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Geomorphological heritage and identification of potential geomorphosites in the municipality of Ubajara - CE/Brazil

Patrimônio geomorfológico e identificação de potenciais geomorfossítios no município de Ubajara – CE /Brasil

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Abstract: Geomorphosites are defined by relief features in which a value is assigned and have varied dimensions. In order to identify the potential geomorphosites of the municipality of Ubajara - CE, these were identified from a preliminary evaluation, considering the parameters of rarity, representativeness, cultural, aesthetic and ecological relevance, scientific knowledge, as well as the characterization of physical aspects and through field work based on the methodology of Santos et al., (2020). The geomorphosites proposed by this study were two, which are spatially classified as geomorphological complexes and relief shape groups, which when delimited and described evidence the potentialities and Geodiversity of the municipality

Keywords: Geomorphosites; Geomorphological Heritage; Geotouristic.

Resumo: Geomorfossítios são definidos por feições do relevo em que um valor é atribuído e apresentam dimensões variadas. Com o objetivo de identificar os potenciais geomorfossítios do município de Ubajara – CE, estes foram identificados a partir de uma avaliação preliminar, considerando os parâmetros de raridade, representatividade, relevância cultural, estética e ecológica, como também o conhecimento científico, além da caracterização dos aspectos físicos e por meio dos trabalhos de campo com base na metodologia de Santos *et al*., (2020). Os geomorfossítios propostos por este estudo foram dois, que são classificados espacialmente como complexos geomorfológicos e grupos de formas de relevo, os quais ao serem delimitados e descritos evidenciam as potencialidades e geodiversidade do município.

Palavras-chave: Geomorfossítios; Patrimônio Geomorfológico; Geoturístico.

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1. Introduction

The relief is considered a guiding element of this article, as it is an indispensable unit of analysis. It is one of the fundamental elements of the natural environment, exhibiting an impressive diversity of forms. According to Falcão Sobrinho (2007; 2020), the relief is the stage for human activities, ranging from the construction of housing to the use and exploitation of the land. In this context, a detailed analysis of the characteristics and processes related to geomorphological evolution provides crucial data for the conservation and preservation of environmental conditions. Some aspects of the relief are so significant to society that they are considered geomorphological heritage.

Geomorphological heritage consists of a set of geomorphosites, which are natural areas where the main attributes are related to geomorphological dynamics and relief forms, at different scales, to which some kind of value is attributed, such as economic, cultural, and others. By valuing geodiversity and its heritage, whether geological or geomorphological, it contributes to the sustainable use and conservation of these territories and their surroundings. These areas are assigned values (scientific, ecological, cultural, touristic, educational, aesthetic, among others) for society, and when they present exceptional values, they should be the targets of geoconservation measures (LOPES, 2017).

These are current and necessary topics for the advancement of science and humanity itself, given the great dependence of the human species on elements of the abiotic portion of the natural environment, such as mineral resources. Due to the prominence they have been gaining, authors in various countries have sought to highlight the values of these elements with the aim of valuing and conserving them, while also seeking methodological standardization.

The heritage linked to environmental concerns has developed, along with socioeconomic aspects and even at the legislative level, a movement towards awareness and heritage conservation in various countries, including Brazil. Currently, societies and public opinion show greater interest in issues related to the state of the environment, landscape protection, and natural heritage, due to the worsening environmental conditions caused by anthropogenic activities and environmental aggressions.

The importance given to environmental protection and awareness is generally not connected to the valuation of heritage, specifically geomorphological heritage, as an environmental resource, a touristic asset, or even as the support of life and the stage for human activities. The limited consideration of this type of heritage is particularly severe at the governmental level, constraining the development of preservationist policies and dissemination.

According to Reynard et al. (2007), various attempts have been made to qualitatively assess geomorphological heritage, highlighting the importance of analyzing these sites based on scientific, aesthetic, economic, cultural, and ecological values. There are various proposed applications that hinder the unification of geomorphological studies due to their complexity in representation.

Given the importance of this theme both internationally and nationally, more specific studies become essential. Due to the great variety of existing geomorphological processes, the adopted classification can be based on the morphogenetic systems that originate and shape geomorphosites, which can be of fluvial, karstic, structural, lacustrine, or other types.

It is necessary to study this theme both theoretically and environmentally. Based on these concepts, the objective of this article is to identify the potential geomorphosites in the municipality of Ubajara – CE. The choice of this area is due to its importance for the tourist, environmental, and socioeconomic development of the municipality and its surroundings, given its plural geodiversity. The municipality of Ubajara is located in the northwest of the state of Ceará on the Ibiapaba Plateau (FALCÃO SOBRINHO, LIMA, 2024), with an area of approximately 421 km² (Figure 1).

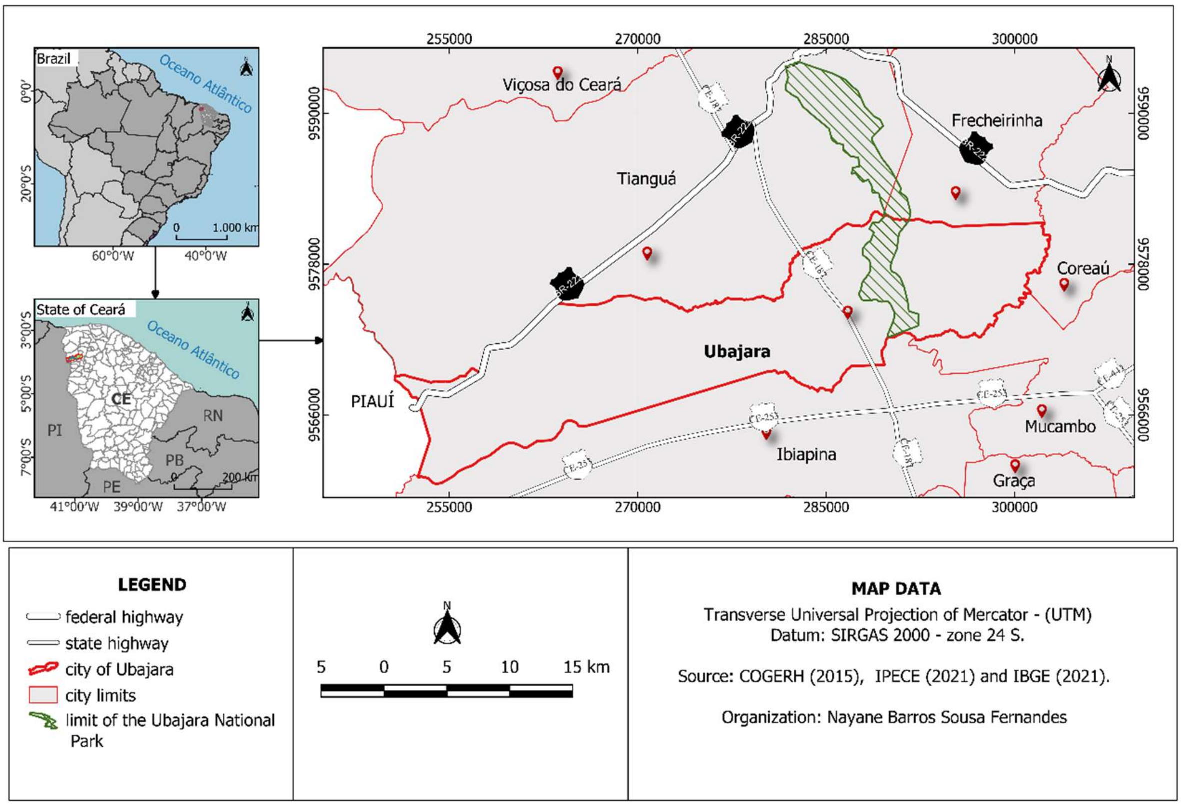

Figure 1 – Location of the municipality of Ubajara -CE.
Source: or authors (2023)

The municipality is known for its exuberant landscapes, featuring escarpments, caves, canyons, hills, and flat areas, and is characterized as one of the most beautiful examples of karst relief in Brazil. It is located within the Ubajara National Park, which houses the most important speleological heritage of Ceará (VERÍSSIMO, 2005). This area has geotouristic potential due to its numerous natural attractions, such as waterfalls, caves, viewpoints, and more.

2. Theoretical support

Nature is composed of two strongly connected, interdependent, and inseparable elements: biodiversity and geodiversity. Maintaining their integrity is fundamental for the quality of life in society and crucial for the balance of ecosystems (BORBA, 2011).

Since the early 1990s, the term biodiversity has been unequivocally defined, formally established at the Second Convention on Biological Diversity held in Rio de Janeiro in 1992. Biodiversity is understood as the variety of biotic elements on Earth. Currently, numerous procedures allow for the valuation of biodiversity, with methodologies widely accepted and disseminated (SERRANO et al., 2007).

In contrast, the concept of geodiversity, unlike biodiversity, is still practically unknown to the public, despite the numerous existing documentaries on biodiversity. While biodiversity refers to the living component of nature (biotic), geodiversity refers to the non-living component of nature (abiotic) (FORTE, 2008, p.26).

In recent years, various authors have focused on the theme of geodiversity, both internationally (STANLEY, 2001; SHARPLES, 2002; GRAY, 2004; KOSLOWSKI, 2004; SERRANO AND RUIZ-FLAÑO, 2007) and nationally (BRILHA, 2005; PEREIRA, 2006, etc.). Although the purpose of this research is not to analyze all aspects of geodiversity or all associated authors, it is important to clearly define this concept and how some authors use it, given its significant relevance in the scientific, environmental, and social spheres.

The term geodiversity was first presented to the scientific community during the Malvern Conference on Geological and Landscape Conservation held in the United Kingdom in 1993. However, it only gained wider recognition after the publication of the article "Geodiversity" by Mick Stanley in 2000 in the quarterly journal Earth Sciences in the United Kingdom.

Initially, the theme was used restrictively, as in Stanley (2001 apud GRAY, 2004, p. 7), where geodiversity is defined as the link between people and culture, the variety of geological environments, phenomena, and active processes that form these landscapes, rocks, minerals, fossils, and soils that provide the structure for life on Earth.

According to Sharples (2002), geodiversity is the diversity of geological (substrate), geomorphological (landscape forms), and soil characteristics, sets, systems, and processes, endowed with intrinsic, ecological, and anthropocentric values.

Gray (2013, p.12) defined geodiversity as the the natural range (diversity) of geological (rocks, minerals, fossils), geomorphplogical (landforms, topograpgy, physical process), soil and hydrological features. It incresm systems and contributions to landscapes.

Koslowski et al. (2004) defined geodiversity as the natural variety of the Earth's surface, in its geological, geomorphological, soil, and surface water aspects (springs, swamps, lakes, and rivers), as well as other systems resulting from natural processes or human activities.

Serrano and Ruiz-Flaño (2007) follow the same line of thought, defining geodiversity as the variability of abiotic nature, including lithological, tectonic, geomorphological elements, soils, hydrological processes, topographic and physical features on the surface of the land, seas, and oceans, generated by natural, endogenous and exogenous processes, systems, and human activities. The anthropic factor brings a great complexity, considering the practical application of the concept, as it makes it more difficult to define what is and what is not part of geodiversity (CARCAVILLA et al., 2008).

Nieto (2001, p. 70) states that geodiversity is the variety of geological structures and materials that constitute the physical substrate of a region, on which organic activity is based, including anthropic activity, which is capable of modifying the environment.

The Geological Service of Brazil (CPRM) defined geodiversity as the study of abiotic diversity (physical environment) considering different environments, compositions, phenomena, and processes that give rise to landscapes, rocks, soils, climate, and other surface deposits. In this context, geodiversity can be related to some type of value, whether intrinsic, cultural, aesthetic, scientific, economic, educational, or touristic (SILVA, 2008, p. 24).

Given the goal of preserving and managing the planet's physical resources, various authors have debated the values these resources possess in nature. One of the first works that defined a value system for geodiversity was by Gray (2004), who determined six values and 32 sub-values for nature's elements. The values listed by Gray (2004) are intrinsic, cultural, aesthetic, economic, functional, and scientific/educational (Table 1).

Table 1 *- Geodiversity Values*

Intrinsic value	The intrinsic value refers to the ethical belief that, in the specific case of geodiversity, it possesses inherent worth, something that exists independently of its usefulness to humans. This value is the most challenging to describe, as it involves ethical and philosophical dimensions of the relationship between society and nature.
Cultural value	It is easily perceived, revealing itself in the numerous relationships that exist between society and the physical environment in which it is embedded and to which it belongs. There is a close connection between the elements of geodiversity and human communities. These elements can influence the occupation of a particular region, its use for survival and development, local toponymy, folklore, religiosity, and the cultural identity of these populations.
Aesthetic value	This concept is quite subjective and therefore difficult to evaluate, as it involves aesthetic appreciation, which is closely tied to human sensitivity. Evaluation becomes easier when the object

	in question is an area with tourist appeal, such as examples of exuberant geomorphological structures.
Economic value	This category of value is easily recognized due to its tangibility and objectivity compared to others. For example, rocks, minerals, sediments, fossils, groundwater, landforms, and soils are elements that, in certain concentrations and applications, can be assigned economic value.
Functional value	Geodiversity plays an essential role in regulating ecosystems, encompassing rocks, soils, and landforms. Although these elements are often considered immutable in relation to ecosystem development, they actually have a crucial functional role in both physical and biological environmental systems. The various combinations of geodiversity elements can provide useful functions in different landscapes, bringing benefits to society.
Scientific and Educational Value	The physical environment acts as a research laboratory, highlighting its scientific and educational value. Studies of geological records have allowed for the reconstruction of Earth's history and the understanding of phenomena such as global climate changes. In addition to scientific research, geological records also serve to illustrate geological and geomorphological principles and processes in various levels of education.

Source: *Prepared by the authors, adapted from Gray (2004).*

Following the concept of geodiversity and its values, it focuses on the conservation and sustainability of the environment considering anthropic influences. As a result, when considered as heritage, it encompasses various themes. Due to the breadth of the topic, many authors, when discussing geological, geomorphological, and related heritage, have found it more appropriate to use the term geopatrimony. This term includes not only geological aspects (minerals, rocks, and fossils) but also geomorphological aspects (landforms and processes), hydrological, climatological, and soil aspects (Figure 2). This is done with due respect to the particularities of each, including their specific concepts and methods.

Guimarães et al. (2022) consider it appropriate for geodiversity elements, their specific objectives, and associated values to be applied individually. For example, geomorphological features can be referred to as geomorphological heritage, and similarly for geological heritage, pedological heritage, among others.

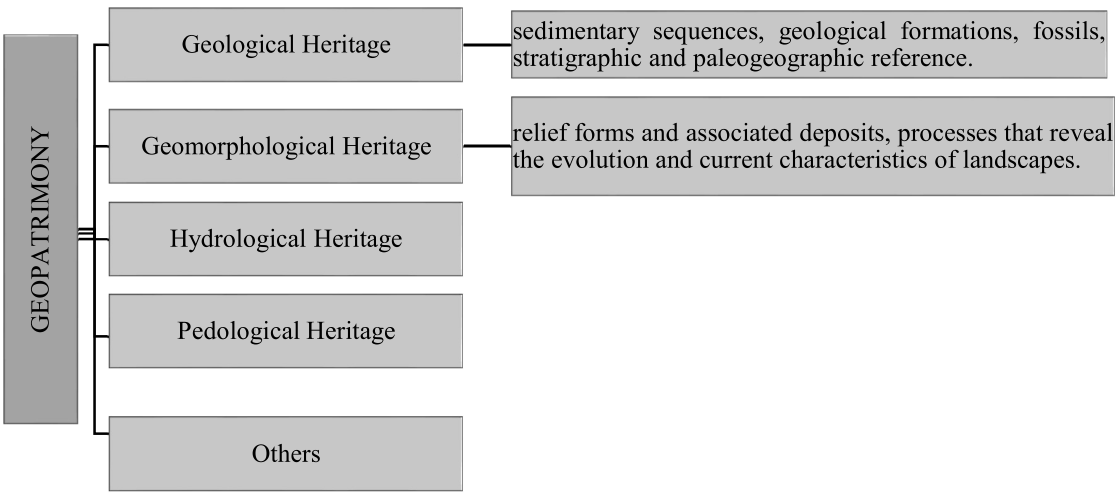

Figure 2 – Geoheritage classification scheme
Source: The authors, adapted from Rodrigues and Freire (2010).

According to Reynard and Panizza (2005), geomorphological heritage, as part of geopatrimony, represents the set of landforms and processes associated with relief that uniquely express a part of the Earth's surface evolution. The relief maintains a geodynamic memory that unfolds over time, thus possessing significant scientific-educational, historical-cultural, aesthetic, and economic/social values.

Various terms are used to describe elements of geomorphological heritage, including geomorphological assets, geomorphological goods, geomorphological points of interest, and geomorphosites, derived from the English term "geomorphosites." According to Lopes (2017), geomorphosites are representations of landforms, deposits, or geomorphological processes present in a landscape, and can be identified at various scales. These elements are assigned values (scientific, educational, cultural, touristic, among others) while interacting with other components of geodiversity, including biological and cultural aspects.

According to Panizza (2001), a geomorphosite is a landscape with particular and significant attributes that qualify it as a component of the cultural heritage (in the broad sense) of a specific territory. The attributes that can confer value include scientific, cultural (in the narrow sense), economic, and scenic values. Once again, scientific value is linked to cultural value in the evaluation of landscapes.

Geomorphosite (geomorphosite), this term was proposed by Panizza (2001), whose definition consists of a geomorphosite being a relief feature to which a value can be assigned. According to Reynard (2009a), in addition to the values of geosites (scientific, in particular), there are three specific aspects for geomorphosites: 1) Aesthetic dimension: the composition of the geomorphological landscape to which a high aesthetic value is attributed. Generally this is the central characteristic, however it is important to emphasize that it should never be the only aspect to be considered, so that physical expression needs to be combined with scientific importance, just as there can be geomorphosites without aesthetic value; 2) Dynamic dimension: observation of natural dynamic processes acting on the relief and/or record of past processes.

Regarding the activity of the processes, Reynard (2009a) separates them into Active, the geological/geomorphological processes are occurring, therefore, it is possible and important to observe them on the surface, and Passive (or fossil), in which the geosite is the witness of the processes and/or natural conditions no longer exist. In relation to this dynamic, in both cases human interference can cause irreparable damage, or at least irreversible damage on a human scale (Reynard, 2009a). 3) Scales: both geosites and geomorphosites do not have a standard size to be followed, nor a maximum or minimum, and can encompass isolated forms or large features in the landscape, however, it is important that their limits are well delineated. Reynard (2009a) exemplifies some types of scale, such as isolated form, object, group of features and landscape, that is, it can be on a micro or macro scale. The contrasting factor of geomorphosites is their dynamic characteristic, as geomorphological processes are observed acting on the evolution of the shape. However, its particularity is also vulnerability, which is a management challenge, considering that active processes lead to the self-destruction of the relief feature and even other processes (Reynard, 2009a).

In the past two decades, various attempts have been made to qualitatively assess geomorphological heritage, which has been approached from different contexts, such as environmental impact assessment, natural heritage inventory, tourism promotion, and management of conservation units.

This underscores the need for adopting appropriate methodologies as well as measures and strategies for geoconservation, which has generated significant interest in the scientific community. One of the aims of this article is to contribute to the development of further work in this area.

3. Methodology

The methodological steps guiding this work were established based on a comprehensive literature review on key topics: geodiversity values, geopatrimony, geomorphological heritage, and geomorphosites. Fieldwork helped identify and detail the geomorphological features and their potential.

As previously mentioned, the concept of geomorphosites refers to landforms with certain values, which can contribute to the sustainable development of the environment considering their geomorphological potentials. The assessment of geomorphosites considered areas with geomorphological contexts that represent the local geodiversity. Among the areas of interest, two geomorphosites were considered, each with distinct characteristics. The criteria for selecting the geomorphosites were based on the methodological proposals of Santos et al. (2020), Santos et al. (2022), and Reynard et al. (2016).

The first establishes a pre-selection stage, referred to as preliminary evaluation. This stage is one of the most neglected in geomorphosite assessment methods, highlighting the importance of establishing a relationship and applying a structural analysis method. The second proposal sets some parameters for determining geomorphosites considering spatial, temporal, and dynamic dimensions. These parameters address issues directly related to values, potential uses, and risks of degradation of geomorphosites. The third author advocates for an inventory method related directly to regional geomorphology, dividing the method into stages such as defining the main geomorphological contexts, such as morphostructural units, morphocultural units, processes, etc.

Based on the proposal by Santos et al. (2020), the preliminary evaluation requires geomorphological data and forms, as well as specific criteria and scores to prevent the inclusion of irrelevant geomorphosites in later stages such as inventory or quantitative assessment. The table with the parameters used and their scores is represented in Table 2.

Table 2 – *Parameters and scores required for the Preliminary Assessment*

Parameter		**Punctuation**
Core Parameters	Representativeness	1 – low
	Integrity	2 – average
	Rarity	3 – high
	Scientific	4 – very high
Additional parameters	Ecological	0 – nenhum
	Culture	1 – low
	Aesthetic	2 - average 3 – average
Usage and management parameters	Accessibility	1 – low
	Security	2 – average
	Infrastructure	3 – high
	Visibility	

Source: *The authors, adapted from Santos et al., (2020).*

After the preliminary evaluation, the identification and location of potential geomorphosites were carried out based on geomorphological characteristics and the possible values they present, primarily aesthetic, cultural, ecological, educational, scientific, and geotouristic. To identify the sites, geoprocessing techniques were used in conjunction with prior knowledge and field activities. For map creation, the QGIS software version 3.22 was utilized. Data acquired during the two field surveys were in the form of cartographic records, points, and spreadsheets. Support was provided by Google Earth images and GPS (Global Positioning System) to record coordinates (Table 3).

Table 3 *– Coordinates of potential geomorphosites in the municipality of Ubajara*

Geomorphosites	Latitude	Longitude	Type
Cânion do Frade (GCF)	3°49’55.70” S	40°53’57.70” O	Widescreen
Cones Cársticos (GCF)	3°52’22.60” S	41°7’13.78” O	Area

Source: *The authors (2024).*

From the collection of coordinates and cartographic production, records and descriptions became possible for a more detailed assessment of the potential geomorphosites in the study area.

4. Results and discussion

Based on the preliminary evaluation, two geomorphosites were identified for the study area, considering their representative landforms as well as their potential educational, geotouristic, and scientific values. Before describing the proposed geomorphosites for the study area, a brief characterization of the geological and geomorphological aspects of these geomorphosites is necessary.

In terms of geological context, the study area features sedimentary lithologies and crystalline basement formations. The Cânion do Frade (GCF) geomorphosite predominantly consists of lithologies from the Serra Grande Group, a basal formation of the Parnaíba Basin from the Paleozoic era. In contrast, the surrounding area mainly exhibits a lowered topography with a more diverse and complex lithological composition due to the intercalation and superposition of various geological groups of different ages (MOURA-FÉ, 2015).

The Jaicós Formation (Ssgj) is predominant in the GCF, consisting of medium- to coarse-grained sandstones with an estimated maximum thickness of over 400 meters, located on the northeastern edge of the basin. These sandstones are light gray in color, predominantly composed of quartz, and exhibit irregular grain size distribution. They display tabular and channelized cross-stratification, as well as claystone lamination. According to Caputo and Lima (1984), the regressive sedimentation of this formation occurred in alluvial and deltaic fan systems, both in outcrop areas and in the subsurface, in front of deltaic fans, which enhances the area's erosion features.

The geological context of the Karstic Cones Geomorphossite (GCC) has a lithological predominance of the Ubajara Group, which is a volcano-sedimentary succession of a Neoproterozoic platform (650-850 Ma), constituted, from base to top, by units of the Caiçaras formations (sediments predominantly clayey and sandy-clayey, with the occurrence of fine sandstones), Trapiá-Frecheirinha (sandstones and limestones) and Coreaú (sandstones and greywackes).

The formation representing the area of GCC is the Frecheirinha Formation (NP2uf), which originates from marine environments and is composed of calcitic and dolomitic metacarbonates. These vary in color from dark gray to bluish gray and have fine granulation. These metacarbonates are found in pure form or with impurities, forming layers of marls, metasilts, and quartzites, frequently cut by calcite veins, as described by Pinéo et al. (2020).

From a geomorphological perspective, Ibiapaba is defined as a glint, a term introduced by Peulvast and Vanney (2002) to describe an angular and uninterrupted escarpment formed by the discordant intersection of a sedimentary formation directly over an eroded substrate. In Ibiapaba, this glint contact occurs between the sertaneja surface and the higher zones of the plateau. Generally, a glint is a large escarpment.

The eastern sector is recognized for its scarp front with a gentle slope and an arenitic cornice. The western part of the municipality exhibits different geomorphology from the moist reverse part, characterized by erosional scarps and structural steps, with steep drops and canyon formations, where the Cânion do Frade Geomorphosite is located. According to Machado (2010), GCF is part of the structural step forms and erosional scarps pattern, characterized by rugged terrain with predominantly straight and concave slopes, slightly rounded ridges and summits, representing a transitional relief.

The GCC is situated within the serranes escarpment forms, characterized by a mountainous and highly rugged relief. It represents a transitional terrain between two distinct surfaces elevated to different altimetric levels, exemplified in the area by the Ibiapaba sedimentary plateau and the sertaneja surface. Generally, the area of the Cânion do Frade Geomorphosite has a topographic variation between 440 and 680 meters in altitude, with well-pronounced slopes. In contrast, the Cones Cársticos Geomorphosite ranges from 200 to 440 meters, representing a more lowered area compared to the first geomorphosite, as shown in Figure 3..

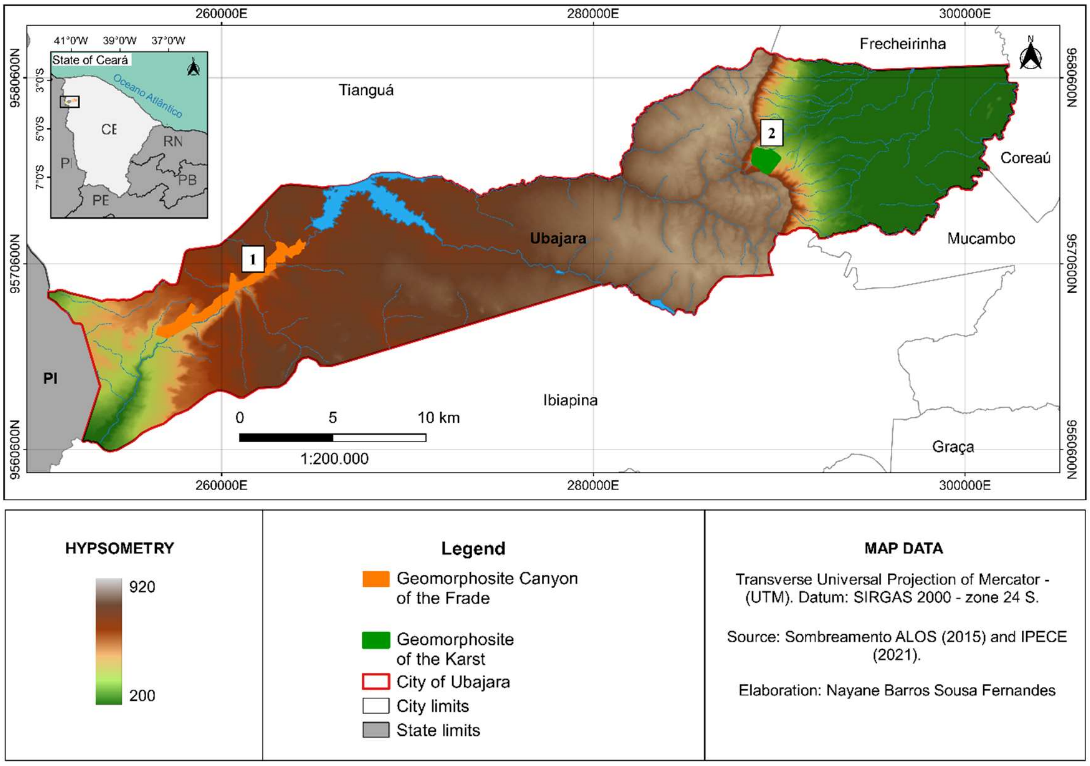

Figure 3 – Hypsometry of geomorphosites in the municipality of Ubajara
Source: The authors (2024).

After defining the geological and geomorphological context of the study area, the geomorphosites were selected to compose the preliminary list. Of the six geomorphosites listed, two were selected to compose the preliminary list of geomorphosites in the municipality, following all the parameters established by the base methodology, the others were not considered as relevant in the geotouristic, educational and scientific sphere. Based on this index, Table 4 presents a brief characterization of these geomorphosites.

Table 4 – Potential geomorphosites included after preliminary assessment

Local	Geomorphological context	Geological context	Spatial classification	Resources	Law Suit
Cânion do Frade – GCF	Sedimentary Plateau	Parnaíba Sedimentary Basin	Surface – Geomorphological complex	Closed valley area on erosional edges	Tectonic processes (inactive) / Denudational processes (active)
Cones Cársticos – GCC	Countryside Surface	Crystalline Basement	Surface – Group of relief shapes	Karst area with lapia and caves	Tectonic processes (inactive) / Dissolution processes (active)

Source: The authors (2024).

Spatially, the geomorphosites present a different classification, one as a geomorphological complex, presenting complex shapes and its own dynamics on erosive edges, which represents approximately 19km2 in length that runs up to the monoclinal depression of Ibiapaba and the other with a surface in a group of shapes, characterized by cones Karsts, as the name suggests, are a punctual and local group. Adding the forms and processes, the geotouristic and scientific potential of the area becomes evident, the cataloged geomorphosites represented in figure 4. Both are located in steep areas in a different geological – geomorphological context.

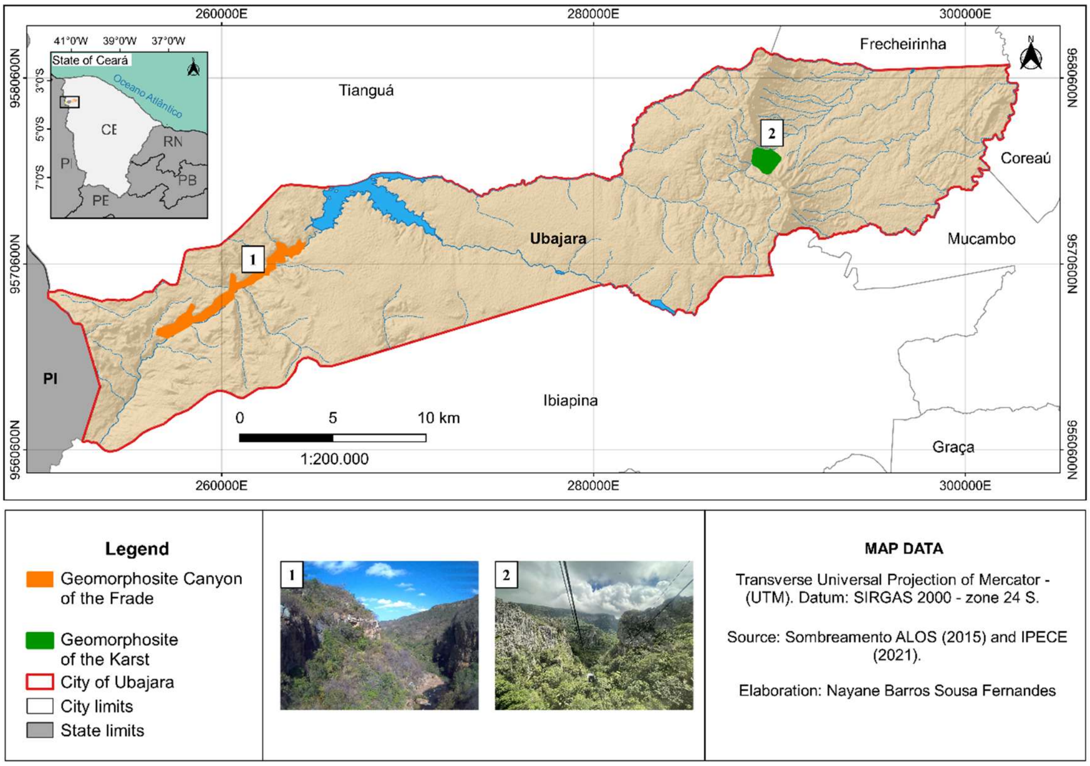

Figure 4 – The geomorphosites of the municipality of Ubajara
Source: The authors (2024).

4.1 Geomorphosite Cânion do Frade (GCF)

Located in the municipality of Ubajara (CE), specifically in the district of Jaburuna, the GCF has an altitude ranging from 440 to 680 meters, in the east-west direction. The GCF exhibits extreme panoramic scenic beauty, with large canyons and imposing rock walls that have dozens of meters between the top and the bottom of the riverbed, as shown in Figures 5a and 5b. Generally, the area has access limitations with extensive trails, and the sections are not properly marked, but the area has good visibility highlighting the erosive processes and rock characteristics belonging geologically to the Serra Grande Group, specifically the Jaicós Formation, which is predominantly composed of sandy rocks. Given that it is a sedimentary area, the overlay of sediments over thousands of years is evident in the landscape through the parallel stratification of rocks, i.e., the layers (Figure 5c).

The GCF covers an area of approximately 19 km², featuring geomorphological complexity with closed valleys and topographical variation characterized as structural steps and erosional escarpments. This creates favorable conditions for the ten waterfalls along its extent, which follow the inclination of the sedimentary lithological layers (Figures 5a and 5b). Considering its values, this geomorphosite has geotourism potential with scientific, educational, aesthetic, and ecological significance. It is a location of great scenic beauty and scientific exploration potential, with significant prospects for tourism use.

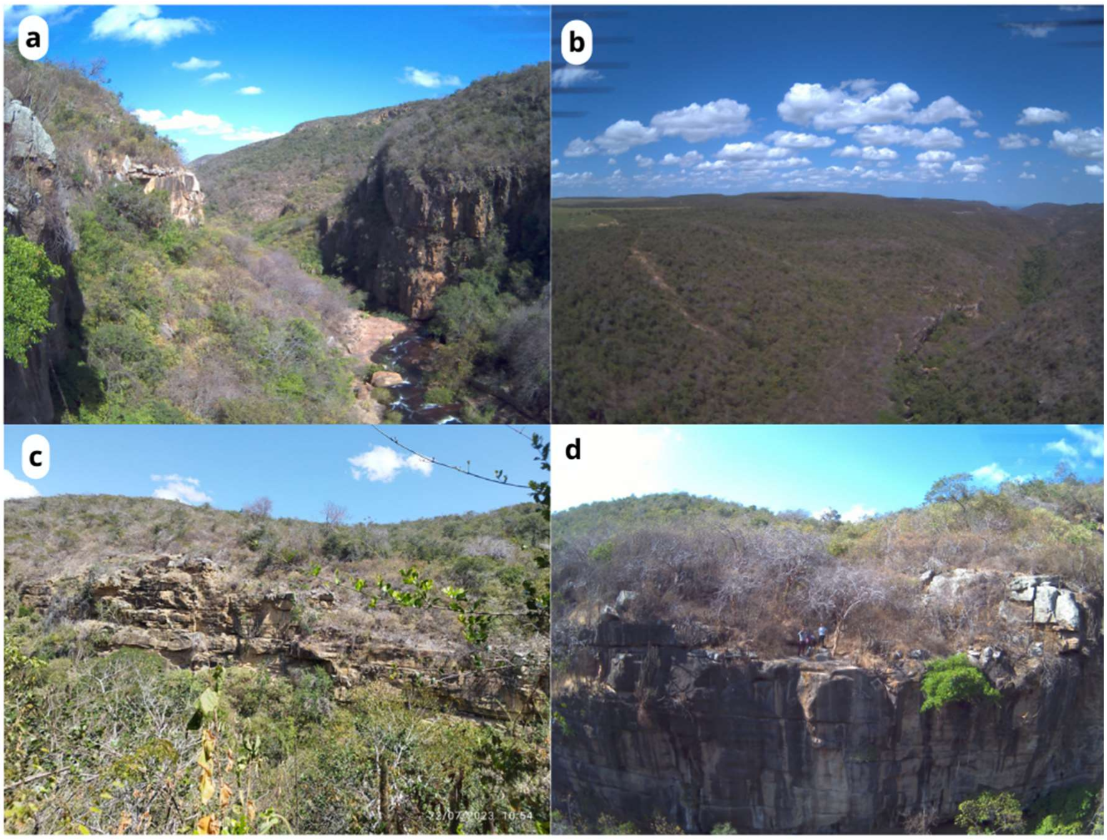

Figure 5 – General characteristics of the Cânion do Frade Geomorphossite
Source: The authors (2024).

The area requires scientific investigation regarding its weathering processes and how these influence its current characteristics, as well as the movement of materials and block falls caused by mass movement, given its highly sloped terrain, highlighting its educational and scientific potential. In terms of conservation, the area is well-preserved, justified by the lack of large-scale tourist exploitation and other factors. A bioindicator of conservation is the presence of lichens frequently found throughout the GCF (Figure 6c). According to Käffer (2011), lichens are sensitive to air pollution and can be used as bioindicators, as they have a close relationship with the atmosphere and serve as monitors of air pollution, with their proliferation occurring in areas with favorable environmental quality.

Along some waterfalls, potholes are formed, as shown in Figure 6b. According to Christofoletti (1981), these are created by the rotational abrasion of pebbles or blocks, which rotate due to the energetic influence of the water. Bigarella (1994) defined potholes as dissolution pans with small-scale weathering features developed by the lateral coalescence of depressions. In general, the vegetation is naturally dense scrub, and the riparian vegetation remains conserved.

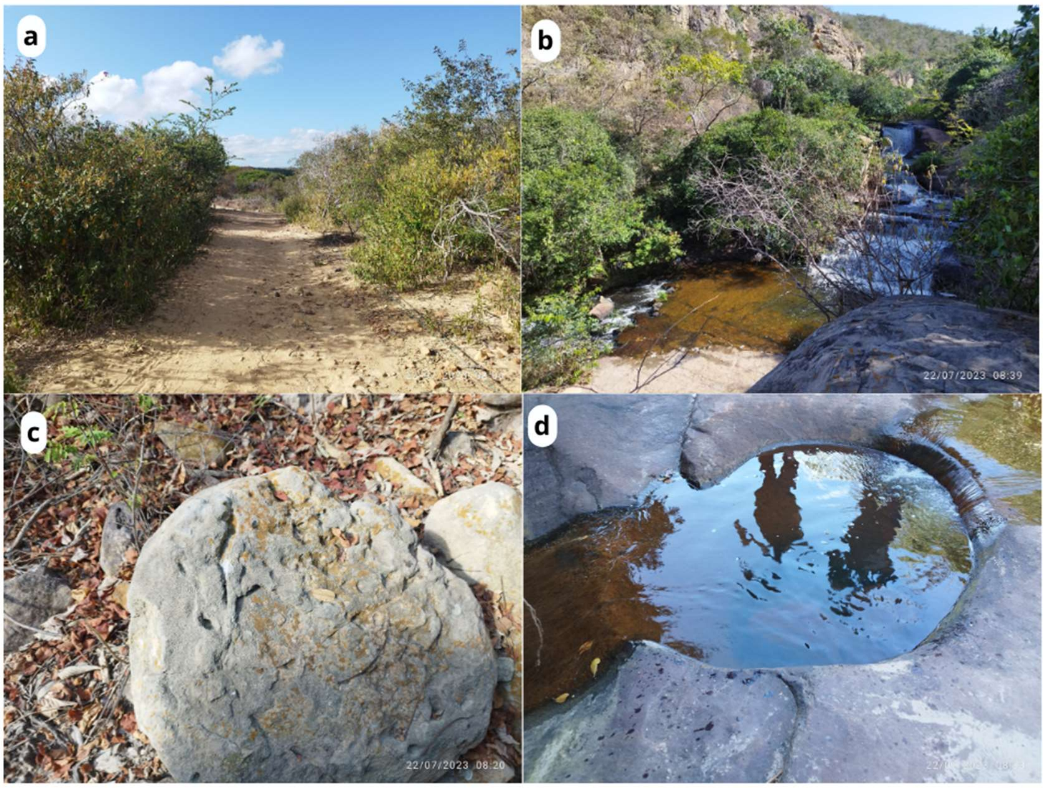

Figure 6 – Natural aspects of the GCF.
Source: The authors (2024).

4.2 Geomorphosite Cones Cársticos (GCC)

The area is represented between the humid slope (scarp) and recent talus deposits, which were formed from rock fragments and sediment deposition due to gravity. In front of the slope, the landscape features karst formations, known as "karst cones," due to their shape. These karst cones are composed of limestone derived from the exhumation of the metacarbonates of the Frecheirinha Formation (Ubajara Group). According to Karmann (2003), these are residual and steeply inclined landforms that resist dissolution, resulting in features like caves, lapies, and karst cones, as shown in Figure 7.

A crucial factor in the shaping of this terrain is the climatic conditions. The humid environment with frequent orographic rains contributes, as noted by Bigarella et al. (1999), to the dissolution of limestone through fissures and joints in the rock due to infiltration. Since the rocks are highly soluble and the area is humid, as noted by Kohler (1995), these factors contribute to the formation of a karst system, along with geo-chemical components like pressure and temperature.

The GCC represents a unique and significant karst formation in the state of Ceará. Although it is already protected by environmental legislation, further advancements in geodiversity research and valuation are needed. It is located on the borders of the Ubajara National Park, offering a broad view of geomorphological features such as the sertaneja surface and massifs. The area has scientific, geotouristic, and geoeducational potential, with trails and viewpoints allowing the analysis of fitoecological and morphopedological aspects.

Despite its geotouristic potential, the area is in good conservation status. Conservation measures of the Ubajara National Park help ensure the preservation of the GCC. The park already promotes geotouristic activities, including trails, waterfalls, and caves, with access provided by the cable car known as the "Ubajara Bondinho," which travels along a 0-meter route along the escarpment. The region is situated between two geomorphological formations, making it a transitional zone with distinct climatic peculiarities, such as higher rainfall compared to adjacent sertaneja surfaces.

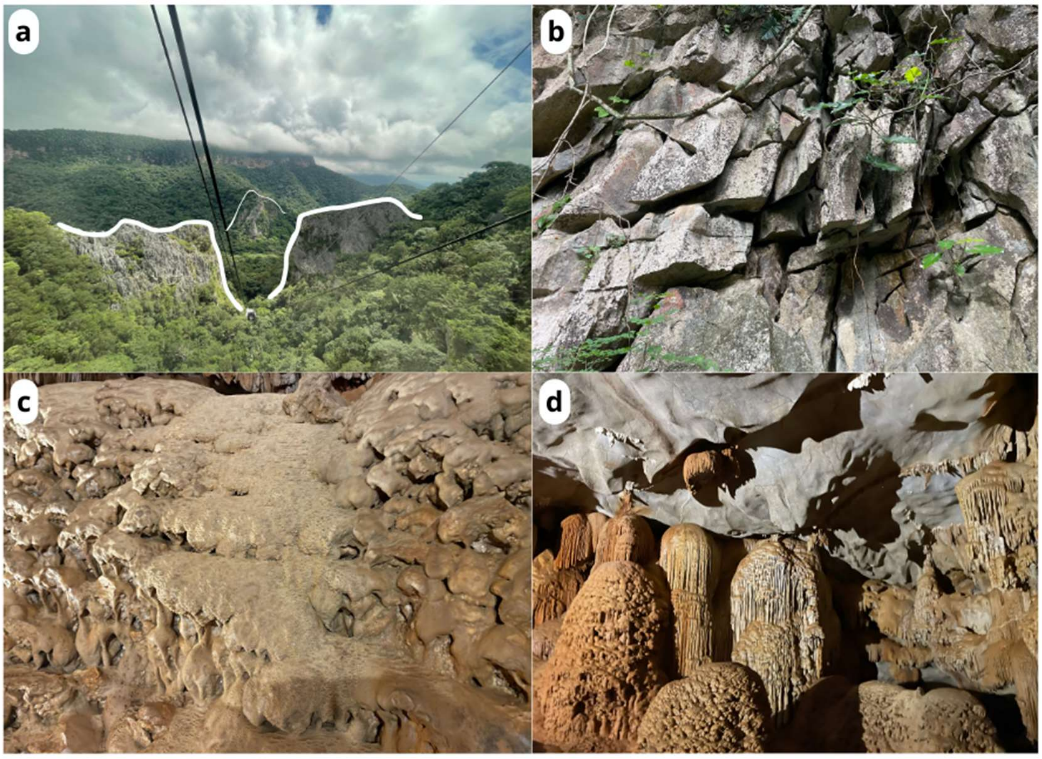

Figure 7 – a) Karst cones, b) formation of lapiás typical of karst models, c) Calcite (gloss particles) evidence of limestone dissolution and d) Presence of speleothems in the Ubajara cave.
Source: The authors (2024).

The GCC has an altitude ranging from 320 to 540 meters, with gentle slopes representing a geomorphological transition zone. The area features humid forest vegetation, which aids in water infiltration and, along with other geochemical agents, conditions the dissolution of carbonate layers, resulting in the formation of speleothems from the metacalcareous rocks of the GCC. Generally, the predominant geomorphological feature of the area is the gently undulating planed surfaces, shaped by the general leveling of the terrain followed by subsequent erosional rejuvenation, which is facilitated by the mild incision of an incipient drainage network. It is characterized by an extensive and monotonous gently undulating relief, without forming a hilly environment, due to its very low elevation amplitudes and long, very gentle slopes (MACHADO, 2010).

However, the landscape features some prominent karst towers situated between the Ibiapaba Plateau and the Peripheral Depression. These are characterized by the formation of lapies in the karst morphology, as shown by the metacarbonate rock features, depicted in Figure 7a, which provides a panoramic view of the three cones accessible by the cable car.

5. Final considerations

Discussing geodiversity and geomorphosites is a necessary task, given the lack of studies with this focus. The results indicate, on a preliminary basis, the identification of two potential geomorphosites in the municipality of Ubajara-CE, highlighting values such as educational, touristic, and aesthetic, among others. Firstly, this study represents the first step towards working with geomorphosites from the perspective of geodiversity. As observed, the areas of the geomorphosites present unique and even rare features at a national level, with diverse geodiversity showcasing forms and processes that make up a landscape of geoturistic, scientific, educational, and aesthetic value. The geomorphosite Cones Cársticos already has adequate infrastructure, unlike the Geomorphosite Cânion do Frade, which requires planning and conservation to enable large-scale tourist activities.

Although the guiding concept of the work is focused on geomorphological aspects, the two selected geomorphosites show correlations with other components of geodiversity and potentials within the municipality, demonstrating the need for more in-depth studies with detailed insights. This will contribute to the planning and promotion of the geodiversity in the study area

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