



# SIGEP

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## Ichnofossils of the Porto Primavera Power Plant, State of São Paulo

*Dinosaur and mammal footprints in rocks from the Caiuá  
neocretaceous desert*

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# **Ichnofossils of the Porto Primavera Power Plant, State of São Paulo**

## *Dinosaur and mammal footprints in rocks from the Caiuá neocretaceous desert*

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The site exhibits records of tetrapodes ichnofossils in sandstones of the Rio Parana Formation (Caiuá Group), Pontal do Paranapanema region, far west of São Paulo state in front of the concrete structure of Porto Primavera hydroelectric plant. The ichnofossils occur in reddish-brown foreset strata of cross-stratified medium to large size aeolian dune deposits, 6 to 8 meters above the basalt contact, on the base of the Upper Cretaceous Sequence. They are preserved in sandstone as concave epirelief that display typical crescent moon shape produced by the displacement of the animal in sandy and tilted substrate. The association is composed of faunistic footprints of tetrapod dinosaurs and small mammals. The tracks are dinosaurs and have biped step angle of around 180° and a half-step with about 13 cm. The footprints are tridactiles, mesaxonics, with claws, and have about 9 cm in length and total divergence of approximately 80°. The mammaloids tracks are possibly quadruped with total primary overlapping and show great variation in the size of the step. The footprints are elliptical and about 5 cm in length. This site constitutes a new record of tetrapods footprints in the Caiuá Group sandstones and enlarges the area of occurrence of this so little known fauna of the Cretaceous Brazilian desert environments indicating that even the most central regions of the Caiuá Desert were occasionally attended by predators or inhabited by animals adapted to aridity.

**Keywords:** Caiuá, ichnofossils, Upper Cretaceous, Bauru, sandstones, Rio Paraná

### **INTRODUCTION**

During the Mesozoic Era, the installation of desert environments occurred several times in the Brazilian territory. Possibly the most conspicuous geological record of this type of depositional system can be observed in the sandstones formed by the wind in extensive fields of sand dunes; examples can be seen in the Botucatu Formation (Guarani aquifer reservoir, Paraná Basin) and the Rio Paraná Formation (Upper Cretaceous, Bauru Basin). Generally, deserts and fields of dunes are not favourable environments for the preservation of organic or skeletal remains; ichnofossils, or records of the activity of organisms living in an environment, are more common and represent a valuable source of information for the palaeontological study of these environments. In such environments, the most frequent ichnites are footprints and tracks produced by vertebrates, as well as invertebrate tracks and galleries.

The only occurrence of fossils found thus far in the Rio Paraná Formation consists of footprints attributed to small mammals and Theropoda dinosaurs. These fossils were registered in the state of Paraná in the so-called "sandstone Caiuá" (Leonardi, 1977). However, the authors of the current study found no material on surveys when searching in the palaeontological collection of the Departamento de Geologia da Universidade Federal do Paraná (Department of Geology of Paraná National University), where this material was deposited. Moreover, according to Leonardi (2005, personal communication), it is impossible to be certain whether the material really comes from the Caiuá or Botucatu units. Thus, these Paraná fossils should be viewed as unconfirmed until additional evidence is found.

New vertebrate ichnofossils (Fig. 1) were previously recorded for certain in the Rio Paraná Formation at the site described (Fernandes et al., 2003), providing data on the palaeofauna of this geologic unit and on the environmental conditions at the beginning of the development of the dune fields

of the Upper Cretaceous Caiuá desert. The ichnological material was studied in situ in March 2004. No samples were collected for preservation of

the site; however, moulds of the most significant material were made of silicone rubber for studies in the laboratory and further construction of replicas.



**Figure 1:** General view of the site of ichnofossil occurrences, left side, downstream of Porto Primavera Hydroelectric Plant.

## LOCATION

The site is located in the municipality of Rosana in the western part of the São Paulo state, in the region known as Pontal do Paranapanema; to be more precise, the site is within the limits of the Porto Primavera Power Plant, immediately downstream from the dam on the left bank of the Paraná River (Fig. 2), with coordinates 52° 57' 28.7" W/22° 28' 57.3" S. The ichnofossils occur in slabs of sandstone over an area of about 1,600 m<sup>2</sup>. The footprints occur in an 800 m<sup>2</sup> area.

## DESCRIPTION OF THE SITE

### Geological setting

The Bauru Basin (Upper Cretaceous) was created on the central-southern South American Platform, after the breaking of Gondwana and the opening of the Atlantic Ocean (Fernandes & Coimbra 1995, 1996). It was formed by subsidence in response to the accumulation of about 2,000 m of basaltic floods (Serra Geral Formation) in the Early Cretaceous.

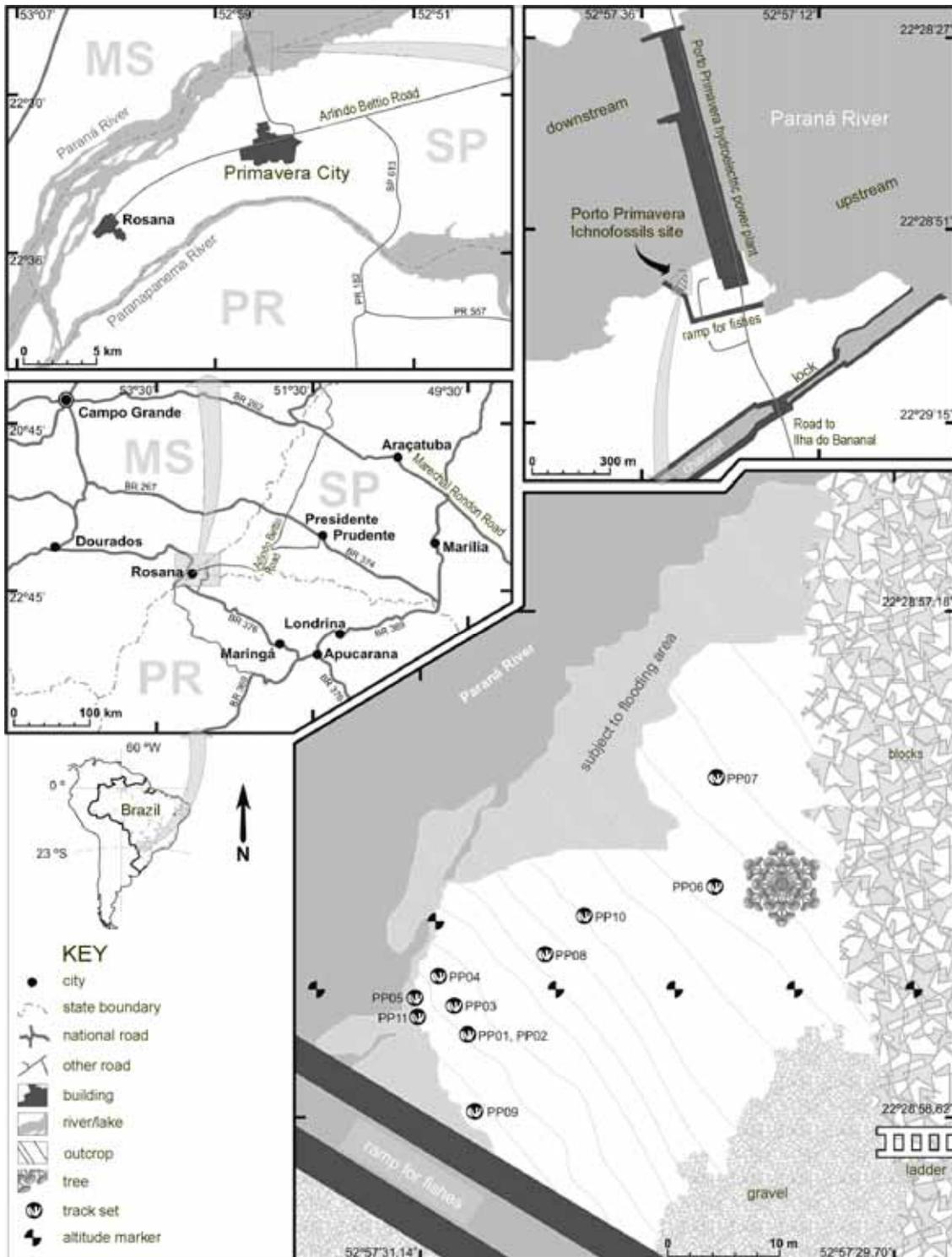
Between the Coniacian and Maastrichtian, the basin was filled by a siliciclastic sandy sequence, which now extends over an area of 370,000 km<sup>2</sup> in the São Paulo, Paraná, Minas Gerais, Mato Grosso do Sul, Goiás and Mato Grosso states alongside northeastern Paraguay (Fig. 2). The sequence has a maximum thickness of about 300 m. In lithostratigraphic terms, the Upper Cretaceous suprabasaltic sequence is formed by two penecontemporaneous groups, the Caiuá and the Bauru. The first comprises the Paraná River, Goio Erê and Santo Anastácio formations. The second consists of the Uberaba, Vale do Rio do Peixe, Aracatuba, São José do Rio Preto, Presidente Prudente and Marília formations, with alkaline volcanic rocks named Taiúva Anacimites interspersed (Fig. 3).

In the southeastern portion of the Bauru Basin, an extensive sandy desert (sand sea) of about 100,000 km<sup>2</sup> called Caiuá (Fernandes & Coimbra 2000, Fernandes 2008, Fig. 4) developed under the predominantly hot and dry climate. This includes accumulated deposits of: a) dry sand sheets, corresponding to the Santo Anastácio Formation; b) midsize sand dunes and humid interdunes in the periphery of the sand sea areas (Goio Erê Formation);

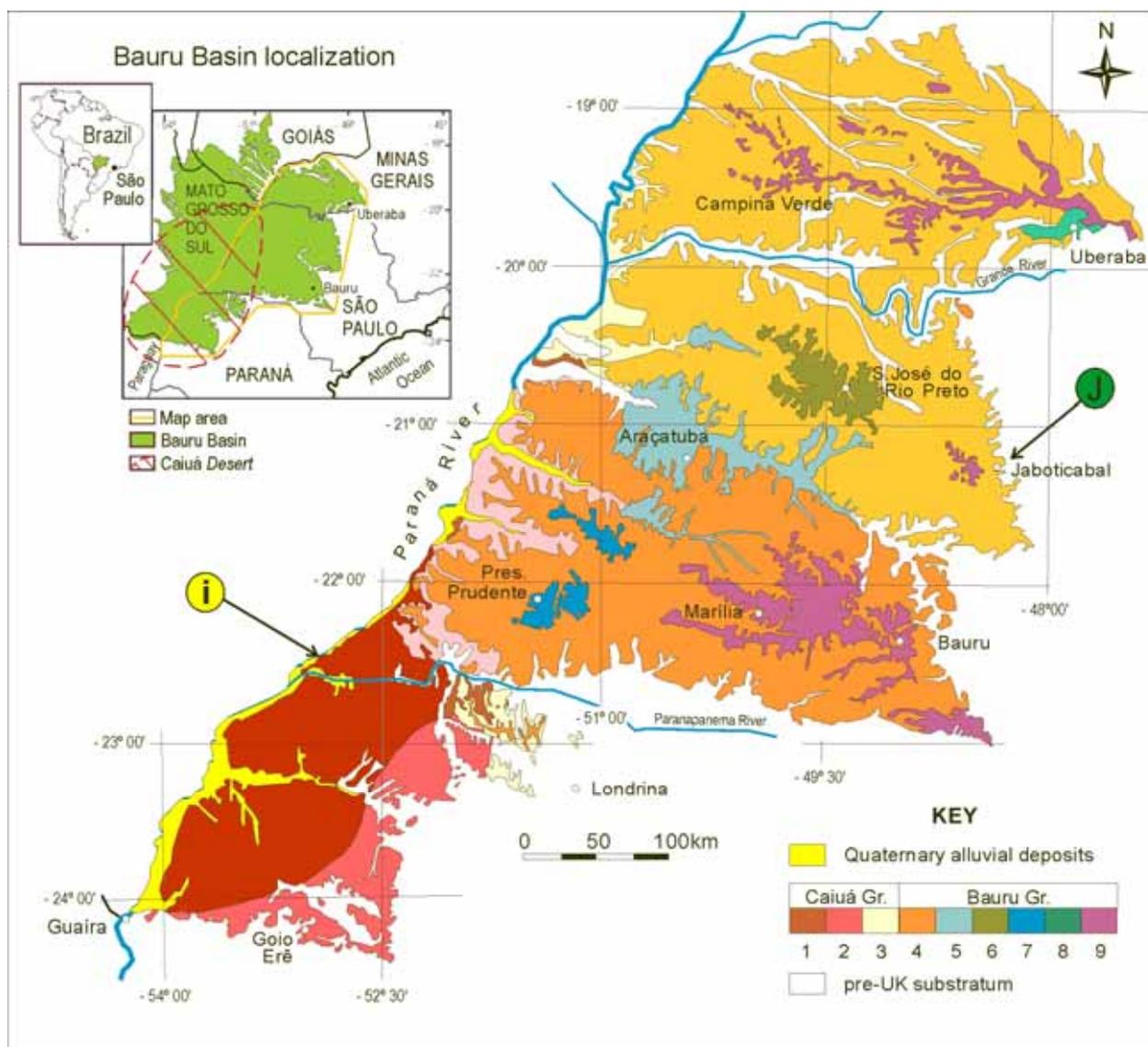
and c) large aeolian dune complexes and draas, corresponding to the central part of the sand sea (Rio Paraná Formation). These formations form the Caiuá Group.

The Rio Paraná Formation is composed of well-sorted fine to medium quartz sandstone reddish-

brown in color, of textural and mineralogical maturity (red beds; Figs. 5, 6b, 6c and 6d). It exhibits typical tabular and trough cross-bedding of great size (sets of up to 15 m high). This corresponds to deposits of large complexes of barcanoid dunes (draas) accumulated by winds to the southwest.



**Figure 2:** Regional and detail location maps, with the position of Porto Primavera ichnofossils.

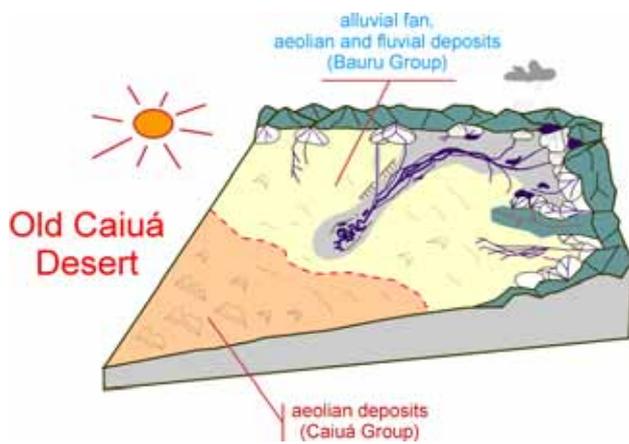


**Figure 3:** Geological map of the Bauru Basin eastern part.

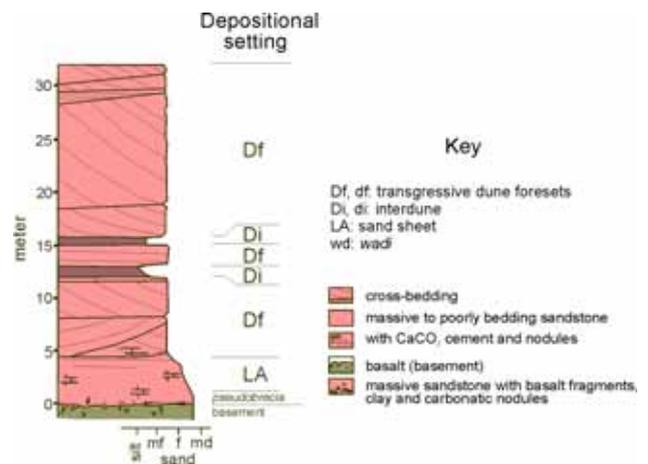
### Palaeoichnology

The ichnofossils occur about 6 to 8 m above the place where basaltic substratum meets sandstone, based on the Upper Cretaceous sequence (Fig. 7). They occur in slabs of sandstone originally deposited as large dune foresets. The ichnofossils were described in a continuous area and grouped in sets numbered PP01 to PP11 (PP = Porto Primavera, Fig. 2). Ichnites produced by invertebrates as well as tetrapod footprints and tracks were recorded. The vertebrate ichnofossils can be grouped into four morphotypes. The first, corresponding to PP01, PP02 and PP03, presents tridactyl, digitigrade and mesaxononic footprints with digits ending in sharp edges, measuring between 3 and 8 cm in length and without a pattern of trackway, though some sequences of footprints are oriented in the same direction, indicating bipedalism. Some of these footprints occur

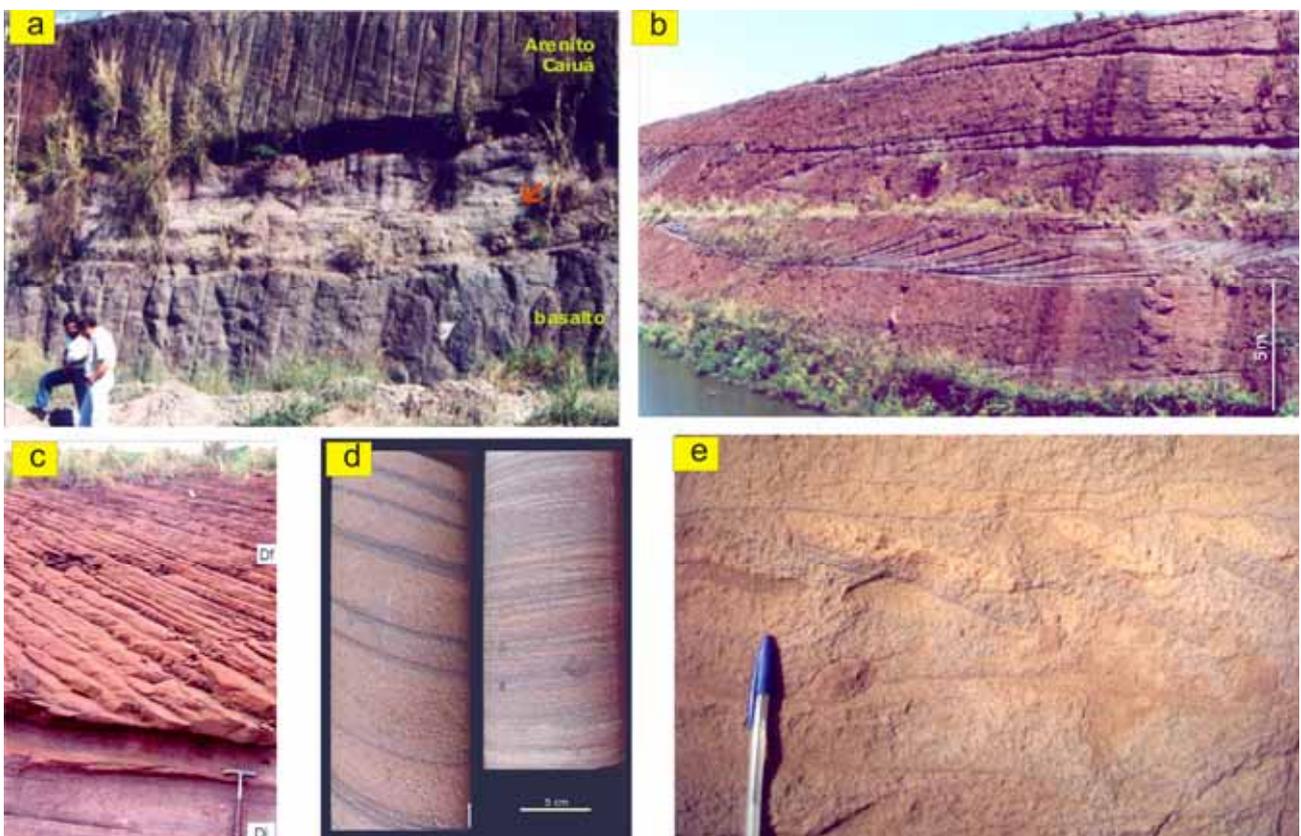
as rounded impressions. The second morphotype, corresponding to PP04 and PP07, presents tridactyl, digitigrade and mesaxononic footprints measuring between 7 and 12 cm in length, with a bipedal gait forming irregular tracks, digits finished in sharp edges and phalangeal and sole pads; stride varies between 21 and 35 cm. The third morphotype, represented by PP06, corresponds to a trackway with a quadrupedal gallop gait and rounded footprints, with hands posterior to feet without overtaking. Most of the footprints studied here are associated with a half-moon of sand, resulting in displacement of the substrate in an inclined surface. The fourth morphotype, corresponding to PP08 and PP10, presents large footprints circular in shape and measuring about 24 cm in diameter, without morphological features of the trackmakers.



**Figure 4:** Depositional setting of the Bauru Basin eastern part



**Figure 5:** Rio Paraná Formation type-section, Porto Primavera Hydroelectric Plant, Pontal do Paranapanema (São Paulo State)



**Figure 6:** a) basal contact of the Rio Paraná Formation/Caiuá Group with basaltic substratum. On the base of the unity, below the cross-stratified sandstone it can see a sandy immature breccia, massive, with angular clasts of basalt, clay nodules and carbonatic cement. Site: Left dam part of the Porto Primavera Hydroelectric Plant, near the ichnofossils occurrences (image from the time of construction of the dam) b) Overview of sandstones with large cross-stratification of deposits front of dunes, the central part of the Desert Caiuá, Rio Paraná Formation c) Detail of the Rio Paraná Formation, with deposits of fronts of large dunes (litofacies Df) and interdunes (Di), Porto Primavera Hydroelectric Plant, São Paulo State d) Rio Paraná Formation, cross-bedded sandstone, characteristic of aeolian processes (core holes of the Porto Primavera Hydroelectric Plant construction); e) rotated fragments of intraformational gravity breccia (of landslides on dune foresets), indicative of moisture in the desert environment. Rio Paraná Formation.

The footprints of the first morphotype can be attributed to small Theropoda dinosaurs based on morphological characters (e.g., Lockley, 1991). Similarly, the ichnites PP04 and PP07, the second morphotype, can correspond to footprints of small-to-medium-sized bipedal Theropoda dinosaurs. Footprints of Theropoda are often the most common in desert environments of the Mesozoic (Leonardi, 1991; Lockley & Conrad, 1991; Carvalho & Kattah, 1998). The footprints of the third morphotype are similar to the specimens of *Ameghinicus patagonicus* with a gallop gait described by Casamiquela (1964) for the La Matilde Formation, Upper Jurassic, Argentina. Similar trackways with a ricochet gait were also described for the Botucatu Formation corresponding to a variation of *Brasilichnium elusivum* (e.g., Fernandes, 2005) and are typical of small mammals, so PP06 could be attributed to this group. The footprints of the fourth morphotype could, in principle, be related to Sauropoda due to their rounded shape, but Sauropoda tracks do not occur in desert and aeolian environments, due to a shortage of food (e.g., Fernandes, 2005). Moreover, Ornithopoda dinosaur footprints preserved in a similar environment occur in the Botucatu Formation with a rounded shape and diameters of up to 34 cm. Thus, these footprints could be tentatively attributed to Ornithopoda herbivorous dinosaurs. The ichnofossils of invertebrates, PP05 and PP09, correspond to horizontal meniscated excavations identified as *Taenidium* sp., often attributed to small arthropods and common in the Aeolian environments of the Mesozoic. Tetrapod footprints in desert environments also occur in Brazil in the Botucatu Formation (Lower Cretaceous, Paraná Basin), the Areado Group (Upper Jurassic-Early Cretaceous, Sanfranciscana Basin) and the Corda Formation (Jurassic, Parnaíba Basin).

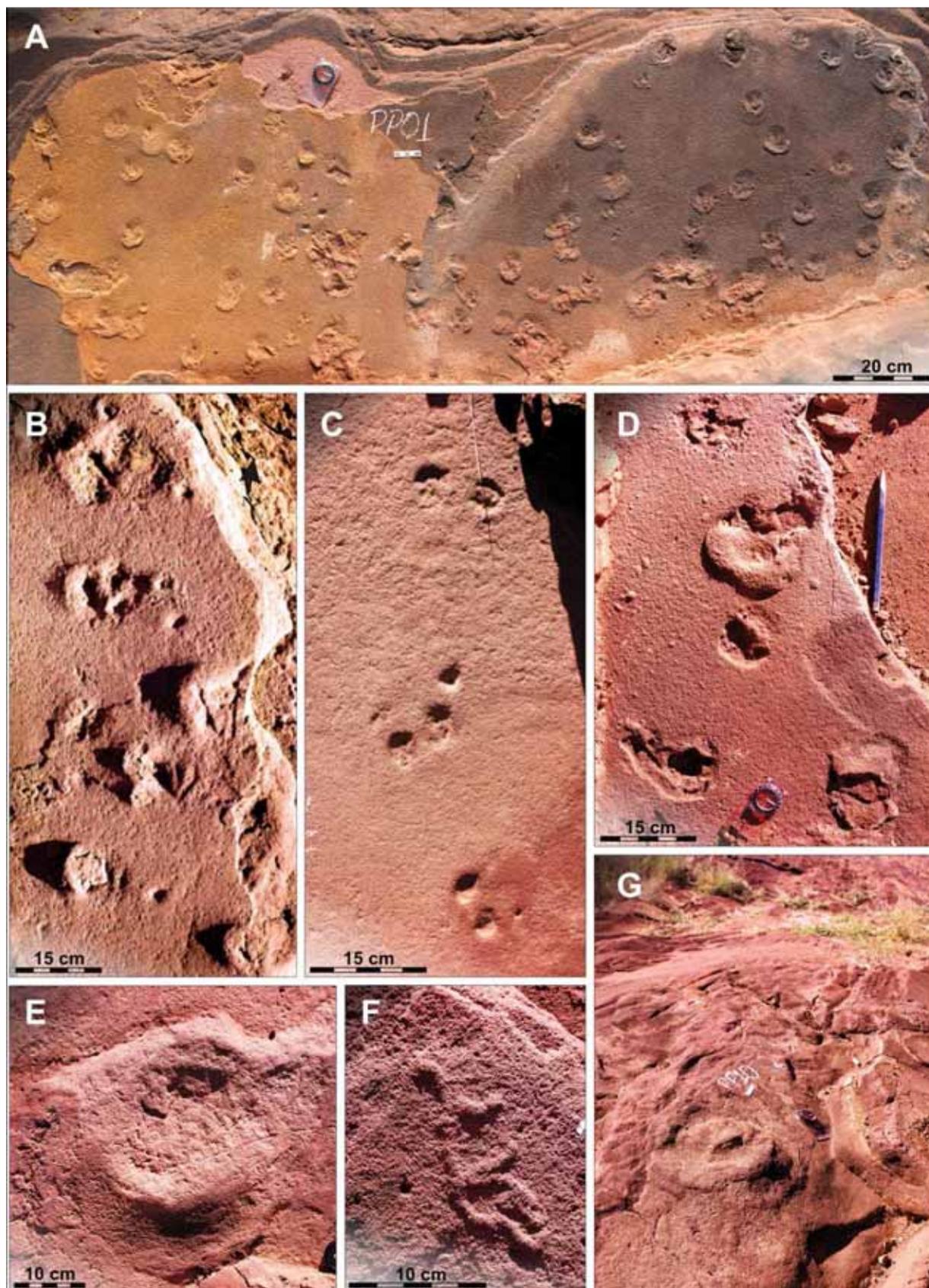
### **Palaeoenvironmental Considerations**

Some palaeontological evidence found at the studied site suggests that the footprints were produced in a damp substrate. Footprints produced in dry sand, when preserved, have a rounded form without distinction of digits or other morphological structures (e.g., Brand, 1979, 1996; McKeever, 1994; Fernandes, 2005). The preservation of digits (including impressions of sole pads and claws), as found in a number of studied footprints, occurs in wet sand (Reynolds, 1991; Lockley, 1991; Brand, 1996). According to Fernandes (2005), the occurrence of footprints in the sandstone of the Botucatu Formation generally does not correspond to the

original area where the marks were produced, but instead represents undertracks generated by the sinking of the autopodia of the trackmaker in the substrate, with the formation of impressions in subsurface layers. This kind of preservation would be more frequent in aeolian environments because the more superficial layers are subject to more droughts, diminishing the chances of preservation of recognizable structures and increasing the chances that structures will be modified. Therefore, the intervals with wet sand would probably be located a few centimeters below the surface of the substrate, impressed by the trackmaker after the sinking of autopodia, and immediately buried by the dry sand. In addition, surface tracks of small arthropods would be preserved only in dry sand since their small body mass would not be sufficient to break the surface tension of the wet sediment; thus, they are less likely to leave marks for preservation (Fernandes, 2005). The absence of such tracks in the studied outcrop would be evidence of damp substrate in the environment of the formation of these deposits.

Intraformational collapse breccias are sometimes present on deposits in the foreset dunes (Fig. 6e). These are features of deformation caused by the slippage of preserved between layers of undeformed beds with aeolian lamination. Such structures are indicative of moisture in the environment, perhaps at night, which causes the aggregation of sand in surface crusts that are fragile, fragmented and rotated in the form of tablets in the slide.

The occurrence of footprints preserved with morphological details produced in damp sediment can be explained by the presence of high groundwater levels in certain areas of deposition. Fluctuations in water table level would result in the preservation of some footprints in detail, while others, produced in dry sediment, would be preserved only in rounded form (Reynolds, 1991; Lockley, 1991; Carvalho & Kattah, 1998). Some of the specimens studied, including PP01, PP02, PP03 and PP06, correspond to erosive unmarked depressions without half-moon or apparent deformation structures. One possible explanation is that the formation of the footprints may generate a difference in the compression and three-dimensional arrangement of the grains in relation to the surrounding rock; this may cause a differential diagenesis, possibly with minor cementation, and make that region more susceptible to erosion. Thus, the erosive depression does not match the original footprints, but rather marks the point where they were produced.



**Figure 7:** Ichnofossils on forests dune deposits, Rio Paraná Formation sandstones, Paraná River. Porto Primavera Hydroelectric Plant, Brazil.

## **SYNOPSIS ON THE ORIGIN, DEVELOPMENT AND GEOLOGICAL IMPORTANCE OF SITE**

The Caiuá Group sandstones were accumulated in foresets of large dune complexes in the central part of an extensive sandy desert in the inner of Bauru Basin (Fernandes & Coimbra, 2000; Fig. 4). This basin developed in hot weather during the Upper Cretaceous period, approximately between 99.6 to 65.6 million of years ago and was wet at the edges and more desert-like in the interior.

The sloping slabs of sandstone where we find the footprints today are the records of tabular foresets of large sand dunes, formed by winds towards the south and southwest during their advance (Fernandes 2008). The marks are printed in slabs of reddish-purple brown sandstone with typical mid-size cross-bedding (Fig. 1).

In general, arid environments are not conducive to the development and post-death preservation of wildlife and floristic elements. The dry sand does not form good moulds due to its natural inconsistency. In turn, the highly oxidizing environment does not preserve the soft organic matter (meat, tissues, and plant parts). Moreover, the shortage of water is an important limiting factor to the existence of larger size forms of both animal and vegetable life. In these conditions, the ichnofossils represent valuable sources of information for palaeontological and palaeoenvironmental studies.

There are very few sources of information about fossils in rocks from the Caiuá Group. The only known occurrences in the Rio Paraná Formation are footprints produced by small primitive mammals and Theropod dinosaurs recorded in Paraná (Leonardi, 1977). The studied site presented a new occurrence of ichnofossils on these sandstones in the region of Pontal do Paranapanema (São Paulo) downstream from the concrete structure of the Porto Primavera Power Plant (Fig. 2). The occurrence is situated in the central area of the ancient Caiuá desert.

The site described is a new and important record of tetrapod footprints in the sandstones of Caiuá Group. These footprints were found in the ancient deposits of desert environments, where it is more difficult to preserve records of life, making these deposits naturally scarcer. Such ichnofossils can, however, expand the area of known occurrence of little-known fauna of the desert environments of the Cretaceous in Brazil and South America.

Another interesting result from a palaeoenvironmental approach and the study of basin evolution is the indication that even the most central areas of the Caiuá desert were relatively wet and occasionally frequented by predators and/or inhabited by animals adapted to arid climates.

## **MEASURES TO PROTECT**

The vulnerability of the site is high. When the sandstone is subjected to saturation and drying cycles of rapid change, it experiences displacement. The site is subject to two types of processes of cycling (alteration): natural, caused by rains, and anthropogenic, induced changes in the river due to the operation of the dam. It is also subject to other forms of attrition as a result of human activities involving trampling of the ichnofossils.

The site should be updated for the maintenance of outdoor fossils in ways that meet conservation measures, such as: 1) construction of a small wall to protect variation in the level of lake water and prevent the cycle of sandstone; 2) coverage of major fossil areas with glass; 3) restriction of access by unauthorized persons, which is feasible since the site is located inside the area of the power plant; 4) limiting the number of daily visitors, with the company held responsible for monitoring, since trampling damages the fossils; 5) regular monitoring of the state of conservation and attrition, and if necessary, maintaining control by impregnating the fossils or filling cracks; and 6) providing for the collection and deposit of the material in a scientific collection if risk to the integrity of the fossils is suspected. Finally, it is recommended that visitors be allowed access for paleontological/geological tourism only while being monitored by personnel, and researchers be allowed access to collect and/or manufacture moulds only when authorized by the relevant bodies or institutions.

The CESP (Energy Company of São Paulo State) showed intent to protect and promote the site as relevant to scientific study. The footprints and tracks are very rare and therefore very valuable from a scientific point of view. However, no action has been taken since the visit for effective identification and study of the site. In addition, we have no knowledge of a management plan or plans for protection of the area on the part of the company. During the visit, the research team offered to discuss measures for the protection of the site and controlled exposure of visitors. The team also offered to assist in the preparation of panels, texts and other means of disseminating scientific information and to help encourage cooperation of the institutions involved.

If the company is able to quickly implement effective measures for protection, then its commitment should be expressed in a declaration attached to the proposal for registration in SIGEP. If not, the ichnofossils should be collected and removed from the area to a museum.

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