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Santana's Outcrop Inventory, Lajedo Municipality: Potential of Geodiversity in the Agreste Region – Pernambuco State – Brazil

Inventário do Afloramento do Santana, Município de Lajedo: Potencialidades da Geodiversidade no Agreste Pernambucano

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Abstract: Geodiversity encompasses the non-living elements of nature, and research on the recognition of significant geodiversity occurrences seeks to understand their characteristics, values, and the importance of conservation. In this study, the objective is to analyze the rocky outcrop of the Santana-AFS rural area, located in the municipality of Lajedo, Agreste region of Pernambuco, from the perspective of geodiversity and geoconservation. The methods employed included the development of a rocky outcrop inventory and the identification of geodiversity values. Through this analysis, it was possible to comprehend the geological diversity of the outcrop, as well as its intrinsic, aesthetic, functional, scientific, and educational values, and to identify its potential uses, limitations, and threats. Moreover, this pioneering work in the region has made an exceptional contribution to geodiversity studies in the municipality.

Keywords: Geodiversity; Geoconservation; Santana's outcrop.

Resumo: A geodiversidade abrange os elementos não vivos da natureza e a pesquisa sobre o reconhecimento de suas ocorrências significativas busca compreender suas características, valores e a importância da conservação. Neste trabalho, o objetivo é analisar o afloramento rochoso do sítio Santana-AFS, localizado no município de Lajedo, Agreste de Pernambuco, sob a perspectiva da geodiversidade e geoconservação. Os métodos utilizados incluíram a elaboração de um inventário do afloramento rochoso e a identificação dos valores da geodiversidade. Através dessa análise, foi possível compreender a diversidade geológica do afloramento, bem como seus valores intrínsecos, estéticos, funcionais, científicos e educacionais, além de identificar suas potencialidades de uso, limitações e ameaças. Além disso, este trabalho pioneiro para a região contribuiu de forma excepcional para os estudos sobre geodiversidade no município.

Palavras-chave: Geodiversidade; Inventário; Afloramento Santana-AFS.

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1. Introduction

Nature is composed of biotic and abiotic elements, which suffer from different types of threats to their existence and maintenance. However, conservation initiatives have referred to these elements in an unequal way, with the biotic aspect being treated as a priority (BORBA, 2011). Nevertheless, given the need to emphasize the conservation of the abiotic part of nature, the term geodiversity was created, analogous to biodiversity. (GRAY, 2004);

There is no consensus on when the term geodiversity was first used in the literature, although Cañadas and Ruiz Flano (2007) claim that it was in the 1940s by the Argentine geographer Frederico Alberto Daus, who used it to refer to the geographical diversity given by socio-cultural representations and the natural elements that make up the landscape. This is a different connotation from the one with which the term is currently associated. However, Gray (2004) points out that the term began to be used in the 1990s by Australian geologists and geomorphologists in studies focused on geological and geomorphological conservation. With this emphasis, geodiversity is configured as a branch of the geosciences, but not in a unified way, with different conceptualizations of the issue emerging. (MEIRA and MORAIS, 2016).

Sharples (2002, p. 6) defines geodiversity as: "the range (or variety) of geological (bedrock), geomorphological (landform), and soil features, assemblages, systems, and processes". Gray (2004) defined geodiversity as "the variety of geological environments (rocks, minerals, and fossils), geomorphic structures (processes and relief features), and soils; and their phenomena, interpretations, systems, properties, assemblages, and relationships. Stanley (2000, p. 15) defines geodiversity as "the variety of geological environments, phenomena, and active processes that make up the landscapes, rocks, minerals, fossils, soils, and other surface deposits that provide the framework for life on Earth. This definition is adopted by Brilha (2005) and by the British Royal Society for Nature Conservation (NASCIMENTO; RUCHKYS; MANTESSO-NETO, 2008). Thus, these definitions consider that abiotic elements are always central to geodiversity.

The conservation aspect of geodiversity is called geoconservation, which aims to conserve and maintain the natural diversity of relevant aspects, geological, geomorphological and soil processes, ensuring the preservation of the history of its natural evolution (SHARPLES, 2002). The aim of geoconservation is not to conserve all geodiversity, as Brilha (2005) points out when he says that society must exploit it, but it is important to (geo)conserve the exceptional elements that make up geopatrimony. Thus, when considering the protection of geodiversity, some questions arise that guide conservation practices, such as: which abiotic elements are subject to conservation strategies? And for what reasons should they be conserved? (BRILHA, 2005). Therefore, it is believed that by addressing these questions, it is possible to more efficiently identify the components that need to be conserved. Thus, the act of conservation and preservation of geodiversity is directly related to the attribution of values. (BRILHA, 2005; NASCIMENTO; RUCHKYS; MANTESSO-NETO, 2008; BORBA, 2011).

However, there is a gap in terms of applied studies and research aimed at a detailed understanding of geodiversity (LIMA; PINTO FILHO, 2018). Even with the development of studies at national, regional and state levels, which include surveys and mapping of geodiversity, local issues are still not routinely technically highlighted (such as Caldeirões, Lajedo, Pedra do Navio, Bom Jardim, Pedra do Martelo and Serra Negra, in Calves). As a result, the potential of geodiversity in the local context is often not understood by society, which can lead to the loss of its attributes and, consequently, its possibilities. (PANTA; OLIVEIRA, 2021).

In this context, the objective of this study is to analyze the rocky outcrop of Santana-AFS rural area, located in the municipality of Lajedo, Pernambuco, from the perspective of geodiversity and geoconservation, in order to identify the characteristics and specificities related to abiotic elements, as well as the social interactions established with the location. It is important to highlight that Diniz et al. (2020) pointed out the need to use geofom as an analytical category in studies of geodiversity, instead of landscape, since the holistic and systemic approach should not be applied to compartmentalized approaches, such as geodiversity.

2. Method

To develop this research, a qualitative approach was adopted, following the methodological guide proposed by Brilha (2005). First, the Santana-AFS rural area was marked on a geological map (see Figure 02) and characterized in the field using an inventory form. The inventory form used was developed by Santos (2016). During the field work, the area was photographed. In addition, a review of the literature related to the study area was carried out based on the bibliography consulted. With the data obtained in the field and the bibliographic information, the characterization of the Santana-AFS rural area was carried out. After the

characterization, the geodiversity values of the AFS rural area were identified, supported by Gray (2004), who defined these values as intrinsic, cultural, aesthetic, economic, functional, scientific and educational.

3. Characterization of the study area

The municipality of Lajedo is located in the Agreste mesoregion of Pernambuco (Figure 01), crossed by the BR-423 (Mestre Dominginhos), PE-180 and PE-170 highways, approximately 191.1 km from Recife. Located between Caruaru and Garanhuns, medium-sized cities, Lajedo presents a dynamic flow of people and goods. (SILVA, 2020).

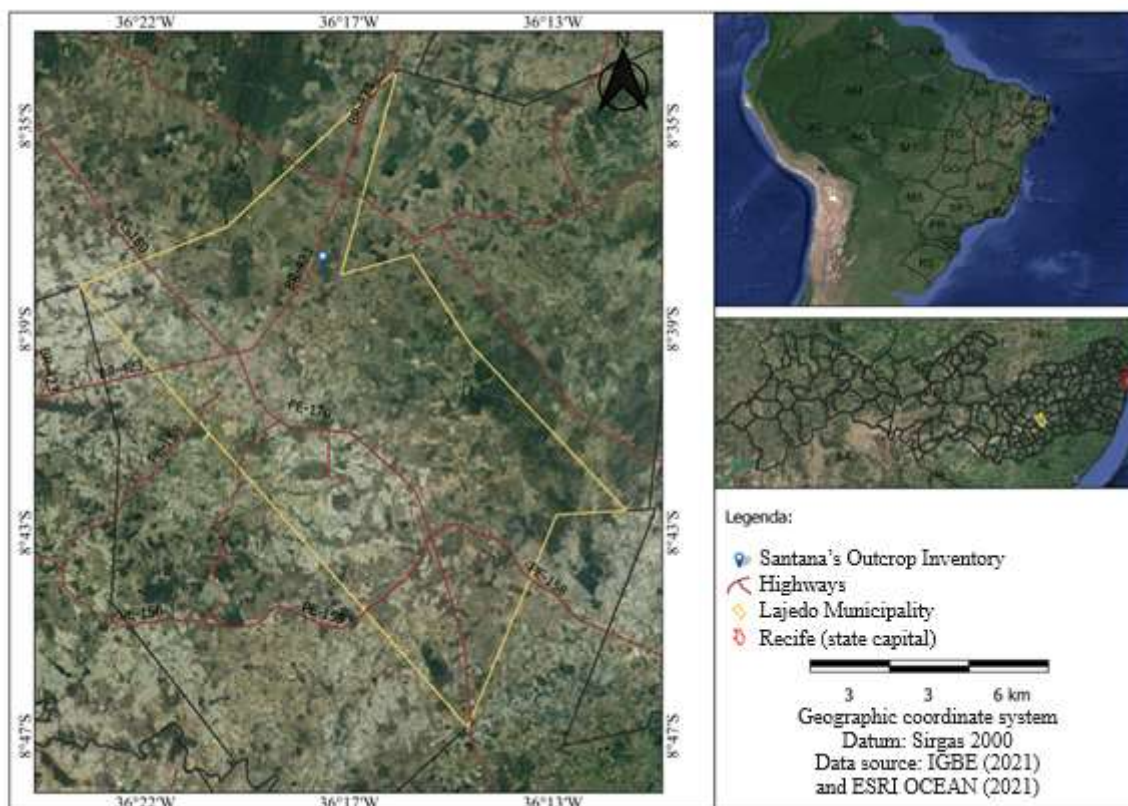


Figure 1 – Location map of the municipality of Lajedo and the Santana outcrop.
Source: Authors (2022).

The lithology of the municipality is located in the Borborema Province and is composed of igneous and metamorphic rocks, distributed in different units (Figure 2), such as Cabrobó1-MPCa1, Brazilian indiscriminate granitoids-NP3i, Ortogneisse mucunã-PP21m, Rio Una unity1-PPru1, Serra Taquaritinga-MP1st, Serra da Caatinga Branca-NP31seb and Sienito Cachoeirinha1-NP33. (CPRM, 2007).

Lajedo's climate is classified as semi-arid (BSh) according to the Köppen-Geiger classification, according to Silva (2020). The rainy season generally begins between January and February and ends in September, although it can last until that month (CPRM, 2005).

Geomorphologically, the region presents a flattened and degraded terrain, with flat to wavy slopes (PANTA *et al.*, 2019), modeled on ductile masses and faulted blocks of the crystalline basement (SILVA, 2008). The altitude varies between 500 and 780 meters and the region belongs to the Borborema Plateau geomorphologic unit.

The soils found in the commune are predominantly flat and podzolic soils, in areas with gently undulating and wavy surfaces. Lithic soils occur in the higher areas, while planosols are found in the river and stream valleys (CPRM, 2005). In terms of vegetation, the municipality has two main types: subdeciduous and deciduous forests (CPRM, 2005). Furthermore, the commune is located in the hydrographic basin of the Una River and in the hydrogeological area of the Fissure.

In terms of population, the municipality had an estimated 36,628 inhabitants in 2010 (IBGE, 2010), with a demographic density of 193.70 inhabitants/km². For the year 2020, the estimate was 40,589 inhabitants (IBGE, 2019).

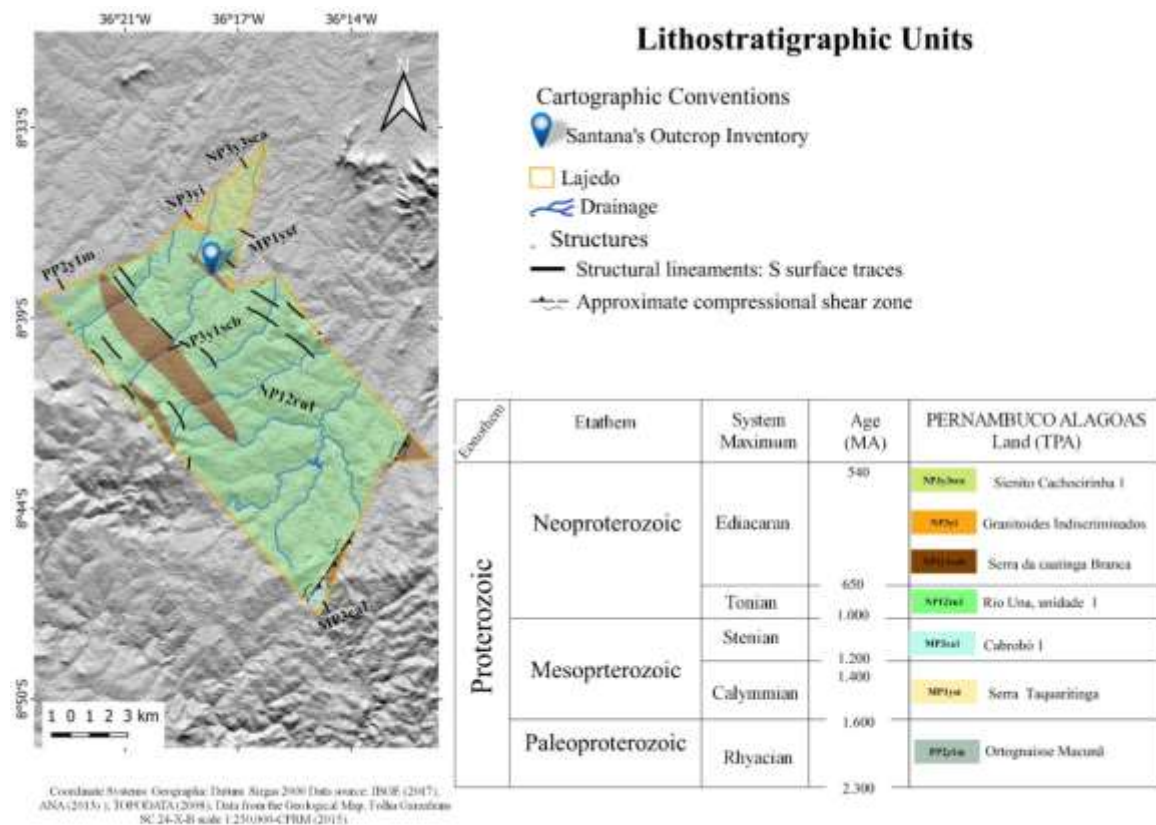


Figure 2 – Geological map of the municipality of Lajedo. Source: Authors (2021).

In this context, in the rural area of the municipality of Lajedo, on the banks of the BR-423, there is a rock outcrop at the Santana-AFS, located in the Serra da Caatinga Branca lithological unit (NP3y1scb), with a mineralogical composition of potassium feldspar with plagioclase minerals, quartz, biotite, with granodioritic gneiss lithotypes, tonalites and fine- to medium-grained and equigranular granodiorites, also with the occurrence of nebular migmatites, with also pegmatite veins, in addition to fractures and dikes with phaneritic texture distributed in some points in the outcrop, which was not completely metamorphosed, and the presence of xenoliths occurred; In terms of genetic character, it is worth highlighting that the structural and lithological formation is associated with regional metamorphism and plutonism events. (CPRM, 2007; 2015).

4. Results and Discussions

The geodiversity of the Santana-AFS rural area presents a variety of values, including aesthetic value, which is evident in its relief forms, which arouse the interest of the local population and/or the urban area of the municipality, making the site an attractive place to visit (as indicated in the "current use" section of Table 01). Therefore, they try to escape from the hustle and bustle of the city and contemplate nature. At the highest point of the outcrop (viewpoint), it is possible to observe partially preserved vegetation, forming a landscape with a predominance of natural elements (biodiversity and geodiversity), as well as visualizing land use and cover practices around the area. In relation to this value, Brilha (2005) points out that the public's amazement at the landscape may be related to geological aspects.

In the municipality of Lajedo, in Pernambuco, the geodiversity is clearly manifested by the different rocky outcrops present throughout the area. These outcrops vary in size and geological form, offering a wealth of

characteristics to the local landscape. Despite the existence of other rocky outcrops in the region, this does not diminish the interest of people to explore and get to know this place, because of its peculiarities related to the presence of preserved natural elements in the landscape, as well as the fact that the highlighted rocky outcrop has a higher topographic position compared to other outcrops in the municipality. This makes it more attractive, given the possibility of using the area for different purposes aimed at enjoyment, either for recreational use (scenic contemplation) and/or for the development of educational practices using the components of geodiversity as a teaching resource.

However, it is important to consider that the existence of these geodiversity elements is not mentioned in the municipal documents, published or promoted for the development of tourist activities. Therefore, visits to these places are autonomous, without an adequate structure to receive visitors.

The functional value of geodiversity manifests itself in two main perspectives: *in situ* and *in support* of ecosystem development and sustainability. From the *in situ* perspective, it is possible to identify the role played by the morphology of weathered and eroded lithological material in the retention of precipitation water, which favors its use by the local population. Furthermore, there has been human intervention in this context, with the construction of a dam to store water from the Doce stream, a tributary that crosses the outcrop (as shown in Figure 3). This intervention highlights the use of the site's hydrological characteristics for practical purposes and demonstrates the functional importance of geodiversity in supporting life and human activities in the region.



*Figure 3 – Riacho Doce dam on outcrop, illustrating the functional value in situ.
Source: Fieldwork carried out in December 2021.*

With regard to the functional aspect of supporting biodiversity, the development of vegetation around the rocky outcrop can be observed at the site. In areas of fractures and humus concentration, it is possible to find plant species such as cacti, *Bromelia laciniosa* (macambira), Fabaceae (jurema) and lichens colonizing the rocks (Figure 4). These plants and organisms play an important role in maintaining ecological balance, contributing to biodiversity and the conservation of local ecosystems. The presence of these species highlights the interaction between geodiversity and biological diversity, providing an environment conducive to life and highlighting the importance of preserving this space.

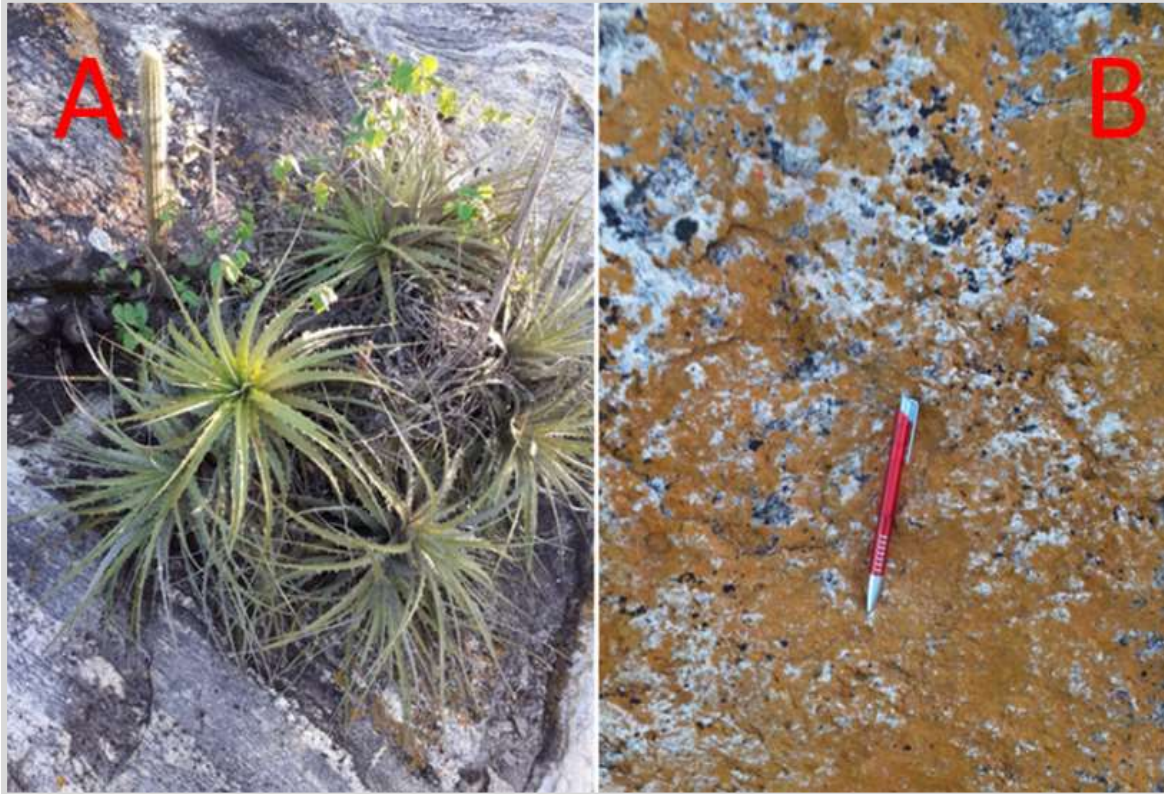


Figure 4 – *Bromelia laciniosa* (macambira) on outcrop (a). Lichens colonizing the outcrop rocks (b).

Source: Fieldwork, December 2021.

In recognition of its scientific value, the rural area does not represent a landscape characterized by unique forms, processes, and materials that help explain the evolution of planet Earth on a global scale. Thus, the scientific value of the area has no bearing on the priority given in the justification for the preservation of the outcrop. However, even if limited to the regional context, it is possible to understand aspects of the evolution of landscapes in the semi-arid region, having highlighted examples, through the fluvial dynamics of the stream that runs through the area, carving the rocky channel linked to genetic processes in distant times, since the lithology of the outcrop refers to rocks of the Ediacaran period, approximately 650 to 540 million years old (CPRM, 2007).

In this sense, the larger geofoms are conditioned by the geological structure in fractures with planes of weakness that direct the river degradation and can be visualized through the drainage line of the stream and can be considered as an embedded valley (Figure 5), where the deepening of the channel in the vertical direction acted intensely, causing the narrowing of the slope and the incidence of steeper slopes (IBGE, 1993; GUERRA and GUERRA, 2008). These deformations are structures formed by stress in a brittle regime, thus the discontinuities are formed after the consolidation of the lithological material, having a direct relationship with the exposure of the intrusive rock bodies and the consequent decrease in pressure, as well as linked to regional efforts marked in the AFS by structural lineaments.



Figure 5 – Section of the valley embedded in the Doce stream in the Santana outcrop.
Source: Fieldwork carried out in December 2021.

It is also possible to observe other geomorphs present in the outcrop, such as marmites/caldeirões (as shown in Figure 06 A) and linear grooves, the result of dissolution associated with fractures, located on the steepest slopes and directing the flow of surface water (as shown in Figure 06 B) (IBGE, 1993; GUERRA and GUERRA, 2008; MAIA, BASTOS and NASCIMENTO, 2018). However, it is important to highlight that these shapes have dimensions that do not exceed ten meters, considering the length, width, depth and area in square meters. Despite their small scale, these geomorphs contribute to the diversity and uniqueness of the rock outcrops, enriching the landscape and providing evidence of the geological processes that have shaped the region over time.



Figure 06 – Initial formation of marmite (Caldeirões) (a). Channels (dashed red line representing flow channels) (b).

Source: Fieldwork carried out in December 2021.

Even in view of the scientific aspects exposed, it is worth highlighting that the scientific value does not present rare elements, therefore they are not occurrences of geodiversity that allow the reconstruction of geological-geomorphological history in the national or regional scenario, however, nevertheless, scientific

knowledge of the outcrop of Santana integrates the possibility of providing opportunities for the dissemination of geodiversity attributes through environmental interpretation, linked to educational practices (formal and/or non-formal) aimed at recognizing and valuing abiotic nature.

In addition, Lopes and Claudino-Sales (2019) state that geoscience education must take into account geodiversity in the classroom, whether it is education in school spaces or/and non-formal educational actions that involve not only the student population. Therefore, the recognition and appreciation of abiotic elements begins with pedagogical practices that interpret the elements arranged in the environment. In this attempt, Gray (2008) points out that education is a legitimate tool for conservation, since lack of knowledge is the greatest threat to the loss of geodiversity.

The attributes present in the study area include elements that permeate the teaching of earth sciences and geography content, through the petrographic characteristics of its igneous and metamorphic rocks; mineralogical with minerals of felsic (silica and aluminum) and mafic (iron and magnesium) composition due to the predominant presence of plagioclase, quartz, biotite; features in fractures, geofoms (lunchboxes / cauldrons and fluting) and physical, chemical and biological weathering processes interact.

In this context, the way of life of the surrounding population expresses the link with the place, which is evident in the use of geodiversity for water storage, whether in concave caves or in the dam of the Doce stream, where this abiotic component supplies houses with water, the main purpose being to subsidize family-based agricultural activities, thus ensuring supply during dry periods and ensuring continuity of productivity. In this sense, the direct use of abiotic nature due to social needs helps to establish an understanding of the relationships between society-nature and the different environmental services provided.

Due to the educational potential of the outcrop, its location is advantageous for its use, because although it is located in a rural area, the site is about 50 meters from the right bank (direction Lajedo-Cachoeirinha) of the BR-423, thus the road infrastructure allows easy access to the location, which is approximately five kilometers from the urban area of the municipality of Lajedo.

The educational value of geodiversity aims to teach aspects that are often limited to the theoretical core, allowing practical experience of content that can only be found in literature. In this sense, Mochiutti *et al.* (2011) point out that learning becomes meaningful when the objects studied can be known, therefore geodiversity studies have education as a basis for understanding the planet and preserving these elements. Therefore, it is necessary to value places that have a didactic importance that allows them to be used in education (PEREIRA; BRILHA; PEREIRA, 2008).

Moreover, the application of the inventory form of Santos (2016) (Table 01) made it possible to identify the characteristics of the rural area and the current state of usufruct, limitations of use and future threats to which the location is susceptible. In addition, the author points out that the items Geological Potential (Scientific/Educational) - PG and Management Use Potential - PU allow the understanding of the elements arranged, as well as the possibilities for the development of sustainable practices.

Table 01 – Sheet with the parameters for the inventory of the Santana outcrop.

Name: Santana Outcrop Location: Lajedo, Pernambuco (Rural Area) Coordinates: 8°37'24.42"S 36°17'59.70"O Geomorphologic Unit: Borborema Plateau. CPRM sheet (1:250,000): Sheet SC.24-X-B Garanhuns		Type: Point (Note: there is the central outcrop and other scattered smaller ones). Predominant lithology: Crystalline. Geologic Context: Serra da Caatinga Branca lithostratigraphic unit (Intrusive Suite).	
Geological Potential/Geosite Potential (PG)		Potential for use and administration (PU)	
Rarity	() Rare () Occasional (x) Common	Accessibility	(x) Easy () Moderate () Poor
The characteristics of the outcrop represent a common occurrence of geodiversity for the community.		It is located on the banks of the BR-423 (Master Dominginhos Highway).	
Visibility	(x) Good () Moderate () Poor	Property	(x) Private () Public () Mixed
Easily view all geofoms and structures.		However, the site is open to visitors.	
Type Location	() Yes () Secondary (x) No	Dimension/Area	() up to 1 hectare (x) up to 5 hectares () > 10 hectares
Common lithological aspects in the community and the Northeast Region		It has a surface area of 1.50 hectares.	
Element Diversity	(x) Low () Moderate () High	Local Infrastructure	() Good () Regular (x) Absent
Geology (igneous and metamorphic), hydrology, geomorphology, and ecology		There is no support space for visitors (such as bathrooms, food facilities, etc.).	
Topics of Interest	(x) 4 or more related topics () 2 to 3 () only one	Conservation Unit	(x) None () Private () National/State Public
Geological, geomorphological, educational and touristic hydrology		The location is not listed in any local, state and/or federal regulations.	
Associated values	(x) Three or more () Up to 2 types () None	Current use of the area	() None (x) Tourism () Mining/Gold
Intrinsic, aesthetic, functional, scientific, educational		It is done punctually and autonomously by visitors who want to appreciate the natural aspects of AFS.	
Location Integrity	() Complete (x) Some degradation () Very degraded	Potential audience	(x) Including lay people () Students () Professionals
It is polluted by the irregular deposit of solid waste (bottles) and by some graffiti.		The diversity of the aspects of geodiversity allows it to be used for activities such as formal and non-formal education, as well as for recreation and tourism.	
Natural fragility	(x) Low () Moderate () High	The nearest settlement	() City () Town (x) Neighboring community
Resistance of crystalline rocks (igneous and metamorphic)		Urban area of the municipality of Lajedo, but with a low density of houses around the outcrop.	
Collection of samples	(x) Possible () Possible with restrictions () Do not collect	Indicators of degradation	() None (x) Reversible () Irreversible
There are no barriers to access. Therefore, samples can be collected.		Due to the pollution of Riacho Doce and the irregular deposition of garbage in some points of the outcrop	
Scientific knowledge	() Thesis/Dissertation () Articles and Books (x) No publications	Future threats	() None () Urban Expansion/Industry (x) Mining/Other
There is no knowledge of any scientific production covering the rural area.		Possible duplication of BR-423, due to the proximity of about 50 meters to the right bank.	

Source: Authors (2021).

It should be noted that the AFS is not registered in the official regulations of the municipality, nor in the National System of Protected Areas (SNUC), so the lack of management is obvious. As a result, tourist visits are sporadic (without planning). Therefore, the deficit of organized educational and recreational practices prevents the valorization of the outcrop in order to promote the identity of the local population in recognizing the values imprinted on their territory.

Another fundamental problematic that can be identified in the area relates to degradation and pollution, even with the occurrence of these processes, mainly in the part of the outcrop facing the side of the highway, making it possible to notice a greater amount of waste, even so the rural area maintains its values, without any disconfiguration of abiotic attributes in the outcrop.

5. Final considerations

With the development of this study, it has been possible to obtain a more in-depth understanding of aspects related to the geodiversity of the Santana Outcrop, highlighting its potential, limitations and possible future threats. The inventory made it possible to identify and characterize the outcrop, filling a research gap in this area. This pioneering research contributes to the advancement of knowledge and the establishment of actions that value the remarkable features of the local landscape, emphasizing the importance of geoconservation at the municipal level. This approach aims to promote the appreciation and conservation of abiotic nature, contributing to conservation efforts at the local level.

Furthermore, it is important to highlight that the use of the inventory form in the context of the study showed satisfactory results in terms of applicability and ease of use. It should be noted, however, that due to the pioneering nature of this work in the study area, additional research is needed in the field. What has been presented here is far from covering all the studies to be carried out, so it is hoped that this work can contribute in this direction. In particular, it is essential to proceed with the following steps to carry out geoconservation, as discussed in the bibliography consulted, which consists of seven steps, of which the inventory is the first and the basis for carrying out the other steps.

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