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INTEGRATED ANALYSIS OF GEODIVERSITY IN THE MUNICIPALITY OF ACARI-RN, BRAZILIAN SEMIARID REGION

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ABSTRACT
Commonly geodiversity is associated with geological knowledge, leaving aside others abiotic components such as geomorphological, pedological and hydrological. Geodiversity, compared to biodiversity, does not yet have the same prestige and political position. In the Brazilian semiarid region, there are still many gaps related to the knowledge of geodiversity. In 2022, the Seridó Global Geopark was recognized by UNESCO as a territory that provides an intriguing insight into the Earth's history through its unique natural landscape, cultural and culinary history. Among the municipalities inserted in the territory of the Seridó Geopark is Acari-RN, which has rich geodiversity. The objective of this work was to present an integrated analysis of the geodiversity of the municipality of Acarí-RN, encompassing information related to variety of geological, geomorphological, pedological and hydrological features and processes. Fieldwork was carried out, we identified and mapped landforms and their physiognomic aspects and georeferenced using portable GPS. We collected soils to represent the different landforms. A ten geosites were characterized in the municipality, four of them belonging to the Seridó Geopark, in which we also sought to consider the information about the relief and soils. In the present work, the term "integrated analysis of geodiversity" was used in order to encourage debate and to make it clear that geodiversity is not limited to geological aspects. The integrated analysis of geodiversity can be a subsidy for geotourism, regional valorization of the semiarid and also preservation of the Caatinga biome. The identification and characterization of potential geosites in Acarí-RN can help for developing efficient municipal policy to combining the conservation of their unique geological heritage with public outreach and sustainable development.
Keywords: Seridó Geopark; Geotourism; Caatinga; Geosites.

ANÁLISE INTEGRADA DA GEODIVERSIDADE NO MUNICÍPIO DE ACARÍ-RN, SEMIÁRIDO BRASILEIRO

RESUMO
Muitas vezes o termo geodiversidade está vinculado exclusivamente ao conhecimento geológico, deixando de lado com frequência as informações dos demais componentes do meio físico, como

os relevos e os solos. A geodiversidade, em comparação a biodiversidade, ainda não possui o mesmo prestígio e posição política. No semiárido brasileiro, ainda existem muitas lacunas referentes ao conhecimento da geodiversidade. Em 2022, o Geoparque Seridó foi reconhecido pela UNESCO como um território com riquezas naturais e culturais a nível internacional. Entre os municípios inseridos no território do Geoparque está Acari-RN, o qual possui rica geodiversidade, além dos geossítios do Geoparque. O objetivo deste trabalho foi apresentar uma análise integrada da geodiversidade do município de Acarí-RN, englobando informações relativas à geologia, geomorfologia, pedologia e processos associados. Realizou-se um levantamento do meio físico do município, com análises de mapas geológicos, caracterização do relevo e coletas e análises de solos. Foram caracterizados 10 geossítios no município, sendo quatro desses pertencentes ao Geoparque Seridó, nesses buscou-se considerar também as informações sobre o relevo e os solos. No presente trabalho utilizou-se o termo "análise integrada da geodiversidade" com o intuito de incentivar o debate e de deixar claro que a geodiversidade não se resume aos aspectos geológicos. A análise integrada da geodiversidade pode ser um subsídio para o geoturismo, valorização regional do semiárido e também preservação da caatinga, afinal, a fauna e flora dependem do substrato que dá suporte a vida. A identificação e caracterização de potenciais geossítios em Acarí-RN pode subsidiar as políticas municipais voltadas a ações de conservação, práticas de educação ambiental, valorização do patrimônio natural e incentivo ao geoturismo.

Palavras-chave: Geoparque Seridó; Geoturismo; Geodiversidade; Geossítio.

INTRODUCTION

Geodiversity describes the variety of geological, geomorphological, pedological and hydrological features and processes (BRILHA, 2005; NASCIMENTO et al., 2008; BRADBURY, 2014). Biodiversity involves the entire biotic set, which is conditioned by geodiversity, since the different organisms need a substrate to perform their fixation and develop their metabolic activities (GONÇALVES et al., 2001; BRILHA, 2005). Geodiversity is important to biodiversity because they support biota in distinct environments conditions, including caves, cliffs, dunes, and among others (BRILHA, 2005). In relation to the human species, geodiversity offers nutritional availability, shelters and materials for its construction (BRILHA, 2005). It supports and offers many vital ecosystem services, including knowledge of physical and chemical processes, based on understanding their spatial and time dynamics (GRAY; GORDON; BROWN, 2013).

Geodiversity is commonly linked to geological knowledge, often leaving aside information on reliefs and soils (NASCIMENTO et al., 2008). Geodiversity, compared to biodiversity, does not yet have the same prestige and political position (CROFTS, 2014). Aspects of geodiversity are still incipient in environmental preservation policies (BRILHA, 2005). Geosciences have an essential contribution to addressing recognized knowledge gaps in ecosystem assessment and the implementation of solutions to environmental issues (GRAY; GORDON; BROWN, 2013).

Geodiversity is manifested, in the natural environment, through landscapes and characteristics of the local physical environment, so inadequate interventions in geodiversity can generate a series of negative impacts, so we must know and understand their meanings, which are systemically connected between geodiversity and biodiversity (SILVA et al., 2008). The Seridó region, in the Brazilian semiarid, corresponds to an environmentally fragile area, in which it suffers from intense erosive processes and the advance of desertification (AB´SÁBER, 1977; MINISTÉRIO DO MEIO AMBIENTE, 2005). The integrated understanding of geodiversity offers contributions to territorial planning and management, considering its potentialities and landscape weaknesses (SILVA et al., 2008).

In the Brazilian semiarid, there are still many gaps related to the knowledge of geodiversity (CLAUDINO-SALES, 2010). In 2022, the Seridó Geopark was recognized by UNESCO, but it is believed that there are still spaces for a more integrative approach, which can act as subsidies for regional valorization and incentives to geotourism practices. The objective of this work was to present an integrated analysis of the geodiversity of the municipality of Acarí-RN, encompassing information related to variety of geological, geomorphological, pedological and hydrological, and considering the features and processes associated with typical semiarid environment (northeastern Brazilian interior).

MATERIAL AND METHODS

Study area

The study was conducted in the municipality of Acari, Rio Grande do Norte, in NE Brazil (FIGURE 1). The municipality of Acari-RN is located in the Seridó region. The climate of the region is semiarid, type "As" (KOPPEN, 1931). Acari-RN is bordered by Currais Novos (RN), São Vicente (RN), Cruzeta (RN), São José do Seridó (RN), Frei Martinho (PB), Jardim do Seridó (RN) and Carnaúba dos Dantas (RN).

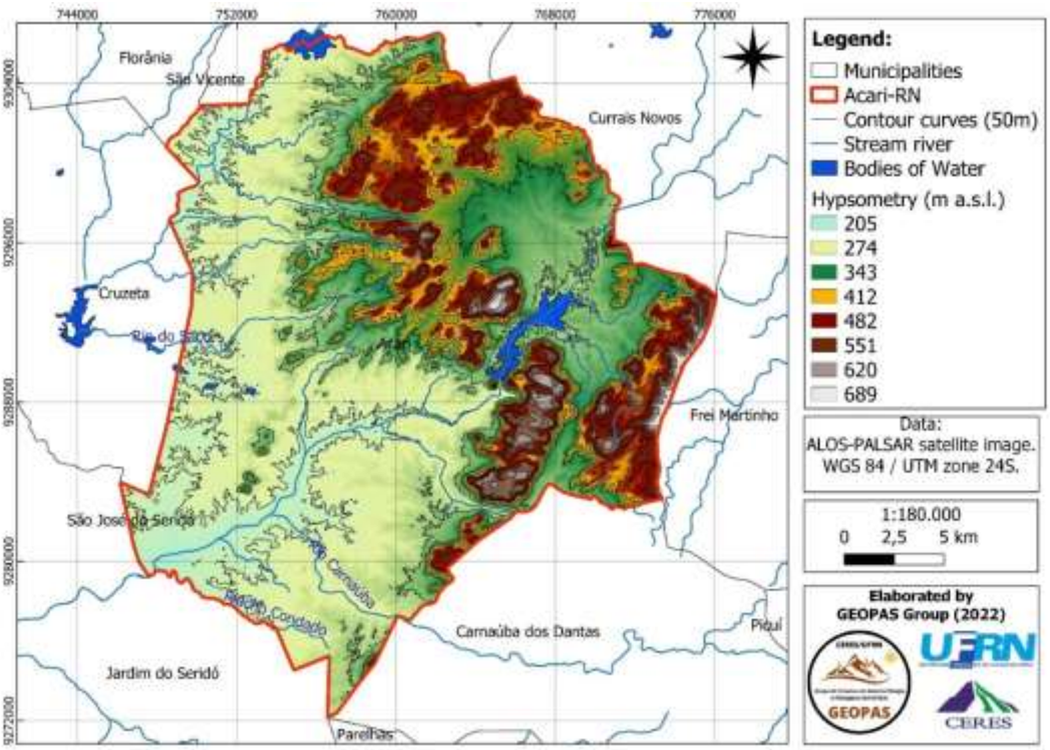

Figure 1: Hypsometric map of the Acari-RN.

The municipality of Acari-RN is part of the Seridó Geopark, having in its territory four geosites recognized by UNESCO (2022). being the "Cruzeiro de Acarí", "Açude Gargalheiras", "Marmitas do Rio Carnaúba" and "Poço do Arroz", which occupy an area of about 5 km², with Gargalheiras being the most extensive with an approximate area of

4.9 km² (CHAGAS et.al., 2022). The Seridó UNESCO Global Geopark covers an area of 2,800 km², it is home to more than 120,000 inhabitants.

The study area has main geomorphic feature is extensive depressions are dotted with inselbergs landforms associated more resistant plutonic intrusions. The relief has altitudes ranging from 205 to 689 m a.s.l. (FIGURE 1). In general, the soils developed in the municipality on the crystalline rocks are shallow, stony and poorly developed, with predominance of Neossolos Litólicos and Luvissolos Crômicos (CPRM, 2005).

The region is geologically located in Borborema Province (SANTOS; FERREIRA; SILVA JR., 2002; ANGELIM et al., 2006), where the lithotype in the study area are the Itaporanga Suite throughout the south-central area of the municipality, and other geological units such as Jucurutu, Ecuador, Seridó, Dona Inês, Poço da Cruz and Serra do Martins (CPRM, 2005; ANGELIM et al., 2006) (FIGURE 2).

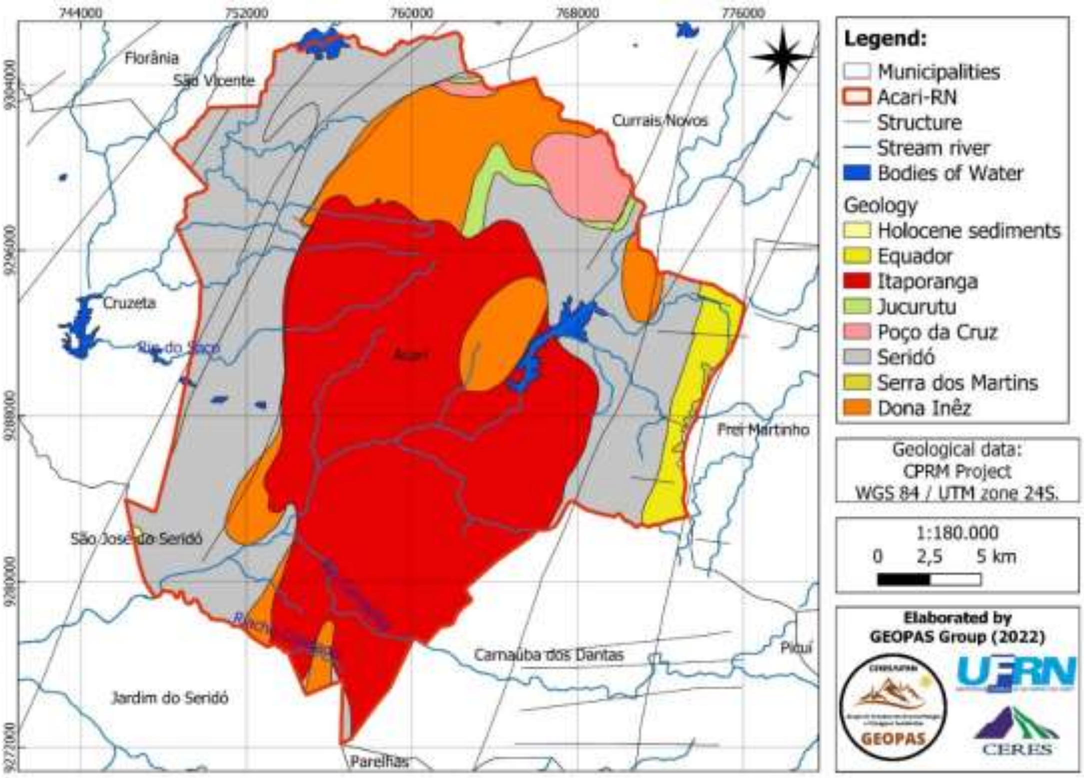

Figure 2: Geological map of the Acari-RN.

Cartographic content analysis

We used the literature and cartographic review of the study area. In order to characterize the Acari-RN territory, cartographic products were prepared using GIS (Geographic Information System). The morphologic aspects maps were produced through field work and photointerpretation, was generated using the ALOS-PALSAR satellite image (Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar), with the Phased Arrayed type L-Band SAR (PALSAR) microwave sensor with a spatial resolution of 12.5 m. Field work consisted in identifying the main landforms and morphogenetic processes on the study area.

Digital Elevation Model (DEM) was generated by ALOS-PALSAR satellite image using remote sensing techniques. The DEM provided good terrain representation of the study area. All processing was done using QGIS software.

The procedures performed were: acquisition of the bibliographic collection, elaboration of the cartographic base, field campaign, elaboration of final products with map, explanatory text, selection of the photographic archive and tables elaborated in Microsoft Excel. The geological information used was based on the cartographic data linked to the Project “Crustal Evolution and Metallogeny of the Brazilian”, elaborated by CPRM (scale 1:350,000).

The final geological map was framed in the scale of 1:170,000. Its definitive layout was elaborated in the QGIS software. A photographic survey and mapping validation were carried out from fieldwork. This step was essential for mapping conference, where it was possible to verify the interpreted and mapped aspects.

Field and laboratory analysis

Fieldwork was carried out during the December, January and February of 2022. During the detailed field sampling at the municipality of Acari-RN, we identified and mapped landforms and their physiognomic aspects and georeferenced using portable GPS.

We collected soils to represent the different landforms. Soil morphological descriptions and sampling followed the recommendations at Embrapa (1997). Soils were classified according to the Embrapa (2018). Deformed samples from all soil horizons were sampled according to Santos et al. (2013). The deformed samples were air-dried and sieved to obtain “air-dried fine earth” (< 2.0 mm) and were used in physical analyses. Soil color was determined using the book of color chips that follow the Munsell System of Color Notation (MÜNSELL, 1994). Physical analysis was performed at the LADGEO (Laboratório Didático de Geociências), at the CERES/UFRN (Centro de Ensino Superior do Seridó/UFRN).

RESULTS

Geosites of Acarí-RN belong to the Seridó Geopark

The Seridó UNESCO Global Geopark has four geosites that each print very unique features in the Acari-RN: I) Gargalheiras, II) Cruzeiro de Acari, III) Poço do Arroz, and IV) Marmitas do Rio Carnaúbas. The geosites Garagalheiras (6º 25' 32"S and 36º 36' 08'W) is represented by the dam and area of its surroundings, being the largest geosite in the municipality. The Gargalheiras Reservoir is the fourth largest reservoir in the Rio Grande do Norte, built in the 1950s. The term Gargalheiras, is associated with the bottleneck or throat formed by the granite massifs of the region, which funneled the passage path of the Acauã River, which was dammed and forms the dam. In the area are inequigranular and equigranular granites of medium granulometry, composed mainly by minerals such as K-feldspar, quartz, plagioclase, biotite and muscovite. The geological formations of the Geosite are related to the Intrusive Suites Itaporanga and Dona Inês (TABLE 1) (NASCIMENTO, 2020).

Table 1: Geosites of Acarí-RN belong to the Seridó Geopark

Geosites	Geographic coordinate	Geological aspects	Geomorphological aspects	Pedological aspects (EMBRAPA, 2018)

Açude Gargalheiras	6º 25' 32''S 36º 36' 08''W	granites associated with Itaporanga and Dona Inês Suite	Dam wall between the granite massifs (bottleneck or throat area)	Neossolos flúvicos (RY) Neossolos litólicos (RL) Neossolos regolíticos (RR)
Poço do Arroz	6º 26' 22''S 36º 36' 52''W	granites associated with Itaporanga Suite	weathering pits on barren surfaces of granites (fluvial action)	Neossolos flúvicos (RY) Neossolos litólicos (RL)
Cruzeiro de Acarí	6º 26' 19''S 36º 38' 28''W	granites associated with Itaporanga Suite	granite rocky outcrop (Sertaneja surface)	Neossolos regolíticos (RR) Luvissolo crômico (TC)
Marmitas do Rio Carnaúba	6º 29' 42"S 36º 41' 31"W	granites associated with Itaporanga Suite	weathering pits on barren surfaces of granites (fluvial action)	Neossolos flúvicos (RY) Neossolos litólicos (RL)

Located downstream of the Gargalheiras Geosite, is the Geosite Poço do Arroz (6º 26' 22"S, 36º 36' 52'W). There are granite blocks of the Itaporanga suite, being characterized as inequigranular, of medium to thick granulometry, composed of minerals such as K-feldspar, quartz, plagioclase, and biotite, among others. The main characteristic of the area are the weathering pits (called "marmitas" in Brazil) that form some wells that favor water storage and some rock paintings near the river bed (NASCIMENTO, 2020).

In the urban area of the municipality is the Cruzeiro de Acarí Geosite (also called "Serrote" by local people) (6º 26' 19"S, 36º 38' 28"W), in the area is a rocky outcrop associated with the Itaporanga Suite characterized by inequigranular granite blocks, of medium to thick granulometry, with the presence of minerals such as K-feldspar of centimetric dimensions, quartz, plagioclase, biotite, amphibolies, among others (NASCIMENTO, 2020).

The "Marmitas do Rio Carnaúba" Geosite (6º 29'42"S and 36º 41'31"W) is located on the riverbed of the Carnaúba River, the geological formation of the area is also associated with the Itaporanga Intrusive Suite, with inequigranular granites. River erosion with weathering pits extends over vast areas of the rocky bed, favoring water accumulation in some points of the intermittent riverbed (NASCIMENTO, 2020).

Geosites of Acarí-RN, in addition to the Seridó Geopark

In addition to the four geosites belonging to the Seridó UNESCO Global Geopark, the municipality of Acarí-RN has several other relevant points that can boost geotourism and geoconservation in the Brazilian semiarid region (TABLE 2).

The Serra do Minador, Serra da Pancada dos Ventos, Serra da TELERN, Serra das Cruzes and Bico da Arara are some of the relevant geosites of the municipality. In general, the dominant lithology is composed of granites associated with the intrusive Suites Dona Inês and Itaporanga. These geosites are associated with summit surfaces, however, in order to achieve regional appreciation and deepen knowledge, analyses should be carried out as a whole, not only with a timely approach, but with a local approach, considering from summit to the toeslope area (all landform components of a hill-slope).

In the areas mentioned, there are summit surfaces overlooking the backcountry depression. Granite rock outcrops were recorded, with the presence of boulders and talus deposits at the toeslope. The main soils found in the areas were Neossolo Litólico, Neossolo Regolítico and Neossolo Flúvico (EMBRAPA, 2018). Due to lithological resistance and the semiarid climate with water deficit, morphogenesis is more active to the detriment of pedogenesis, resulting in shallow, poorly developed and stony soils (TABLE 2). At some specific points there are remnants of lateritic materials on the summit surfaces, such as in the Serra da TELERN.

Table 2: Geosites of Acarí-RN, in addition to the Seridó Geopark.

Geosites	Geographic coordinate	Geological aspects	Geomorphological aspects	Pedological aspects (EMBRAPA, 2018)
Serra do Minador	6°24'56.64"S 36°37'5.71"W	granites associated with Dona Inês Suite	summit surfaces, massifs with granite outcrops, presence of boulders and talus deposits	Neossolos litólicos (RL) Neossolos regolíticos (RR)
Serra da Pancada dos Ventos	6°24'18.14"S 36°36'45.17"W	granites associated with Dona Inês Suite	summit surfaces, massifs with granite outcrops, presence of boulders and talus deposits	Neossolos litólicos (RL) Neossolos regolíticos (RR)
Serra da TELERN	6°23'29.31"S 36°36'15.13"W	granites associated with Dona Inês Suite	summit surfaces, massifs with granite outcrops, presence of boulders and talus deposits	Neossolos litólicos (RL) Neossolos regolíticos (RR)
Serra das Cruzes	6°25'42.61"S 36°36'17.77"W	granites associated with Itaporanga Suite	summit surfaces, massifs with granite outcrops, presence of boulders and talus deposits	Neossolos litólicos (RL) Neossolos regolíticos (RR)
Bico da Arara	6°28'49.38"S 36°36'13.12"W	granites associated with Itaporanga Suite	Weathering landforms with tafoni (singular: tafone), shallow caverns formed in boulders and granite rock faces	Neossolos flúvicos (RY) Neossolos litólicos (RL) Neossolos regolíticos (RR)

Integrated characterization of geosites

The study of natural landscapes is extremely important for evaluating the geodiversity, since the landscape represents a synthesis of all elements of the physical environment (DANTAS et al., 2008), that is, an integrative approach, considering rocks, soils and reliefs.

Among the geosites analyzed in the municipality of Acarí-RN, one (Bico da Arara Geosite) was selected to make an integrated approach, debating on the information related to geological, geomorphological and pedological knowledge. The Bico da Arara Geosite is located to the east of the Acari-RN (6°28'49.38"S and 36°36'13.12"W).

The geological structure of the Geosite is associated with the intrusive suite Itaporanga with the presence of granites. The geomorphological features have the presence of tafoni (tafone in the singular): polygenic cavity product of weathering actions, immense granite walls, with the presence of Neossolo Flúvico (RY), Neossolo Litólico (RL) and Neossolo Regolítico (RR). The area presents some erosions features, thus being modeled by Bico da Arara River that make up the micro watershed of the area (FIGURE 3).

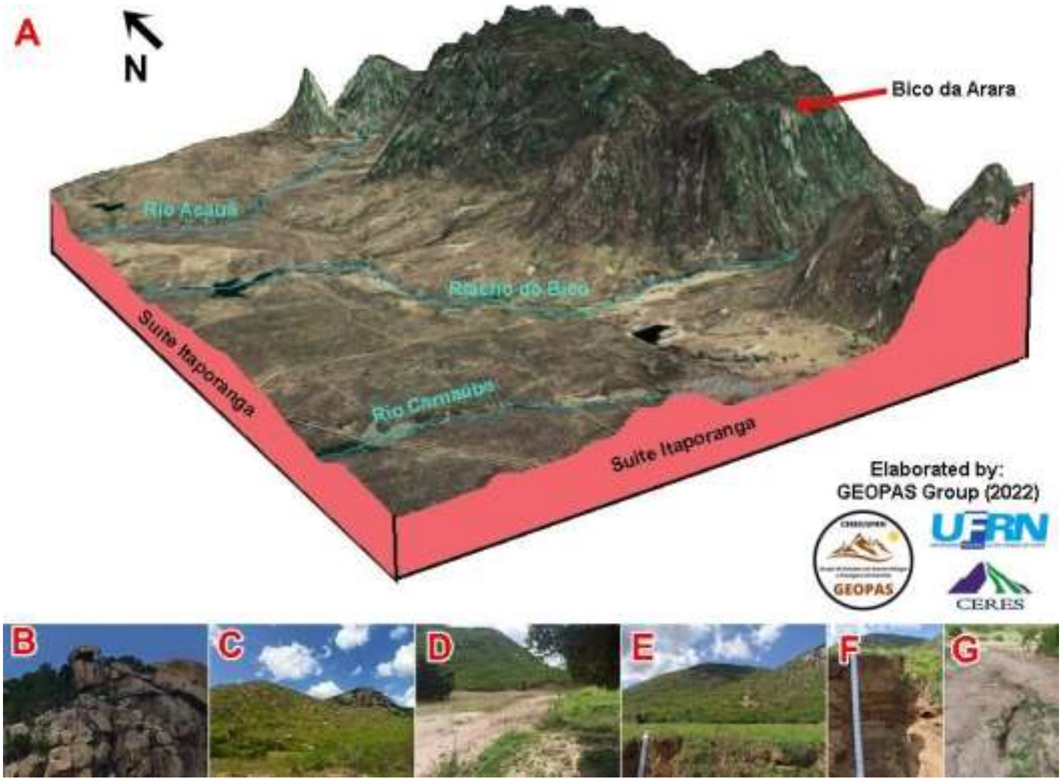

Figure 3: A – Schematic diagram showing the Bico da Arara Geosite, Acarí-RN, with two geomorphological domains, highlands (Crystalline massifs) and lowlands (Sertaneja surface). of the surrounding area. B –Bico da Arara Geosite; C – rock chaos; D – fluvial environment with intermitente stream; E – fluvial terrace; F – Soil profile in river alluvium; G – rill erosion.

DISCUSSIONS

The importance of geodiversity for the Brazilian semiarid

Brazil has great potential in relation to the creation of Geoparks, due to its great territorial extension, allied to its rich geodiversity, having testimonies of practically the entire geological history of the planet and also records of the history of humanity (NASCIMENTO et al., 2008).

There are still gaps in relation to the knowledge of national geodiversity (NASCIMENTO et al., 2008). This scenario is further aggravated in the knowledge of the geodiversity of northeastern Brazil and more specifically of the semiarid region. According to Claudino-Sales (2010), distortions are identified in the national geodiversity information when analyzing the concentration of geosites in the southeast and southern regions of Brazil. This situation is due to the fact that these regions are concentrators of scientific institutions in the country (CLAUDINO-SALES, 2010). In this sense, efforts should be made to expand the search for knowledge of geodiversity in regions with greater information gaps.

There are several perspectives that can help promote the development of conservation practices through the riches of the physical environment (SILVA et al., 2008). The functional value of geodiversity can be used in situ. The value of this geodiversity can be used as a substrate for the support of physical and ecological systems on the earth's surface (BRILHA, 2005). Scientific value can be considered as a basis for access and study of geodiversity at different levels of education (BRILHA, 2005). Finally, one can use the educational value that is closely related to education in Earth Sciences, and may occur as formal educational activities, regarding non-formal educational activities, directed to the general public (BRILHA, 2005; NASCIMENTO et al., 2008).

Knowledge related to the physical environment needs to be disseminated in different educational spheres, in order to disseminate concepts of preservation and rational use of natural resources (SILVA et al., 2008). Similarly, one should seek the proliferation of awareness of the population as a whole, in relation to the occupation of risk areas, aiming at a more harmonious relationship between society and nature (SILVA et al., 2008).

Seridó region has rich geodiversity, associated with distinct lithologies, singular relief forms, exceptional soils in the Brazilian context (marked by predominance of hot and humid tropics) and complex geological and geomorphological processes. In this scenario, the Seridó Global Geopark was created, recognized by UNESCO (2022), in order to create mechanisms for regional valorization and preservation of natural wealth. However, knowledge about the geodiversity of Seridó should not be limited only to geosites and information from the Seridó Geopark, there are several other relevant sites that deserve to be studied (TABLE 2) and disseminated to leverage conservation practices and local geotourism (NASCIMENTO et al., 2008). Geotourism can be defined as ecological tourism with information and attractions of geodiversity, such as natural monuments, waterfalls, caves, fossil sites, mines, among others (NASCIMENTO et al., 2008). The integrative analyses of geodiversity become essential for greater dissemination of geoscientific knowledge, because the more information about a given Geosite, the greater valorization.

Integrated geodiversity analysis

The traditional approach to conservation mainly covers aspects related to biodiversity (BRILHA, 2005; NASCIMENTO et al., 2008). These aspects are successful in the search for the preservation of ecosystems in political issues and put pressure on governments to seek the preservation of resources (SILVA et al., 2008). The application of geosciences in land management and nature conservation is hampered by the lack of a systematic classification covering the totality of geodiversity (BRADBURY, 2014). There are a number of key elements in the development of biodiversity that function as lessons for geodiversity, and greater valorization of terrestrial systems and processes is necessary as a support for the existence of life (BRILHA, 2005; CROFTS, 2014). It is essential that they walk together in policies aimed at environmental preservation, functioning as a complementary link (BRILHA, 2005; SILVA et al., 2008; CROFTS, 2014).

Geodiversity is a concept that encompasses the abiotic set, encompassing rocks, minerals, soils and fossils (BRILHA, 2005; NASCIMENTO et al., 2008). Commonly, approaches to geodiversity emphasize geological aspects to the detriment of other elements of the physical environment (DANTAS et al., 2008; NASCIMENTO et al., 2008). Biodiversity is based on geodiversity and is directly dependent on geodiversity, because rocks undergo weathering when subjected to exogenous processes resulting in pedogenesis, which in turn offers an essential substrate for plants (DANTAS et al., 2008; SILVA et al., 2008).

Most of the information associated with Geoparks is linked to geological aspects (NASCIMENTO et al., 2008), and one of the main elements of analysis in the study of the physical environment is the natural landscape or geomorphological landscape, existing on the earth's surface several models with distinct genesis and development (DANTAS et al., 2008).

Geodiversity should be addressed considering the natural diversity of the geological component (rocks, minerals, fossils, geological processes), geomorphological (form of relief, slope, geomorphological processes), pedological (soil types, genesis, development and pedogenetic processes) and hydrological (characterization of water bodies and surface and underground flows) (BRILHA, 2005; DANTAS et al., 2008; NASCIMENTO et al., 2008). According to Silva et al (2008), when conducting a study of geodiversity, the various components of the abiotic environment that constitute the landscape of the physical environment are analyzed considering a set of geological, geotechnical, geomorphological, pedological and hydrological parameters.

Some elements of the physical environment, such as rocks, relief and soils are perceived by people in a little expressive or ignored way (MUGGLER et al., 2006; NASCIMENTO et al., 2008), which contributes to its degradation or disorderly occupation. As a consequence, there is the continuous growth of environmental problems, such as: erosion, pollution, landslides, silting of watercourses, among others (MUGGLER et al., 2006).

Thus, it is needed to increase the appreciation of geodiversity and understanding of its dynamics and processes involved, in order to have sustainable development (SILVA et al., 2008). This practice can encourage people's awareness of Geosciences within a concept that considers the principle of sustainability (MUGGLER et al., 2006). Geological, pedological and geomorphological knowledge has much to contribute to disseminate regional geodiversity and encourage geoconservation and geotourism practices (NASCIMENTO, et al., 2008). The application of knowledge about geodiversity can be used in different ways, including those related to organization and territorial and environmental planning (SILVA et al., 2008).

CONCLUSIONS

The approach to the conservation of the caatinga biome mainly considers aspects related to biodiversity, and often the aspects related to geodiversity are obscured. However, geodiversity has strong ties with biodiversity, in that the nature of the substrate (soil or rock) is a key factor in determining the distribution of habitats and species.

Commonly, geodiversity is associated with geological knowledge, leaving aside others abiotic components such as geomorphological, pedological and hydrological. Thus, bringing light to this problem, in the present work we used the term "integrated analysis of geodiversity" in order to encourage the debate and to make it clear that geodiversity is not limited to geological aspects.

The integrated analysis of geodiversity can be a subsidy for geotourism, regional valorization of the Brazilian semiarid region and also preservation of the caatinga biome.

The identification of potential geosites in the municipality of Acarí-RN can support municipal policies aimed at conservation actions, environmental education practices, enhancement of natural heritage and incentive to geotourism.

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