



Assessment of the scientific value, degradation risk and potential educational and tourist use of geosites of Paraúna State Park in Goiás, Brazil

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ABSTRACT

The present study aimed to quantify the scientific value, degradation risk, potential educational, and tourist use of Serra das Galés and Serra da Portaria geosites of Paraúna State Park, in the municipality of Paraúna, state of Goiás, Brazil. Analysis of the geosites used the quantification method of the digital platform *Geossit*, managed by CPRM Serviço Geológico do Brasil. Serra das Galés is a site of geomorphological interest that occurs in the sandstones of the Aquidauana Formation. The strata of the unit include reddish sediments with fine to medium grains rich in iron oxide. There is a variety of geofoms in the sandstone rocks of Serra das Galés, including animals, objects and human figures. The Serra da Portaria site is of paleontological and geomorphological interest and some of its features are preserved in a sandstone level of the Aquidauana Formation (Permian-Carboniferous). The upper portion contains portions of the Adamantine Formation (Turonian-Santonian), where isolated residues of indeterminate tetrapods and carnivorous dinosaurs were recently reported. Both geosites are considered of national relevance.

Keywords: Geoconservation, Geodiversity, Paraúna State Park, Serra das Galés geosite, Serra da Portaria geosite.

Avaliação do valor científico, do risco de degradação e do potencial uso educacional e turístico dos geossítios do Parque Estadual de Paraúna, em Goiás, Brasil

RESUMO

O presente estudo teve como objetivo quantificar o valor científico, o risco de degradação, o potencial de uso educacional e turístico dos geossítios Serra das Galés e Serra da Portaria do Parque Estadual de Paraúna, no município de Paraúna, estado de Goiás, Brasil. Para a análise dos geossítios utilizou-se o método de quantificação da plataforma digital *Geossit*, gerenciada pela CPRM Serviço Geológico do Brasil. A Serra das Galés é um sítio de interesse geomorfológico que ocorre nos arenitos da Formação Aquidauana. Os estratos da unidade incluem sedimentos avermelhados com grãos finos a médios ricos em óxido de ferro. Existe uma variedade de geofomas nas rochas areníticas da Serra das Galés, incluindo animais, objetos e figuras humanas. O sítio Serra da Portaria é de interesse paleontológico e geomorfológico e algumas de suas feições estão preservadas em nível de arenito da Formação Aquidauana (Permiano-Carbonífero). A porção superior contém porções da Formação Adamantina (Turoniano-Santoniana), onde foram recentemente relatados resíduos isolados de tetrápodes indeterminados e dinossauros carnívoros. Ambos os geossítios são considerados de relevância nacional.

Palavras-chave: Geoconservação, Geodiversidade, Parque Estadual do Paraúna, geossítio Serra das Galés, geossítio Serra da Portaria.

Introduction

Earth is a dynamic and complex planet, with continuous changes occurring since its formation approximately 4.6 billion years ago. Taken together, all of the planet's parts and interactions constitute the Earth system. The diversity of natural abiotic elements, which are understood as Geodiversity, are inserted in this system. According to Grey (2023), the term "Geodiversity" can be understood as a summarized form of "geoscientific diversity". This concept goes beyond purely geological phenomena, encompassing a much broader and more diverse sense. According to Reynard and Brilha (2018), the last 25 years has seen growing scientific interest in topics related to Geological Heritage, in addition to a large set of territorial initiatives that have emerged around the world giving new approaches related to this category of heritage. Mantesso-Neto (2009) states that some concepts related to the remarkable features of Earth are gaining importance in the scientific community, among which Geodiversity, Geoconservation and Geological Heritage are the most predominant.

The concept of Geodiversity refers to the variety of geological elements, encompassing not only rock formations, but also geomorphological, pedological and hydrological components, resulting from tectonic processes, hydrogeological dynamics and internal and external forces of the Earth's crust (Ivanovic, 2024). In addition, some scientific approaches incorporate climatic processes as an integral part of Geodiversity, given their influence on the physical environment (Ivanovic, 2024).

According to Bailey et al., (2024), Geodiversity also encompasses the characteristics and processes of the Earth's surface and subsoil that support natural systems essential to life. These elements are fundamental to the interaction between humans and biodiversity, in addition to providing resources indispensable to everyday life. In this context, Geodiversity plays a crucial role in so-called ecosystem services, that is, benefits that ecosystems offer to society. Research indicates that the degradation of soils and aquifers, for example, can compromise vital functions, such as water purification and climate regulation (Gordon et al., 2022). In addition to its ecological value, Geodiversity also has cultural and educational relevance, which contributes to awareness of environmental conservation (Brilha et al., 2021).

However, Geodiversity faces several threats, both natural and anthropogenic. According to Anougmar et al., (2024), activities such as mining, urban expansion, inadequate forest management and intensive agricultural practices can lead to soil degradation, erosion and changes in geomorphological processes. Uncontrolled tourism and construction work in coastal and river areas also pose risks as they can interfere with the natural cycles of these environments.

In view of these challenges, the application of the concept of Geodiversity has expanded to areas such as spatial planning, sustainable resource management, and environmental education. Studies show that its integration into public policies can mitigate the impacts of climate change (Hjort et al., 2022). In addition, Geotourism, a type of tourism that values geological heritage, emerges as a sustainable strategy to promote Geoconservation (Pereira et al., 2021).

Geoconservation is the conservation of representative elements of Geodiversity and it has direct implications for the entire environment. The term Geoconservation has been increasingly used and is understood as a series of actions, techniques and procedures that aim to guarantee the conservation, preservation and monitoring of Geological Heritage based on the analysis of its intrinsic value, vulnerability and degradation risk (Diez- Herrero, et al., 2018). The main scope of Geoconservation is the management of sites and elements of Geodiversity through specific methods of inventory, evaluation, conservation, valuation and monitoring (Brilha, 2018).

Brilha (2022) highlights that the last five decades have witnessed significant progress in the field of Geoconservation, marked by a growing recognition of the need to protect and adequately manage the elements of the physical environment. This progress is manifested in two complementary dimensions: first, through greater awareness in several countries about the importance of Geological Heritage, which has led international organizations to incorporate this topic into their agendas; second, by the strengthening of global debate, which has encouraged nations to adopt specific Geoconservation policies in their legal frameworks and to implement practical preservation actions.

This global movement is based on the three fundamental pillars of Geoconservation: identifying, protecting and promoting geological heritage. The identification process consists of mapping and carefully evaluating geological

elements with scientific, educational or cultural value, establishing the basis for subsequent interventions. Protection is achieved through the creation of areas specifically dedicated to preservation, such as geoparks and natural monuments, which serve as a barrier against degradation processes. Promotion encompasses environmental education initiatives and the promotion of Geotourism, essential strategies for increasing social recognition of the value of Geological Heritage (Tukiainen et al., 2024).

As Brilha (2021) points out, this triple structure must be understood in an integrated manner with biodiversity conservation policies, since abiotic components (such as geological formations and water systems) maintain fundamental ecosystemic relationships with biotic elements. This holistic vision has guided the practical application of Geoconservation, which manifests itself through several complementary strategies. Among these strategies, the creation of geoparks stands out, being recognized by UNESCO as models that reconcile geological preservation and sustainable development (Gordon et al., 2022).

Geological Heritage consists of the geosites of a given area. Prosser et al., (2018) address the importance of geosite conservation, and state that the existence of accessible geosites with well-exposed characteristics and processes, that are relatively intact or functioning naturally, is essential for scientific study, educational use, training, geotourism and provisioning of a variety of other ecosystem services. In addition, they are geographically located in natural or cultural heritage areas.

The municipality of Paraúna, with abundant areas of natural and cultural heritage, is located in the southern mesoregion of the state of Goiás, in the microregion of Vale do Rio dos Bois (IBGE, 2010). It possesses a diversity of elements of Geodiversity, which must be conserved and preserved. In this sense, previous works have been carried out aiming to characterize the natural elements present in the municipality (Ferreira, 2016; Ferreira and Lima, 2018; Ferreira et al., 2020).

Paraúna State Park (PEPa) is located in Paraúna and was created by Law Decree nº 5,568 of March 18, 2002. In addition to biodiversity, another relevant aspect for the creation of this park was the relief of the area, which represents important abiotic elements of the Geodiversity of the County. Two geosites were found in the legal divisions of PEPa, as identified by Ferreira (2016): Serra das Galés and Serra da Portaria. According to Ferreira (2016), both places are of scientific,

touristic and educational importance, as they characterize the processes resulting from terrestrial dynamism. Thus, the present work aims to quantify the scientific value, degradation risk and the potential educational and tourist use of these geosites.

Although previous studies have identified and inventoried the Serra das Galés and Serra da Portaria geosites in Parque Estadual de Paraúna (Ferreira; 2016, 2022), important knowledge gaps persist. First, there is a lack of quantitative assessments that objectively measure their value. Second, the risks of degradation seem underestimated, especially when compared to other conservation units that have already implemented specific management plans for Geoconservation. Finally, the potential of these sites for Geotourism and Geoeducation remains largely unexplored, in contrast to successful experiences in regions with similar characteristics.

In view of this, the present study is based on the hypothesis that: (1) the geosites in question have high scientific value due to their geomorphological features and important paleontological records; (2) they face moderate to high risks of degradation, aggravated by the lack of adequate protective infrastructure; and (3) they have educational and tourism potential that is still underutilized and which could be significantly expanded through the implementation of adequate valorization and conservation strategies.

To assess these hypotheses, this study quantitatively evaluated these geosites using a methodology that has been used in several areas of Brazil and other countries. The results provide important support for the inclusion of these sites in public Geoconservation policies, for the development of Geotourism activities, and for the development of educational strategies based on local Geological Heritage.

The relevance of this research is evident on multiple levels. Scientifically it contributes to research and knowledge about the Geological Heritage of the Brazilian Center-west, a region that still needs more studies in this regard. From the perspective of territorial management, the results will help formulate more effective policies for the conservation of these geological records. Through economics, the study can foster the sustainable development of the region through Geotourism, generating income for local communities while promoting the conservation of natural heritage. Finally, in the educational sphere, the research will provide the basis for the creation of programs that use these geosites as natural laboratories and in fieldwork, enriching the teaching of Geosciences at all levels.

Geological setting brief presentation Paraúna State Park

According to Goiás (2008), the topography of Paraúna was shaped by the lithology of the Paraná Sedimentary Basin, an extensive intracratonic structure formed on the continental crust, occupying an area of approximately 1,400,000 km² in Brazil, Argentina, Uruguay and Paraguay (Milani et al., 1998). This sedimentary basin was formed by the reactivation of Brazilian structures through field compressional forces triggered by the orogeny that occurred in the Ordovician, around 450 Ma (Milani et al., 1998). The geological records of the basin in Goiás are represented by the following groups: Rio Ivaí, Paraná, Itararé (Aquidauana and Furnas formations), São Bento (Botucatu and Serra Geral formations) and Bauru (Adamantina and Marília formations; *sensu* FERNANDES; COIMBRA, 1996).

Records of the Aquidauana Formation, with isolated outcrops of rocks from the Adamantina Formation at the top of Serra da Portaria, are present within PEPa (not mappable on the scale presented in Figure 01). The Aquidauana

Formation occurs in the southwest region of the state of Goiás, in a strip greater than 300 km long (E-W) and 65 km wide, extending from the Paraúna region to the state of Mato Grosso (Goiás, 2008). The base of this lithostratigraphic unit presents conglomerates formed of quartz and sandstone pebbles. These rocks are mainly redpurple in color and comprise medium to coarse sandstones that are friable, sometimes feldspathic, with cross-stratification, silicified levels and coarse to locally conglomeratic white sandstones (diamictites) followed by finely stratified siltstones and mudstones and red to greenish gray shales, common to the presence of rhythms formed by thin levels of clay and fine sandstones and siltstones (Goiás, 2008). According to Schneider *et al.* (1974), the rocks of the Aquidauana Formation indicate deposition that occurred in a fluvial and lake environment, with the collaboration of diamictites that suggest glacial influence. Palynological data attributes the age of the unit to the Upper Carboniferous (Daemon and Quadros, 1969).

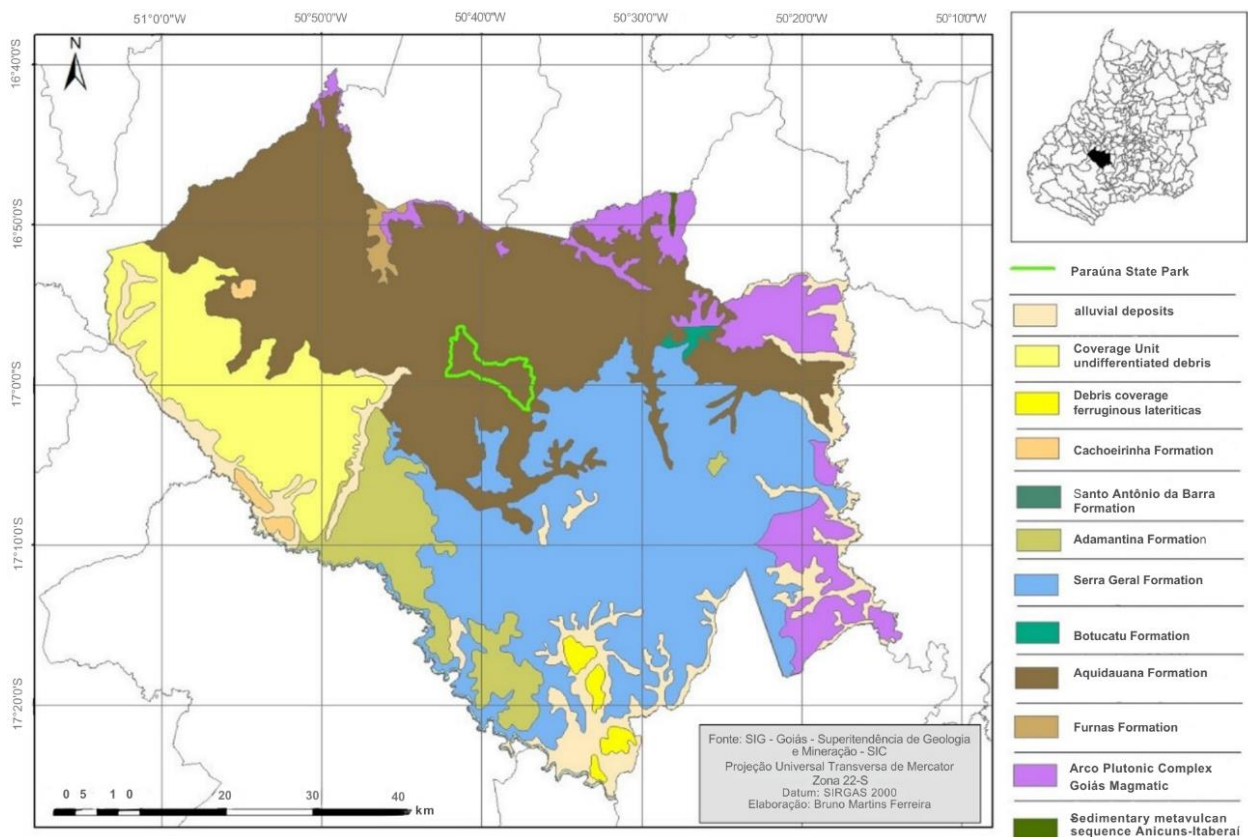


Figure 01. Geological map of the municipality of Paraúna (from Ferreira *et al.* 2020).

The Adamantina Formation (Bauru Group, Upper Cretaceous) occurs as patches

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overlying the rocks of the Aquidauana Formation (Upper Carboniferous). According to Fernandes

and Coimbra (1996), the Adamantina Formation is formed by light gray, beige or pink solid sandstones with fine to very fine grains (medium grains occasionally occur) that are often poorly sorted and presenting subordinate plane-parallel cross-stratification. For these authors, the lithological and sedimentary characteristics of this formation indicate fluvio-lacustrine sedimentation. The Adamantina Formation was dated from ostracod content as belonging to the Turonian-Santonian (*sensu* Dias-Brito et al., 2001) and emerges irregularly in the south and southwest regions of the state of Goiás. This lithostratigraphic unit occurs in the southeast region of the municipality of Paraúna. Within PEPA, the superposition of the Adamantina Formation on the Aquidauana Formation occurs in the Serra da Portaria mountain range.

Methodology

Analysis of bibliographic sources was based on the hermeneutic method, that is, on the investigation and interpretation of information in the original source (Albert, 1996). This method allows discoveries, new contributions and critical reviews, thus expanding the horizon of possibilities. The bibliographic research also included a discussion about the tools that support the approaches of Geodiversity, Geoconservation and Geosites. The selected references about the municipality of Paraúna include studies on local geography, as well as historical and cultural aspects that emphasize the importance of the studied area.

Quantification of the sites used the digital platform *Geosit* of CPRM. This application aims at the inventory, qualification and quantitative assessment of geosites and Geodiversity sites at the national level and in areas that cover geoparks. The research was initially structured through the methodologies of Brilha (2005) and Garcia-Cortés and Urquí (2009). Currently, this application adopts the methodology of Brilha (2016), following some adaptations, involving quantitative evaluation criteria, in tables of scientific value, degradation risk and potential educational and tourist use (<https://www.cprm.gov.br/geosit/>).

Brilha (2016) presents several criteria, indicators and parameters that contribute to the scientific value, degradation risk and potential for educational and tourist use of sites. The following criteria were selected for the scientific value of the analyzed sites: representativeness, location-type, scientific knowledge, integrity, geological diversity, rarity, use limitations and scientific value. The following were selected for degradation risk: deterioration of geological elements,

proximity to areas/activities with potential to cause degradation, legal protection and population density. The following were selected for potential educational use: vulnerability, accessibility, use limitations, security, logistics, population density, association with other values, setting, uniqueness, observation conditions, educational potential and geological diversity. And lastly, the following for potential tourist use: vulnerability, accessibility, use limitations, security, logistics, population density, association with other values, setting, uniqueness, observation conditions, potential for dissemination, economic level and proximity to recreational areas.

The features of relief of the Serra das Galés geosite that resemble animals and objects are referred to as geoforms in this work. When citing geoforms, Nascimento et al., (2008, p.151) state that the different forms of the terrestrial surface, or geoforms, form the relief that results from the action of forces or agents (endogenous and exogenous) during millions of years. The concept of geoforms in the field of Geodiversity has been addressed in several studies (Borba and Meneses, 2013; Pereira, 2010; Silva et al., 2017). Another factor that helps in understanding the interpretation of geoforms is pareidolia. According to Marques and Pereira (2019), pareidolia is a process that consists of a casual stimulus, which is more connected to image and sound, being perceived as something distinct with meaning, a perceptual distortion. This phenomenon is effective when used as a strategy for valuing geoforms, as it can generate identity, identification and belonging in the target audience, making interactivity and the process of valuing Geodiversity much closer, intimate and effective.

Quantitative analysis of the data applied the statistical method of multicriteria analysis (Malczewski, 2018), following the approach of Brilha (2016), which allows integrating different parameters in a weighted evaluation. In addition, descriptive statistics were used to calculate means and standard deviations to compare the scores obtained for each criterion. In this way, the spatial analysis tool ArcGIS was also used, which helped in the visualization of georeferenced data, the relationship between degradation risk.

This methodological approach combined qualitative interpretation (hermeneutics) with quantitative evaluation (*Geosit* and statistics), to ensure a robust analysis that can be applied both for academic purposes and for the management and dissemination of geosites. The integration of scientific, educational and tourism criteria, combined with the strategic use of pareidolia, contributed to a broader understanding of the

potential for the conservation and valorization of Geodiversity in the studied region.

Results and discussion

Serra da Portaria Geosite

The Serra da Portaria geosite (Figure 02) is located 38 km from the urban area of Paraúna. A residual part of this unit is located on the private property of Fazenda São Domingos, however, access is free for visitors. Serra da Portaria is carved into rocks of the Aquidauana Formation (Ferreira et al., 2020; Lacerda et al., 2011), with a small, isolated outcropping area of the Adamantina Formation. The features of this geosite are preserved in a sandstone layer of the Aquidauana Formation (Permian-Carboniferous) (Figure 07). The strata of this unit include reddish sediments with fine to medium grains rich in iron oxide. Some isolated patches form the Adamantina Formation (Turonian-Santonian) and are found in the upper portion of the geosite, where isolated remains of indeterminate tetrapods and carnivorous dinosaurs were recently reported (Candeiro et al., 2020).



Figure 02. The Serra da Portaria geosite, exposed in the Paleozoic rocks of the Aquidauana Formation and in the Upper Cretaceous rocks of the Adamantina Formation.

The upper part of the site reaches 884 m in altitude and is level with the peaks of the surrounding elevations. It also exhibits extremely steep edges that represent the surface of the great plateau of Central Brazil. The main water courses in the region are Ribeirão Formoso and Córrego do Macaco, the respective beds of which are at an altitude of around 620 m.

The relief of Serra da Portaria is presented as a Chapada (Figure 03), which are characterized by horizontal tops, resulting or not from erosive flattening, coinciding with the structural layout,

often supported by ferruginous benches that offer resistance to the retreat of the slopes (Cassetti, 2005). This difference possibly reflects the advanced stage of erosion of the geological structures of the Aquidauana Formation that support the geomorphological structure of Serra da Portaria.

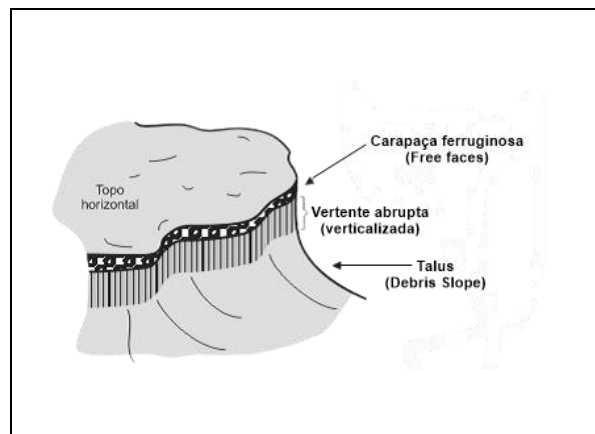


Figure 03. Morphological relationship with the concordant sub-horizontal structure in the municipality of Paraúna (from Cassetti, 1994).

Cassetti (2005) also describes that Serra da Portaria is a siltstone-sandstone sequence in a concordant horizontal structure and demonstrates the formation of levels or steps produced by differential erosion. In the region's current humid climate, sandstones with siliceous cements are more resistant than silty shales, which results in the development of staggered levels. The levels are maintained by the sandstones, whose regressive evolution occurs more intensely in the underlying shale sequences of siltstones, mainly due to erosion caused by surface runoff or the presence of water flows in layers between the sedimentary sequences: while the sandstones allow more water to percolate, the low permeability of the siltstones retains the stored water. Thus, water flows in lithological contact, a process frequently observed in erosive or structural scarps (piping effect).

The record of crocodyliforms and dinosaurs from the Late Cretaceous of the state of Goiás was reported for the rocks of the Adamantina and Marília formations (Bauru Group) of Quirinópolis and Rio Verde by Candeiro et al., (2018). The residuals of the Adamantina Formation (Turonian-Santonian) of Serra da Portaria from the exploration of the present thesis registered for the first-time teeth of crocodyliforms and carnivorous dinosaurs (theropods) for the municipality of Paraúna (Figure 04), in addition to undetermined materials of crocodyliforms, theropods and herbivorous sauropod dinosaurs. These records

demonstrate the great potential of paleontological prospecting.

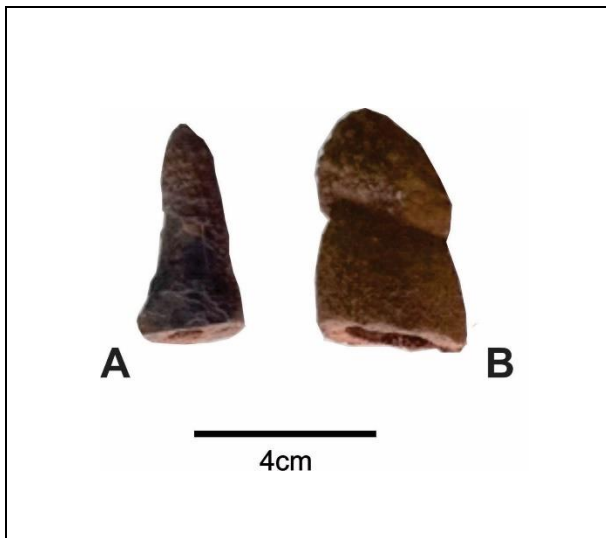


Figure 04: Species of reptiles in fossils found in the Adamantina Formation of the Serra da Portaria geosite: A, carnivorous dinosaur tooth; B, crocodyliform tooth.

The Tourist Guide of Paraúna (2013) reports that the mountain received its name due to the existing escarpments that show traces of sealed portals; these escarpments lead to a Geodiversity site of remarkable aesthetic value. According to the Paraúna Tourism Inventory (Paraúna, 2007), the local population recognizes this geosite as a mystical place and some residents claim that the area is visited by unidentified flying objects. Another cultural aspect is the Serra da Portaria Institute, located in the mountainous area. This institution is dedicated to mystical subjects and is a reference center for the study, research and training of integrative therapies. There are no visitation restrictions and many residents and tourists from Paraúna visit the place. Access to the area is safe and of intermediate difficulty, being much frequented by visitors from educational institutions who are interested in the geology and geomorphology of the region.

Serra das Galés Geosite

The Serra das Galés geosite is located 28 km from the urban area of Paraúna. According to the Tourist Diagnosis of Paraúna (2007), the mountain range has a total area of 271 ha, where sandstone monuments known as Cálice (chalice), Tartaruga (turtle/tortoise), Índia (Indian woman), Três Reis Magos (three wise men), Lagartixa (lizard/gecko), Bigorna (anvil), and Cérebro de Pedra (stone/rock brain), among others, are located. Serra das Galés is located at an altitude of

710 m and is level with the peaks of the surrounding elevations. The main watercourses in the region are Ribeirão Formoso and Córrego do Macaco, the respective beds of which are an altitude of around 600 m. This geosite of geomorphological interest occurs in the sandstones of the Aquidauana Formation (Figure 05). The strata are made up of reddish sediments with fine to medium grains rich in iron oxide. Serra das Galés corresponds to a series of “morros testemunhais em ruínas” (“testimonial hills in ruins”; *sensu* MELO, 2006), supported by highly eroded sandstones, contrasting with other adjacent sandstones, which are less dissected sandstone residues. This contrasting difference mainly reflects the more advanced stage of erosion in the area of the site, comprising an exceptional landscape marked by “formas topográficas bizarras, os chamados relevos ruiformes” (“bizarre topographic forms, the so-called ruiniform reliefs”; Guerra and Marçal, 2015; Melo, 2006; Santos, 2001).

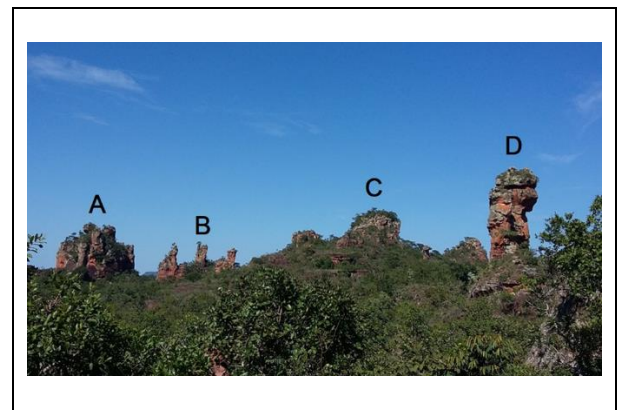


Figure 05. Geofoms carved in the sandstones of the Aquidauana Formation located in the Serra das Galés geosite: A, Paredão; B, Os Três Reis Magos (the three wise men); C, Pássaro (bird); D, Índia (Indian woman). Adapted from Ferreira et al., 2020.

The geofoms resemble cups, human forms or objects and present a variety of ornaments that reflect the characteristics of the rock and the processes of fracturing or erosion. The age of the rocks where the ruiniform relief of the Serra das Galés geosite occurs was considered as belonging to the Upper Carboniferous by Schneider et al., 1974. These geofoms are approximately 12 meters high and composed of reddish sandstones with ferruginous cementation, rocks these constitute the escarpments of the regional relief.

A relevant factor in the process of internalization and mental construction of these geofoms by people is pareidolia. Marques and Pereira (2019) address that it is a process that

consists of a casual stimulus, which is more connected to image and sound, being perceived as something distinct with meaning, a perceptive distortion. This phenomenon is effective when used as a strategy for valuing geoforms, as it can generate identity, identification and belonging in the target audience, making interactivity and the process of valuing Geodiversity much closer, intimate and effective. In this sense, through pareidolia, PEPa visitors acquire a certain perception in relation to these geoforms, including naming them.

The geoform Índia (Figure 06) has ridges on top of the sandstone walls of the Aquidauana Formation. This structure was formed by the combination of erosion processes and the dissolution and removal of sandstone grains that removed the most fragile parts and exposed the most resistant areas of rock. This geoform is similar to the suspended blocks reported by Melo (2006) for Vila Velha, Paraná. This author considered these blocks as formed from erosive processes that progressively excavate and isolate sandstone blocks, which, under the action of the force of the weight imposed by the action of gravity, can assume positions of unstable equilibrium. This feature is visually interpreted by observers as an Indian woman facing the horizon.

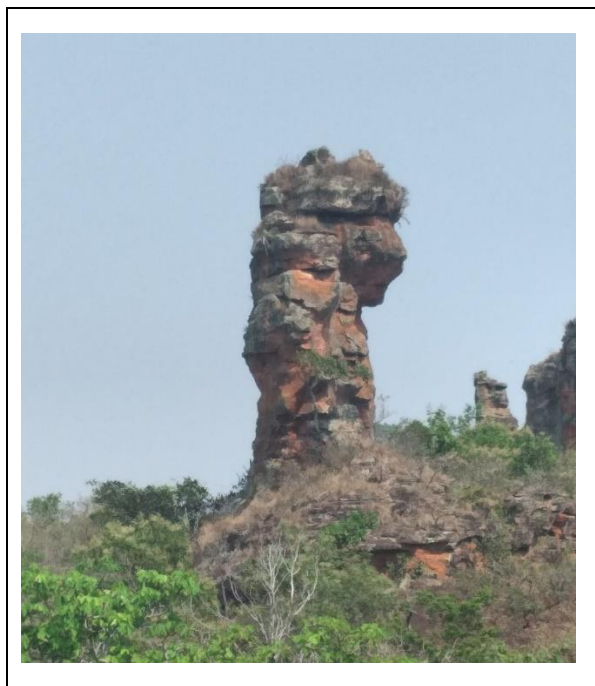


Figure 06. Sandstone geoform named Índia (Indian woman).

The Cálice geoform (Figure 07) is a sandstone column with a wide top and a narrow base, shaped after differential erosion where the main erosive agent has been rainwater flow that

dissolves soluble minerals and removes sandstone grains. This geoform is also similar to those present in Vila Velha, Paraná. When describing the formation process of these geoforms, Melo (2006) addresses that preexisting fractures in the rock as well as the flow of surface water concentrated in channels that can help in the formation of towers and pillars. Like the previous geoforms, the name Cálice (chalice in English) was coined by local residents due to its resemblance to a "cup".



Figure 07. Sandstone geoform named Cálice (chalice/cup).

The Tartaruga geoform (Figure 08) is the result of the weathering of the Aquidauana Formation sandstone. The angular shape at the top of the structure resembles the shell and the small elevations are seen as the head and shell of a turtle/tortoise. To explain these angular shapes, Mainguet (1972), stated that polygonation or "crocodilage" occurs by the action of granular disaggregation, according to the planes of fractures that exist in the rock; this action highlights the polygonal pattern of existing fractures in the rocks. Such processes are frequent in sandstone rocks and, as a result of these processes, presents similarity with contraction cracks. When describing these angular forms present in the sandstone in Vila Velha, Melo (2006) reports that the action of the sun heats the surface of the sandstone, causing invoices by the phenomenon of successive expansion and contraction, originating many of the surface features of the plateau.



Figure 08. Sandstone geoform named Tartaruga (turtle/tortoise).

Quantification of geosites

Serra da Portaria and Serra das Galés geosites, located in PEPa, are important for Geodiversity at the national level, since they have elements of Geological Heritage described for the first time for the geological formations of the Paraná Basin in the Center-West region of Brazil. The criteria of weights and scores proposed by Brilha (2016) were adopted for the quantification of these geosites, which evaluate the scientific

value, degradation risk and potential educational and tourist uses. Brilha (2016) considers that, within the scope of scientific value, the scientific significance of the occurrence is expected to be evaluated, regardless of its immediate potential use. A geosite with scientific value should be conserved for what it represents, regardless of the potential scientific use it may provide in the short term.

Within the scope of educational and tourist value, it is relevant to consider the potential educational and tourist use of the sites. These types of values are intrinsically related to the use of the site, and it only makes sense to conserve a site with educational value if it will be effectively used as an educational resource. A similar justification can be made for geosites with tourist value, where their conservation is deeply related to their use as tourist attractions.

Table 01 provides the scientific values of Serra das Galés and Serra da Portaria geosites. Both sites achieved a total scientific value of 215 points. The main geological elements of the geosites are well preserved, being the only occurrence of this type in the study area. It is possible to carry out sampling or field work in the area of these sites after overcoming existing limitations. Within the scope of geological diversity, the Serra das Galés geosite presents only one geological aspect — geomorphological. The Serra da Portaria geosite has two geological aspects — geomorphological and paleontological.

Table 01: Scientific values of Serra das Galés and Serra da Portaria geosites.

PARAMETERS OF SCIENTIFIC VALUE	WEIHT	POSSIBLE SCORES FOR PARAMETERS	SERRA DAS GALÉS GEOSITE	SERRA DA PORTARIA GEOSITE
Representativeness	30	0, 1, 2, 4	2	2
Location-type	20	0, 1, 2, 4	0	0
Scientific knowledge	5	0, 1, 2, 4	2	2
Integrity	15	0, 1, 2, 4	4	4
Geological diversity	5	0, 1, 2, 4	1	1
Rarity	15	0, 1, 2, 4	4	4
Limitations of use	10	0, 1, 2, 4	2	2
Scientific value:			215	215

Brilha (2016) mentions that the criteria of representativeness, location-type, scientific knowledge, integrity, geological diversity and rarity are intrinsically related to the geological characteristics of a geosite, which makes sense since what is being evaluated is its scientific value.

However, the limitations of use criterion is not related to value, but to potential use. The inclusion of this criterion is justified by the fact that part of the scientific value of a geosite is related to the possibility of use for present and future research.

Therefore, this criterion intends to assess whether there are limitations to scientific research.

Serra das Galés and Serra da Portaria geosites have the same scientific value, which is not surprising given the criteria addressed within the scope of the proximity of these sites and the size of the study area. Brilha (2016) considers that for small areas, the respective score should be the same for all locations, which does not contribute to the necessary discrimination of the geosite. In consideration of the score achieved, these geosites are considered of national relevance, with considerable scientific value, and therefore

important for the geological heritage of the state of Goiás.

The two geosites had 150 points, presenting the possibility of deterioration of the main geological elements. Within the proximity of areas/activities with the potential to cause degradation, they do not apply. The geosites are located in an area with legal protection, but without access control, and are accessible via a non-distant road and in a municipality with less than 100 inhabitants/km².

Table 02. Degradation risk of Serra das Galés and Serra da Portaria geosites.

PARAMETERS OF DEGRADATION RISK	WEIGHT	POSSIBLE SCORES FOR PARAMETERS	SERRA DAS GALÉS GEOSITE	SERRA DA PORTARIA GEOSITE
Deterioration of geological elements	35	0, 1, 2, 3, 4	3	3
Proximity to areas / activities with potential to cause degradation	20	0, 1, 2, 3, 4	0	0
Legal protection	20	0, 1, 2, 3, 4	2	2
Accessibility	15	0, 1, 2, 3, 4	2	2
Population density	10	0, 1, 2, 3, 4	1	1
Degradation risk:			15	185

Brilha (2016) mentions that a geosite has a higher degradation risk when its main geological elements have a high probability of damage by natural or anthropic factors, when the site does not

have legal protection and when it is located close to an area or activity harmful to the site. Table 03 reports the potential touristic use of the Serra das Galés and Serra da Portaria geosites.

Table 03: Potential touristic use of Serra das Galés and Serra da Portaria geosites.

PARAMETERS POTENTIAL TOURISTIC USE	WEIGHT	POSSIBLE SCORES FOR PARAMETERS	SERRA DAS GALÉS GEOSITE	SERRA DA PORTARIA GEOSITE
Vulnerability	10	0, 1, 2, 3, 4	2	4
Accessibility	10	0, 1, 2, 3, 4	2	2
Limitations of use	5	0, 1, 2, 3, 4	2	2
Security	10	0, 1, 2, 3, 4	1	1
Logistics	5	0, 1, 2, 3, 4	3	3
Population density	5	0, 1, 2, 3, 4	1	1
Association with other values	5	0, 1, 2, 3, 4	3	3
Scenic beauty	5	0, 1, 2, 3, 4	2	1
Singularity	5	0, 1, 2, 3, 4	2	3
Observed conditions	10	0, 1, 2, 3, 4	4	3
Potential for disclosure	10	0, 1, 2, 3, 4	3	3
Economic level	5	0, 1, 2, 3, 4	1	1
Proximity to recreational areas	5	0, 1, 2, 3, 4	3	3

Touristic value:	215	225
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The Serra das Galés geosite reached 215 points, which presents the possibility of deterioration of the main geological elements by anthropic activity. This vulnerability is in relation to visitation, accessible via a road not far away that can be used by students and tourists, but after overcoming certain limitations, without security infrastructure (fences, stairs, handrails, etc.), nor mobile communications network and located more

than 50 km from an emergency service. Accommodations and restaurants with the capacity for groups of 50 people are less than 50 km from the site.

The municipality has less than 100 inhabitants per km², with a lower Human Development Index (HDI) than found for the state. Within the scope of ecological and cultural values, there are less than 10 km from the site, the geosite

Table 04. Potential educational use of Serra das Galés and Serra da Portaria geosites.

PARAMETERS OF POTENTIAL EDUCATIONAL USE	EIGHT	POSSIBLE SCORES FOR PARAMETERS	SERRA DAS GALÉS GEOSITE	SERRA DA PORTARIA GEOSITE
Vulnerability	10	0, 1, 2, 3, 4	2	4
Accessibility	10	0, 1, 2, 3, 4	2	2
Limitations of use	5	0, 1, 2, 3, 4	2	2
Security	10	0, 1, 2, 3, 4	1	1
Logistics	5	0, 1, 2, 3, 4	3	3
Population density	5	0, 1, 2, 3, 4	1	1
Association with other values	5	0, 1, 2, 3, 4	3	3
Scenic beauty	5	0, 1, 2, 3, 4	2	1
Singularity	5	0, 1, 2, 3, 4	2	3
Observed conditions	10	0, 1, 2, 3, 4	4	3
Didactic potential	20	0, 1, 2, 3, 4	4	4
Geological diversity	10	0, 1, 2, 3, 4	1	2
Educational value:			245	265

is usually used in local tourist campaigns, showing geological aspects. On the other hand, there are unique and rare features in the region; observations of all the geological elements indicates they are in good condition; and the public needs to have some geological knowledge to understand the elements of the site, which is also located less than 10 km from a recreational area or tourist attraction.

The Serra da Portaria geosite reached 225 points and the geological elements do not present the possibility of deterioration due to anthropic activities. accessible on a road that is not far away, can be used by students and tourists, but, after overcoming certain limitations, without security infrastructure (fences, stairs, handrails, etc.), nor a mobile communications network and located more than 50 km from an emergency service. There are accommodations and restaurants with the capacity for groups of 50 people are less than 50 km from the site. The geosite is located in a municipality with less than 100 inhabitants per km², and with a

lower HDI than that for the state. Certainly, there is the occurrence of unique and rare aspects in the state of Goiás, which are the fossils. There are obstacles that make it difficult to observe the fossils, however, the mountain range can be seen clearly, at certain angles in the lookout. The public needs to have some geological knowledge to understand the elements of the geosite, which is located less than 10 km from a leisure area or tourist attraction.

Brilha (2016) states that a geosite has a high potential for tourist use when the geological elements have a notable aesthetic relevance (generally the geomorphological elements are those with the greatest potential to be aesthetically appreciated by the general public) and can be easily understood by people without geoscientific background, as well as being associated with a low risk of degradation by human activity (low vulnerability). The existence of good facilities and visiting conditions are essential assets for touristic use of a site.

In terms of relevance, these sites can be used in Geotourism, as they have characteristics that contribute to conscious geological tourism, conserving and preserving aspects of the area's Geodiversity. The municipality does not yet have tourist flow, however, with investments, this possibility of Geotourism can be realized. Next, Table 04 presents the potential educational use of Serra das Galés and Serra da Portaria geosites.

The Serra das Galés geosite obtained 245 points, and so the possibility exists for deterioration of the main geological elements by anthropic activity. This vulnerability is in relation to visitation, accessible on a not far road, can be used by students and tourists, but, after passing certain limitations. It is without security infrastructure (fences, stairs, handrails, etc.) or mobile communications network and located more than 50 km from an emergency service. Accommodations and restaurants with the capacity for groups of 50 people less than 50 km from the place of interest. It is located in a municipality with less than 100 inhabitants per km², with diverse ecological and cultural values less than 10 km from the site, and is usually used in local tourist campaigns, showing geological aspects. However, there are occurrences of unique and rare features in the region. This site presents the occurrence of geological elements that are used in all levels of education and observations of all the geological elements indicates they are in good condition. Within the scope of geological diversity, it presents only one element — geomorphological.

The Serra da Portaria geosite reached 265 points, and the geological elements do not present the possibility of deterioration by anthropic activities. It is accessible via a road that is not far away, can be used by students and tourists, but after overcoming certain limitations. It is without security infrastructure (fences, ladders, handrails, etc.) or mobile communications network and located more than 50 km from an emergency service. The site is located in a municipality with less than 100 inhabitants per km², with diverse ecological and cultural values less than 10 km from the site, and is used in local tourist campaigns. It presents the occurrence of unique and rare aspects for the state of Goiás, which are the fossils. There are obstacles that make it difficult to observe the fossils, however, the mountain range can be seen clearly, at certain angles from the lookout. Geological elements are used at all levels of education and two elements stand out in relation to geological diversity — geomorphological and paleontological.

Brilha (2016) reports that a site has a higher potential for educational use when the

Geodiversity elements are resistant to eventual destruction caused by students (low vulnerability) and when they can be easily observed by students of all school levels. This type of site can also be easily reached by means of transport and provides safe conditions for certain types of users who may engage in reckless behavior, particularly those in certain age groups.

Due to their importance, potential educational use and applicability as an educational resource, these sites are relevant to teaching and learning processes and, therefore, must be preserved. Several disciplines of university courses use this area for field work due to the details in the geological field and geomorphological aspects of the place.

The quantitative analysis based on the methodology of Brilha (2016) identified high scientific value for both geosites (215 points each), comparable to other sites of national relevance, such as the ruiniform reliefs of Vila Velha (Melo, 2006; sic page 82 and fig. 66) and the geoforms of Geoparque Seridó (Nascimento, 2023; sic page 155 and fig. 2). However, while the Serra das Galés geosite stands out mainly for its ruiniform geomorphological features, Serra da Portaria also has important paleontological records of crocodyliform and theropod fossils from the Late Cretaceous (Candeiro et al., 2020), which increases its relevance for paleobiological studies.

Regarding degradation risk (185 points), the two geosites present moderate vulnerability, where the lack of monitoring and unregulated tourist pressure are constant threats. However, unlike geosites in fully protected conservation units, such as Parque Nacional da Chapada dos Veadeiros (Brazil, 2009), the lack of a specific management plan for Geoconservation in Parque Estadual de Paraúna increases exposure to anthropogenic damage, such as vandalism and livestock occupation.

The tourism potential of Serra da Portaria (225 points) slightly surpasses that of Serra das Galés (215 points), mainly due to its lower vulnerability and the uniqueness of its fossil record. The scenic beauty and pareidolia (Marques and Pereira, 2019) of the Serra das Galés landforms (e.g., "Índia", "Cálice") are underutilized assets that, if explored with adequate infrastructure (viewpoints, interpretive signs), could approach the success of places such as Vale da Lua (Goiás) or Parque Estadual de Vila Velha (Paraná).

Serra das Galés scored 245 points for educational potential while Serra da Portaria scored 265. The latter geosite stands out for its geological diversity (geomorphology and paleontology), similar to geosites used in university extension

programs found in Geoparque Uberaba (Ribeiro et al., 2012; e.g., Univerdecidade Geosite and Caieira Geosite). However, the lack of safety and accessibility infrastructure limits both sites, and contrasts with successful initiatives such as those of the Araripe and Uberaba geoparks, which combines marked trails with educational programs for all ages (Oliveira et al., 2020).

Final considerations

The present study aimed to quantify the scientific value, risk of degradation and educational and tourism potential of Serra das Galés and Serra da Portaria geosites in Parque Estadual de Paraúna. The results obtained confirm the relevance of these sites for the geodiversity of the state of Goiás and provide essential support for their conservation and sustainable use.

Paraúna State Park comprises two geosites — Serra das Galés and Serra da Portaria which reached 215 points within the scope of scientific value, being considered geosites of national relevance. The Serra da Portaria geosite is part of the Aquidauana Formation, but also contains rocks from the Adamantina Formation. Its structure is part of the tabular relief. This site is used by several local residents and has relevant cultural value for the Paraúna community. The Serra das Galés geosite, in the Aquidauana Formation, is notable for its geofoms that resemble objects and animals. These geofoms are composed of sandstone and sculpted by progressive erosion along its length up to the point where a block is isolated from the surrounding massif.

The geosites reached relevant values. In terms of degradation risk, Serra das Galés and Serra da Portaria both obtained 185 points. For potential touristic use, Serra das Galés achieved 215 points and Serra da Portaria 225 points. Potential educational use was the criteria that presented the highest score in relation to the geosites, with Serra das Galés reaching 245 points and Serra da Portaria 265 points. These data clearly highlight the geosites of Paraúna State Park as being relevant to the Geodiversity of the state of Goiás and must be conserved and preserved.

In this sense, it can be concluded that the geosites of Parque Estadual de Paraúna are Geological Heritage sites of national relevance and that they require conservation strategies, such as monitoring, management plans and legal protection. They also require touristic valorization through sustainable infrastructure, geotourism routes and dissemination, as well as educational use through environmental interpretation programs and curricular integration. Thus, this study not only achieved its main objective of a quantitative

evaluation, but also provided concrete bases for future actions, contributing to the preservation of Goiás' geodiversity and the socioeconomic development of the region.

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