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Eolian sedimentation record in the western part of the Bauru Basin: Rio Paraná Formation (Upper Cretaceous)

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Abstract

The Bauru Supersequence comprises two chronocorrelates groups, namely, Caiuá and Bauru. While substantial efforts have been dedicated to detailed mapping in the eastern portion of the Bauru Basin, the western part, specifically the Caiuá Group, remains unresolved and undivided. The aim of this research was to characterize the occurrence area of the Rio Paraná Formation in the state of Mato Grosso do Sul, which is located in the Midwest region of Brazil, as well as its lithostratigraphic characteristics, and the implications for a better understanding of the paleoclimate and paleogeography of that region during the Cretaceous. The Rio Paraná Formation is constituted by six lithofacies: sandstone with cross-stratification (Sct), sandstone with trough cross-stratification (Sct-t), sandstone with cross-stratification pebbles (Sctp), massive sandstone (Sm), massive sandstone with fragments of basalt (Smb), and sandy mudstone (Fme). It was possible to group three facies associations: large-size eolian dunes, interdunes, and sand sheet deposits. The direction of paleocurrent is southwest, which is similar to those previously recognized in the eastern part of the basin and chronocorrelates basins in Brazil. Based on the results obtained in this research, it was possible to provide evidence for the future paleogeographic reconstruction of the Late Cretaceous in South America.

KEYWORDS: Group Caiuá; sand sea; eolian systems; Mato Grosso do Sul.

INTRODUCTION

The Bauru Basin (Upper Cretaceous) spans extensive regions in South, Southeast, and Central West Brazil, comprising economically significant areas within the region. A thorough investigation of regional geology is imperative for effective planning and mitigation of occupancy-related challenges, in both urban and rural/agricultural domains. Furthermore, conducting sedimentary and stratigraphic analyses of the Bauru Basin deposits holds potential for their utilization in water resource exploration and preservation efforts. Additionally, this research contributes to the development of evolutionary models that are applicable to inland continental basins in Brazil. The Bauru Supersequence basin comprises two chronocorrelates groups, namely, Caiuá and Bauru (Fernandes and Coimbra 2000). Over the past decade, studies on the depositional context of the Bauru Basin, such as Batezelli (2015), Fernandes and Magalhães-Ribeiro (2015), and Menegazzo *et al.* (2016), have been published. On the contrary, diverse and detailed studies are reduced in the western part of the basin, especially in Mato Grosso do Sul (Weska 2006, Basilici *et al.* 2007, Dal' Bó 2008, Basilici *et al.* 2009, Basilici *et al.* 2012).

Lithostratigraphic studies in the western portion of the Bauru Basin are needed to solve paleoclimatic factors that are still undefined, since the majority of knowledge gathered about the sedimentary filing, stratigraphic, paleoenvironmental, paleontological, and tectonosedimentary studies in this basin over the past decades has focused on its eastern portion (São Paulo, Paraná, and Minas Gerais states).

Here, we present the outcropping area and characterize the Rio Paraná Formation, Caiuá Group, in Mato Grosso do Sul, which was not previously recognized in this state. One quarter of the state territory was previously mapped as Caiuá Group (CPRM, 2006a), with the Rio Paraná Formation not being individualized. The scarcity of data pertaining to the environmental conditions, specifically the climatic aspects, during the Late Cretaceous period in South America is a noteworthy issue. Consequently, the novel discoveries presented in this research, focusing on the cartographic updating of the Rio Paraná Formation within the western sector of the Bauru Basin, will significantly enhance our understanding and provide novel perspectives concerning the Bauru Basin and its paleogeographic evolution.

Geological setting

The Bauru Basin occupies an area of approximately 370,000 km^2 and is filled with an essentially sandy, siliciclastic sequence, with a maximum thickness of 480 m in the eastern portion (Fernandes and Magalhães-Ribeiro 2015). The Upper Cretaceous Bauru Supersequence (Milani *et al.* 2007) extends over the states of Minas Gerais, São Paulo, Paraná, Mato Grosso do Sul, and Goiás, in Brazil, and the northeast of Paraguay.

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The sedimentation process occurred concomitantly with a progressive uplift along the boundaries, demarcated by tectonically positive structures that isolated Bauru Basin from other neighboring Cretaceous Basins (Rondonópolis Anteclise and Uplift Alto Paranaiba, Coimbra 1991, Riccomini 1997). The breakup of Gondwana led to a massive magmatic event (Paraná-Etendeka Continental Flood Basalt) in this area, accumulating over 2,000 m of basaltic lava that posteriorly caused a subsidence. For this reason, Fernandes and Coimbra (1996) separated the Upper Cretaceous sequence of the sedimentary record of the Paraná Basin, considering it to have been accumulated in a new basin, named Bauru Basin.

Menegazzo *et al.* (2016) considered the infilling of the Bauru Basin as a first-order stratigraphic sequence, accumulated in response to supracrustal loading and flexural deflection resulting from the onset of the Andean Orogeny. These authors classified the Bauru, Solimões, and Parecis basins, as back-bulge provinces of a foreland retroarc system, developed in western South America. Based on the shape of the basin infilling, the authors interpreted that there was a migration of the depocenter over time, which might indicate an orogeny in the western border of the South American Plate.

The infilling of the siliciclastic sequence is divided into two chronocorrelates groups. First, the Caiuá Group is composed of the Rio Paraná, Goio Erê, and Santo Anastácio formations, whereas the Bauru Group comprises Uberaba, Vale do Rio do Peixe, Araçatuba, São José do Rio Preto, Presidente Prudente and Marília formations, and Analcimitos Taiuva (Fernandes and Coimbra 2000).

After its recognition, the "Sandstone Caiuá" was the subject of several studies during the last century, since its original description by Baker (1923). Those studies were mainly carried out in the states of São Paulo and Paraná (Washburne 1930, Maack 1941, Bigarella 1949, Scorza 1952, Popp and Bigarella 1975, Soares *et al.* 1980, Jabur and Santos 1984, Bigarella and Mazuchowski 1985, Fernandes 1992, 1998, Fernandes and Coimbra 1994, 2000). They have reported the essential characteristics of eolian processes for this lithostratigraphic unit.

After conducting a comprehensive regional review in the states of São Paulo and Paraná, Fernandes and Coimbra (1994, 2000) introduced a new stratigraphy for the Bauru Basin. They reclassified the Caiuá Formation as a group, encompassing the Rio Paraná Formation and Goio Erê Formation (deposits from the central and peripheral areas of the sand sea, respectively) and Santo Anastácio Formation (deposits of sand sheets).

The western part of the basin has an area of 190,000 km^2 where only the Rio Paraná and Santo Anastácio formations of the Caiuá Group and Vale do Rio do Peixe and Marília formations of the Bauru Group are recognized (Fig. 1). The Caiuá Group corresponds to an interior eolian system tract of the Caiuá desert (Fernandes and Magalhães-Ribeiro 2015). It consists of complex large wind dune deposits in the central region of a sand sea. The Santo Anastácio Formation is characterized by poorly selected, massive, subarkosic sandstone, with subordinate silt fraction and decimeter-thick tabular strata. The depositional paleoenvironment can be interpreted as sand sheets at the desert margins (Fernandes and Magalhães-Ribeiro 2015) and paleosols (Fulfaro 1999a, 1999b, Batezelli 2010).

MATERIALS AND METHODS

The research was carried out by geological surveys on a regional scale, developed in sections by highways, aiming at the recognition and characterization of the large lithostratigraphic units of the Mato Grosso do Sul state, Brazil. We have mapped the eastern area of the state at a scale of 1:1,000,000, based on sections in highways and by searching the lateral and vertical contact relationships between the units.

The sites of potential rock exposures were selected during a meticulous analysis of satellite images. The target areas were pre-selected based on the morpho-structural anomalies, topography, and erosive features. Consultations were also held on research reports of federal and state organizations, as well as the collection of the state tubular well drilling companies. All those potential areas indicated via satellite image or by the governmental report were visited in several fieldwork stages. A total of 208 profiles of deep tube wells were analyzed, allowing us to establish the maximum thickness of the sedimentary sequence.

The field studies aimed to characterize the lithostratigraphic units and their regional distribution. We also recognize the architecture of faciological associations, through the analysis of the lateral and columnar sections, the measure of attitudes of sedimentary structures for the study of paleocurrents. With these characteristics, representative outcrops as well as respective samples for each mapped unit were selected. The samples were then documented and labeled for posterior petrographic characterization in the laboratory.

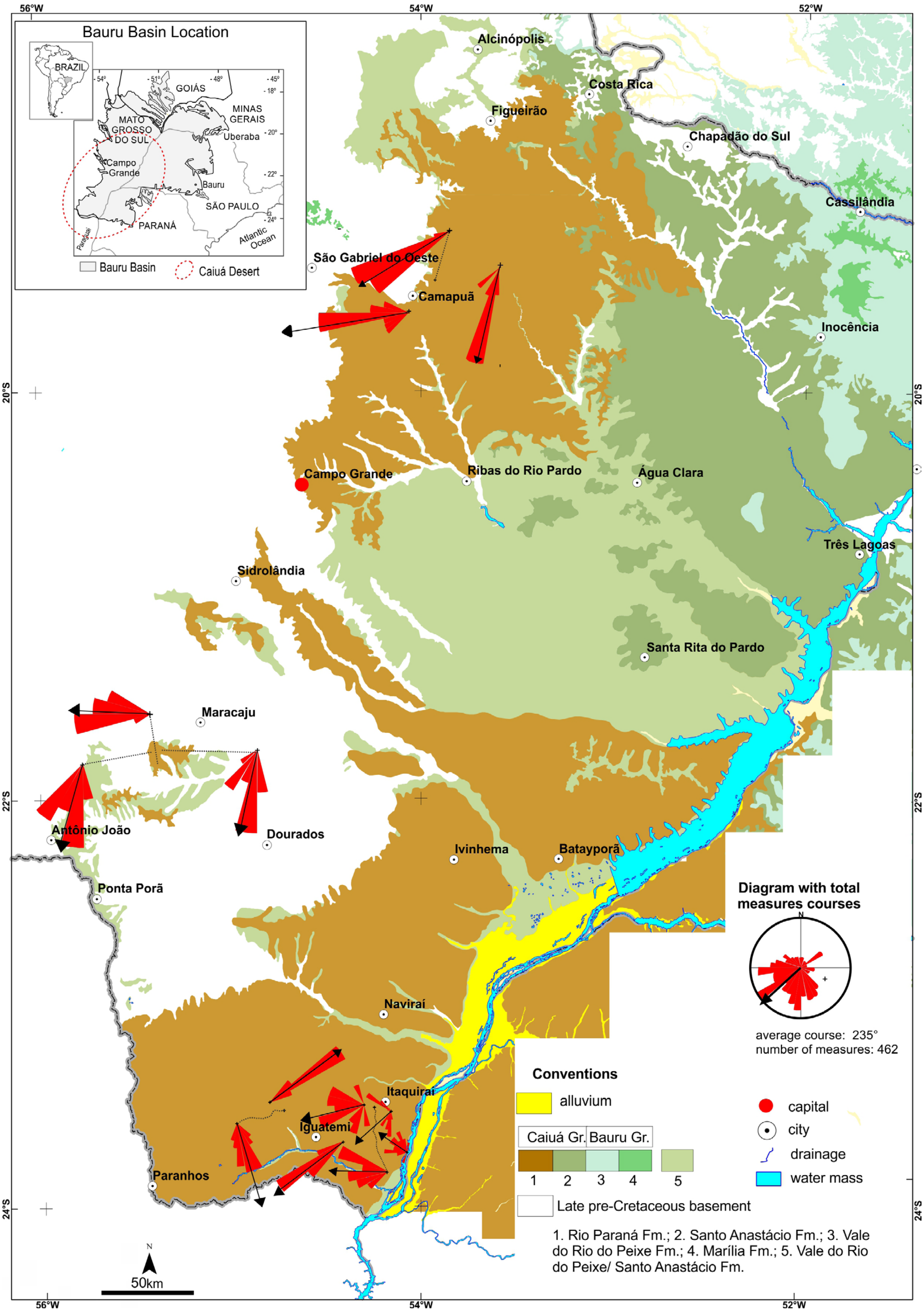
The sedimentary lithofacies recognition and facies associations (Miall 1985, 1999) were based on the lithological constitution, internal structures, depositional architecture, thickness, paleocurrent pattern, and presence/absence of fossils.

Cross-stratifications were classified according to their size (S) as suggested by McKee and Weir (1953) and modified by Fernandes (1992): S > 3 m as a large set; 3 < S < 0.3 m as a medium set; S < 0.3 m as a small set.

The paleocurrent analysis used the attitudes of cross-stratification foresets in sandstones, which are measured according to the Potter and Pettijohn's method (1977). We use the Stereonet v.11.0.9 software (Cardozo and Allmendinger 2012, Almendinger *et al.* 2012) to plot these data in rosette diagrams. The angular range of representation, which corresponded to the width of the petals of the circular diagram, was defined as 30°.

The macroscopic and microscopic scales of sample description were used focusing on the textural and mineralogical characterization of both framework and matrix. The framework was described in terms of grain size, selection, rounding, sphericity, and mineral composition. The characterization of cements and pores distribution provided evidence about the diagnostic processes. The samples were classified according to Folk (1968, 1974).

To differentiate interdune (DI) from sand sheet (SS), deposits were classified as follows: sedimentary structures: in



Source: CPRM cartographic update 2004a, 2006a.

Figure 1. Bauru Basin: Occurrence of the Rio Paraná Formation in the western part.

general, poorly defined plane-parallel stratification or massive aspect; lithofacies associations: interdune strata interspersed with tabular bodies with conspicuous cross-stratification (dune foresets facies and metric to submetric thickness, sometimes with a slightly lenticular character; possible occurrence of nodule and carbonate concretions) and massive aspect: in tabular units of metric thickness, sometimes with internal stratification with a low dip angle, may present possible carbonate rhizocretions.

RESULTS

The exposures of the Rio Paraná Formation in Mato Grosso do Sul were found in the south, southeast, and central north of the state (Fig. 1). The more expressive and representative outcrops (Fig. 2) are located north of the municipality of Camapuã, MS-422 highway, between the municipalities of Camapuã and Figueirão. The main outcrop has a composite profile of about 45-m thick. In the subsurface, according to the wells' profiles, the thickness of the Rio Paraná Formation reaches 180 m in Ivinhema. When considering the high difference between silicified rocks at the top of witness hills in the Maracaju region and the lower contact with basalt measured in perforations, the thickness of the Rio Paraná Formation reaches 120 m.

Facies and facies association

A total of three facies associations were interpreted from the six sedimentary facies recognized within the study area (Fig. 3). The descriptions and respective depositional processes of each facies are summarized in Table 1.

Figure 2. Rio Paraná Formation at the north-central part of the Mato Grosso do Sul state, outcropping on the Highway MS-422, between Camapuã and Figueirão cities. The dotted lines indicate the columnar section's positions and the arrows indicate the average paleocurrents. The purple-brown indicates the result of iron oxide cementation and coating of quartz grains. Reference exposure, on the MS-422 highway. Coordinates (latitude/longitude): A) 19°26'35" S, 53°56' 59" W; B: 19°28'30" S, 53°58' 34" W; C) 18°48'17" S, 53°47'23" W. Conventions: Very fine (mf), fine (f), and medium (md) sand.

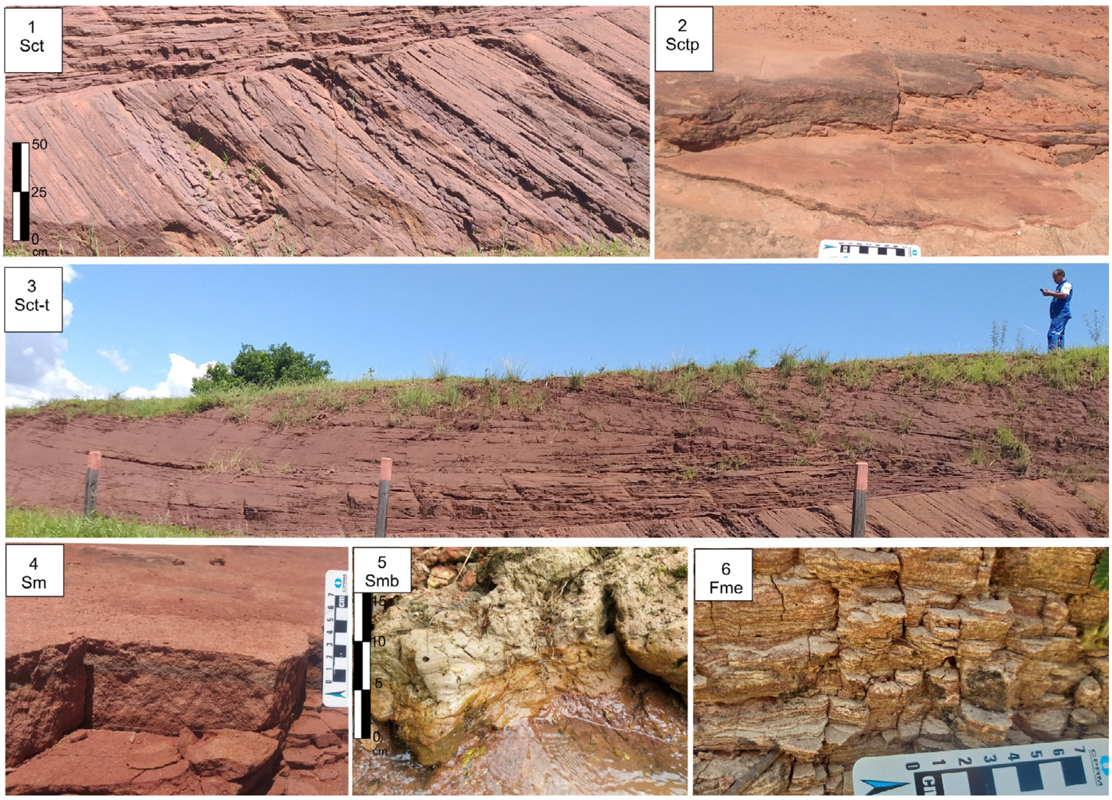


Figure 3. Facies of the Rio Paraná Formation.

Table 1. Facies and depositional processes of the Rio Paraná Formation.

Facies Codes	Lithofacies	Sedimentary Structures	Description	Depositional Processes
Sct	Sandstone with tabular cross-stratification	Tabular cross-stratification	Red to purple, fine-to-very-fine-grained sandstone, with well-rounded grains. Mineralogically supermature. The grains are well sorted by laminae or bedding planes. Most of them display an opaque surface and have iron oxide/hydroxide film cementation. Present characteristic tangential at base crossbedding, ranging in size from medium to large (0.3–3 m). Quartzarenite.	Lower flow rate, transport by saltation, under wind action, grain flow, grain fall stratification, in dunes foresets (DF)
Sct-t	Sandstone with trough cross-stratification	Trough cross-stratification	Red to purple, fine-to-very-fine-grained sandstone, with well-rounded grains. Mineralogically super mature and with good textural maturity. The grains are well selected by laminae. Most of them display an opaque surface and have iron oxide/hydroxide film cementation. It presents trough cross-stratification from large size (> 3 m). Quartzarenite.	Lower flow rate, transport by saltation, under wind action, in dunes foresets (DF)
Sctp	Sandstone with pebbles	Tabular cross-stratification	Fine-to-medium grains, moderately selected, with well-rounded grains, with good textural maturity, mineralogically super mature. It presents siliceous pebbles and fragments of carbonated pebbles (bone?) at the base. Has metric thicknesses. Quartzarenite.	Lower flow rate, transport by saltation, under wind action, grain flow, grain fall stratification, in dunes foresets (DF) Deposited in rocky substrate (Botucatu Formation). (DF)
Sm	Massive sandstone	Massive	Fine-to-medium grains, with well-rounded and selected grains. Its aspect is usually a massive structure or inside stratification. It has metric thicknesses. Quartzarenite.	Transport by saltation, under the action of the wind. Sand sheet deposits (SS)
Smb	Massive sandstone	Massive with fragments of basalt	Medium-size grains, well-selected quartz, well-rounded grains, and predominance of grains of opaque surface. Its aspect is a massive structure, with millimetric and centimetric fragments of basalt. It has metric thicknesses. Quartzarenite.	Deposited on basaltic substrate. Rock of the basement fragmented and covered by grains of sand brought by eolian sedimentation. Sand sheet deposits (SS)
Fme	Sandy mudstone	Parallel-plane stratification	Fine-to-medium grains, in matrix Lamitic (sandy mudstone). Sometimes, carbonate horizon displays. It has metric thicknesses. Sandy mudstone.	Settling of mud Interdune deposits (DI)

Foresets deposits (DF): facies Sct, Sct-t, and Sctp

The most expressive facies association of Rio Paraná Formation, in terms of thickness and extension in area, is the DF. It shows 0.3–3 m cross-stratification sets, with sets limited by second-order surfaces (Brookfield 1977) (Fig. 4). A total of 462 attitudes of crossbedding were measured in 13 outcrops, with a minimum of 5 and a maximum of 100 measures per outcrop. The average vector of each set was calculated, the results of which are shown on the map (Fig. 1). The regional analysis of paleocurrent indicated a trend heading preferably to the southwest.

In general, the sandstones are of fine to very fine grain size, are reddish to purplish in color, are mineralogically super mature, and have good textural maturity. The sandstones can be classified as quartzarenites (Fig. 5), following Folk (1974), from subrounded to rounded grains (Fig. 5A), which are the smallest subangular grains. The grains are effectively sorted by laminae, which is indicative of bimodality (Fig. 5B), separating into thin larger and relatively more rounded grains from smaller and less rounded grains (Figs. 5C and 5D).

Most of them display an opaque surface and have iron oxide/hydroxide film cementation. In these sandstones, cross-stratification (tabular and through) is observed, with their distribution and proportions controlled by the size of the cross-stratification sets. Furthermore, the sandstone with cross-stratification pebbles (Sctp) facies occasionally exhibits siliceous pebbles and carbonate fragments at the base of the sedimentary layers.

Deposits formed in sand sheets (SS): facies Sm and Smb

The investigated samples exhibit a medium-to-fine grain size with moderately selected grains. They display

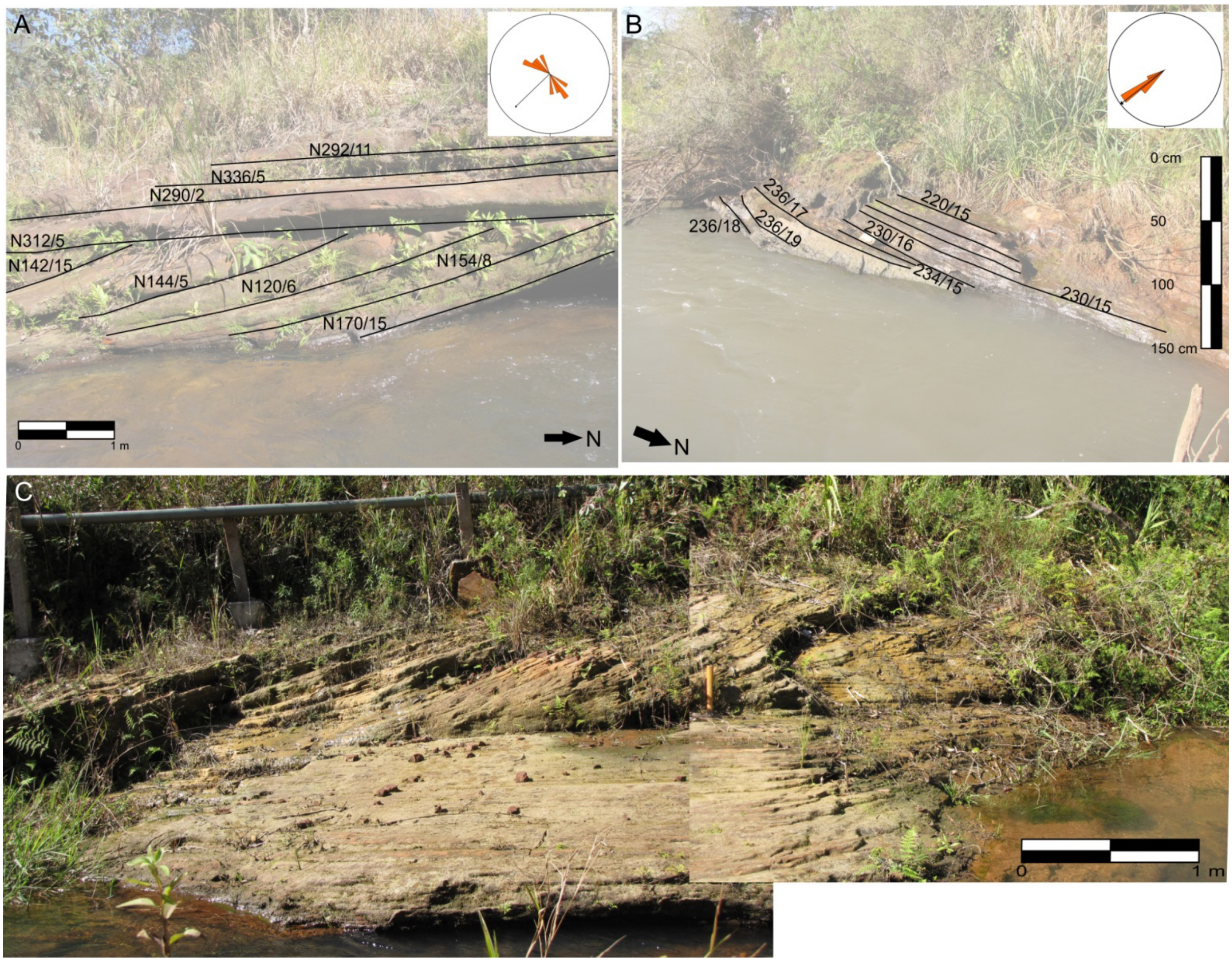


Figure 4. Exposures of *the Sct* facies to the south of the state. (A and B) Paleocurrent measurements obtained from attitudes of crossbedding. (A) For *N* = 10, resulted in an average course of 214 (black arrow on the diagram). Location: Acosta Farm, Eldorado (23°46'52" S, 54°18' 36" W). (B) For *N* = 32, resulted in an average course of 233 (black arrow on diagram) (23°33'23" S, 54°16' 54" W). Location: Itaquiraí. (C) Superposition surface (Brookfield 1977) (N116/6). Location: Aurora Creek, Nova Espadilha Farm, Itaquirai. Coordinates (23°33'33" S, 54°12' 20" W).

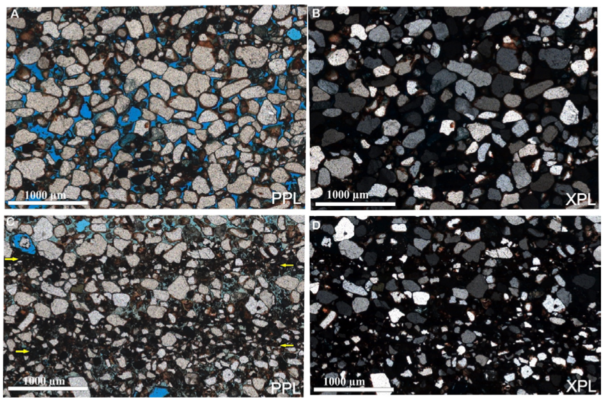


Figure 5. Facies Sct, quartzarenite (following Folk 1974). (A) Framework composed essentially of well-rounded single-crystalline grains, without matrix. Note discrete grain orientation in B. (C and D) Bimodal textures and concentration of iron oxide and hydroxide cement in the lamina of very fine grains. Photomicrographs were obtained with uncross-polarizers (PPL, A and C) and cross-polarizers (XPL, B and D). Locations: (A and B) 23°46'52" S, 54°18' 36" W; (C and D) 23°33'33" S, 54°12' 20" W.

mineralogical maturity and good textural maturity. Most grains have an opaque surface that is coated with an iron oxide/hydroxide film.

Interdunes deposits (DI): consisting of the facies Fme and Sm

This association is composed of fine-to-medium grains, with a muddy matrix (sandy mudstone). Occasionally, it presents interbedded carbonate cementation horizons. The most common characteristics of these deposits are planar cross-stratification and carbonate cementation horizons.

Depositional environment interpretation

The sediments deposited by wind exhibit some peculiar characteristics:

i. horizontal layers with large-scale cross-stratification;
ii. good sorting by laminae;
iii. marked differences in grain size within similar thickness laminae;
iv. maximum grain size transported by the wind on the order of 1 cm (those larger than 5 mm are rare);
v. larger grains tend to be well-rounded;
vi. absence of clay, with rare clay drapes;
vii. preserved curled mud flakes, suggesting that the mud was covered by eolian sand;
viii. non-cemented sand grains display a matte surface;
ix. absence of mica among the framework grains (Collinson *et al.* 2006).

Such characteristics were found in the Rio Paraná Formation.

In the DF facies association, processes that are active in the formation of these types of deposits are grain fall, reworking by grain flows (avalanches). They form in flat areas and constitute the major part of the eolian depositional system. Controlling factors include sediment source and supply, grain size, sand grain composition, wind direction, wind intensity, and the nature of the surface on which the sand is deposited. Eolian dunes assume various sizes and shapes based on these controlling factors.

In the microscopic description of facies Sct, predominant plane and punctual contacts between grains indicate that the sedimentary deposits were submitted to mechanical compaction processes (rotation and better grain fitting), having reached an eodiagenetic stage.

In the sand sea, the sandy deposits formed can be classified into three types of bedforms based on their dimensions: draas, dunes, and eolian ripples. Draas are extensive bedforms, spanning kilometers in length and reaching heights of tens of meters. "Megadunes" or complex dunes (draas) occur only in the largest sand seas with high rates of supply and transport of eolian particles (Collinson *et al*. 2006, Wilson 1972). Dunes are bedforms with lengths ranging from tens to hundreds of meters and heights measured in meters, occurring in simple or superimposed forms, thus giving rise to draas. Eolian ripples are centimeter-sized bed features that can occur on top of draas and dunes.

Interdune deposits (dry, wet, or aqueous) are typically located between dunes and draas in relatively low, flat regions. Within interdune areas, erosional eolian and non-eolian processes predominantly give way to depositional processes. The sedimentation and accumulation in interdunes are primarily driven by fluctuations in the water table in relation to the depositional surface. Interdune deposits can include residual deflationary sediments, sand with vegetation, massive sand with micro-ripples, cross-stratified sands, lacustrine deposits, as well as playa and sabkha environments (McKee 1983). We suggested that the formation of carbonate horizons is influenced by physico-chemical changes caused by variations in the water table level over time.

Sand sheets are extensive, flat areas with gentle, slightly asymmetrical ripples and no-slip faces, which are formed by eolian ripples or transverse dunes (Kocurek and Nielson 1986). Sand dunes with slip faces form when there is sufficient amount of loose, dry sand, typically ranging from 0.1 to 0.3 mm in grain size, and when the wind is capable of transporting it. Additionally, time is required for dune development. In contrast, sand sheets form where conditions are not suitable for dune formation. This can be due to factors such as grain size, a high water table, surface cementation, the presence of coarser grains, and vegetation. In the case of modern sand sheets in hot climates, grain size and vegetation are the most common factors for their formation. A distinctive feature of these deposits is low-angle crossbedding formed by transverse ripples (Kocurek and Nielson 1986). The lower part of the Rio Paraná Formation exhibits a massive structure with centimeter-sized, subangular basaltic clasts embedded within a sandy clay matrix. These deposits can be interpreted as concentrated mainly by the process of wind deflation, with less transport. The substrate, which was exposed to physical weathering, was unbundled in fragments, incorporated, and involved in a wind-sandy matrix (Smb facies).

The facies associations observed in the Rio Paraná Formation are interpreted as eolian depositional systems (Fig. 6). They are composed of foresets deposits (DF), deposits formed in extensive sand sheets (SS), and, locally, deposits of interdunes (sandy mudstones) (DI). As shown in the columnar sections in Fig. 6, the facies association DF exhibits a thickness of 40 and 30 m in the southern and northern regions of the state, respectively. The deposits of interdunes are more strictly in the central-north portion of the state (Fme facies), with fine grain in the frame and a calcrete horizon. The depositional context of the Bauru Basin comprehended draas of the central region of the sand sea.

Stratigraphic framework

The lower contact of the Rio Paraná Formation is an unconformity with the basement of the Bauru Basin (Fig. 7).

In the south and southeast of the Mato Grosso do Sul state, the contact overlays the Serra Geral Group (Fig. 7A). In contrast to what occurs in the northern region of the state, in the southern region, fragments of the Serra Geral Group are identified as embedded within the sandstone of the Smb facies. This observation may suggest the presence of a substrate influenced by physical weathering. Overlaid by a layer of sand containing small fragments of basaltic rocks (Fig. 7B), there is an immature sandstone bed, of centimetric to metric thickness.

In the state of Mato Grosso do Sul, when progressing northward, the accumulated thickness of the Serra Geral Group gradually diminishes toward the basin peripheries, leading to instances within the Bauru Basin where the Rio Paraná Formation directly rests upon the Botucatu Formation (Figs. 7C and 7D). Furthermore, the uplifts of the Bauru Basin margin (Riccomini 1997) during the Cretaceous (Rondonópolis Anteclise and Uplift Alto Paranaiba) may have exposed these thin layers of the Serra Geral Group, thereby facilitating physical weathering, thus explaining their absence in the region. Another hypothesis is that there may have been no deposition of the Serra Geral Group in this portion of the Basin.

Locally, Cenozoic deposits cover the Rio Paraná Formation, as well as in the south of the state (Fig. 8).

DISCUSSION

As presented in this manuscript, the lithostratigraphic understanding of the western part of the Bauru Basin is essential for advancements in our knowledge of the paleogeography and paleoclimate of South America during the Cretaceous period.

Eolian sediments accumulate in vast sand seas called ergs. They are dynamic sedimentary bodies that constitute part of regional-scale sand transport systems, in which sand is moved by the wind from source zones to depositional sinks (Lancaster 1995, 2009). Draas are large sand bedforms with

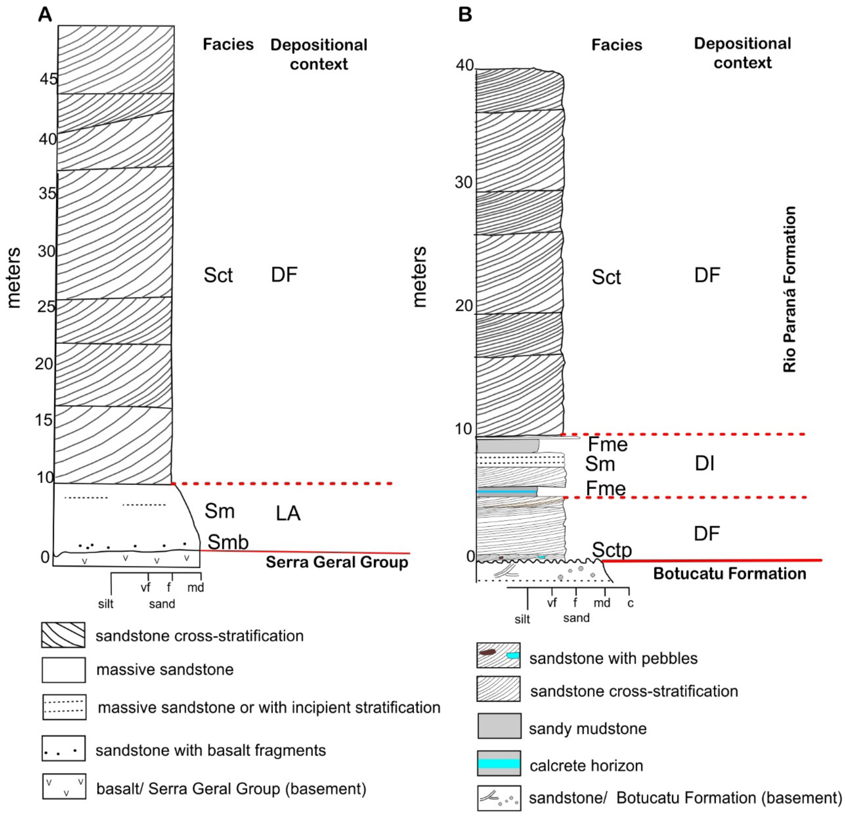


Figure 6. Columnar sections of the Rio Paraná Formation in the Mato Grosso do Sul state. (A) Schematic composite section of the unit in the south of the state. (B) Composite columnar section, Camapuã-Figueirão highway.

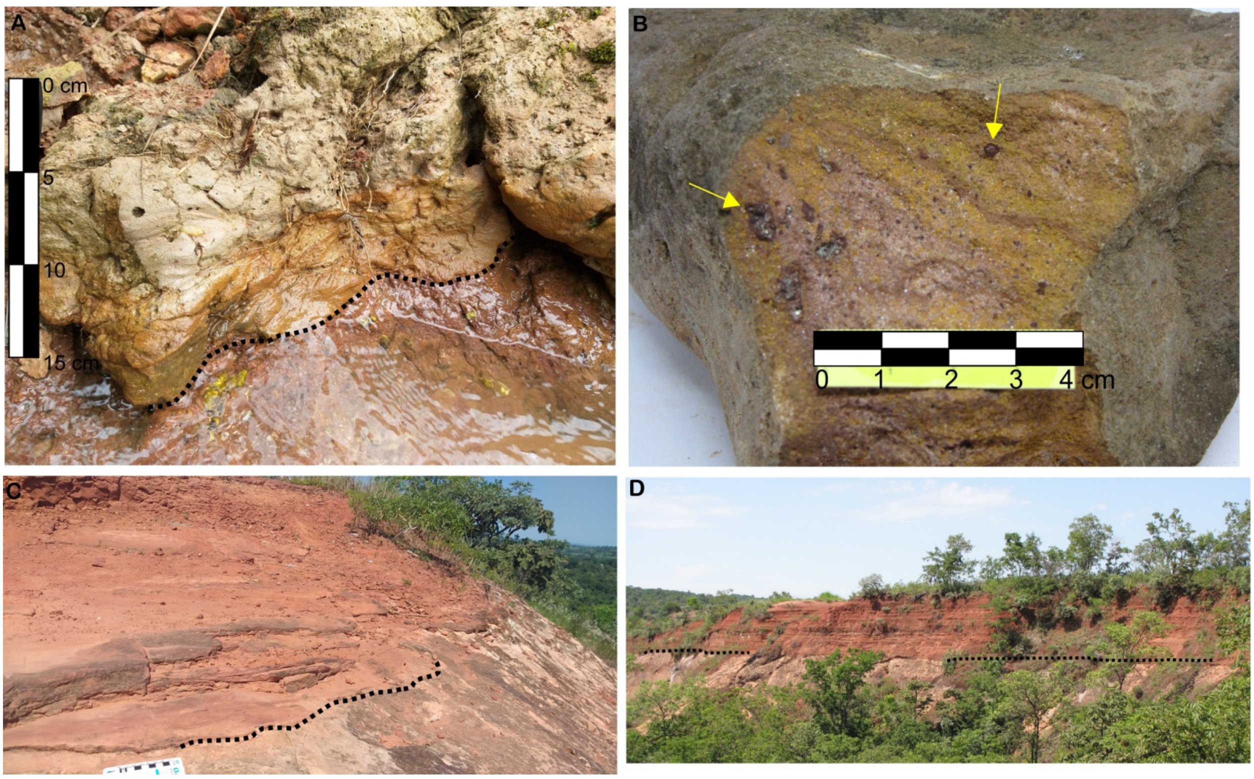


Figure 7. Contacts of the Rio Paraná Formation with the basement of the Bauru Basin: (A) Contact with basalt of the Serra Geral Group (22°57'36" S, 54°07' 37" W). (B) Basalt fragments (arrows), at the base of the sandstone observed in B (basal pseudo-breccia). (C and D) Contact with the Botucatu Formation in Camapuã City (estimated thickness of 5 m). Location: 19°32'38"S, 54°02' 38" W.

heights between 20 and 450 m, characterized by the superimposition of smaller dunes (Brookfield 2011, Brookfield and Silvestro 2010). In the study area, columnar sections of at least 45 m were reconstructed. Interdunes are an integral part of eolian bedform systems (Kocurek 1981). Sand sheets consist of flat areas of plane-bedded coarse sand usually overlying finer material and are basically lag deposits. Furthermore, sand sheets are an important part of some ancient sand seas and are recognized by plane bedding and low-angle lamination in coarse sands (Brookfield and Silvestro 2010), as well as in the Sm and SMb facies.

The South American Platform has maintained its latitudinal position for the past 165 million years, characterized by two significant Upper Cretaceous eolian sandstones: the Caiuá Group in the Bauru Basin, Brazil (Fernandes *et al.* 2007) and the Lecho Formation in the Salta Basin, Argentina (Marquillas *et al.* 2005). Within the context of the South American Plate, the Bauru, Sanfranciscana, and Parecis basins represent distinct geotectonic entities situated in different regions of the Brazilian territory. Nonetheless, these basins share a remarkably similar sedimentary record from the Cretaceous period, particularly in their aeolian phases (Batezelli and Ladeira 2016), which directly implies the understanding of the climate of South America during that time. Given that the extent of the Caiuá Group (specifically, the Rio Paraná Formation) in Paraguay (Acaray Formation, Fulfaro 1996) remains unknown, it is plausible that the Caiuá Desert may extend for thousands of additional kilometers.

Systematic analysis of dune type in the eastern portion of the Bauru Basin with attitude diagrams of cross-stratification (Glennie 1970; modified by Bossi *et al.* 1977) allowed classifying them as barchanoid constructions or dominantly transverse ridge dune complexes sinuous, common in well-developed ergs (Fernandes 1992, Fernandes and Coimbra 1999).

The average dip course of foresets, measured in this same lithostratigraphic unit, on the western portion of the basin, could indicate the prevailing sand transport directions during the Cretaceous. The paleocurrent measurements show the course of the winds to the Southwest, agreeing with that observed in Paraná and São Paulo states (Fernandes and Coimbra 1996, Fernandes and Magalhães-Ribeiro 2015) where the Rio Paraná Formation is exposed. Furthermore, Batezelli and Ladeira (2016) considered the sediment source area for the eolian facies in both the Bauru Basin and the Parecis Basin to be the transport of sediments from the north/northeast to the south/southwest, indicating a preferred wind direction during the Cretaceous, which is significant for comprehending the paleoclimate of South America.

The uplift of the basin margins during the Late Cretaceous activated the tectonics of the Bauru Basin (Riccomini 1997). Seismic records are reported throughout the basin (Fernandes *et al.* 2007), and silicified rocks of hydrothermal origin are associated with neocretaceous magmatism at the basin margins (Martin 2018). On the contrary, the uplifts that occurred within the South American Plate, as indicated by unconformity K-1A reported by Batezelli and Ladeira (2016), suggest arid to semi-arid climatic conditions. According to the authors, the presence of paleosols indicates cycles of tectonic stability and reduced sedimentation rates, with time gaps, in the sedimentary evolution of the basin.

In this regard, based on the analysis of underground water well data, a maximum thickness of 180 m was found for the Rio Paraná Formation, which represents the supersequence in the Mato Grosso do Sul state. The recognition extension area of occurrence of the Rio Paraná Formation (Caiuá Group) in the Mato Grosso do Sul state is one of the main contributions presented about the local stratigraphy because one-quarter of the territory was mapped (CPRM, 2006a) simply as undivided Caiuá Group.

Therefore, based on the lithological characteristics (i.e., grain size, good selection by slides, absence of matrix, and opaque surface), the association of facies as presented in Fig. 6, and the analysis of the dominant direction of paleocurrent (Fig. 1), our conclusion is that eolian processes are the primary mechanisms for sediment transport and deposition in the central, north-central, and southern regions of the Mato Grosso do Sul state. This observation can be integrated into a broader perspective by considering other Brazilian basins in the context of South America, as previously discussed (Batezelli and Ladeira 2016). The sedimentary context that we observed in this area is predominantly eolian, indicative of a desert environment, which is consistent with the description of the eastern portion of the basin (Fernandes and Coimbra 2000). Consequently, it is plausible to infer that the depositional environment of the southern section of the Rio Paraná Formation extended from the eastern region to the western part of the Mato Grosso do Sul state.

Based on the results presented here, we propose that the region corresponding to the present-day Mato Grosso do Sul state, Brazil, exhibited a significantly larger exposed area under arid paleoclimatic conditions. Corroborating the findings of Batezelli and Ladeira (2016), it is possible to establish a correlation between wind systems and climate during the Late Cretaceous of South America.

CONCLUSIONS

The Bauru Supersequence is a predominantly sandy siliciclastic unit of continental dimensions. The geological mapping of the western portion of the Bauru Basin in the Mato Grosso do Sul state, associated with the geological knowledge of the adjacent states of São Paulo and Paraná, allowed the recognition of the territorial extension of the Rio Paraná Formation in an area much larger than previously reported. The unit is located in the south and north-central regions of the state, with its most significant exposures situated to the north of Camapuã, along the Camapuã–Figueirão highway.

The Rio Paraná Formation corresponds to a facies association interpreted as eolian depositional system, specifically an interior desert depositional system in this portion of the Bauru Basin. The regional paleocurrents indicate a trend preferably to the southwest. Concordant with the known regional paleocurrents trend found in the eastern portion of the basin and compared with the findings in the eolian sequences of other Brazilian Cretaceous basins, this may provide us with insights into the paleogeography of South America during the Upper Cretaceous. Furthermore, the lithofacies described here, as well as the facies association, indicate the predominance of arid to semi-arid climate.

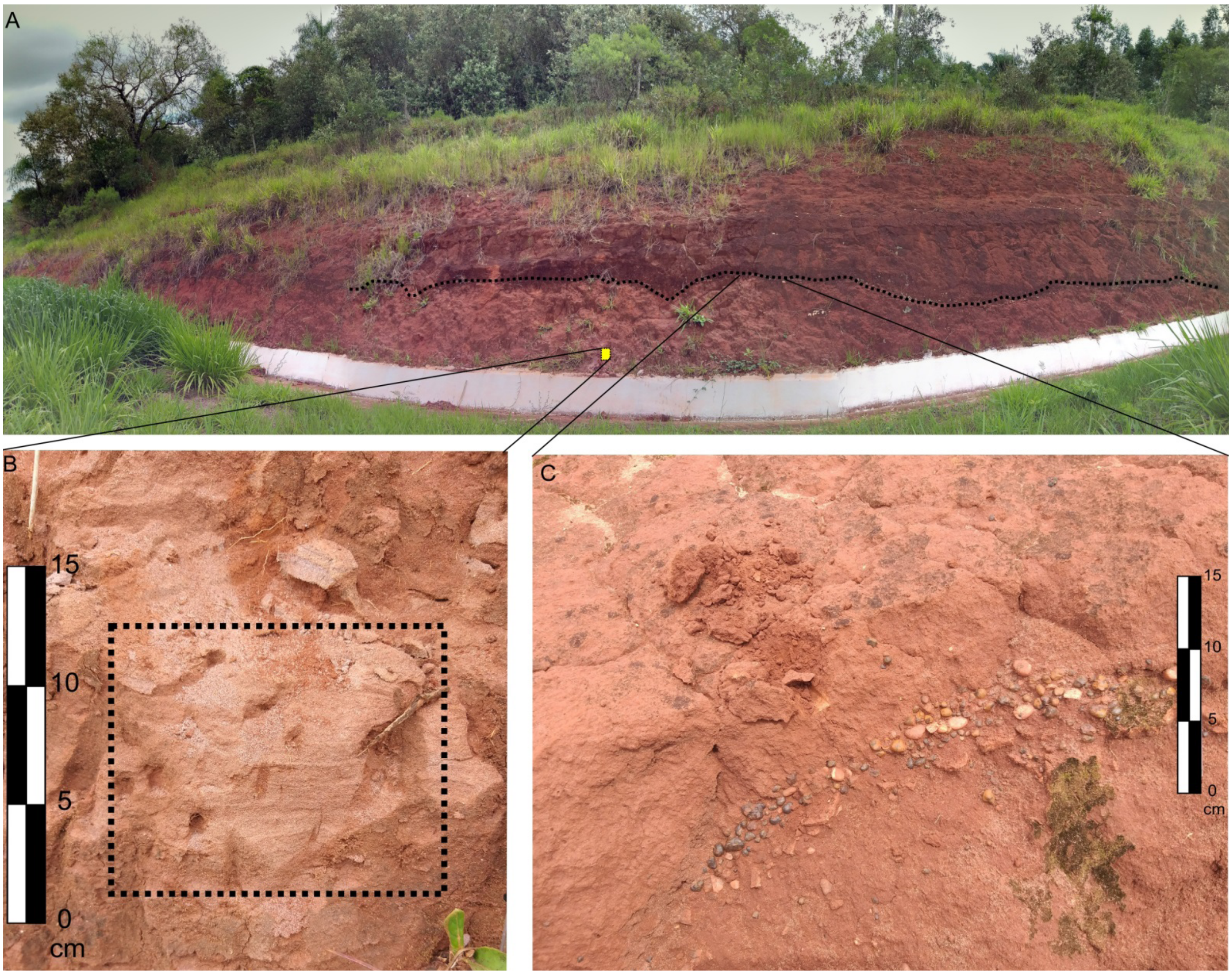


Figure 8. (A) Erosive discordance surface between sandstones of the Rio Paraná Formation and the Cenozoic colluvial deposits. (B) Weathered sandstone of the Rio Paraná Formation, with relict cross-stratification. (C) Detail of erosion surface and Cenozoic deposits with ferruginous concretions and siliceous pebbles (stone line), showing basal deposits of the covering (*stone line*). Location: Highway MS-141, 61 km (22°32'42" S, 54°01' 25" W).

It is noteworthy that the ancient Caiuá Desert may possess an even greater expanse, particularly if we incorporate the northeastern part of Paraguay, represented by the Acaray Formation. The increased exposure area of the Rio Paraná Formation, stemming from the outcomes presented in this study, significantly enhances our comprehension of the Late Cretaceous paleogeography and paleoclimate in the South American continent. Nonetheless, further investigations focused on regional integration, particularly within the Paraguay context, are imperative to construct a comprehensive framework for the paleogeographic reconstruction of the Late Cretaceous in South America.

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