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Geodiversity of the Farias Brito and Altaneira municipalities, Ceará: Analyzing Geomorphological Heritage

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A B S T R A C T

The conservation of the biotic and abiotic environment occurs through the application of strategies that, while favoring the maintenance of these resources, allow their use in favor of territorial development. This work presents a study section that borders a municipality that is part of the UNESCO Araripe Geopark, for example, Crato, in Ceará. This work stands out in the identification of "Geomorphosites" and "Geomorphodiversity Sites" in the municipalities of Farias Brito and Altaneira, both in the State of Ceará. Thus, the development of studies that corroborate the recognition of natural potential, values and sustainable ways of use, combined with conservation and economic practices, are of fundamental importance, especially for geotourism. Methodologically, scientific value is attributed to the location considered a geomorphosite. Thus, the discovery of features originating from etchplanation in the municipality of Farias Brito-CE represents a great scientific advance in relation to the knowledge of its natural landscapes, which allowed the classification of a geomorphossite (Pedra Redonda), also highlighting the identification of six sites of geomorphodiversity (Cachoeira do Sítio Cedro, Pontal do Padre Cícero, Caldeirões da Umburana, Pedra de Salomão, Pedra Grande and Pedra dos Dantas), which have great geotouristic potential.

Keywords: Geotourism, Geomorphosite, Geomorphodiversity Sites, Geoconservation.

Geodiversidade dos municípios de Farias Brito e Altaneira, Ceará:Uma análise acerca do Patrimônio Geomorfológico

R E S U M O

A conservação do meio biótico e abiótico se dá através da aplicação de estratégias que, ao tempo em que favorecema manutenção desses recursos, permitem a utilização dos mesmos em favor do desenvolvimento territorial. O presente trabalho traz um recorte de estudo que faz limites com um município integrante do Geoparque UNESCO Araripe, a exemplo, Crato, no Ceará. Este trabalho destaca-se na identificação de "Geomorfossítios" e "Sítios da Geomorfodiversidade" dos municípios de Farias Brito e Altaneira, ambos no Estado do Ceará. Assim, justifica-se, pois, o desenvolvimento de estudos que corroboram para o reconhecimento das potencialidades naturais, valores e maneiras sustentáveis de utilização, aliado às práticas conservacionistas e econômicas, são de fundamental importância, principalmente para o geoturismo. Metodologicamente, atribui-se valor cientifico para o local considerado geomorfossítio. Assim, a descoberta de feições oriundas da etchplanação no município de Farias Brito-CE representa um grande avanço científico em relação ao conhecimentodas suas paisagens naturais, o que permitu classificar um geomorfossitio (Pedra Redonda), destaca-se também a identificação de seis sítios da geomorfodiversidade (Cachoeira do Sítio Cedro, Pontal do Padre Cícero, Caldeirões da Umburana, Pedra de Salomão, Pedra Grande e Pedra dos Dantas), os quais têm grande potencial geoturístico.

Palavras-chave: Geoturismo, Geomorfossítio, Sítios da Geomorfodiversidade, Geoconservação

Introduction

Over the last few years, geodiversity has been receiving increasing appreciation and, consequently, conservation efforts (Guerra; Jorge, 2018). Thus, the development of studies that support the recognition of natural potential, values, and sustainable ways of use, combined with conservation and economic practices, is of fundamental importance.

The conservation of the biotic and abiotic environment occurs through the application of

strategies that, while favoring the maintenance of these resources, allow their use in favor of territorial development. That is, the conservation of biodiversity and geodiversity happens because of conscious work aimed at sustainable development.

The concepts of geodiversity and geomorphological heritage have been increasingly adopted in the field of Geosciences, since the geoconservation of natural elements, composed of abiotic elements, is necessary for maintaining the quality of life of species, as well as leading to the understanding of the origin and evolution of the planet (Jorge; Guerra, 2016). Although Brazil is rich in geodiversity, there is a lack of studies and inventory methodologies, which represents a barrier to the development of geoconservation programs (Oliveira; Pedrosa; Rodrigues, 2013).

The concept of geodiversity is relatively new. It was probably mentioned for the first time in Tasmania (Australia) and began to be disseminated from the 1990s onwards (Gray, 2005), during the International Geoconservation Conference. Subsequently, the topic was addressed at the Malvern Conference on Geological and Landscape Conservation held in the United Kingdom in 1993 (Bento, 2011).

Sharples (1995) relates geodiversity to the abiotic elements of nature, defining it as the diversity of geological (bedrocks), geomorphological (landform), and soil features, assemblages, systems, and processes. Subsequently, Stanley (2000) defined geodiversity as the variety of geological environments, phenomena, and processes that make landscapes, which provide a framework for life on Earth. Sharples updated his concept in 2002, defining geodiversity as the diversity of characteristics, groups, systems, and geological (substrates), geomorphological (landforms), and soil processes, endowed with intrinsic, ecological, and anthropocentric value.

A more recent concept of geodiversity was presented by Claudino-Sales (2021), the author states that: *"itrepresents the variety of elements and processes associated with the abiotic environment – geological diversity, geomorphodiversity, pedodiversity, hydrodiversity, climodiversity – in any forms, spatial and temporal scales, and modes of interaction"* (Claudino-Sales, 2021, p. 46).

That is, the author also includes climate diversity as an element of geodiversity, which can be presented in any formand spatial and temporal scales of interaction.

Geologists and geomorphologists began to use the term to describe the diversity within abiotic nature, seeking since then to compensate for the emphasis given to biological aspects in policies focused on valuing and protecting nature (Pereira, 2006). The term was proposed in comparison with the term biodiversity, which refers to the biological diversity of the planet and the need for its preservation.

This work deals with an area that borders municipalities that are part of the UNESCO Araripe Geopark, such as Crato, in Ceará (Figure 1). This geopark has the potential for the development of recognized geotouristic and educational activities. Also noteworthy is a concentration of research on geodiversity coinciding with its boundaries. Thus, studies of adjacent areas are necessary. For being a pioneer in approaching the municipalities of Farias Brito and Altaneira (Ceará), this research may serve as a basis for guiding further studies in this same area, or adjacent ones.

Thus, the objective of this article is to highlight the richness of geodiversity in the limits of the Araripe Geopark, specifically in the municipalities above, aiming to promote and allow the implementation of geotourism in the region, focused on implementing economic practices associated with sustainable development based on the abiotic richness present there.

Methodology

This work included bibliographic surveys on the concepts of geodiversity, geomorphological heritage, and geomorphosites, in addition to inventory methodologies and the use of geoprocessing and fieldwork.

The inventory methodology was based on Pereira (2006), Araújo (2021) and Lopes (2017), mainly for assessing relief and geoforms in crystalline rocks as a Geomorphological Heritage. The inventory procedures were selection, characterization of the site, and assessment, based on geodiversity values, as pointed out by Henriques (2023), reserving the quantitative assessment for later work.

The research was conducted in stages, with emphasis on the survey of geomorphosites and qualitative analysis in the municipalities of Farias Brito and Altaneiras. The initial perspective was to obtain a theoretical basis to identify and characterize geomorphosites in the study area and perform their geomorphological description.

To conduct the qualitative assessment, it is

always necessary to focus on a clear objective to ensure that the selection of sites occurs under the same criteria. To define this objective, four questions were considered: the theme, thevalue, the scale, and the use (e.g., Lima; Brilha; Salamuni, 2010). Still, according to Henriques (2023) whose research was based on that by Brilha (2016), in the fieldwork, we sought geoforms that best synthesized the criterion of integrity, rarity, and scientific and educational importanceThe fieldwork was essential for the recognition of the study area and for its characterization and photographic records. In addition, the coordinates and bases of the location were obtained through the GPS Essentials software, used in a mobile application. Field work also resulted in the possibility of interacting with local communities.

To select potential sites and determine what will constitute the geomorphological heritage, based on the qualitative analysis, a screening of geoforms previously raised was conducted, selecting the ones that best represented the area, as defended by Henriques (2023). The selection followed three inclusion criteria (attributes A, B, and C), one of them being the main one and the others supplementary.

In order of importance, in the inclusion of sites, the status of "high scientific value" (Attribute A) was adopted as mandatory, regardless of factors such as size (isolated, in an area or panoramic), location, and accessibility. For the scientific value, the criterion of **representativeness** of geomorphological forms and processes was observed, considering **uniqueness**, which indicates the occurrence of unique and differentiated characteristics, consisting of an important geomorphic set in the region; **rarity** (scarcity) of these types of occurrences in the study area; **relevance**, which indicates the action of extraordinary geomorphic processes in the semi-arid region, such as etchplanation and dissolution, and the state of conservation (**integrity**) of the geoform in relation to deterioration by anthropic agents, in addition to considering its importance for the present and future knowledge of the history of the planet.

In this bias, it should be noted that the sum of attributes A, B, and C corroborate the teaching value of the geoforms that can be used in field classes and learning in Geosciences, regardless of education level (basic or higher education) (Henriques, 2023).

Still, as a complementary aspect, preference was also given to geoforms with a panoramic dimension (Attribute B) or isolated location/area (Attribute C), but with a high value in one or more of its other types (ecological, cultural, aesthetic, etc.). Sites with a panoramic dimension must have good or very good visibility over other places of geomorphological interest (Henriques, 2023).

As for the ecological value, it can be associated with geoforms with the presence of nesting birds of prey on steep slopes, bat habitats in caves, and altitude vegetation. The aesthetic value concerns the scenic highlight of the geoform in the landscape or comparison with other places in the same area. Geoforms that denote a good relationship with cultural/historical and religious elements were also considered, as indicated by Henriques (2023).

Inventory of Geomorphological Heritage

Table 1, below, represents the synthesis of the qualitative evaluation that was conducted regarding the geomorphological heritage of the Farias Brito and Altaneira municipalities, in the state of Ceará.

Pedra Redonda Site (Farias Brito Municipality)

The Pedra Redonda site (Figure 2), as it is popularly known, is inserted in the coordinates Lat. 06° 56.157, Long. 39° 28.639'. It can be reached by car or motorcycle, even though there are no paved roads. There are also no short or long-distance trails. The site presents good conditions for observation, with a panoramic dimension. However, there areevident barriers to access, such as precarious roads, and no signs.

The site is already used for geotourism purposes, albeit on a small scale. Carvalho-Neta (2019) mentions Pedra Redonda as a place of potential for geodiversity, and points out the need for studies, located beyond the limits of the Araripe sedimentary basin.

Pedra Redonda has an altitude of 426 m and comprises a magnitude of about 0.1 ha. From a geological point of view, it is characterized by granitic lithology (CPRM, 2014; 2018; Queiroz, 2020). From the geomorphological point of view, it constitutes a boulder rock, representing a feature that corresponds to an elevation of the sertaneja surface.

This feature probably originates from etchplanation processes, resulting from the chemical destruction of the rock inthe subsurface, followed by the removal of the weathering mantle and consequent exhumation of the saprolite,

leaving in the landscape the most resistant portion of granite that was not destroyed (e.g., Goudie, 2004). Thus, boulders constitute the exhumed saprolite, forming compact features of the remaining material, as described by Goudie (2004), Maia and Nascimento (2018), and Queiroz (2020).

According to Maia and Nascimento (2018) and Claudino-Sales (2016), the exhumation of plutons (intrusive igneous rocks) syn-, late- and post-orogeneses, represents a large sample of diversified granitic forms, in the extreme Northeast of Brazil. There are features such as massifs, slabs, and fields of inselbergs that stand out and characterize the landscape amid the extensive planing surfaces. Such features represent different typologies such as bornhadts, boulders, inselbgibergs, castle koopies, etc. (Queiroz, 2020).

The presence of echplanation in the northeastern semi-arid region is proof of the occurrence of climatic alternations in the area over geological time and is of great paleogeomorphological importance (Maia; Nascimento, 2018). It should also be noted that even in environments with a predominance of physical weathering, it is possible to observe that the features undergo an intense process of chemical weathering in a semi-arid environment, which is notorious for darker marks generated by rainwater runoff (drainage type) (Peulvast; Claudino-Sales, 2002).

From Pedra Redonda, it is possible to observe residual ridges associated with the Maciço de Quincucá (Figure 5), studied by Cordeiro (2017). The author argues that the fact that the relief is commonly arranged in sequences of residual ridges and dissected valleys stems from the control of the accommodation and the elongated shape of the Serra do Quincuncá crystalline massif, showing good agreement with the NE-SW system of dextral kinematics in Brazilian shear zones, associated with the Patos Lineament. Furthermore, these zones, in general, control the accommodation of several granite bodies (Cordeiro, 2017).

Given these data, the Pedra Redonda site is defined as a geomorphosite, as it is characterized by high scientific relevance, covering the criteria of representativeness, the rarity of the type of boulder, and integrity, which is associatedwith the intensity of physical-chemical weathering, conditioned by lithological characteristics.

Other elements are included in the analysis of the site. It is possible to observe, for example (Figure 3), the changein vegetation in 2022, with the rainy season (April) represented in Figure 3A, and the dry season (October) represented in Figure 3B. This vegetation supports biodiversity.

Pedra Redonda also fits the cultural value, seen from the point of view of religiosity. Devotees to Padre Cícero Romão Batista have built a small memorial at the top of the boulder, housing a statue of him. Although it is located in aprivate area, it already has a growing number of visitors. In the fieldwork, it was possible to verify residents of the community (Sítio Cedro) building a ladder that gives access to the top of the boulder. In a dialogue established with them, we could verify that the material used was donated by the population itself, due to their devotion.

Sites of Geomorphodiversity

According to Brilha (2016), Sites of Geomorphodiversity are not those endowed with great scientific value, but with the other values addressed in this work (ecological, aesthetic, and cultural). They exist in both municipalities mentioned here, and are presented in the following terms:

Site Sítio Cedro Waterfall

The Sítio Cedro waterfall (Figure 4) was the second location inventoried. It is in coordinates Lat. 06º 56,692`,Long. 39º 28,709, and has an altitude of 382 m. It can be accessed via roads, although they are not paved or have signs. Even so, it can be reached by car or motorcycle, similar to the Pedra Redonda site.

The Sítio Cedro waterfall presents characteristics of a slab (outcropping platform), which is a type of recurrent geoform in the sertaneja surface. It is a feature resulting mainly from the exhumation of magmatic rock, of the granite type (CPRM, 2018), modeled at the same time by the action and geomorphological force of external agents throughout the Cenozoic. The slab is weathered, with the occurrence of gnama pits (dissolution basins), which is facilitated by the high degree of fracturing and structural deformation that the rock presents, exposing fractures, joints, and lineaments.

A medium scientific value is attributed to the flagstone, as it supports the understanding of the evolutionary, geological (structural deformations), and geomorphological (chemical weathering and mechanical erosion) processes. However, from the point of view of rarity, it is not important, as there are other flagstones in the region. It also has aesthetic value, related to its size

and the presence of water, which brings visual comfort for contemplation in the middle of a semiarid region. It also has an ecological value, related to the presence of water, making it an environment that supports biodiversity, with the presence of birds, small amphibians, reptiles, and insects.

Site Pontal do Padre Cícero

The Pontal do Padre Cícero (Figure 5) is in a portion of the Serra do Quincuncá crystalline massif, in the Altaneira municipality, which comprises a geomorphological feature of regional size, arranged in the E-W direction, supported by granitic rocks, (granodiorite and diorite - CPRM, 2018). From Pontal do Padre Cícero, it is possible to contemplate the sertaneja surface and the residual ridges in alignment (panoramic view), in addition to the fluvial plain of the Cariús River, part of the upper Jaguaribe river basin.

The differential erosion that was established, according to the structural planes of Precambrian deformation, defined by the Patos Lineament, distinguished the metamorphic basement from the intrusive nucleus, leading to the progressive exhumation of the Quincuncá Massif and the formation of parallel residual ridges and incised valleys (Cordeiro, 2017). In this way, the conditioning of the erosion processes along the shear zones of Aiuaba, Jordão, Limoeiro, Tatajuba, and Farias Brito originated lineaments that confine the drainage channels, to the west and east of the Maciço do Quincuncá, guiding the dissection and, sometimes, the aggradation of the river (Cordeiro, 2017).

The area of the Maciço de Quincuncá presents an intrusive structure. Residual features of the escarpment type are visualized between the top and the slope, conditioning the rainfall actions through surface runoff. In this area,thermoclastic-type weathering also occurs.

The Pontal do Padre Cícero represents a geodiversity site of the viewpoint type, as indicated by Diniz and Araújo (2022). From it, it is possible to visualize, as indicated in Figure 5, the Sertaneja Surface, which represents the floor surface of the Brazilian Northeast, elaborated in the Cenozoic by the denudation agents, from which the elevated reliefssuch as the massifs stand out (similar to the Massif of Quincuncá). Structural crystals are also visible, supported by more resistant lithologies of the basement, normally controlled by structures such as folds and transversal faults to the geoform, which tend to stand out above the leveling surface as small steep slopes. It is also possible to visualize the fluvial plain of the Cariús River.

These natural features that can be viewed from the vantage point add geoscientific and geoeducational value to the viewpoint. It is mentioned that educational institutions already conducted field classes there, demonstrating its importance for geoeducation. In addition, over the last few years, tourism has been growing, especially of the cultural and religious types, and geotourism.

This site has been assigned a medium scientific value. The observation site has low ecological value. On the other hand, it presents high aesthetic value, due to its panoramic view. Its cultural value is also considered high, due to the devotion to Padre Cícero. Indeed, there is a memorial on the site, telling the historical formation of the community.

Site Caldeirões da Umburana

The site Caldeirões da Umburana, as it is popularly known (Figure 6), is in the rural area of the Farias Brito municipality, CE, Lat. 06º 50.150`, Long. 039º 38.399`, with an altitude of 462 m. It is also located in the crystalline massif of Serra do Quincuncá.

Access routes to the site are via roads, similar to the sites Pedra Redonda and Sítio Cedro waterfall. However, there is no pavement, and the roads are precarious and made for wagons, making the path difficult to access. Observation conditions are medium, and there is medium-sized vegetation in its surroundings. In addition, there are obstacles such as fences since it is a private area. It is currently used for rural activities, with many of the surrounding residents using the local water for livestock and agriculture.

The Caldeirões da Umburana geoform evolved from faulted and fractured structures, present in granite, granodiorite, and diorite rocks (CPRM, 2018). These rocks were worked on in the Neogene by dissection processes, which led to the formation of a river valley. The surface runoff water lodges in the deformation structures that the rock presents, providing the formation of intermittent waterfalls.

The site has medium scientific value, as it allows the visualization and study of tectonic processes (faults and fracturing) and morphogenetic processes (chemical and physical weathering, and mechanical and fluvial erosion). Other values are associated with it, such as aesthetics, which is considered high due to the

presence of water and a panoramic view. An additional added value is the ecological one, determined here as medium, as the site supports the surrounding biodiversity. The cultural value is low, as the place is little visited and does not have great historical or even touristic representation.

Site Pedra de Salomão

The Pedra de Salomão (Figure 7), as it is popularly known, is named after the former owner and resident of the place. It is in coordinates Lat. 06º 58.097´, Long. 039° 38.402`, with an altitude of 380 m, in Sítio Bananeira, in the São Romão District, part of the Altaneira municipality. The access is difficult, and there are obstacles such as fences in a private area. It is mainly used for rural activities, such as agriculture and livestock, representing the economy of the community. To reach Pedra de Salomão, there is a short trail of medium difficulty. It has potential use for tourism and teaching.

From the lithological point of view, it is configured as metamorphic, characterized by the presence of metalimestone rock. The action of chemical weathering produced dissolution in the rock, despite the semi-arid climate, resulting in the formation of limestone pavement (karren, fluting), a type of parallel microforms, typical of the karst relief. These features were identified in the area by Cordeiro (2017).

The medium scientific value is justified by the fact that it is an outcrop of metalimestones that exposes karst reliefin the middle of the hot and dry northeastern hinterland. The aesthetic value was considered high, because from the site it is possible to have a panoramic view of the area, visualizing the São Romão river and different plantations (corn, beans). It has a medium ecological value, as it shelters species and serves as a support for biodiversity, mainly because there is a river nearby. Its cultural value was considered low due to its location.

Site Pedra Grande

The site (Figure 8) is in coordinates Lat. 06º 58.167', Long. 039º 38.973', with an altitude of 569 m. It is in the São Romão District, in the Altaneira municipality. The access road is not paved but with good traffic conditions.

Pedra Grande, as it is popularly known, is a rocky outcrop supported by granite and granodiorite rocks, in the Serra do Quincuncá (CPRM, 2018). The geoform represents a residual feature, generated by the process of differential erosion (action of thermoclastic-type physical weathering, erosion of surface runoff water, exploration of the fragility of the rocks by all external agents) that has been sculpting the slopes of the massive crystalline. It is configured, in short, as a geoform with a steep slope in the crystalline massif, with apparent morphodynamic processes, presenting a dominant action of physical weathering of the thermoclastic type.

It was attributed medium scientific value due to the action and presence of external processes. It has low ecological value since it is home to species such as birds but on a small scale. The aesthetic value was considered high, due to the panoramic view. Its cultural value was considered high, based on religiosity in the shape of the devotion to Padre Cícero, with a small memorial in his honor at the top.

Site Pedra dos Dantas

This site (Figure 9) is in the Altaneira municipality (CE), Lat. 06º 59.776´, Long. 039º 45.290`, with an altitude of 606 m. It is the site of the highest altitude of those identified here. The access route is via largely paved roads.

It is located in a portion of the Serra do Quincuncá crystalline massif, bordering the Assaré municipality to the west, and is supported by magmatic rocks, such as granite, granodiorite, and diorite (CPRM, 2018).

The area corresponds to the dissected plateau of the massif, in a residual escarpment feature. It presents apparent morphodynamic processes, through weathering with thermoclasy, producing blocks, in addition to chemical weatheringof the dissolution type.

It is noteworthy that the scientific value of this geoform was considered low. It presents, however, medium tourist value, as the area is associated with adventure tourism, being used for the practice of abseiling. It has medium ecological value, as it is home to species such as birds, but on a small scale. Its aesthetic value was considered medium, due to the panoramic view, and the cultural value was considered null since there are no human or affective relationships with the place.

Final considerations

It is necessary to highlight the relevance of this research, as it is a pioneering study on the geomorphological heritage in the municipalities under analysis. The potential of the locations

identified beyond the limits of the UNESCO Araripe Geopark is confirmed, demanding further and more detailed studies, to better disseminate knowledge about geodiversity and geomorphological heritage.

Thus, the survey addressed in this research points to a place with potential and values associated with geodiversity, specifically with geomorphological heritage. The discovery of these features originated from etchplanation in the Farias Brito municipality, CE, represents a great scientific advance in relation to the knowledge ofits natural landscapes, which allowed classifying a geomorphosite (Pedra Redonda). It should be noted that the geomorphosite already suffers impacts in the face of active anthropic agents. In addition to this, we also highlight the identification of six geodiversity sites (Cachoeira do Sítio Cedro, Pontal do Padre Cícero, Caldeirões da Umburana, Pedra de Salomão, Pedra Grande, and Pedra dos Dantas), which have great geotourism potential and geo-educational, additionally to cultural and religious values.

This research indicates the urgency of actions that lead to the geoconservation and dissemination of the identified sites of geomorphological heritage, seeking to associate the values and potentialities present in the identified places with greater relevance. This research is based on the valuation of geomorphological heritage and geodiversity, in the perspective that it may contribute to the advancement of geosciences, especially Physical Geography, and to the sustainable development of the region under analysis.

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