



# Geoconservation of the paleontological heritage of the geosite of dinosaur footprints (sauropods) in the locality of São Domingos, municipality of Itaguatins, state of Tocantins, Brazil

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## Abstract

The present study aimed at performing a quantitative evaluation to propose a geoconservation plan to the São Domingos geosite, and, therefore, to contribute with feasible actions, to the preservation of this paleontological heritage. The study area is located in the district in the Itaguatins municipality, northern Tocantins state, Brazil. The studied geosite is characterized by the presence of track fossils. The tracks have been assigned to herbivorous dinosaurs, basal sauropods, which were living in the area during the first periods of the Cretaceous. The following aspects were quantitatively evaluated: risk of degradation and potential for the educational and touristic use of the area. All these aspects were quantitatively evaluated with the methodology described in the app web GEOSSIT, administered by the Companhia de Pesquisa de Recursos Minerais. The São Domingos geosite has a high scientific value, with a national relevance, a moderate potential of educational use, a low potential of tourist use, and a high risk of degradation. The site, with interest and paleontological value, has the potential to be used in all level educational activities at, and it is important it should be used for such activities. The elements of the geosite are currently in an advanced degree of degradation, and urgent measures are required to mitigate the erosive activities that affect the footprint-bearing surfaces and that gradually increase their erosion.

**Keywords** Dinosaur footprints · Geoconservation · Paleontological heritage · Ichnofossils

## Introduction

Dinosaur footprints are widely recorded in Brazil rocks, being the first report of these ichnofossils at the end of the nineteenth century (Leonardi 1994). The tracks were discovered from the Cretaceous Brejo das Freiras and Sousa basins, located in the northeast region of Brazil. These basins have

both isolated footprints and trackways of theropod and ornithomimid dinosaurs, as well as traces and excavations assigned to arthropods and annelids (Leonardi and Carvalho 2002; Silva et al. 2003).

After the first discovery, new footprints were recorded in other Brazilian sites. Leonardi (1980) reported the finding of a paleontological site in the Corda Formation (Lower Cretaceous), Parnaíba Basin, which contained tracks assigned to herbivorous dinosaurs. The geosite is located on the left margin of the Tocantins river, next to the São Domingos village, in the municipality of Itaguatins, Tocantins state.

Initially, the discovery consisted of about seven in situ vertebrate trackways, accounting for 56 footprints, first assigned to iguanodontid dinosaurs, and later revised and re-assigned to sauropod dinosaurs (Leonardi 1994; de Valais et al. 2015; Tavares et al. 2015). Until today, these São Domingos records are the only fossil evidence of vertebrates from the Corda Formation (de Valais et al. 2015).

The ichnofossil geosite of São Domingos (Itaguatins municipality, northern Tocantins State) has a significant scientific value due to its rare record of footprints assigned

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to sauropod dinosaurs at the beginning of the Early Cretaceous, which were distributed in areas nowadays known as the North and Northeast regions of Brazil and Western Africa. Thus, this Lower Cretaceous outcrop should be the object of geoconservation strategies and maintenance programs because the footprints are an important contribution to the record of the Cretaceous ichnofauna from the Southern Hemisphere, such as the ichnofossils from Sousa, Paraíba state, Brazil (Leonardi 1994; Leonardi and Carvalho 2002).

Although the scientific importance of the São Domingos tracks has been previously discussed (Leonardi 1980; de Valais et al. 2015; Tavares et al. 2015), no scientific work on methods for the geoconservation of the São Domingos site has been proposed yet, including a systematic inventory and quantification of the values and vulnerability of the geosite.

The geoconservation refers to a series of strategies and techniques that support the conservation of a geological heritage by analyzing its values and vulnerabilities (Gray 2011; Prosser et al. 2013; Rocha et al. 2014). The conservation plans must integrate measures that result in the interpretation, administration, protection, and public awareness of a given natural heritage (Sharples 2002; Brilha 2005). The stage of inventory is crucial to any geoconservation strategy, as well as the recognition of the vulnerability degree of the geosite. These measures prevent from ineffective conservation actions concerning valuable geological features and that could lead to its degradation or even destruction (Gray 2011; Rocha et al. 2014).

Nowadays, many studies are carried out about evaluation strategies, management, and geoconservation plans (e.g., Braga 2002; Pereira et al. 2007; Prosser et al. 2013; Mansur et al. 2013a; Rocha et al. 2014; Brilha 2016). Besides, there

are several evaluation methods to categorize the values of a determinate geosite (Gray 2004; Brilha 2005; Pereira et al. 2007; Reynard 2009; Brilha 2016).

The present study aims to perform a quantitatively evaluation to propose a geoconservation plan to the São Domingos geosite, and, therefore, to contribute with feasible actions, to the preservation of this paleontological heritage.

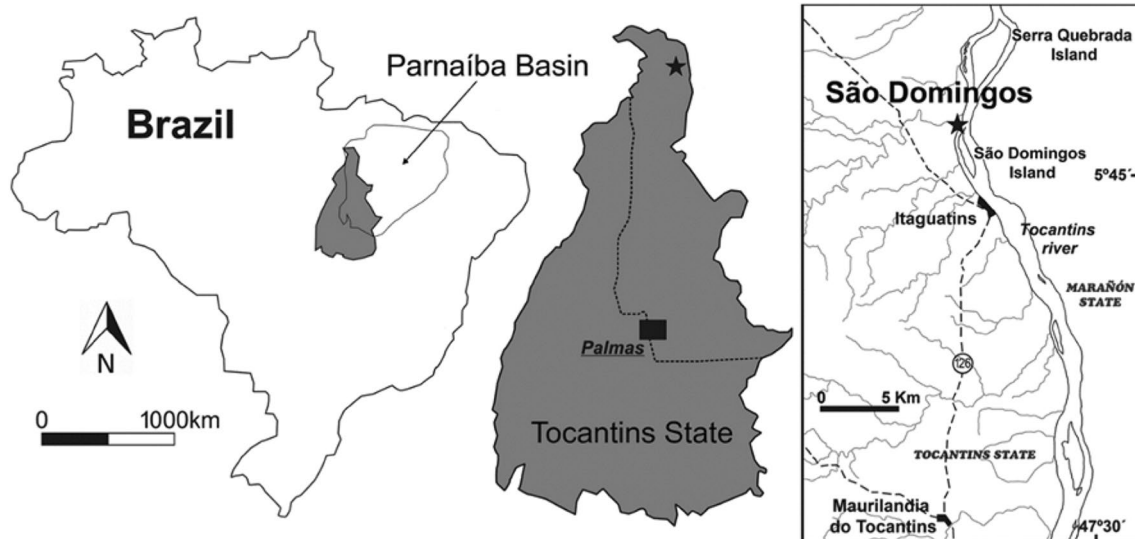
## Study area

The São Domingos geosite is located in the municipality of Itaguatins, north Tocantins state, Brazil (Fig. 1). The footprints were found in a private property on the margins of the Tocantins river, occupying an area of about 1 km<sup>2</sup>.

The São Domingos geosite is located 0.5 km north-east from the homonymous village (Fig. 2), in a transition area between the Cerrado and the Amazon Forest. The access to the outcrop is by a small embankment to the footprint-bearing flood plain of the Tocantins river. The coordinates of the outcrop are LAT: 5° 42' 58" S, LON: 47° 29' 48" W.

## Geological setting

The Corda Formation outcrops in the studied area. It belongs to the intracratonic sedimentary of the Parnaíba Basin, located in northern Brazil (Aguiar 1971), also designated as “Província Sedimentar do Meio Norte” (Middle-Northern Sedimentary Province) by Góes (1995) and Góes and Coimbra (1996). The Parnaíba Basin occupies an area of at least 600,000 km<sup>2</sup> between the states



**Fig. 1** Location map of the São Domingos geosite (from de Valais et al. 2015)



**Fig. 2** Aerial view of the geosite area

of Tocantins, Pará, Maranhão, Ceará, and Bahia (Góes and Feijó 1994). The unit is usually subdivided into four smaller sub-basins: Parnaíba (Silurian–Triassic), Alpercatas (Jurassic–Lower Cretaceous), Grajaú (Cretaceous), and Espigão Mestre (Cretaceous) (Silva et al. 2003).

The Corda Formation outcrops in the central area of the Parnaíba Basin; its rocks cover an area between the Parnaíba river and the mouth of the Araguaia river (Aguiar 1971). The lithology of this unit is composed of red, reddish brown, white, and purple to gray sandstones that range from very finely grained to fine and medium grained; besides, they are rich in iron oxides and zeolites. The sedimentary deposits of the Corda Formation are superimposed and continuous to the Pastos Bons Formation, and discontinuous to the basalts of the Mosquito Formation (Aguiar 1971; Silva et al. 2003).

The sedimentary process of the Corda Formation is appointed as a desertic environment of dry and hot weather conditions with fluvial systems of high energy in its interior. Given this context, the preservation of the previously mentioned fossils was an unusual event (Aguiar 1971; Silva et al. 2003; Santos and Carvalho 2009).

The main sedimentary structures in the Corda Formation are large-size packages with trough cross stratification and grain flow that are intercalated with layers of plane-parallel laminations (Aguiar 1971). These structures are interpreted as deposits of eolian dunes and interdune regions. The unit is assigned to the Lower Cretaceous (Barremian) based on the presence of the conchostracean arthropod *Macrolimnadiopsis* (sensu Lima and Leite 1978).

## Methodology

### Methods of quantitative evaluation of the geosite

The study of the place of interest and paleontological value was initiated with the inventory of fieldworks and geodiversity elements of heritage value, which are still preserved in the geosite to understand the ichnofossil preservation state. Then, the vulnerability of the site has been evaluated, by analyzing which main natural and anthropogenic factors are putting at risk the integrity of these ichnofossils and their degree of erosion.

The following aspects were quantitatively evaluated: risk of degradation and potential for the educational and touristic use of the area. All these aspects were quantitatively evaluated with the methodology described in the app web GEOSSIT (<https://www.cprm.gov.br/geossit/>), administered by the Companhia de Pesquisa de Recursos Minerais (CPRM). The evaluation tables used for this methodology are based on the proposal of Brilha (2016). Once the results were available, suggestions were made for the geoconservation of the paleontological heritage of the São Domingos geosite.

### GEOSSIT: method of quantitative evaluation of the CPRM

GEOSSIT is a web application, developed by CPRM, for the registration and quantification of geosites. The tool allows the integration and quantification of inventory data to characterize geological heritage in the Brazilian territory. According to Mansur et al. (2013b), the web application operates as a standardization tool of geosite registrations

in Brazil and gives free access to users to explore existing geosites.

The system contains several spreadsheets to be completed to perform the quantitative evaluation and obtain the relevance of the studied geosite. The GEOSSIT also gives some recommendations about the urgency and need for protection regardless of the use of the locality (e.g., as a tourist spot or for educational purposes). After completing all parameters, the system analyzes the geosite and assigns it a mean value of relevance at international, national and regional levels.

For the evaluation of the potential for educational and tourist uses (Brilha 2016; Table 5) of the studied area, the following criteria were used: vulnerability, accessibility, use limitations, safety, logistics, population density, association with other values, scenery, uniqueness, observation conditions, educational potential, geological diversity, interpretative potential, economic level and proximity to recreational areas. Yet, the criteria “educational potential” and “geological diversity” are only used in the quantification of the educational use potential, and the criteria “interpretative potential”, “economic level” and “proximity to recreational areas” are used only to quantify the tourism potential. When applicable, each criterion receives a score from 1 to 4 and each criterion has its own weight (Brilha 2016; Table 6). At the end of the process, the weighting is done by the GEOSSIT and a numerical result with the classification of the geosite potential (low, moderate or high) is presented.

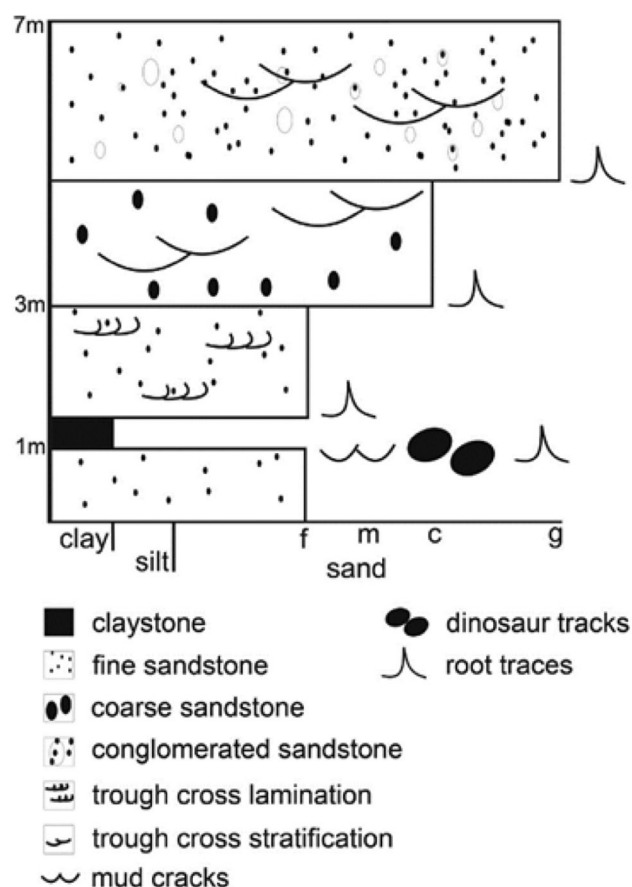
The assessment of the risk of degradation (Brilha 2016; Table 7) was estimated using five criteria: deterioration of geological elements, proximity to areas/activities with the potential to cause degradation, legal protection, accessibility, and population density. GEOSSIT gives scores from 1 to 4 (Brilha 2016; Table 8), to the criteria applied in the studied area, and it establishes the risk of degradation as low, moderate or high (Brilha 2016; Table 9).

## Results and discussion

### The São Domingos geosite

The site of paleontological interest contains ichnofossils preserved in a sandstone level (Fig. 3) of the Corda Formation (Barremian, Lower Cretaceous). The stratum includes reddish and grayish sediments with fine to medium grains rich in iron oxide and zeolites. The layer also contains more recent sediments from the high-energy floods of the Tocantins river.

The vegetation around the geosite is mainly formed by environments where the forest formations Cerradão, Campo Cerrado, and semi-deciduous forest overlap (Dambrós et al. 2003). The climate is equatorial with rainfalls throughout



**Fig. 3** Stratigraphic column of the geosite with the positioning of the footprints in the layer (from de Valais et al. 2015)

the whole year, mean annual temperature of 26 °C and low thermal amplitude (Dambrós et al. 2003).

Currently, the geosite displays at least 20 footprints distributed in four trackways. They are moderate to poorly preserved due to the pronounced erosion (Fig. 4). De Valais et al. (2015) considered the São Domingos ichnofossils as belonging to the *Parabrontopodus*-like group or narrow gauge.

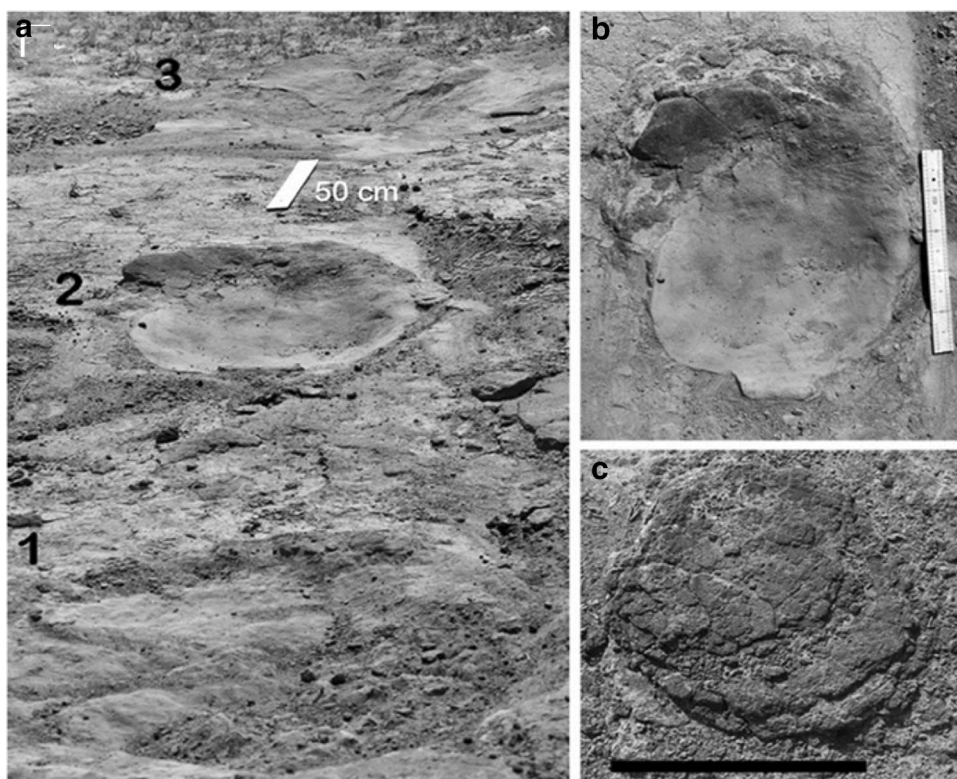
The tracks are represented by pes imprints, mostly circular to subcircular, some of them with a subtriangular sole, variation probably due to erosion, which can be inferred given that some trackways are composed of both subtriangular and subcircular footprints (Fig. 5). All of them lack digital and claw impressions. The footprints are slightly longer than wide, ranging from 59- to 80-cm wide, with an average of 66 cm, and from 66-cm to 82-cm long, with an average of 70 cm. No distinguishable manus imprints are present.

### Quantitative assessment of the geosite

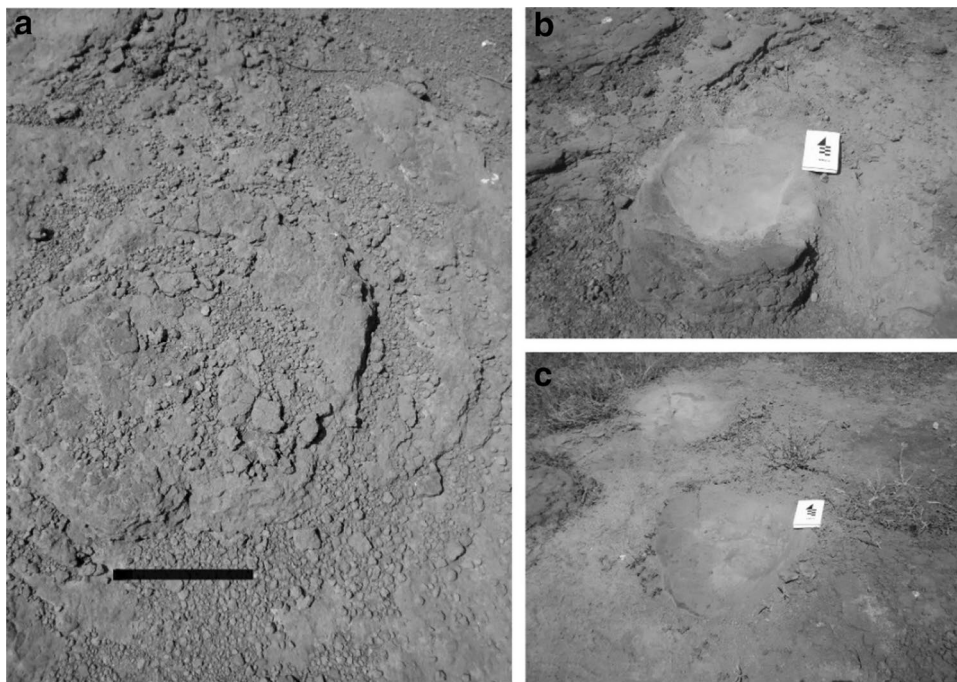
The studied geosite is characterized by the presence of track fossils. The tracks have been assigned to basal



**Fig. 4** In situ tracks from the São Domingos track site. Scale bars 50 cm. **a** Three footprints displaying a trackway (1–3): the nearest track is covered by modern sediments; **b** and **c** moderately preserved footprints (from de Valais et al. 2015)



**Fig. 5** Footprints of sauropod dinosaurs found in the São Domingos site, Itaguatins, Tocantins state. Scale bars of 20 cm. **a–c** Isolated footprints in the geosite



herbivorous sauropods that lived in the area during the first periods of the Cretaceous. The elements of paleontological value found in the São Domingos geosite can also be classified as of heritage value for its scientific and educational relevance, because they represent the national

paleobiodiversity, and besides they are unique records from throughout the region where they are located.

Although there are previous scientific works about the São Domingos geosite, a systematic inventory has never been carried out to analyze its values. Despite being only

one geosite, it is necessary to evaluate its value and, thus, use the available methodologies to identify the real quantitative importance of the geosite and to decide whether geoconservation strategies are needed in the studied area.

The importance of the ichnofossiliferous outcrop of São Domingos becomes evident when compared to the quantitative evaluation of other geosites with superlative value and their importance for already recognized geoconservation (e.g., the ichnofossil geosites from Sousa municipality, Paraíba state, Brazil). As the geosite of São Domingos, the geosite of Sousa municipality also contains dinosaur footprints, and it is characterized by having average low scientific and tourist values, moderate educational value, and high vulnerability (Santos et al. 2016).

The scientific relevance of the São Domingos geosite was demonstrated earlier in the present contribution by detailing its valuable scientific elements, besides the references of previous published works. Therefore, its scientific value, referred to the paleontological interest, is assumed a priori with no further considerations.

### Potential for educational and tourist use

The studied geosite is an excellent example of a locality, which illustrates a geological process or characteristic, and besides, it represents a significant contribution to the understanding of topics on biological evolution and biogeographic and geological changes. This is a clear evidence of the educational relevance of this area for the teaching of Paleontology and other disciplines within Geosciences.

The geosite of São Domingos has a moderate educational value of national relevance. Although the geosite features

correspond to quite representative geological events, which have recorded ichnofossils and are testimony of the national paleobiodiversity, the poor preservation of the tracks results in a reduced value in the quantitative analyses (Table 1). A higher conservation of elements reflects on a higher educational value because the use of these areas will be less restricted and the risk of damage to the elements of heritage value will be lower.

The potential for tourist use was considered low in the quantitative analyses. This is also explained by the poor conservation of the elements of the geosite and the absence of elements nearby the area that contains scenic beauty or that can be used for recreational activities.

The value for educational use obtained here shows that the studied area has elements that should be used in didactic activities for all levels of education. This outcrop is unique in the region and it can improve the comprehension of contents taught both in basic education classes and geography, biology, and geology courses.

### Assessment of the risk of degradation

The São Domingos geosite is located at the margins of the Tocantins river, and, therefore, it is vulnerable to drainage floods. This natural phenomenon is the main factor that contributes to the erosion of the ichnofossils, causing their deterioration and covering them with modern sediments.

The São Domingos geosite was classified as having a potential high risk of degradation of its elements of paleontological value (Table 2). This classification reflects the high erosion levels of superlative value, because they are continuously affected by the floods of the Tocantins river.

**Table 1** Criteria, weights and punctuation proposed by Brilha (2016) used for the assessment of the potential educational and touristic uses at the app Geositi and score attributed to the geosite

Parameters of the potential educational (EU) and touristic uses (TU)	Weights		Possible score for the parameters		Score attributed to the geosite	
	(EU)	(TU)	(EU)	(TU)	(EU)	(TU)
Vulnerability	10	10	0, 1, 2, 3, 4	0, 1, 2, 3, 4	2	2
Accessibility	10	10	0, 1, 2, 3, 4	0, 1, 2, 3, 4	1	1
Use limitations	5	5	0, 1, 2, 3, 4	0, 1, 2, 3, 4	2	2
Safety	10	10	0, 1, 2, 3, 4	0, 1, 2, 3, 4	2	2
Logistics	5	5	0, 1, 2, 3, 4	0, 1, 2, 3, 4	2	2
Density of population	5	5	0, 1, 2, 3, 4	0, 1, 2, 3, 4	1	1
Association with other values	5	5	0, 1, 2, 3, 4	0, 1, 2, 3, 4	2	2
Scenery	5	15	0, 1, 2, 3, 4	0, 1, 2, 3, 4	0	0
Uniqueness	5	10	0, 1, 2, 3, 4	0, 1, 2, 3, 4	4	4
Observation conditions	10	5	0, 1, 2, 3, 4	0, 1, 2, 3, 4	3	3
Didactic potential	20	0	0, 1, 2, 3, 4	0	4	0
Geological diversity	10	0	0, 1, 2, 3, 4	0	1	0
Interpretative potential	0	10	0	0, 1, 2, 3, 4	0	3
Economic level	0	5	0	0, 1, 2, 3, 4	0	2
Proximity of recreational areas	0	5	0	0, 1, 2, 3, 4	0	3

**Table 2** Criteria, weights and punctuation proposed by Brilha (2016) used for the assessment of the degradation risk at the app Geossit and score attributed to the geosite

Degradation risk (DR)			
Parameters	Weights	Possible score for the parameters	Score attributed to the geosite
Deterioration of geological elements	35	0, 1, 2, 3, 4	4
Proximity to areas/activities with potential to cause degradation	20	0, 1, 2, 3, 4	4
Legal protection	20	0, 1, 2, 3, 4	3
Accessibility	15	0, 1, 2, 3, 4	3
Density of population	10	0, 1, 2, 3, 4	1

Another added factor to this risk is the lack of protective measurements and intervention to avoid further erosion of these paleontological elements.

In addition to the normal drainage of the Tocantins river—that contributes to the damage of the structure of the ichnofossil bearing-rocks of the São Domingos geosite—there were modifications in the flow regime of the drainage during the past 5 years as a result of the installation and operation of the Estreito Hydroelectric Power Plant, located 150 km upstream of the geosite. These changes in the water flow over the sandstone increased the degradation of this important geosite, seeing that the mechanical force produced by the outflow of drainage waters was increased after the construction of the Estreito Hydroelectric Power Plant has caused a more pronounced erosive action on the rock in which the footprints are preserved.

At last, another circumstance that also offers great risk to the conservation of this paleontological heritage is the raising of cattle nearby the area where the ichnofossils are recorded, because the animals can frequently overpass the fence that separates the livestock area from the geosite area.

### Conservation proposals and valuation strategies

The São Domingo paleontological site is exposed to seasonal floods of the Tocantins river and it has a high risk of degradation. Other paleontological sites from various regions around the world also contain in situ dinosaur tracks, such as the footprints from La Rioja, in Spain (Calatayud et al. 2003) and the tracks from Sousa, Paraíba, Brazil (Santos et al. 2016). These localities are target of geotourism activities, which can be used as an important tool for protection and conservation of the São Domingos geosite, and attraction for school and tourist excursions destined to observe and learn about the dinosaur tracks.

Even with the low quantitative index for the tourist use of the geosite, it is possible to improve the logistics for visitors can get more easily the area where the footprints are located. The placing of interpretive panels would also help visitors to better understand the significance of those elements. As not all footprints are submerged during the flooding periods, visitation to the paleontological site can be continuous

throughout the year. On guided tours, the general public can learn about evolution, geology, the local paleofauna, and peculiarities of the regional dinosaurs which produced the footprints.

To preserve the ichnofossils of the geosite analyzed in the present contribution, it is necessary to continuously perform studies on the area for paleoenvironmental detailing and searching for new footprints and other ichnofossils. It is essential to display sign boards with information for the visiting public, explaining the prohibition of removing any material from the geosite, as well as implementing educational programs to the local community, which is unaware of the importance and even of the existence of this heritage. Another important measure to preserve this heritage is developing extension and intervention activities through technical work to restore the ichnofossils, which can be done with a partnership between the university and the local public power.

### Conclusion

The ichnofossiliferous record from the São Domingos site has elements of great paleontological value that are testimony to the paleobiodiversity of Gondwana. In addition, these specimens could be directly related to basal diplodocoids. A confirmation of this relationship in future studies implies that these tracks would be the oldest evidence of this taxon for the Early Cretaceous North Gondwana (de Valais et al. 2015).

Until now, the studied geosite is the only site that contains superlative elements of geodiversity in the region where it is located. Therefore, the analysis of values of the traditional inventory performed to choose priority conservation sites is not applicable and the evaluation of values should only consider the researched paleontological site. The quantitative analyses of a specific geosite were acceptable, with results that make it possible to visualize the real importance and state of risk of the studied geosite.

The site of interest and paleontological value has the potential to be used in educational activities at all levels of education, and it should be used for such activities. The



elements of the geosite are in an advanced degree of degradation and urgent measures are required to mitigate the erosive pressures on the footprint-bearing surface and that gradually increases its erosion.

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