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Porto Primavera Ichnofossil Geosite, Brazil: Geoconservation Measures in a Protected Area

Geossítio Icnofósseis de Porto Primavera, Brasil: Medidas de Geoconservação em Área Protegida

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Abstract

Porto Primavera geosite comprises aeolian sandstones with tetrapod trace fossil cropping out at the Porto Primavera Hydroelectric Power Plant, São Paulo State, Brazil. The Upper Cretaceous Rio Paraná Formation, which contains these tracks, is composed of medium–fine quartzarenites well-sorted and supermature, with typically large tabular/trough cross-bedding. They accumulated in complexes of large barchanoid dunes, moved by winds to the south-west. The Porto Primavera association consists of tracks of theropod dinosaurs and small mammals preserved in concave epirelief. These rare records in aeolian desert environments from the Late Cretaceous of Brazil indicate that even the interior Caiuá desert was occupied by organisms. The study focused on the characterization of the ichnofossils, assessing their susceptibility to degradation by natural and anthropogenic processes, and proposing measures to manage the geosite. Because the risk of degradation of the geosite is high, it is proposed that prior to their removal the slabs should be replaced with synthetic resin replicas made using silicone rubber moulds. The sense of disconnection between the objects and their natural geological context could be addressed by depositing the objects near the geosite in the Museum of Regional Memory. The geosite is indicated as a new holostratotype to the Rio Paraná Formation.

Keywords: Aeolian sandstones; Tracks; Caiuá

Resumo

O geossítio Porto Primavera é formado por arenitos eólicos com pegadas fósseis de tetrápodes, aflorantes na Usina Hidrelétrica de Porto Primavera, no estado de São Paulo. A Formação Rio Paraná, unidade do Cretáceo Superior que contém os icnofósseis, é composta por quartzoarenitos médio a -finos bem selecionados e supermaturos, com típica estratificação cruzada tabular/acanalada de grande porte. Tais depósitos acumularam-se em complexos de grandes dunas barcanóides, movidas por ventos para sudoeste. A associação de Porto Primavera é composta por pegadas de dinossauros terópodes e de pequenos mamíferos, preservadas em epirrelevo côncavo. Esses raros registros em ambientes desérticos eólicos do Cretáceo Superior do Brasil indicam que o interior do *deserto do Caiuá* foi ocupado por organismos vivos. O estudo centrou-se na caracterização dos icnofósseis, com avaliação da sua susceptibilidade à degradação por processos naturais e antropogênicos, e indica medidas preliminares de gestão para o geossítio. Como o risco de degradação do local é alto sugere que as placas sejam substituídas por réplicas de resina sintética feitas com moldes de borracha de silicone. A possível sensação de desconexão entre os objetos e seu contexto geológico natural poderia ser resolvida depositando-se as lajes resgatadas próximo do geossítio, no Museu da Memória Regional. O geossítio é aqui indicado como um novo holostratótipo para a Formação Rio Paraná.

Palavras-chave: Arenitos eólicos; Pegadas; Caiuá

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1 Introduction

The Porto Primavera ichnofossil geosite contains aeolian sandstones that include tetrapod ichnofossils (Figure 1), which outcrop downstream of the concrete structure of the Porto Primavera Hydroelectric Plant (Figures 2, 3 and 4). The footprints were reported by Fernandes et al. (2003) and described by Fernandes et al. (2009). The main objectives of this communication are to characterize the site as a relevant geological heritage, present results of the assessment of its vulnerability and risk of degradation, as well as discuss geoconservation strategies. The geosite is in the Rosana municipality, in the extreme western part of São Paulo State, Brazil, in the region known as Pontal do Paranapanema. Tracks are found in an area of about 800 m^2 immediately in front of the dam on the left bank of the Paraná River (52°57′28.7″ W, 22°28′57.3″ S). The geosite was registered by the Brazilian Commission of Geological and Paleobiological Sites (SIGEP) (Winge et al. 2009).

The ichnofossils are important for two main reasons: 1) the tracks were made on foresets of aeolian dunes, in the inner of a desert, meaning that the animals inhabiting the area were specially adapted to survive in that environment, where large animals might find survival difficult; and 2) the tracks were preserved in dry and unstable sandy material on the dune foresets, that does not favour fossilization since the absence of water decreases the cohesion between the grains, making the deposit liable to collapse when trampled (*e.g.* Loope 2006).

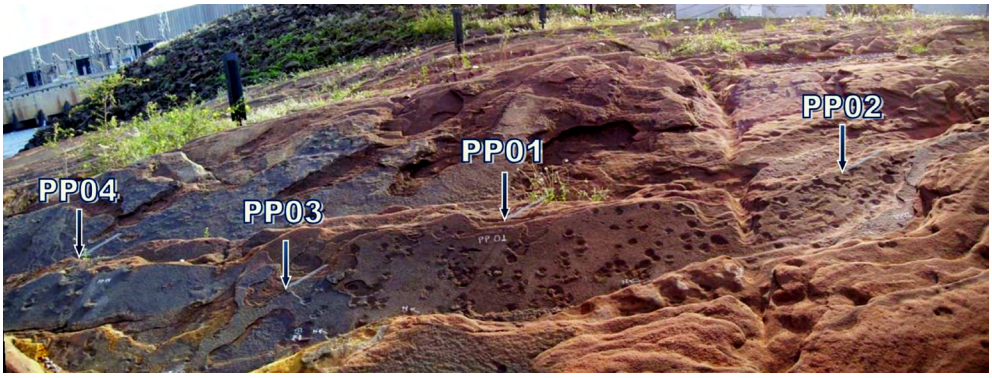

Figure 1 General view of the ichnofossil geosite on the left bank of the Paraná River downstream of the Porto Primavera Hydroelectric Plant, in Rosana municipality in São Paulo State. Tracks of theropod dinosaurs and small quadruped mammals, concave epireliefs in sandstones (PP01–PP04). Typical displacement rims, produced by displacement by animals in inclined sandy substrates of wind dune foresets.

Figure 2 Geosite location in the Bauru Basin.

Figure 3 Geosite location on the left bank of the Paraná River (yellow arrow and circle) downstream of the concrete structure of the Porto Primavera Hydroelectric Plant, 52º57'28.7" W, 22º28'57.3" S. Images from Google Earth, accessed on 14/09/2020.

Figure 4 The geosite: aeolian sandstones outcrop of the Rio Paraná Formation where the tracks occur is on the right. The concrete structure of the dam of the Porto Primavera Hydroelectric Plant is in the background.

We present the results of studies of the conservation of the Porto Primavera ichnofossil geosite performed by the Geoconservation and Geological Heritage Research Group at the Universidade Federal do Paraná (UFPR) and by engineers at the Companhia Energética de São Paulo (CESP; São Paulo Energy Company), geologists at the Agência Nacional de Mineração (ANM, National Mining Agency, former DNPM/SP), and Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT; Technological Research Institute of São Paulo State). A brief history of research at the geosite is presented in Table 1.

2 Geological Context and Characterization of the Geosite

The aeolian sandstones of the Rio Paraná Formation accumulated in the Bauru Basin as extensive deposits of compound dunes (*draas*) in a large (~100,000 km^2) inland desert called Caiuá in a predominantly hot and dry climate. The basin developed during the Upper Cretaceous in the south–central part of the South American Platform after the Gondwana rupture and the formation of the Atlantic Ocean (Fernandes & Coimbra 1996; Fernandes & Magalhães-Ribeiro 2015). The basin was filled by a mainly sandy siliciclastic supersequence with a maximum thickness of 500 m composed of the penecontemporaneous Caiuá and Bauru groups. A geological map of the Bauru Basin is shown in Figure 5.

The Rio Paraná Formation in which the ichnofossils occur is part of the inner old desert area and is composed of medium to fine quartzarenites that are well sorted and textural and mineralogically mature with typical large tabular/trough cross-bedding, of sets up to 15 m high. They correspond to deposits of large barchanoid compound dunes that accumulated due to winds from the southwest (Figures 6, 7 and 8).

Table 1 Main research activities at the Porto Primavera ichnofossil geosite.

2003 (February)	**Invitation from IPT researchers, studies started; first communication on the ichnofossils at the 18th Brazilian Congress of Paleontology (July 2003).**
2004 (10 March)	First field survey of the geosite by researchers from UFPR and IPT.
2009	Publication in the national registry SIGEP, vol. II, ch. 13 (Fernandes et al. 2009).
2012 (7 November)	Technical visit to delimit the geosite and removal trials by personnel from the DNPM, CESP, and UFPR.
2014 (12 August)	Visit to the geosite. Geosite classed as representative of the "Bauru Basin" framework by a team from the Inventory of Geological Heritage of São Paulo State, that was included (Garcia et al. 2017).
2015	Delivery of the final report on the Inventory of Geological Heritage of São Paulo State (Garcia et al. 2017; Report CAPES/Sciences without frontiers, Brazil).
2017	Publication of the results of the Inventory of Geological Heritage of São Paulo State in the *Revista Pesquisa FAPESP* journal (Fioravanti 2017).
2018 (11 December)	Privatization of the Porto Primavera Hydroelectric Plant*. Uncertainty over whether the previous CESP plans would be maintained.
2021	Contacts with Votorantim Group restarted by researchers from UFPR and IPT.

* Since December 2018, CESP has been controlled by a joint venture between the Votorantim Group and the Canada Pension Plan Investment Board.

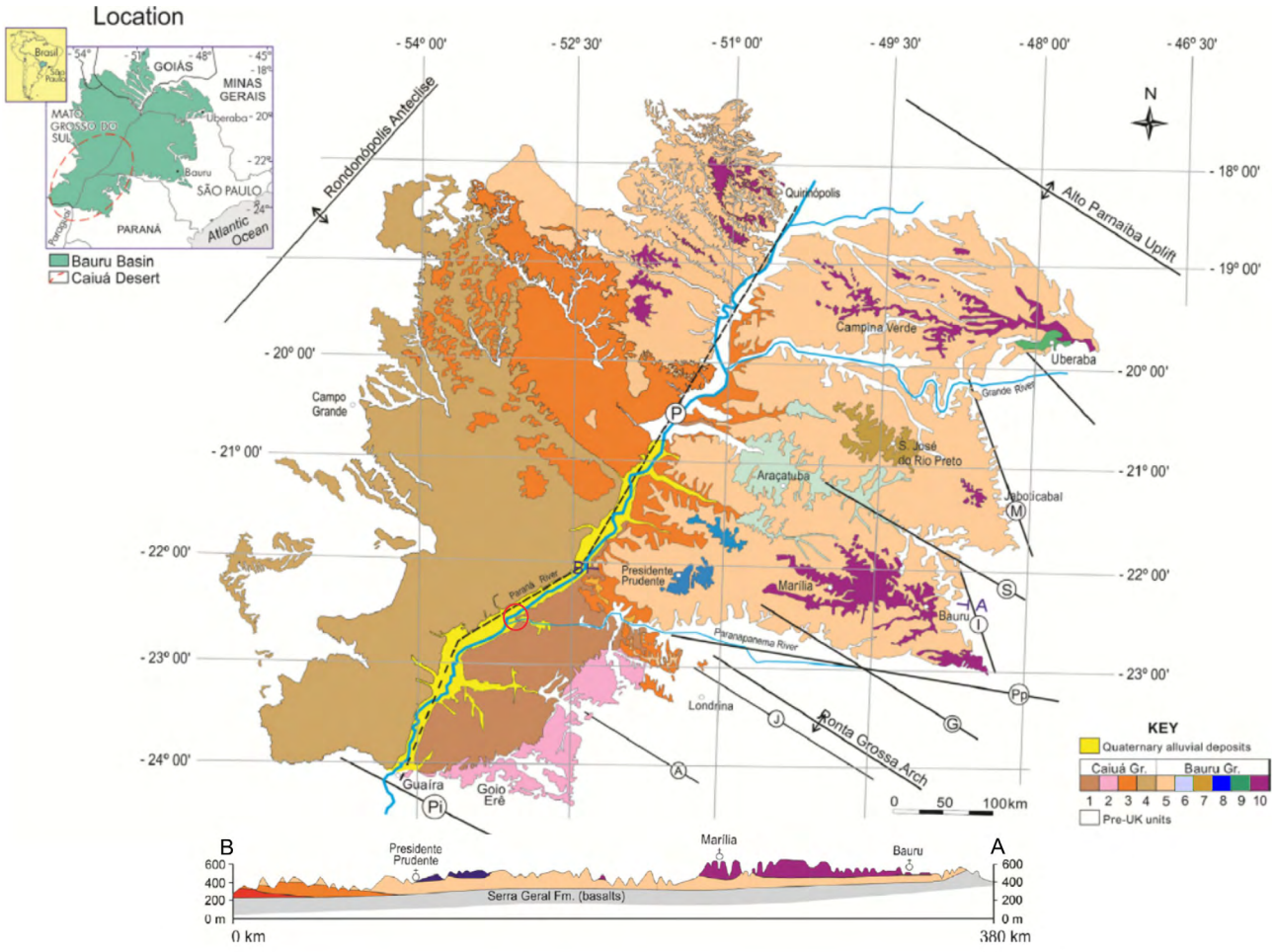

Figure 5 Geological map of the Bauru Basin. Lithostratigraphy: 1. Rio Paraná Formation. 2. Goio Erê Formation. 3. Santo Anastácio Formation. 4. Undivided Caiuá Group. 5. Vale do Rio do Peixe Formation. 6. Araçatuba Formation. 7. São José do Rio Preto Formation. 8. Presidente Prudente Formation. 9. Uberaba Formation. 10. Marília Formation. Structural alignments: Piquirí River (Pi), Alonzo River (A), São Jerônimo-Curiúva (J), Guapiara (G), Paranapanema (Pp), Ibitinga-Botucatu (I), Moji Guaçú River (M), São Carlos-Leme (S), Paraná River (P). Red circle: geosite location. Modified from Fernandes and Magalhães-Ribeiro (2015).

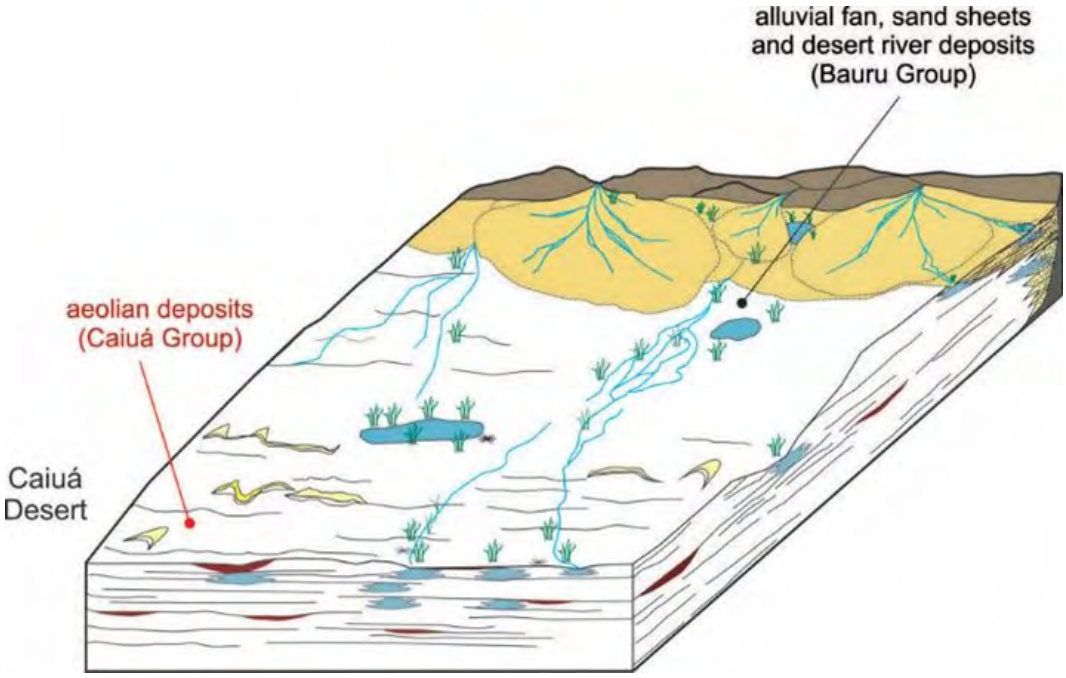

Figure 6 The Bauru Basin depositional environments.

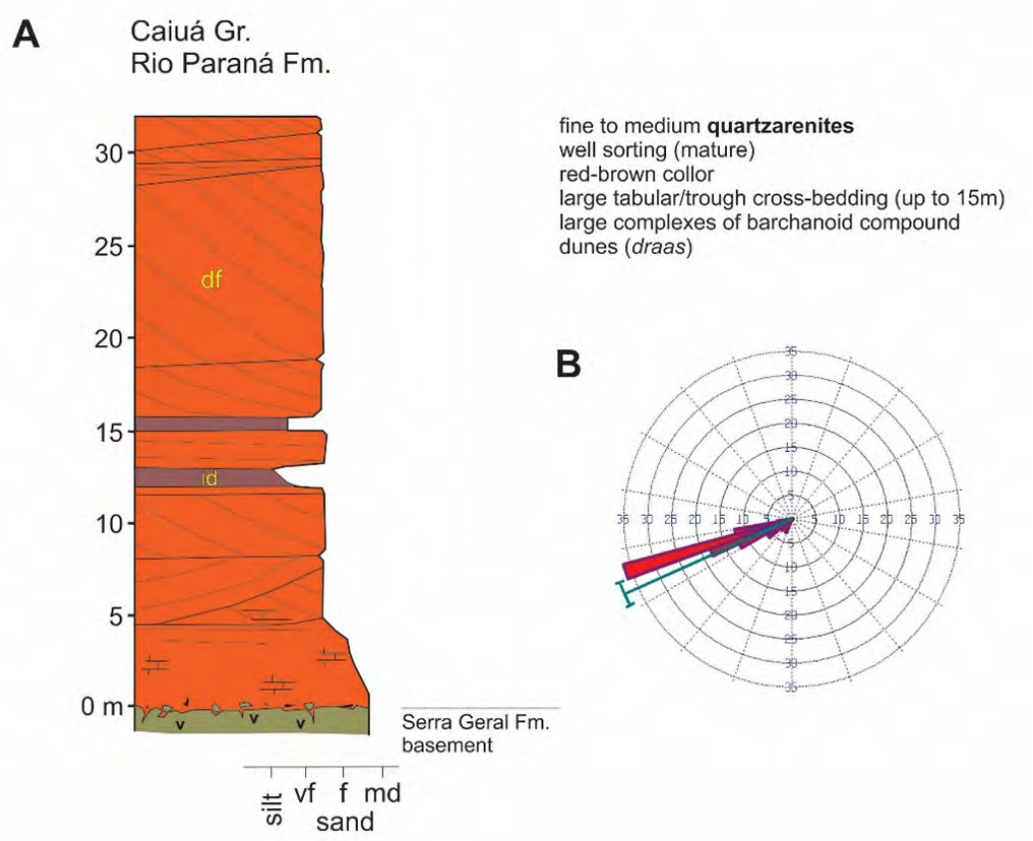

Figure 7 A. Rio Paraná Formation type-section, corresponding to aeolian facies association of foreset dune (df) and interdune deposits (id). Location: Porto Primavera Hydroelectric Plant, Pontal do Paranapanema region (São Paulo State); B. Predominant paleo-wind-direction, based on cross bedding diagram, n = 33.

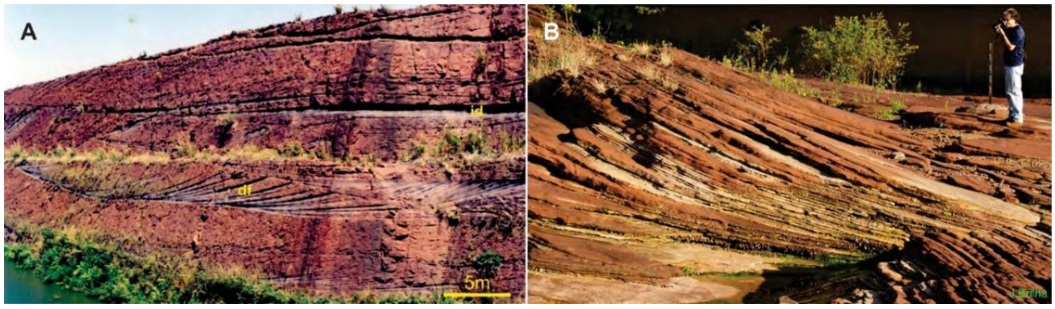

Figure 8 A. Rio Paraná Formation: brown purplish to reddish quartzarenites with large cross-bedding of foreset dune (df) and minor dry interdune deposits (id); B. Dune foreset deposits showing typical large cross-bedding. Photo B by J. Brilha (2016).

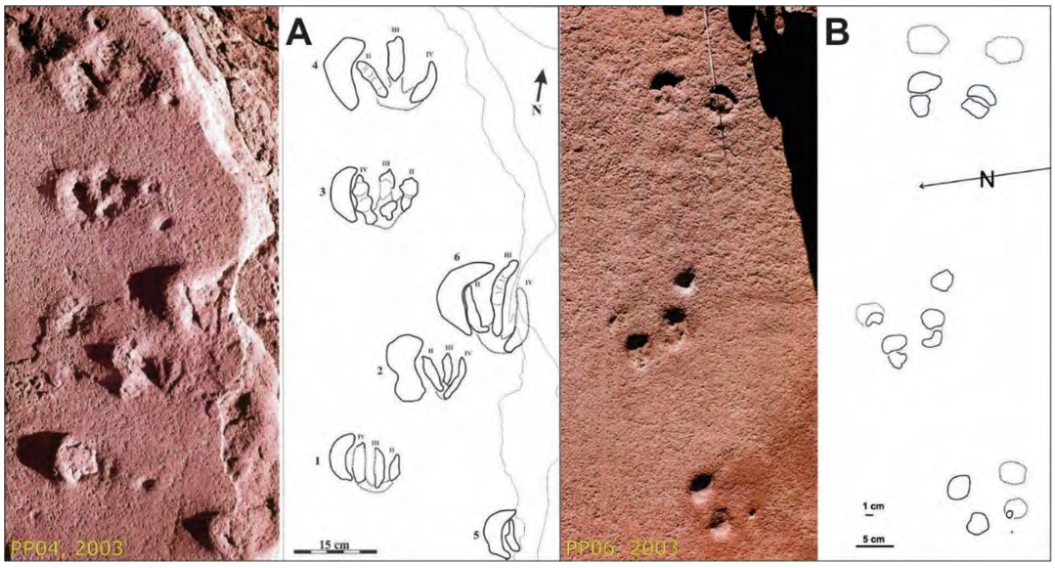

Figure 9 The Porto Primavera site contains tracks preserved as concave epireliefs in sandstones, exhibiting typical displacement rims: A. Theropod dinosaurs; B. Small mammals.

3 Characterization of the Ichnofossils

The Porto Primavera ichnofossils was described by Fernandes et al. (2003, 2009) as 11 sets, numbered as PP01 to PP11 (PP = Porto Primavera). All of them were found in situ in a sandstone 6–8 m above the basaltic basement at the base of the Upper Cretaceous Bauru supersequence. The ichnofossiliferous association consists of tetrapod tracks preserved in concave epirelief and invertebrate burrows as full relief (Figure 9).

Ichnofossils are not contemporary, but they must have been formed in a relatively short period of time, or at least without large gaps between them, since they occur on 7 dune foresets of the same sandstone layers with planar cross bedding. PP01 to PP04 sets occur on the same surface. Most of the tracks show crescent-shaped rims of sand displacement produced when the trackmaker stepped on an inclined sandy substrate. The overall shape of the tracks is poorly defined, as is common in tracks produced on dunes, and some occur only as rounded prints. According to Fernandes et al. (2009), the ichnofossils can be grouped into five types:

Small theropod dinosaurs – present in sets PP01, PP02 and PP03, these tracks have typical theropod characters (*e.g.*, Lockley 1991). They are tridactyl, digitigrade and mesaxonic tracks, with digits ending in sharp ends (suggesting claws), measuring between 4.5 cm in average length and 4 cm in average width. The divarication angles between digits II-IV is 70º to 80º. The surface is considerably trampled, and it is difficult to recognize trackway patterns.

Medium-sized theropod dinosaurs – present in sets PP04 and PP07, consist of tridactyl, digitigrade and mesaxonic tracks measuring on average 12 cm long by 12 cm wide, forming bipedal and irregular trackways with pace angulation of ~180° and pace length of 21 to 35 cm. The average divarication angles between digits II-IV is

50º, and the central digit is the longest. Digit ends and hypices are acute and some phalangeal pad impressions also occur. Theropoda tracks are often the most common and abundant in Mesozoic desert environments (*e.g.*, Leonardi 1991; Lockley & Conrad 1991; Carvalho & Kattah 1998).

Hopping mammals – present in the PP06 set, corresponds to a quadrupedal trackway with a ricochet gait (*sensu* Leonardi 1987), with 3 sets comprising four tracks each. The tracks do not have morphological details and are rounded to oval, with about 3 to 5 cm in length, but the posterior tracks of each set are larger and more elongated, suggesting that the hands are anterior to the feet, without overlap between them. These tracks are like *Ameghinicnus patagonicus* from Upper Jurassic of Argentina (Casamiquela 1964) and variations of *Brasilichnium elusivum* from Upper Cretaceous Botucatu Formation (*e.g.*, Fernandes 2005), both with ricochet gait and considered typical of small mammals capable of locomotion by hopping, which allows us to assign the PP06 tracks to mammals.

Possible ornithopods – present in PP08 and PP10 sets, correspond to larger tracks with a circular shape measuring 24 cm in diameter, without any morphological characteristics of the autopodia of the trackmaker. These tracks could be related to Sauropoda due to the rounded shape, but the occurrence of sauropod dinosaurs in aeolian environments would be unlikely due to the scarcity of food sources in enough quantity for large animals (*e.g.*, Fernandes 2005) and the rarity of Sauropoda tracks in deposits of dunes. On the other hand, tracks of Ornithopoda dinosaurs occur in the Botucatu Formation in similar facies (Fernandes & Carvalho 2007), with a rounded shape and diameters of up to 34 cm. Thus, these tracks could be tentatively attributed to the herbivorous Ornithopoda dinosaurs.

Taenidium isp. – the invertebrate ichnofossils, present in the PP05 and PP09 sets, correspond to horizontal endostratal meniscated burrows, with the same filling as the rock, without lining, identified as *Taenidium* isp., an ichnogenus frequently attributed to small arthropods and common in Mesozoic aeolian deposits (Fernandes et al. 1990).

In general, the ichnofossils are similar to the paleoichnofauna of the Botucatu Formation (Lower Cretaceous, Paraná Basin) found in the municipality of Araraquara (*e.g.* Leonardi 1994; Fernandes et al. 1990; Fernandes & Carvalho 2007, 2008; Leonardi et al. 2007; Francischini et al. 2015, 2020), in particular in the preservation without major details, since they represent similar facies, in the presence of mammals with a ricochet gait, in the absence of very large animals and in the predominance of carnivorous dinosaurs in relation to herbivores. Tetrapod tracks from Porto Primavera do not present sufficient characteristics for the determination of ichnotaxons.

The ichnofossils are a rare record of tetrapods in Caiuá Group sandstones and indicate that the study area had a greater faunal diversity than was previously thought, thus adding to our knowledge of the poorly understood ichnofauna of desert environments during the Upper Cretaceous in Brazil (Fernandes et al. 2009). The Porto Primavera ichnofossils and recent discoveries of pterosaurs, lizards, and a small dinosaur (Manzig et al. 2014; Simões et al. 2015; Kellner et al. 2019; Langer et al. 2019) at Cruzeiro do Oeste (Paraná State) suggest that even the most central parts of the ancient Caiuá desert were eventually occupied by animals. The paleofauna from Cruzeiro do Oeste (Manzig et al. 2014; Simões et al. 2015; Kellner et al. 2019; Langer et al. 2019) indicates a more humid paleoenvironmental context on the periphery of the driest desert area. In lithostratigraphic terms, the Cruzeiro do Oeste occurrences are in the transition between the Rio Paraná and Goio Erê formations. The Cruzeiro do Oeste area corresponds to deposits related to wind dunes and humid interdunes and lakes that eventually formed in the area during the rainiest periods (*e.g.*, Fernandes & Coimbra 1996), despite the general desert context.

4 Materials and Methods

The studies carried out aimed to characterize and evaluate the geosite, using the GEOSSIT application, as well as to assess the vulnerability to natural and anthropogenic degradation processes. The analysis indicated management measures for the conservation of the geosite, with recovery of the slabs with tracks, and potential scientific, educational and tourist uses.

The GEOSSIT application (CPRM 2020) has been designed to compile an inventory of geosites and to evaluate geosites qualitatively and quantitatively at the national scale. GEOSSIT uses methods published by Brilha (2005) and García-Cortés and Carcavilla-Urqui (2009), and was later adapted, as described by Brilha (2016), to assess sites quantitatively and to produce tables indicating the scientific value, potential educational and tourist uses, and risks of degradation of sites of interest.

The *scientific value (SV)* of the geosite is calculated based on the seven criteria: representativeness (30%), rarity, integrity (15%), if it was type-locality or type-species (20%), degree of knowledge (5%), geological diversity (5%), and limitations of use (10). *Representativeness* reflects how adequately the geosite represents geological elements or processes of its geological category. *Rarity* reflects its importance given the scarcity of similar geological elements or processes at the state scale. *Integrity* reflects the extent

to which its features of geological interest are preserved. *Type-locality* or *type-species* criterion refers to its being the geographic locality where a given geological unit, fossil content or mineral species was first described. *Degree of knowledge* refers to its scientific interest as measured by the number of geoscientific publications about it, or its estimated potential for future research. *Geological diversity* refers to the number of different types of geological interest (tectonic, paleontological, mineralogical etc).

The *vulnerability* or *risk of degradation* is calculated based on the criteria: 1) deterioration of geological elements (35%), 2) proximity to areas/activities with the potential to cause degradation (20%), 3) existence or not of legal protection (20%), 4) accessibility (15%) and 5) population density (10%).

The *risk of degradation* was assessed according to criteria defined by García-Cortés et al. (2019), which are summarized below. *Fragility* is the property of a geosite that makes it alterable due to its intrinsic characteristics, such as its lithological type, degree of tectonization or weathering, that is, its quality of being easily broken or damaged. *Natural vulnerability* is the criterion that assesses the possibility of alteration of a geosite due to real or potential natural processes (threats). *Anthropogenic vulnerability* is the criterion that assesses the possibility of geosite modifications due to actions (or threats) of human activities (territorial occupation, mining, susceptibility to vandalism. *Degradation susceptibility* refers to the ease of the geosite to degrade due to its fragility, size, and vulnerability (natural and/or anthropic).

Risk of degradation is the estimated value that combines the geosite's susceptibility to degradation with its scientific, educational and tourist value. It assesses the potential harm or damage against the magnitude of site degradation. As with the susceptibility to degradation, the risk of degradation will be greater the greater the value of the geosite. In practice, the risk of degradation also indicates the priority that should be given to the geosite for conservation.

Potential Educational (EV) and *Tourist/recreational (TV) use values* are calculated by assigning appropriate parameters for each of the two uses, based on the criteria: 1) vulnerability (10%), 2) accessibility (10%), 3) limitations of use (5%), 4) safety (10%), 5) logistics (5%), 6) population density (5%), 7) association with other values (cultural, historical etc.; 5%), 8) scenic beauty (EV: 5% or TV: 15%), 9) uniqueness (EV: 5% or TV: 10%), 10) observation conditions (EV: 10% or TV: 5%), 11) educational potential (EV: 20% or TV: 0%), 12) geological diversity (EV: 10% or TV: 0%), 13) potential for dissemination (EV:0% or TV: 10%), 14) economic level (EV: 0% or TV: 10%), and 15) proximity to recreational areas (EV:0% or TV: 5%).

The GEOSSIT application classifies the geosites by what it names *global interest*, by the simple arithmetic mean between scientific, educational, and tourist/recreational values [GI = (SV+EV+TV)/3].

5 Results and Discussion

The GEOSSIT app classifies the Porto Primavera ichnofossil geosite as National Relevance, giving it Scientific values of 295, Educational of 335, Touristic of 305; with Risk of Degradation of 260 (Medium) (Figure 10).

However, the assessment of medium risk of degradation or vulnerability (VU) is because the geosite is within an area managed by the hydroelectric plant. This makes

Figure 10 The Porto Primavera ichnofossil geosite classification, as National Relevance, by the GEOSSIT app. Source: CPRM (2021).

the criteria of proximity to activities with the potential to cause degradation (20%), legal protection (20%), accessibility (15%) and population density (10%), whose weights add up to 65% of the final VU, do not express, in calculated value, the seriousness of the situation. The criterion "deterioration of geological elements", used in the calculation, corresponds to 35% of the final vulnerability value. But the low cementation of sandstone makes the effective very high risk.

For this publication, the reassessment of data obtained in a field campaign coordinated by ANM/SP, carried out between November 6 and 8, 2012, geologists and engineers from UFPR, IPT and CESP concluded that it was necessary to remove, as soon as possible, four slabs with footprints, considering the indicators listed in Table 2. The reassessment used criteria from García-Cortés et al. (2019), which more faithfully portray reality.

In fact, the vulnerability of the geosite at Porto Primavera was found is very high. Sandstone rapidly changes, in about ten years. The rock becomes broken, displaced on slabs, and slowly disintegrates, when it is alternately water saturated and dried. The geosite is affected by rainfall and changes in river level due to the operation of the dam. The geosite can also be subject to wear through people walking on the slabs and ichnofossils. The first idea of protecting the geosite with a wall and/or glass was abandoned because the barrier(s) would not prevent water covering the rocks and more rapidly erode them.

The ichnofossils are within the area managed by the hydroelectric plant, which means that access and visit frequency can readily be controlled.

CESP expressed great interest in protecting the ichnofossils and in adapting the area by making minor changes to control visitor numbers. UFPR researchers proposed to cooperate to create and install panels, to produce divulgative leaflets, to build a protective fence to prevent people walking on the areas containing the tracks, and even to build a wall to prevent waves washing over them.

Prior to the technical visit of 6–8 November 2012, the consensus was that the ichnofossils should not be removed (Figure 11).

Table 2 Indicators that geoconservation measures were required at the geosite.

Criterion*		Intensity	Reasons	Observations
Fragility		Very high	Sandstones are easily disaggregated by weathering and the mechanical action of waves and flowing water.	Intrinsic, lithological characteristics: porous and slightly cemented quartz sandstones.
Vulnerability	Natural	Very high	Weathering caused by rainfall and temperature variations.	Fast erosion and modification of the shape of the footprints, noted in about 9 years (March 2003-November 2012)
	Anthropogenic	Very high	Variations in the river level caused by the hydroelectric plant operation; and walking on slabs containing ichnofossils.	Saturation and drying cycles promote rapid rock alteration, depletion and disintegration.
Susceptibility to degradation		Very high	Very high lithological fragility due to weathering; and very high vulnerability.	
Risk of degradation		Very high	Very high scientific and educational values; and very high susceptibility to degradation.	

* The criteria used were defined by García-Cortés et al. (2019).

Figure 11 A. In situ studies performed in March 2004, when minimal intervention was selected. It was considered then that there were no major risks to the integrity of the geosite; B-C. Manufacture of silicone rubber moulds to ensure that information of great paleontological interest was recorded and secured.

However, rapid degradation of the sandstone and tracks (Figures 12 and 13) led to the recommendation that the material should be removed and deposited in a suitable scientific collection. It was suggested that the removed slabs should be replaced with synthetic resin replicas made from silicone rubber moulds. Visitors would continue to be allowed to access the geosite accompanied by tourist guides trained in paleontology/geology. School groups and researchers would also be allowed access. Sampling and mould-making would be permitted only under the authorization of competent scientific bodies or institutions.

5.1 Suggestions for Geoconservation

Tests using a circular saw (Figure 14) were not approved, mainly due to the fragility of the sandstone, because it would not be possible to remove slabs of any reasonable size without breaking them. Two techniques were suggested for removing the material, cutting with a jet of water or cutting with diamond wire. Techniques that introduced stress could cause the sandstone to disintegrate due to its fragility. Use of diamond wire appeared to be more appropriate than the use of water jets for making both vertical and horizontal cuts (Figure 15). The procedure would be monitored by researchers, engineers, and geologists from CESP and IPT under the supervision of ANM. The sandstone beds have different degrees of cohesion, meaning that there could be a more or less friable layer immediately below any particular stratum. Resistance to uniaxial compression in the sandstone was found to vary between 30 and 300 MPa, which needed to be considered when selecting the procedure because it would determine the equipment to be used. A water jet would only be suitable if the equipment produced a fine enough jet, because of potential problems relating to contact between the strata, natural discontinuities, or variations in cementation grade and porosity/permeability between strata of the sandstone. Hydraulic fracturing and uncontrolled cutting would occur if the water pressure were distributed radially. Diamond wire cutting would be less risky than cutting with a water jet because the effects was concentrated in the vicinity of the cut and only hydrostatic pressure would be applied to the sandstone. When making a horizontal cut using a diamond wire, the mechanical action (lever) involved in moving and lifting a slab would be likely to damage the slab. It was proposed that the sandstone would be impregnated with Paraloid B-72 resin to make the slabs sufficiently tough to be removed without damaging the tracks. Paraloid B-72 resin is soluble in pure dry acetone and becomes fully transparent when set. A well-diluted solution of Paraloid B-72 resin was found to readily infiltrate the material. A plaster bandage around a cut slab was proposed to increase the resistance

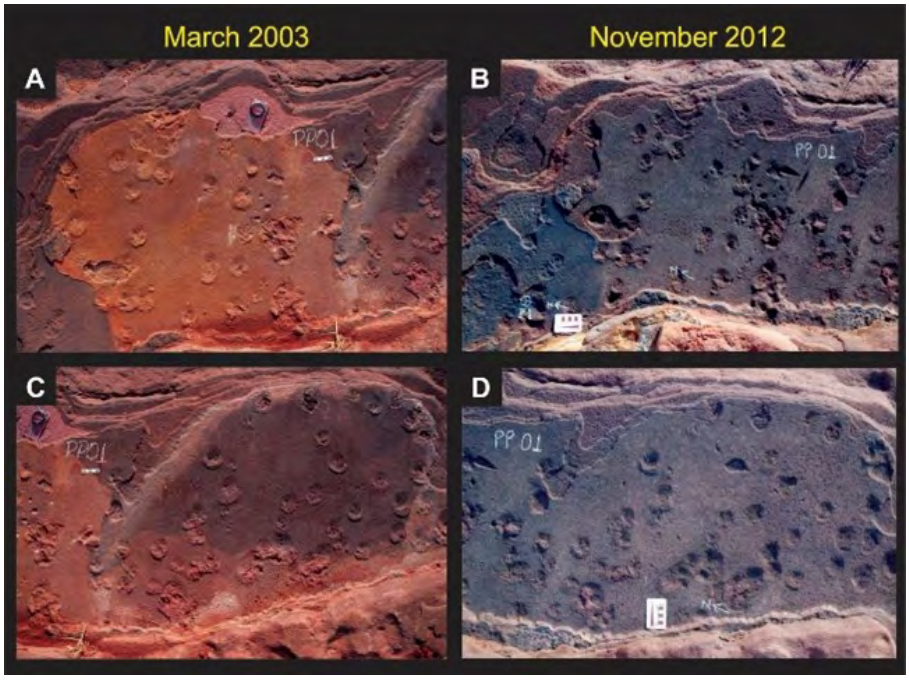

Figure 12 Ichnofossil sets PP01, tracks of small Theropoda dinosaurs in sandstone cross-bedding plans from ancient deposits of dune foresets in the Caiuá Desert. Note the effects of weathering and river and rainfall erosion in about 9 years: A-C. March 2003; B-D. November 2012.

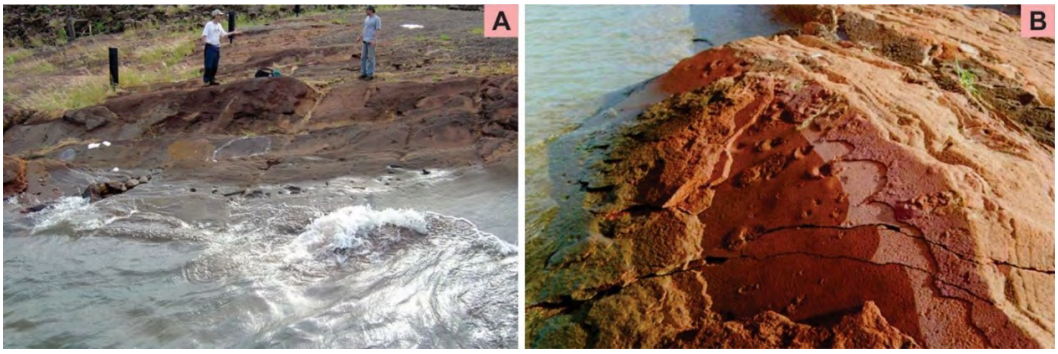

Figure 13 A-B. Very high fragility and natural vulnerability (causing very high risk of degradation) of the geosite.

Figure 14 A-B. Testing sandstone cutting methods using a circular saw to remove slabs by researchers and CESP engineers and technicians on 6–8 November 2012.

Figure 15 A-B. Proposed method for cutting the rock using a diamond wire machine with a rotating head; C. An example of the cut rock.

of the slab, to allow it to be removed, perhaps using a crane transported by river. The researchers recommended that the objects be deposited at CESP's Regional Memory Museum (Figure 16), located close to the geosite, to preserve the greatest possible physical connection between the removed slabs and their original geological context.

It is interesting to note that erosion of the site is not necessarily a bad thing because it could reveal new ichnofossils currently contained within the rocks. It is therefore important to monitor the site each year, particularly at the height of the dry season, to look for new ichnofossils. Sporadic cleaning of the site, with removal of material generated by any alterations, is an important conservation measure because it prevents accumulation of soil on the outcrop.

It was suggested that digital 3D models of the slabs should be made using photogrammetry in the field (i.e., before the slabs were removed). It is easy and cheap to make such models, and the models would allow good quality information to be retained. Digital 3D models could also be acquired during annual monitoring to compare and qualify erosion and damage to the exposed surfaces.

Figure 16 The CESP Regional Memory Museum that was proposed to receive the removed sandstone slabs for custody and exhibition. Views of the museum where the slabs will be conserved and made available for viewing: A-B. Entrance; C. Interior.

5.2 Type-section Update and Geoheritage

Fernandes and Coimbra (1994, 2000) defined sections of the sluice gate of the Porto Primavera Hydroelectric Plant, in Pontal do Paranapanema region, as a type-section (holostratotype) of the Rio Paraná Formation. The authors pointed out other good displays of the unit: a cut from the rod. BR 376, located at km 501, near Paranavaí City, Paraná State (parastratotype); and walls up to 15 m high, on the left bank of the Paraná River, in the vicinity of Porto São José and Porto Rico cities (Paraná State), and Presidente Epitácio City (São Paulo State), indicated as hypostratotypes.

Currently, the sections of the sluice gate are covered and inaccessible to visitors. The geosite area is indicated as a new holostratotype, substitute, to the Rio Paraná Formation, due to its geological similarity and proximity to the originally defined location. In this replacement, conservation safety is maintained, as it is located within the area of the hydroelectric power plant.

The management plan for the geosite of the tracks and stratigraphic reference of national interest will deal with the conservation of scientific heritage, as well as the regional educational and tourist use.

6 Conclusions

Ichnofossils from Caiuá sandstones are rare and highly precious records from a scientific point of view. For this reason, including, the geosite at Porto Primavera was added to the Brazilian SIGEP, register as number 13. It lies within the property of the hydroelectric plant, which allows access and visitor frequency to be controlled.

In addition to the scientific value, the educational and tourist values must also be considered. The hydroelectric plant receives visits from school students, mainly, and tourists. There is a potential to increase these types of geosite uses, with the enrichment of the visitors' experience, by aggregating geoscientific content and concepts of a conservationist nature.

The *risk of degradation* of the geosite is very high. UFPR researchers and IPT, CESP, and ANM representatives concluded that at least four threatened and/or representative slabs containing ichnofossils should be removed and exhibited at the CESP Regional Memory Museum. As an urgent geoconservation measure. It was proposed that these slabs should be replaced with synthetic replicas made using silicone rubber moulds prior to their removal.

The geosite was accurately delimited by the CESP topography service. When work by the UFPR/CNPq research group on *Geoconservation and Geoheritage* and CESP, IPT, and ANM resumes, the work will involve defining a salvage plan for the slabs, depositing them in the museum, and obtaining funding for the work. A plan for managing and conserving the area also needs to be developed further.

CESP has always intended to protect the geosite and promote it as being of interest to scientists and educationalists. The area could, for example, be modified slightly to allow controlled visits. Visitors to the geosite would need to be accompanied by personnel trained in paleontology and geology, schoolteachers, or researchers. Sample collection or mould-making may be authorized by competent scientific committees or institutions created for managing the geosite. The UFPR/CNPq research group on Geoconservation and Geoheritage can provide scientific support for creating and installing panels, text, flyers, videos, and other products for disseminating scientific information in collaboration with the institutions involved. Informal consultations with the personnel of the current manager of the hydroelectric plant indicated that it is possible to maintain those intentions of CESP. However, discussions were not resumed after the privatization of the company.

In 2012, it was proposed that the geosite should be nominated a Geological Monument of São Paulo State. The nomination, however, would only be a scientific title

because it would not imply that the area formed part of the National System of Conservation Units or make the geosite an asset of the *Conselho de Defesa do Patrimônio Histórico, Arqueológico, Artístico e Turístico do Estado de São Paulo* (Council for the Protection of Historical, Archaeological, Artistic, and Tourist Heritage of São Paulo State).

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Luiz Alberto Fernandes: conceptualization; formal analysis; methodology; validation; writing - original draft; writing review and editing; visualization. **Fernando Antonio Sedor:** formal analysis; methodology; validation; writing review and editing. **Rafael Costa da Silva:** conceptualization; formal analysis; methodology; validation; writing - original draft; writing review and editing. **Adalberto Aurélio Azevedo:** methodology; validation. **Luiz Roberto da Silva:** methodology; validation. **Ana Lúcia Gesicki:** validation. **Irma Tie Yamamoto:** validation.**Wilson Shoji Iyomasa:** methodology; validation.

Conflict of interest

The authors declare no potential conflict of interest.

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All data included in this study are publicly available in the literature.

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