been first mapped to the third hierarchical taxon (morphological units) by Diniz *et al*. (2017) at 1: 250,000. The present work aims to identify landforms up to the fourth taxon, corresponding to types of relief forms, according to Ross's (1992) methodological proposal for the geomorphological mapping of Brazil.

In 2022, UNESCO approved the designation of the Seridó UNESCO Global Geopark in the semi-arid Northeast of Brazil, acknowledging the uniqueness of the territory's geological, biogeographical, and cultural heritages. The Geopark comprises 21 geosites in diverse geomorphological settings, encompassing residual plateaus, structural ridges, pediments, and canyonlands. Nonetheless, the area lacks the mapping of its landforms at an adequate scale for conservation and planning purposes. Hence, this research sought to elaborate a landform map for the Seridó UNESCO Global Geopark (SUGG) at the scale of 1:50,000. This mapping can be used to determine where and how landform conservation policies should be applied to planning or development applications.

This work is an effort to improve the supply of data for planning the SUGG. Recently, researchers from the SUGG's scientific committee proposed a mapping of the area's use and occupation units (BERNARDINO *et al*., 2023), and this study is now being presented by the same committee, considering that the work is fundamental for understanding the geomorphology of the SUGG's territory, as well as its geosites.

2. Materials and Methods

The following tasks were undertaken to accomplish the landform mapping of the SUGG: 1) a thorough bibliographic and cartographic review of various archives containing information regarding the relief and other landscape elements of the study area; 2) elaboration of the landform map in a GIS platform; 3) validation of remote sensing imagery and GIS mapped relief units by visiting and photographing the landforms directly in the field.

The first step to define the geomorphic units of the SUGG was the delimitation of the study area in the geomorphological map of Rio Grande do Norte, elaborated by Diniz et al. (2017) at 1:250,000, where forms were identified to the morphological units level (ROSS, 1992). Other reference materials, such as the geomorphological map of the Jardim do Seridó Topo Map at 1: 100 000 (VASCONCELOS et al., 2019) and of the Seridó region at 1: 100,000 were consulted (VITAL; SANTOS; SANTOS, 2021).

The geological framework of the SUGG was defined by fieldwork validation of the geological units of the Rio Grande do Norte Geological Map (ANGELIM; MEDEIROS; NESI, 2006), at 1: 500,000, as well as the geological surveyings of the following localities at 1:100,000, Jardim do Seridó (LEGRAND et al., 2009), Picuí (CAVALCANTE et al., 2018), Currais Novos (MEDEIROS et al., 2012) and Santa Cruz (OLIVEIRA; CUNHA, 2014).

Landforms were mapped initially by using the altimetric data from Alos' Palsar sensor with a spatial resolution of 12.5 m. In a GIS platform, images acquired in the WGS 1984 datum were converted to SIRGAS 2000 (Geographical Coordinates System). An image mosaic was composed to generate a sole raster layer to produce support cartographical material for the landforms mapping, such as slope gradient, terrain aspect, and contour lines.

Landform hierarchy was established following the morphological taxon typology proposed by the RadamBrasil Project and described by (1992). The first three taxons correspond to those of Diniz et al. (2017) for the Rio Grande do Norte geomorphological map. However, for this study, the fourth taxon was added. The used morphological taxons are described as follows:

1°) Morphostructural Units – defined by the megastructures that condition the regional landforms;

2°) Morphosculptural Units – result from the interactions between tectonic and climatic processes upon the lithostructural framework conditioning the morphological evolution of landforms;

3°) Morphosculptural sub-units – sets of landforms individualized within the morpho-sculptural units due to their distinctive morphologies and planform texture patterns;

4º) Relief Units– morphologies organized by their genetic properties, such as planation, dissolution, aggradational, or dissection forms (ROSS; MOROZ-CACCIA GOUVEIA, 2002).

The color palette applied to the map was based on the Technical Handbook in Geomorphology (IBGE, 2009) proposal. Orange tones of the original color chart were replaced for contrast enhancement by pink and brown ones, applied for fold-belt structures, and yellow for Quaternary aggradational landforms. Fieldwork was conducted to validate and adjust the mapping procedures, particularly remote sense imagery interpretation of relief units.

According to the geomorphological map of Diniz et al. (2017), the first three landform taxons were identified for the SUGG. Following, morphologies corresponding to the fourth taxon were added at a 1:50 000 scale in ArcGIS 10.3. Further information from SRTM data analysis, such as the spatial extension of the mapped units and altimetric range, among others, were combined in a landform attributes spreadsheet.

3. Results

The SUGG was approved by UNESCO's International Geoscience and Geoparks Programme on the 13th of April of 2022. Its territory is entirely situated within the State of Rio Grande do Norte (RN), Northeast of Brazil, in a region known as the Seridó Potiguar, roughly delimited by the coordinates 4º50'S to 7º00' S and 35º00' W to 38º30'W.

The territory of the SUGG encompasses the municipalities of Acari, Carnaúba dos Dantas, Cerro Corá, Currais Novos, Lagoa Nova, and Parelhas. The area is dominated by semi-arid climates with 8 to 10 dry months yearly (DINIZ; PEREIRA, 2015). The area lies within the River Piranhas-Açu watershed, whose regime is intermittent.

The first, second, third and fourth geomorphology taxon maps of the SUGG with the geosites located are shown in figures 1, 2, 3 and 4 respectively.

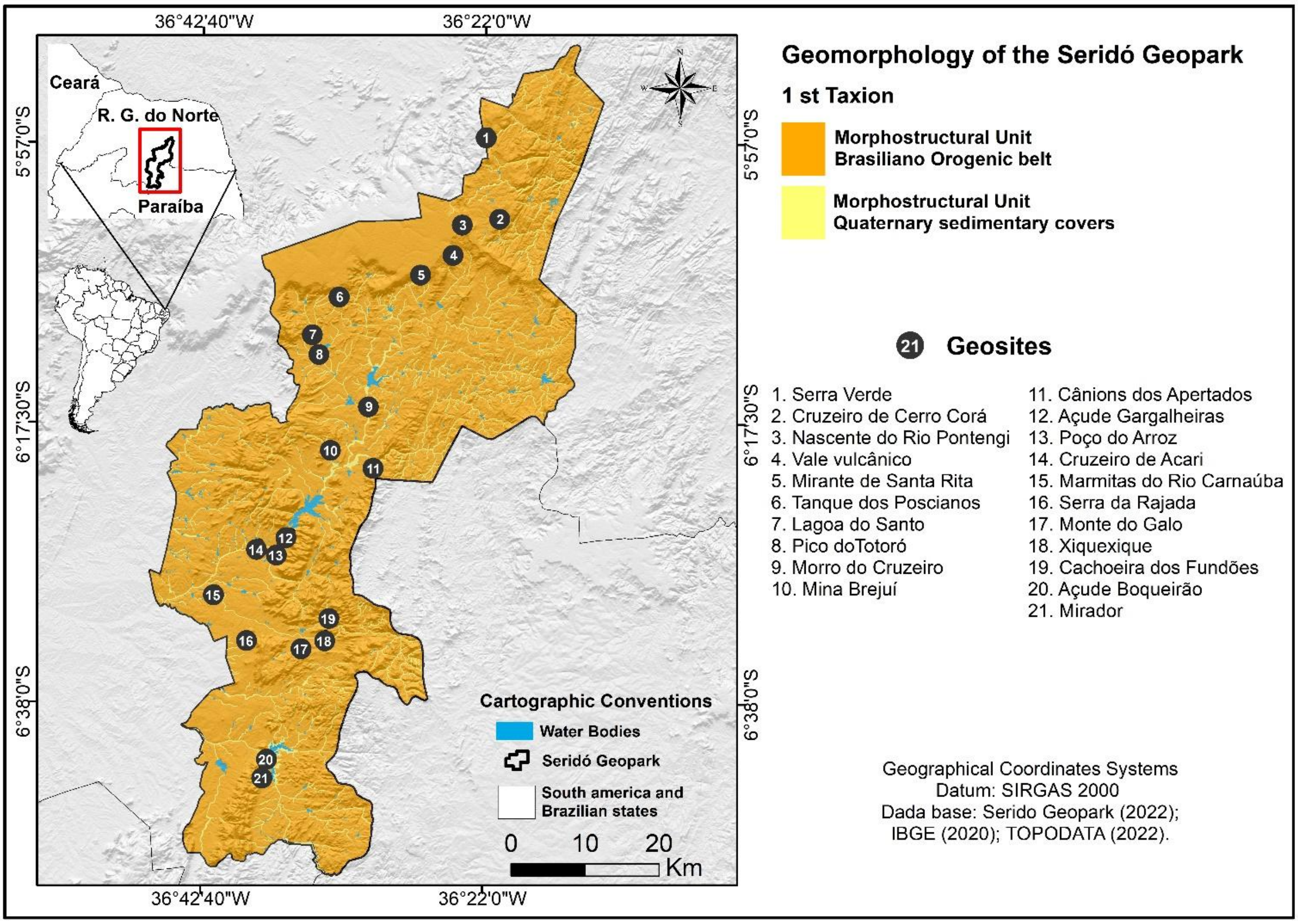


Figure 1. Map of morphostructural units of the Seridó UNESCO Global Geopark showing the two morphostructural units identified (geographical coordinate system). A colorful map showing the two morphostructural units of the SUGG and the location of its 21 geosites. There is a small figure locating the study area on the South American continent. **Source:** elaborated by the authors.

The maps related to the first and second taxon can be used in geoeducation activities with primary school students in the GUSS territory, bringing them closer to geomorphology in a broader way, while the maps of the third and fourth taxon show geomorphological details that are better suited to secondary and higher education students, as well as being useful for use in geoconservation strategies.

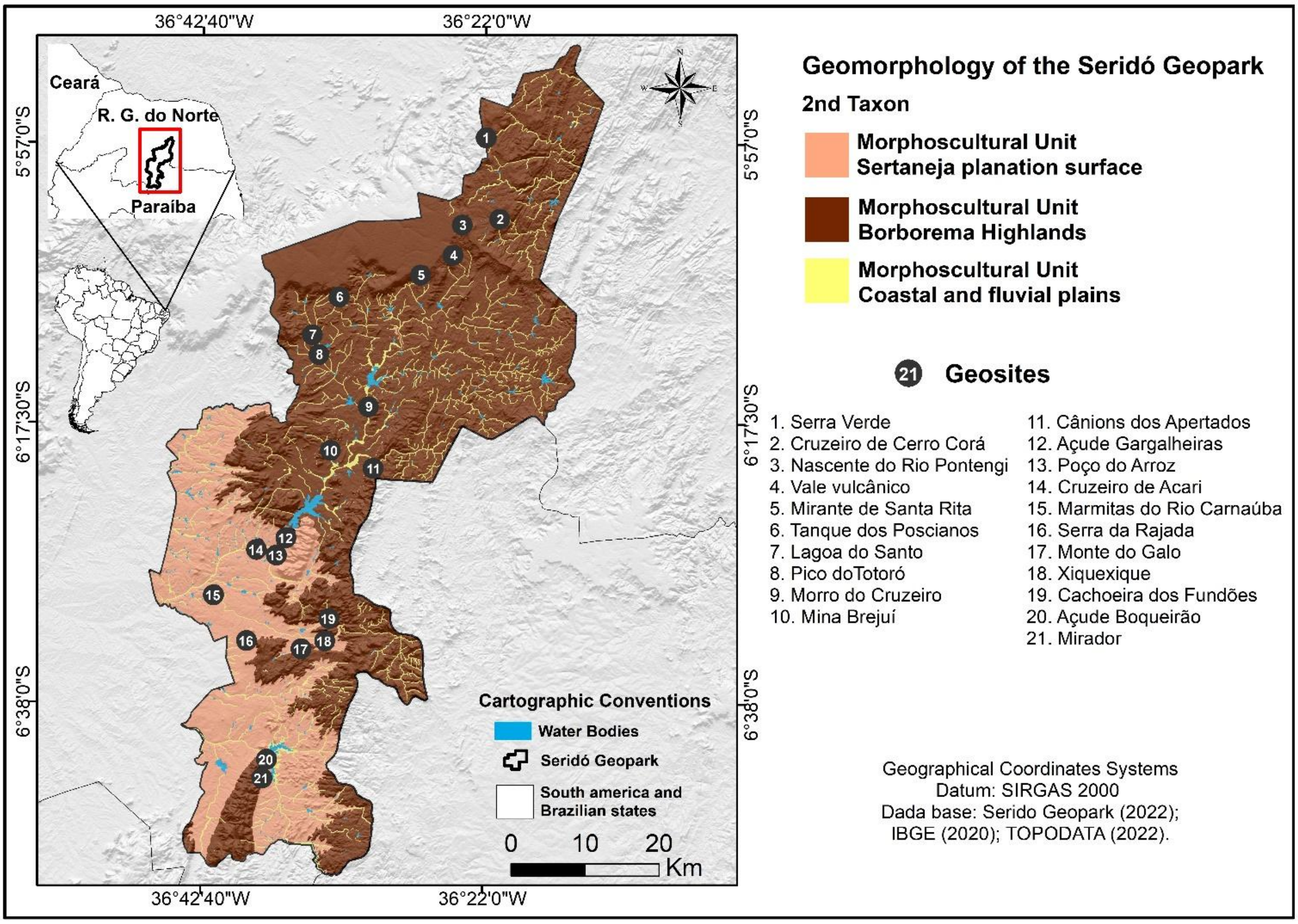


Figure 2. Map of morphoscultural units of the Seridó UNESCO Global Geopark showing the three morphoscultural units identified (geographical coordinate system). A colorful map showing the three morphoscultural units of the SUGG and the location of its 21 geosites. There is a small figure locating the study area on the South American continent. **Source:** elaborated by the authors.

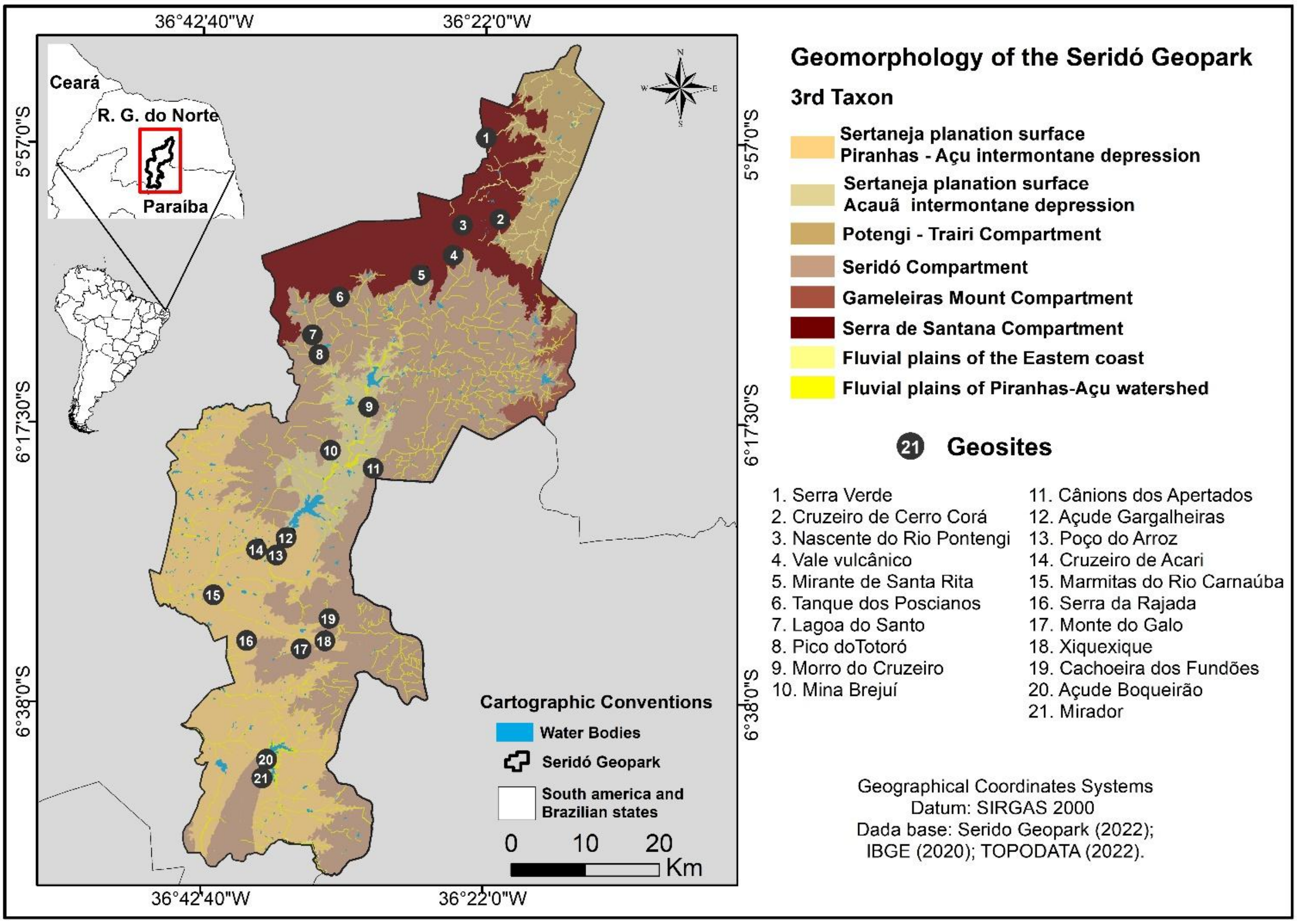
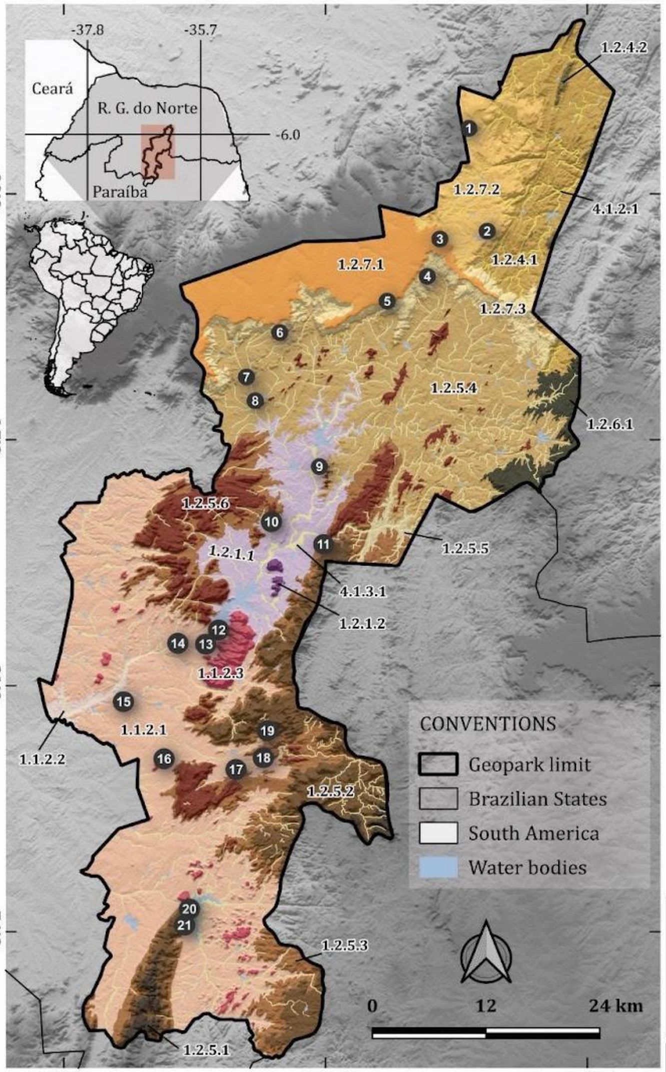


Figure 3. Map of morphoscultural sub-units of the Seridó UNESCO Global Geopark showing the 8 morphocultural sub-units identified (geographical coordinate system). A colorful map showing the 8 morphoscultural sub-units of the SUGG and the location of its 21 geosites. There is a small figure locating the study area on the South American continent. **Source:** elaborated by the authors



1st Taxon Morphostructural Unit	2nd Taxon Morphosculptural Unit	3rd Taxon Morphosculptural Sub-unit	4th Taxon Relief Units	
Brasiliano Orogenic Belt (1)	Sertaneja Planation Surface (1.1)	Sertaneja Planation Surface Piranhas-Açu intermontane depression (1.1.2)	Seridó 2 Pediplain (240 to 360m)	1.1.2.1
			Seridó 1 Pediplain (below 240 m)	1.1.2.2
			Inselbergs and residual massifs	1.1.2.3
	Borborema Highlands (1.2)	Acauã intermontane planation surface (1.2.1)	Acauã Pediment (below 350m)	1.2.1.1
			Acauã inselbergs and residual massifs	1.2.1.2
		Potengi-Trairi Compartment (1.2.4)	Potengi-Trairi compartment hillslopes (350 to 480m)	1.2.4.1
			Potengi inselbergs and residual massifs	1.2.4.2
		Seridó Compartment (1.2.5)	Summit surface above 750m	1.2.5.1
			Seridó compartment hillslopes (480 to 750m)	1.2.5.2
			Seridó compartment hillslopes (350 to 480m)	1.2.5.3
			Currais Novos pediplain (Pd 3 - 360 to 480m)	1.2.5.4
			Apertados pediment (below 350m)	1.2.5.5
			Inselbergs and residual massifs of the Seridó Compartment	1.2.5.6
		Gameleiras Mount Compartment (1.2.6)	Gameleiras Mount compartment hillslopes (480 to 750m)	1.2.6.1
		Serra de Santana Plateau Compartment (1.2.7)	Serra de Santana Plateau	1.2.7.1
			Dissected sedimentary Plateau	1.2.7.2
			Serra de Santana Plateau escarpment	1.2.7.3
Quaternary sedimentary covers (4)	Coastal and fluvial plains (4.1)	Fluvial plains of the Eastern coast (4.1.2)	Fluvial and lacustrine plains of the Potengi watershed	4.1.2.1
		Fluvial plains of the Piranhas-Açú watershed (4.1.3)	Fluvial and lacustrine plains of the Seridó watershed	4.1.3.1

21 Geosites

1. Serra Verde
2. Cruzeiro de Cerro Corá
3. Nascente do Rio Potengi
4. Vale Vulcânico
5. Mirante de Santa Rita
6. Tanque dos Poscianos
7. Lagoa do Santo
8. Pico do Totoró
9. Morro do Cruzeiro
10. Mina Brejuí
11. Cânions dos Apertados
12. Açude Gargalheiras
13. Poço do Arroz
14. Cruzeiro de Acari
15. Marmitas do Rio Carnaúba
16. Serra da Rajada
17. Monte do Galo
18. Xiquexique
19. Cachoeira dos Fundões
20. Açude Boqueirão
21. Mirador

Geographical Coordinates Systems - Datum: SIRGAS 2000 - Data base: Seridó Geopark (2022), IBGE (2020), TOPODATA (2022). The numeric sequencing of the geomorphic units follows the proposal of Diniz et al. (2017) for the geomorphological map of Rio Grande do Norte.

Figure 4. Map of relief units of the Seridó UNESCO Global Geopark showing the 19 relief units identified (geographical coordinate system). A colorful map showing the 19 relief units of the SUGG and the location of its 21 geosites. There is a small figure locating the study area on the South American continent. **Source:** elaborated by the authors.

4. Discussion

The SUGG lies in a geomorphologically complex sector of the Northern Northeast of Brazil, where relict and contemporary landscapes combine to produce an area of exceptional scenic beauty and unique landform diversity. From the morphostructural standpoint, the area is dominated by neoproterozoic foldbelt remnants associated with the Brazilian Orogeny from 800 to 500 Ma (BRITO NEVES; SANTOS; SCHMUS, 2000; BRITO NEVES; FUCK; PIMENTEL, 2014).

The outcropping lithologies correspond to the roots of an ancient Himalayan-style mountain range (CABY; ARTHAUD; ARCHANJO, 1995) distributed on a NE-SW trend. This old orogen marked the collage zone related to the assemblage of the West Gondwana continent. This plate convergence phase was also characterized by extensive magmatism and regional metamorphism, controlled by a dense network of faultlines and ductile to brittle shear zones (BRITO NEVES; SANTOS; SCHMUS, 2000). Millions of years after the Brazilian Orogeny, regional denudation placed rocks originally formed at depths exceeding tens of kilometers at the crust's surface.

In the Upper Cretaceous, approximately 130 Ma ago, a new phase of tectonic reactivation set in, this time under a distensive regime, which resulted in the rifting of the West Gondwana continent and the consequent separation between Africa and Eastern South America with the opening of the South Atlantic basin (MATOS, 1992). Regarding landforms, the reactivation brought about considerable changes to the landscape, promoting the uplift of the Borborema Highlands (CORRÊA et al., 2010; CORRÊA et al., 2019), a remarkable regional landform along the eastern seaboard of the Northeast of Brazil.

Tectonic events affecting the study area were not restricted to the Neoproterozoic or Cretaceous. The Cenozoic was characterized by several post-rift reactivation pulses linked to the intraplate magmatism (Macau magmatism) that affected the area (ALMEIDA et al., 1988; SILVEIRA, 2006; KNESEL et al., 2011; OLIVEIRA; MEDEIROS, 2012), as well as tectonic deformation that took place along Proterozoic shear zones (BEZERRA, 2011; BEZERRA et al., 2014). Such events promoted new episodes of uplifting that affected both the Borborema Highlands and the adjacent sectors, leading to the rearrangement of the drainage network and landform dissection patterns (CORRÊA et al., 2010; CORRÊA et al., 2019; OLIVEIRA; MEDEIROS, 2012; OLIVEIRA, 2019).

Within this context of tectonic reactivations and magmatism, occurring from the Proterozoic to the Cenozoic, the landforms of the SUGG reached their present geomorphic configuration. They represent the product of the interaction between the structural dynamics and shifting climatic patterns, the latter affecting the morphogenesis of the area well into the Upper Holocene. Hence, one must add to this picture the role of the climatically driven Quaternary depositional dynamics, concentrated primarily along riverbeds and colluvial hillslopes at the base of the area's main escarpments.

Two morphostructural compartments have been individualized within the first morphological taxon: the Brasiliano orogenic belt and the Quaternary surface coverings (Figure 1). In the second taxon, three morpho-sculptural units were identified (Figure 2) and further divided into eight morpho-sculptural sub-units representing the third taxon (Figure 3). Finally, eighteen relief forms were defined, corresponding to the fourth taxon (Figure 4).

Relief dissection in the studied area is considerably conditioned by the lithostructural framework, characterized by differences in resistance to erosion of the various lithologies and the spatial distribution of fault lines and Proterozoic shear zones, as well as the positioning of the Cenozoic intraplate magmatism.

The highest elevation compartments associated with the Borborema Highlands are located in the Brazilian Orogenic Belt sectors, where the litho-structural control variables over the relief play a more significant role. On surfaces where the post-rift deformational processes were less expressive, the drainage network was able to develop and cut through the interfluves, creating a set of erosive ramps at lower elevations with slope gradients lower than 7°, identified as pediments, which coalesce to form the morpho-sculptural unit of the Sertaneja Planation Surface (Figure 2). A level planation surface mainly characterizes this morpho-sculptural unit, the Rocky Pediplain with detrital coverings, subdivided into two relief units, a lower surface that reaches elevations up to 240 m and a higher one reaching elevations up to 360 m. In the latter, Geosite 13 (Figure 5), Poço do Arroz, is in outcrops of the Acari Granite. Both surfaces are dotted with residual reliefs, that is, inselbergs and inselberg fields, such as in Geosite 16 Serra da Rajada, Geosite 14 Cruzeiro de Acari and Geosite 17 Monte do Galo (Figure 5).

Figure 5. Geosite 13 Poço do Arroz, Geosite 16 Serra da Rajada, Geosite 14 Cruzeiro de Acari, Geosite 17 Monte do Galo, Geosite 15 Marmitas do Rio Carnaúba, Geosite 5 Mirante de Santa Rita, Geosite 4 Vale Vulcânico, and Geosite 6 Tanque dos Poscianos. Mosaic of colorful photographs of geosites 13, 16, 14, 17, 15, 5, 4 and 6. **Source:** SUGG collection.

The lowest sectors of the landscape correspond to the alluvial plains, referred to in local toponymy as "várzeas". These areas have considerable economic importance for the development of traditional agricultural activities in the region. Rock outcrops may occur in the middle of the alluvial plain, often in the shape of rock-cut basins (pits) created by vortices within the water current. Pits can be partly filled with coarse sand and gravel, characteristic of the bedload of the region's intermittent streams, as in the case of the remarkable pits of the Carnaúba River, Geosite 15 (Figure 5).

The highest levels of the Borborema Highlands in the SUGG occur in the morpho-sculptural sub-unit of the Serra de Santana Compartment (Figure 4) at altitudes ranging from 650 to 800 m. The lithology in this sector corresponds to the Serra do Martins Formation (SMF), a sandstone or sandstone-conglomeratic cover, occasionally silicified, whose deposition is attributed to a period between the Paleogene (64 Ma) and the Neogene (20 Ma) (LIMA, 2008; MORAIS NETO et al., 2009). These siliciclastic covers that now cap the summit surface of the region were deposited in a meandering to braided fluvial environment (MENEZES, 1999). The fact that this ancient river plain currently lies on the highest regional summit surface implies the operation of conspicuous post-rift deformational processes that have been associated with the Cenozoic magmatism (OLIVEIRA; MEDEIROS, 2012) and pulses of tectonic reactivations (OLIVEIRA, 2019; BARROS, 1998) well into the Neogene. Geosite 4 Vale Vulcânico (Figure 5) represents a basaltic spill from the Macau volcanism (25 Ma) and occurs close to the foot of the Serra de Santana, in the contact between the basement and the sandstone cover.

From a morphological point of view, the SMF presents itself as a tabular sedimentary relief, locally known as "chapada", with little or no inclination of the sedimentary layers underlain by the crystalline basement. At some locations, the sandstone covers are more preserved from erosion, forming more continuous mesa-like plateaus such as the Serra de Santana (Figure 4), where Geosite 5 Mirante Santa Rita (Viewpoint) (Figure 5) is located. In other areas, fragments of the SMF have been individualized by dissection, creating buttes and other residual forms grouped into the Dissected Sedimentary plateau unit.

The flat relief of the summit surface contrasts with the surrounding cliffs and escarpments with slope gradients varying from 7° to 30°, marking the transition to the lower elevation levels in crystalline rocks. The Geosite 4 Vale Vulcânico and Geosite 6 Tanque dos Poscianos (Figure 5) lie on the escarpment unit. The steepness of some hillslopes does not favor the area's traditional forms of land use, and these are the sectors with the least anthropically altered vegetation cover. Several river springs occur in the contact between the sandstone plateau and the crystalline basement, such as the Potengi River, Geosite 3 (Figure 6).

Figure 6. Geosite 1 Serra Verde, Geosite 2 Cruzeiro de Cerro Corá, Geosite 12 Açude Gargalheiras, and Geosite 3 Nascente do Rio Potengi. Mosaic of colorful photographs of geosites 1, 2, 12, and 3. **Source:** SUGG collection.

A remnant of the Dissected Sedimentary Plateau unit strongly controlled by NE-SW trending regional structures occurs to the northeast of the Serra de Santana (Santana Range). This sector corresponds to the northernmost extension of the Borborema Highlands, which is drained by the watersheds of the Potengi and Trairi Rivers. Rectangular and trellis drainage patterns highlight the role of structural controls on landscape evolution. Granite outcrops that occur amidst this geomorphic Unit are associated with Geosite 1 Serra Verde (Green Range) and Geosite 2 Cruzeiro de Cerro Corá (The Cross of Cerro Corá) (Figure 6), both situated on the escarpment at altitudes of 350 and 480 m respectively.

The elevations of the Serra de Santana (Santana Range) are bounded to the South by the Acauã intermontane surface in altitudes below 360 m, which is characterized by coalescing rocky pediments structured on the schists of the Seridó Formation. Geosite 12, Gargalheiras Reservoir (Figure 6), is located on this depression named the Acauã pediplain. The dam was built on a water gap that cuts through the Acari granite (Figure 6).

In the Seridó compartment, a planation surface occurs in elevations ranging from 360 to 480 m (The Currais Novos Pediplain). Above this level surface lies a higher pediplain bounded with the lower by a line of escarpments at elevations from 480 to 750 m. The Currais Novos pediplain is characterized by granite outcrops like in Geosite 7 Lagoa do Santo (Santo Lagoon) (Figure 7). Some granite intrusions form residual landforms, inselbergs, as in Geosite 8 Pico do Totoró (Totoró Peak) (Figure 7). An inselberg on pegmatite, in the shape of a Kastle Koppie stands out in the area as Geosite 9 Morro do Cruzeiro (Cross Hill) (Figure 7). Still on the Currais Novos Pediplain Geosite 10, the Brejuí Mine (Figure 9) is dedicated to the occurrence of scheelite mineral (CaWO4), placed between gneisses and marbles of the Jucurutu Formation.

Figure 7. Geosite 7 Lagoa do Santo, Geosite 8 Pico do Totoró, Geosite 9 Morro do Cruzeiro, Geosite 10 Mina Brejuí and Geosite 11 Cânions dos Apertados. Mosaic of colorful photographs of geosites 7, 8, 9, 10, and 11. **Source:** SUGG collection.

In the SUGG, the pediplains are formed by gentle ramps with slope gradients below 7°, marking the transition between the steeper hillslopes and the local fluvial base level (CORRÊA, 2001; GOUDIE, 2013). The rocky pediments show a thin sedimentary cover, with loose clasts and boulders forming a detrital pavement on the surface (THOMAS, 1994). These pavements are formed by the action of the unchanneled surface run-off in the form of sheet flows that remove the finer fractions, leaving a veneer of gravel-sized clasts covering the surface.

The higher sectors of the Seridó Compartment correspond to summit levels reaching an elevation of 750 m. Along the principal escarpment, at elevations ranging from 480 to 750 m, lies Geosite 11 Cânion dos Apertados (Apertados Canyons) (Figure 7), in the segment where the Picuí River cuts a canyon through the quartzites of the Equator Formation. At the bottom of the canyons, the riverbed is sided by a narrow alluvial plain. Geosite 18 Xiquexique (Figure 8) and Geosite 19 Cachoeira dos Fundões (Fundões Waterfall) (Figure 8) also lie on the escarpment at 350 and 480 m altitudes, respectively.

Figure 8. Geosite 18 Xiquexique, Geosite 19 Cachoeira dos Fundões, Geosite 20 Açude Boqueirão, and Geosite 21 Mirador. Mosaic of colorful photographs of geosites 18, 19, 20, and 21. **Source:** SUGG collection.

As it occurs at Serra de Santana, some isolated elevations are covered by the sandstones of the SMF; however, in this sector, the drainage has dissected the latter, leaving a series of narrow interfluves. The Serra do Abreu (Abreu Range) and the Serra Nova Sorte (Nova Sorte Range) present a spatially restricted sandstone capping where the catchments of the Carnaúba River are located. Sandstone clasts from the backwearing of the summit surface are transported to the Carnauba Riverbed and deposited on its alluvial plain. The availability of these materials along the course of the river was of capital importance for the pre-historic peoples of the region, who used the sandstone gravels along with silexite as raw material for their lithic industries (MUTZENBER, 2007).

Another elevated level in the south of the SUGG is the Serra das Queimadas (Queimadas Range), which is structured on the quartzites and meta-conglomerates of the Equator Formation (BEZERRA et al., 2009). The Serra das Queimadas is mostly a symmetrical isoclinal ridge, with some asymmetrical (homoclinal) segments in areas where the headward erosion has lowered the highest divide. At the northernmost sector of the ridge, the drainage cuts discordantly through the geological structures, opening a water gap where the dam of the Boqueirão de Parelhas reservoir was placed, corresponding to Geosite 20 (Figure 8).

The hillslopes of the Serra das Queimadas, where Geosite 21 Mirador (Viewpoint) (Figure 8) is located, are heavily dissected, displaying a serrated aspect, occasionally exhibiting triangular facets not necessarily conditioned by active faulting. Nonetheless, surface deformation pulses during the Cenozoic may be linked to lowering the local base levels and triggering aggressive erosive episodes that produced the facets. The evenly spaced erosive valleys have been carved by a set of entrenched streams, which led to the triangular or trapezoidal configuration of the escarpment in the shape of chevrons (GUTIÉRREZ; GUTIÉRREZ, 2016). This process is typical of regions where sedimentary layers of different resistances are placed side by side; however, this is not the case in the study area. The high concentration of muscovite in the quartzites that outcrop along the ridge contributes to the mechanical weathering of bedrock, forming plates that accumulate at the footslope as talus deposits.

The Gameleiras Mount has the second-largest capping of the SMF sandstones over the Borborema Highlands (DINIZ et al., 2017). Nonetheless, only a segment of the hillslopes of this relief compartment lies within the limits of the study area at elevations exceeding 740 m. Dissection is more pronounced than on the hillslopes of Serra de Santana, forming a topographic hollow overlooking the rocky pediments of the Seridó Compartment.

Amidst the loftier areas of the Borborema Highlands, a lowered surface was developed at an average elevation of 360 m due to the erosive action of the Acauã River and its tributaries. The morphological characteristics of this intermontane depression are similar to those of the Seridó pediment Compartment, i.e., a rocky surface covered by a thin veneer of a detrital pavement. Residual reliefs are also dispersed throughout the area.

Inselbergs and residual massifs dot the pediments, both on the elevated surfaces of the Borborema Highlands and on the Sertaneja Surface Lowlands (Figure 4). These landforms are structured on more resistant lithologies, generally granites, but not exclusively, and rise abruptly from the flat surfaces with slopes marked by steep knick angles (HUGGETT, 2017). These landforms reach a maximum altitude of 600 m. Granitic inselbergs tend to assume a dome-like shape (Figure 5, Geosite 16), while under metamorphic lithotypes, elongated ridge morphologies predominate. The spatial distribution of these relief units generally follows the regional NE-SW structural trend, indicating the influence of the Proterozoic shear zones on producing more resistant lithologies and controlling the drainage dissection pattern (MAIA; BEZERRA, 2014).

The Sertaneja Surface is the second largest morpho-sculptural unit in extension within the limits of the SUGG. The Seridó River, a tributary of the Piranhas-Açu River, and other ephemeral tributaries dissect this unit. The dendritic drainage pattern predominates; however, trellis or rectangular patterns appear in sectors with greater structural control by Proterozoic shear zones and fault lines. The dissection progresses from the lateral overlap of erosive amphitheaters that develop from the headward erosion of higher elevations. Hence, the morphology of the area is dominated by the coalescence of rock pediments with thin detrital cover, which are divided into two stepped levels, one up to 240 m and the other reaching 360 in altitude. Inselbergs and residual massifs occur as erosional remnants on more resistant or less fractured lithologies, generally oriented according to the regional NE-SW trend of the Proterozoic shear zones.

Quaternary depositional zones are mainly concentrated in the riverbeds and adjacent plains where depositional processes surpass erosional ones. In these sectors, gravelly and sandy-gravelly sediments predominate, which points to the energy of the torrential events that characterize the morphodynamics of these ephemeral semi-arid drainages. Fluvial plains and terraces have limited spatial extension, with several stream segments where deposition does not exceed the limits of the channel bed and where sedimentation is related to occasional flash floods that create undivided sedimentary deposits (CORRÊA, 2011). As mentioned, sandstone clasts from the FSM can also occur dispersed among the sandy-gravelly material, originating from the dissection of the headwater areas. The lateral contribution from hillslope gravity flows also plays a significant role in infilling the valley bottoms.

The location of the geosites in the appropriate taxonomic units is shown in Table 1, it should be noted that 19 of the 21 geosites in the SUGG are of geomorphological interest.

Table 01. Summary table of the relief and area of the geosites in the Seridó UNESCO Global Geopark.

Geosite	Litology	Interest (main, secondary)	Visualization Scale	Geomorphology 4th Táxon – Relief Units		
Serra Verde	Granite, Pegmatite	Geomorphological, Paleontological	Area - 12.40 ha	1.2.7.2		
Cruzeiro de Cerro Corá	Granite	Geomorphological, Igneous	Point - 0.37 ha/Observatory	1.2.5.1		
Nascente do Rio Potengi	Sandstone, Conglomerate	Hydrogeological, Geomorphological	Area - 0.60 ha	1.2.7.1		
Vale Vulcânico	Basalt, Sandstone, Gneiss	Igneous, Geomorphological	Area - 3.00 ha	1.2.7.3		
Mirante Santa Rita	Sandstone, Conglomerate	Geomorphological, Sedimentary	Area - 0.60 ha/Observatory	1.2.7.1		
Tanque dos Poscianos	Granite, Sandstone	Geomorphological, Igneous	Area - 0.65 ha/Observatory	1.2.7.3		
Lagoa do Santo	Granite	Igneous, Geomorphological	Area - 5.47 ha	1.2.5.4		
Pico do Totoró	Granite	Geomorphological, Igneous	Area - 42.80 ha	1.2.5.6		
Morro do Cruzeiro	Pegmatite, Schist	Geomorphological, Igneous	Point - 0.10 ha/Observatory	1.2.5.6		
Mina Brejuí	Paragneiss, Marble, Calcissilicate	Mineralogical, Metamorphic	Area - 73.00 ha	1.2.3.3	1.2.5.4	
Cânions dos Apertados	Quartzite, Pegmatite	Geomorphological, Hydrogeological	Section - 6038 m	4.1.3.1		
Açude Gargalheiras	Granite	Geomorphological, Igneous	Area - 485.00 m	1.1.2.3	1.2.5.2	4.1.3.1
Poço do Arroz	Granite	Igneous, Geomorphological	Section - 749 m	4..1.3.1		
Cruzeiro de Acari	Granite	Igneous, Mineralogical	Point - 0.10 ha	1.1.2.3		
Marmitas do Rio Carnaúba	Granite	Geomorphological, Igneous	Area - 3.65 ha	1.1.2.1		
Serra da Rajada	Granite	Geomorphological, Igneous	Area - 296.00 ha/Observatory	1.1.2.3		
Monte do Galo	Pegmatite, Schist	Geomorphological, Igneous	Area - 29,20 ha/Observatory	1.1.2.3		

Xiquexique	Quartzite, Pegmatite	Geomorphological, Metamorphic	Area - 5.00 ha/Observatory	1.2.5.3			
Cachoeira dos Fundões	Quartzite, Pegmatite	Geomorphological, Metamorphic	Section - 399 m	1.2.5.3			
Açude Boqueirão	Metaconglomerate, Quartzite	Geomorphological, Metamorphic	Area - 221.00 ha	1.1.2.1	1.1.2.3	1.2.5.2	4.1.3.1
Mirador	Metaconglomerate	Geomorphological, Metamorphic	Area - 7.33 ha	1.1.5.2	1.2.5.3	1.2.5.4	

Source: elaborated by the authors with informations by Nascimento et al. (2021).

5. Conclusions

The SUGG has 21 geosites located in its territory, 15 of which are of geomorphological interest and are located in various relief units throughout the territory.

As well as presenting appropriate cut-outs of the maps of the first, second and third taxa, this work mapped and described the dynamics of 19 relief units in the fourth taxon at a scale of 1: 50,000, considered suitable for the geoconservation policies developed in the Geopark territory.

Geomorphological heritage is one of the most prominent within geoheritage, mainly because it is strongly associated with scientific, educational and tourist uses, the latter often being used in different tourist practices, such as geotourism, ecotourism, adventure tourism, among others.

Knowing which relief unit, a geosite is associated with favours not only appropriate use in terms of tourism practices, but also serves to promote the popularization of knowledge in scientific research and educational practices. It is also important for promoting different geoconservation strategies and public policies for appropriate use.

This mapping of observable relief units at a scale of 1:50,000 has enormous potential for geoconservation actions that take into account the vulnerability and fragility of the terrain of the SUGG and adds to the classification of land use and occupation carried out by Bernardino (2023) as a cartographic subsidy for future studies of this nature, which is of fundamental importance for promoting the environmental integrity of the SUGG's geosites. The mapping at the scale presented here can be the basis for models such as that of Crepani et al. (2001), for example, which proposes a methodology based on the integration of thematic maps, such as geology, geomorphology, soils, land use, slope and altitude, to assess environmental fragility and which is often adapted in studies on environmental planning and natural resource management.

The taxonomic system adopted can be replicated in other UNESCO Geoparks in different parts of the world, and geomorphological maps can be drawn up at different scales of detail, with multiple possibilities for using the maps, whether in geo-education activities, with a target audience ranging from primary school pupils, to geo-conservation activities proposed by the geopark's technical staff, including its geoscientists and tourism experts, among other professionals.

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