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Abstract

Upper Jurassic sedimentary rocks of Guará Formation record the environmental and geotectonic changes of the early break-up stages in the southwestern portion of Gondwana. Newly-described occurrences of this formation allow the expansion of its areal distribution to the central part of the Paraná Basin, Brazil. Four vertical sections are presently described in Paraná State, Brazil. Nineteen lithofacies were grouped in five facies associations, through the classical method of facies analysis. The facies analysis included Guará Formation and the adjacent portions of the underlying Pirambóia Formation and the overlying Botucatu Formation. The depositional system of Pirambóia Formation was wet aeolian fluvial-influenced and is composed by aeolian dunes, aeolian sandsheets/interdunes and ephemeral fluvial deposits facies associations. The Guará Formation is composed of multistorey fluvial facies association constituting a highly amalgamated perennial fluvial system. It is overlaid by the Botucatu Formation, characterized as a dry aeolian system formed by aeolian dune deposits. The stratigraphic units are separated by regional unconformities marked by a shift in facies and depositional systems that reflect climatic changes. The Guará Formation depositional model, established in correlation with southern sections, represents a broad fluvial system with aeolian interaction deposited in a wide basin with more than 800 km in extension. This large depositional paleoenvironment, together with other Upper Jurassic records in southwestern Gondwana, represents the early rift stage of Gondwana break-up.

Keywords: Fluvial-aeolian interaction, braided fluvial, climatic changes, Upper Jurassic, southwestern Gondwana

1. Introduction

Understanding depositional systems are essential for palaeogeographic and palaeoclimatic reconstructions. The period between Late Jurassic and Early Cretaceous was marked by several palaeoenvironmental changes in Western Gondwana, promoted mainly by tectonic processes of continental break-up and opening of the South Atlantic Ocean (Kuchle et al., 2011; Seton et al., 2012; Salomon et al., 2017). Sedimentary basins are an essential record to in understanding the palaeoenvironmental evolution of a particular area, and the Paraná Basin, due to its large extension and location around the forming South Atlantic rift, is a key laboratory to study such evolution.

In the last years, different studies have identified Upper Jurassic fluvial-aeolian deposits in the southern portion of Paraná Basin, encompassed in the Guará (southern Brazil) and Tacuarembó (Uruguay) Formations (Scherer and Lavina, 2005, 2006; Perea et al., 2009; Reis, 2016; Amarante et al., 2019; Francischini et al. 2015). These formations represent the distal portion of a big distributive fluvial system that flowed to the southwest (Amarante et al., 2019). However, there are doubts about the extension of this system to the central part of the Paraná Basin, as well the possible faciologic variations in the proximal portions of the distributive system. We presently expand the areal distribution of the Guará Formation and evaluate the significance of this in terms of basin evolution inside the southwestern Gondwana context.

Facies analysis of four vertical profiles led to the identification of facies associations and depositional systems of Guará Formation, individualizing it from the adjacent Botucatu and Pirambóia Formations. Correlation of the profiles with previous occurrences allowed the establishment of Guará Formation as a record of a distinct paleoenvironmental and geotectonic setting in the evolution of Paraná Basin; a huge fluvial system interacting with aeolian systems in a wide endorheic basin.

2. Geological Setting

The Paraná Basin is an intracratonic basin covering an area of 1,400,000 km² across Brazil, Argentina, Uruguay, Paraguay with a small remnant Huab Basin in Namibia (Milani et al., 2007; Fig. 1A and B). The basin records various periods of subsidence and sedimentation from Ordovician to Cretaceous (Milani, 1997; Milani et al., 1998, 2007). The Paleozoic basin fill was constructed by three second-order transgressive-regressive cycles (Milani, 1997; Milani et al., 1998, 2007). The Mesozoic record is composed of continental successions that comprise six lithostratigraphic units bounded by regional unconformities (Milani, 1997; Scherer et al., 2000; Fig. 2): (1) Sanga do Cabral Formation (Scitian), consisting of fluvial, lacustrine and aeolian deposits; (2) Santa Maria and Caturrita Formation (Ladiniam to Norian) composed of fluvial-lacustrine deposits; (3) Mata Sandstone (Norian) deposits of braided fluvial system; (4) Guará Formation (Upper Jurassic), constituted by fluvial and fluvial-aeolian systems; (5) Botucatu Formation (Lower Cretaceous), recording dunes of dry aeolian system fossilized under the Serra Geral Formation volcanic lavas; and (6) Bauru Group (Upper Cretaceous) composed of fluvial and aeolian deposits. The Pirambóia Formation occurs in the northwestern portion of the basin, with fluvial-aeolian deposits of undetermined age, possibly Permian to Eocretaceous (Giannini et al., 2004). The unconformities are related to active margin tectonics of southwestern Gondwana and to South Atlantic rifting process (Milani, 1997; Zerfass et al., 2003, 2004). These tectonic events activated and reactivated the NW-SE, NE-SW and E-W fault systems, main drivers of sedimentation and preservation of stratigraphic units (Milani, 1997; Milani et al., 1998, 2007; Quintas et al., 1999; Zerfass et al., 2004, 2005).

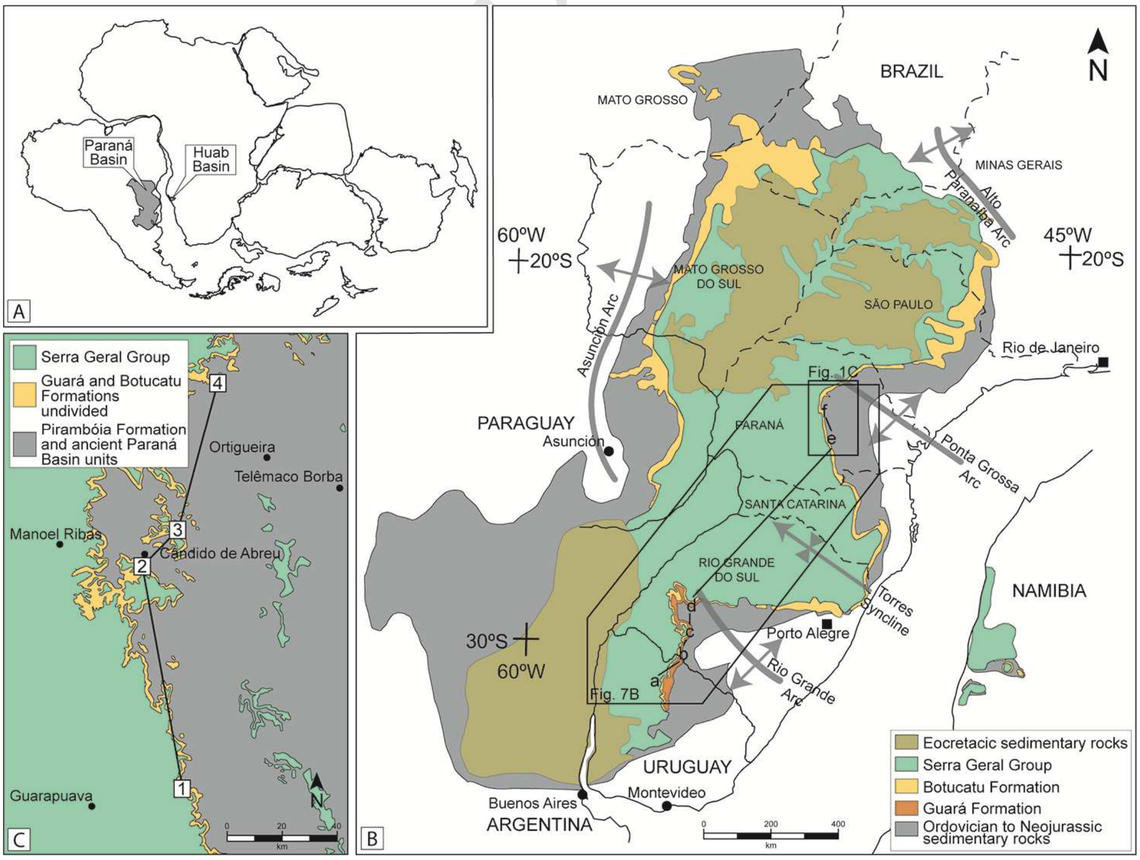


Figure 1. Location of the studied area and correlated sections in the contexts of Paraná Basin and Gondwana. A) Paraná Basin and its counterpart in southwestern Africa Huab Basin, positioned in Upper Jurassic Gondwana (based on Schmitt and Romeiro, 2017). B) Paraná and Huab Basins locations. The original occurrence of Guará Formation is in orange (small letters a, b, c and d). The newly discovered occurrences of Gará Formation are in the area with the letters f and e, highlighted in Fig. 1C (Modified from Zalán et al., 1987; Scherer and Lavina 2005, 2006; Scherer and Goldberg, 2007; Amarante 2017; Rossetti et al., 2017) C) Study area in central Paraná state, the numbers (1 to 4) are the logged sections where Guará Formation was recognized in this work..

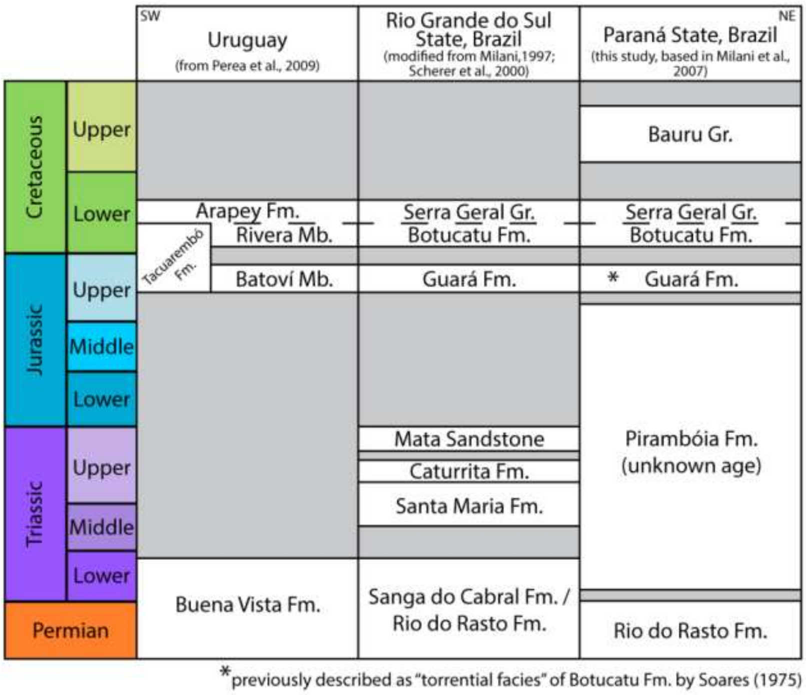


Figure 2. Stratigraphy of southern to central portions of Paraná Basin, from Upper Permian to Mesozoic, highlighting the stratigraphic position of Guará and Botucatu Formations, and the controversial age of Pirambóia Formation. Modified from Soares (1975), Milani (1997), Scherer et al. (2000), Milani et al. (2007) and Perea et al. (2009). SW - southwest; NE - northeast; Gr. - Group; Fm. - Formation; Mb. - Member.

The Pirambóia Formation is recognized in the study area as dunes and wet interdunes. Despite extensive and inconclusive discussion about nomenclature, age and areal distribution of Pirambóia Formation (Francischini et al., 2018), this work is restricted to the unit's definition on the study area, in Paraná States (Fig. 2). Firstly described by Pacheco (1927), the Pirambóia Formation was later detailed (Soares et al., 1973; Soares, 1975), allowing the recognition of an erosive unconformity between Pirambóia Formation and overlying Lower Cretaceous Botucatu Formation. Modern sedimentological concepts demonstrate that the Pirambóia Formation consists of aeolian dunes, wet and dry interdunes and ephemeral fluvial (wadis) deposits, composing a fluvial-aeolian system (Wu and Caetano-Chang, 1992; Caetano-Chang and Wu, 1994).

The Lower Cretaceous Botucatu Formation is considered a record of a palaeodesert that covered an area of more than 1,500,000 km² (Bigarella and Salamuni, 1961; Scherer and Goldberg, 2007), cropping out in the edges of Paraná Basin in Brazil, Uruguay, Argentina, Paraguay, and has correlative deposits in Namibia (e.g. Twyfelfontein Formation; Stanistreet and Stollhoffen, 1999; Fig. 1). Morphological reconstructions of aeolian dunes Performed in Botucatu Formation in southern Brazil demonstrated the occurrence of simple to compound crescentic aeolian dunes and complex linear draas (Scherer, 2000, 2002). Conglomerates and gravelly sandstones occur above its basal contact, brought by ephemeral streams (Bigarella and Salamuni, 1961; Soares, 1975; Almeida and Melo,1981; Scherer, 2002). Soares (1975) identified, in his Paraná State study area, a package of sandstones with fluvial origin overlain by aeolian dunes which he termed the "torrential facies" of the Botucatu Formation. These fluvial deposits are the main focus of our study, in which we present a different origin for them, as part of Guará Formation. Despite this, Botucatu Formation deposits are considered a dry aeolian system developed in a hyper-arid climate (Scherer and Lavina, 2006). The upper boundary of the unit is overlain by volcanic rocks of Serra Geral Group which are concordant and transitional, as indicated by the preservation of features of interactions between the lava flows and active aeolian dunes, as impressions of lava lobes in the entirely preserved topset of dunes, recording their whole morphologies under lava-flows (Scherer, 2002; Waichel at al., 2008). Due to absence of internal hiatuses in the aeolian succession (supersurfaces, Scherer, 2002) and the intimate relation between aeolian sandstones and lava-flows, the age of Botucatu Formation is close to the beginning of Serra Geral Group magmatism, dated between 134.1 and 134.8 Ma (Valanginian; Renne et al., 1992; Thiede and Vasconcelos, 2010; Rossetti et al., 2017).

Upper Jurassic rocks in Paraná Basin were recorded in Uruguay, where it is known as the Batoví Member of Tacuarembó Formation (Perea et al., 2009) and in its counterpart, the Guará Formation in the Rio Grande do Sul State, southern Brazil (Scherer and Lavina, 2005,

Fig. 1). The relative ages are attributed to their respective fossil and ichnofossil assemblages (Scherer and Lavina, 2005; Perea et al., 2009; Francischini et al., 2015). The Batoví Member is a fluvial-aeolian system (Perea et al., 2009) composed by five facies associations: aeolian dunes, aeolian sandsheets, ephemeral fluvial channels, perennial braided fluvial channels and distal sheetfloods (Amarante et al., 2019). The paleocurrent pattern indicates paleowinds to the ENE, and fluvial paleoflows to the SSW (Amarante et al., 2019). The Guará Formation consists of fluvial (in its proximal northern portion) and fluvial-aeolian (in its distal southern portion) depositional systems, forming wetting-upward cycles (Scherer and Lavina, 2005). Paleocurrents of aeolian dunes in Guará Formation were to the NE and the fluvial paleocurrents were to the SSW (Scherer and Lavina, 2005).

3. Methods

The Guará Formation crops out along escarpments that cross the central part of Paraná State in Brazil. The locations to study are identified looking for places where this escarpment are cut by roads, quarries or rivers, spots in which the vegetation cover was opened. Four outcrops distributed along an N-S belt in (Fig. 1B and C, Fig. 3) are logged in vertical sections. Section 1 (25°19’27” S; 51°11’43” W) is from vertical road cuts at kilometre 290 of BR-373 road, on the limit between Guarapuava and Prudentópolis municipalities. Section 2 (24°36’37” S; 51°20’59” W) is located 3 km to the south of Cândido de Abreu town, along a dirt road. Section 3 (24°29’24” S; 51°13’21” W) is situated 15 km to the northeast of Cândido de Abreu town, along a dirt road. Section 4 (23°59’50” S; 51°05’33” W) is located next to BR 373 between Mauá da Serra and Ortigueira, inside a farm.

Four vertical sections were constructed at a 1:50 scale, totalizing 88 m of rock succession (Fig. 3). Sedimentological data collected were classified with traditional methods of facies analysis (*sensu* Walker, 1992), in which the genetically-related lithofacies define facies associations corresponding to subenvironments within a depositional system. Lithofacies were codified by the principles of Miall (1977): the first capital letter represents the grain-size (G for gravel, S for and F for fine sediments, i.e. mud) and the second lower case letter indicates sedimentary structure. Letter (e) was used to distinguish facies formed by aeolian processes. Measures of dip azimuths of foresets present in cross-bedded sandstone sets indicate paleocurrent orientations.

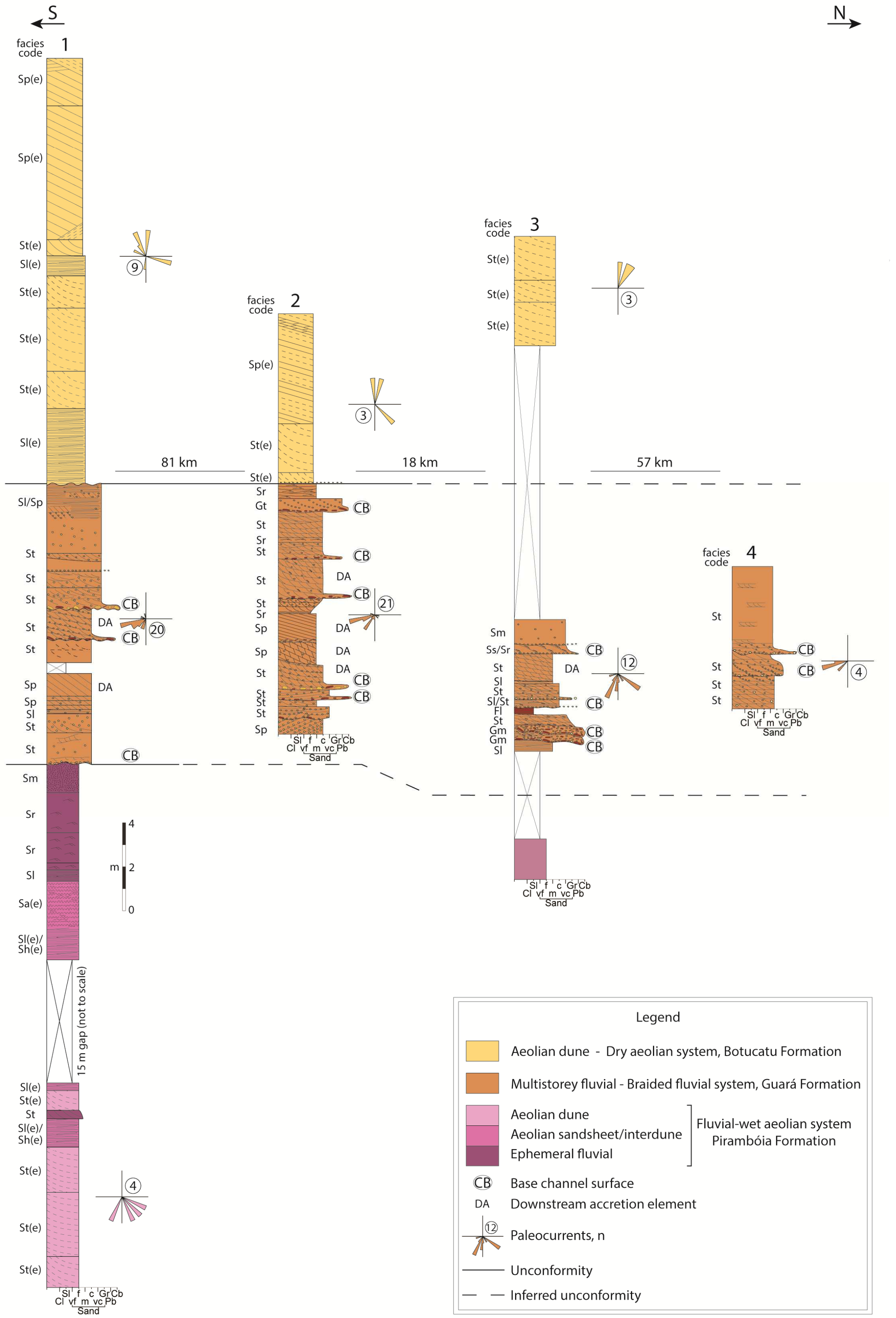


Figure 3. Logged vertical sections, divided by facies associations, depositional systems and stratigraphic units.. See Figure 1 for the location of logs. See Table 1 for facies code. The Pirambóia Formation show a diversity of aeolian facies associations and paleocurrents pattern to

S. There is a 15 m gap on the logged section of Pirambóia Formation is Section 1 due to vegetation covering the outcrop. The Guará Formation is between two regional unconformities, showing a series of amalgamated channels with paleoflow to SW in all the 3 sections. Botucatu Formation, constituted by aeolian dunes, show a variable range of paleocurrents. Where the unconformity surface was covered by vegetation, the surface is a dashed line and the top and base of Guará Formation is estimated.

4. Lithofacies

Here we present a brief summary of the general composition and texture of the sediments in each Formation recorded. Are stated here only features observable in macroscopic analysis in the field. The detailed descriptions and interpretations of each lithofacies are in Table 1.

The Pirambóia Formation succession presents a variety of lithofacies formed by subaqueous and wind-related processes (Fig. 3, Table 1). The macroscopic analysis in samples identified fine-grained sandstones with quartz and feldspar, indicating arkosic to sub-arkosic composition. The presence of argillaceous white material is notable, probably a diagenetic product. Sorting varies from well-sorted in the aeolian facies to poorly-sorted in subaqueous facies and the grains are well-rounded in general.

Lithofacies identified in Guará Formation are mainly cross-stratified medium- to very coarse-grained sandstones (rarely fine-grained), gravelly sandstones and conglomerates (Fig. 3, Table 1). Sand is poorly to very poorly-sorted with subrounded to rounded grains. The gravel fraction varies from rounded to subangular – normally the quartz clasts are more rounded while the mud clasts and lithoclasts are subrounded to subangular. Concerning the detrital composition, the sandstones and conglomerates of Guará Formation are very homogeneous. They are basically quartzarenites in sand fraction, while the gravel fraction is composed by quartz (granules to pebbles), mud clasts (granules to boulders) and sedimentary lithoclasts (pebbles to boulders). The presence of sedimentary lithoclasts is notable in gravel fraction, as it is composed of fine- to medium-grained sandstone clasts varying from pebble to boulder size classes (Fig. 4D and E, Fig. 5C and D), and granule to boulder-sized mud clasts (Fig. 4D). Fine sediments are restricted to mud clasts and one occurrence of laminated mudstone in Section 3 (Fig. 3).

Lithofacies of Botucatu Formation are sandstones deposited by aeolian processes, homogeneous in composition and texture (Table 1). They are basically fine- to medium-grained sub-arkosic sandstones, well-sorted and well-rounded sandstones.

Table 1. Summary of lithofacies, with description and interpretation of the forming process of each lithofacies. The Lithofacies are grouped by stratigraphic unit (e.g., Pirambóia, Guará and Botucatu Formations).

Code	Description	Interpretation
Pirambóia Formation		
St(e)	Fine-grained sandstones, well-sorted, trough cross-stratified in large scale sets (1.4-3.0 m thick, Fig. 4A). Foresets formed by millimetric pin stripe inversely-graded lamination.	Sinuous-crested (3D) aeolian dunes alternating grainflow and translatent subcritical wind ripple migration in the lee side (Hunter, 1977; Hunter and Rubin, 1983).
Sl(e)/S(h)	Fine-grained sandstone, well-sorted, horizontal to low-angle lamination formed by thin pinstripe inversely graded laminae.	Translatent subcritical wind ripple migration over a plane to quasi-plane surface (Kocurek, 1981).
Sa(e)	Fine-grained sandstone, well-sorted, with crenulated plane-parallel lamination (Fig. 4B).	Adhesion structures originated by adherence of dry sand grains that were carried by wind over wet surfaces (Kocurek, 1981; Kocurek and Fielder, 1982).
St	Fine- to medium-grained sandstone, moderately-sorted, in normal graded trough cross-stratified sets.	Migration of subaqueous sinuous-crested dunes in unidirectional flow (Allen 1963; Miall, 1977; Collinson et al, 2006).
Sr	Fine-grained sandstone, poorly-sorted, with ripple cross-lamination	Migration of unidirectional subaqueous ripples with subcritical climbing angle (Allen, 1963; Miall, 1977).
Sl	Fine-grained sandstone, poorly-sorted, low-angle cross-stratified.	Structures formed in unconfined high energy flows, in transitional flow regime between upper and lower (Harms et al., 1982; Bridge and Best, 1988).
Sm	Fine-grained massive sandstone, moderately-sorted.	Fast deposition of subaqueous unidirectional high energy flow, hyper-concentrated in sediments, fluidization or intensive bioturbation (Miall, 1978, 1996)

Guará Formation		
Gt	The clast-suported sandy conglomerate, quartz pebbles, trough cross-bedded. Green muddy cobbles at the set base.	Migration of subaqueous sinuous-crested gravel dunes in unidirectional flow (Todd, 1996).
Gm	The clast-supported conglomerate, pebble-sized quartz clasts, reddish muddy intraclasts and sandstone lithoclasts cobble to boulder-sized, massive (Fig. 6B). Frequently at the base of cross-strata sets. Resting upon erosive surfaces, filling scours.	Deposition of bedload as diffuse gravel sheets (Hein and Walker, 1997) in the channel bottom, resulting from erosion of previous gravelly sands (quartz pebbles), overbank deposits (mud clasts) and ancient sedimentary rocks (sandstone lithoclasts).
Sm	Very coarse-grained sandstone, massive. Muddy pebbles at the bed bottom.	Fast deposition of subaqueous unidirectional high energy flow, hyper-concentrated (Scherer et al., 2015) in sediments, fluidization or intensive bioturbation (Miall, 1978, 1996).
St	Medium to very coarse-grained gravelly sandstone, trough cross-stratified (Fig. 4D and F, 5B and E, 6C, E and F). Sets varying from 10-20 up to 40 cm thick. Foresets and sets normally graded. Quartz and muddy granules and pebbles dispersive, at the set base and marking the foresets. Frequently deposited above Gm facies bed. Compound cosets with set bases gently inclined downstream. Cosets and sets with plane or concave base.	Migration of subaqueous sinuous-crested dunes in unidirectional flow (Allen 1963; Miall, 1977; Collinson et al, 2006). Compound downstream accretion elements of mid-channel bars (Allen, 1983; Haszeldine, 1983; Wizevich, 1992; Miall, 1996).
Sp	Medium to coarse-grained sandstone, planar cross-stratified. Dispersive quartz granules. Mudclasts and quartz granules and pebbles at the set base. Sets varying from 10-20 up to 40 cm thick. Simple large scale sets (up to 1.25 m). Compound cosets with set bases gently inclined downstream.	Migration of subaqueous straight-crested dunes in unidirectional flow (Allen 1963; Miall, 1977; Collinson et al, 2006). Simple and compound downstream accretion elements of mid-channel bars (Allen, 1983; Haszeldine, 1983; Wizevich, 1992; Bridge, 1993; Miall, 1996; Jo and Choug, 2001).
Sl	Medium to coarse-grained sandstone, moderately to poorly-sorted, low-angle cross stratification, alternated with facies St (Fig. 6B and D).	Structures formed in transitional flow between subcritical and supercritical (Harms et al., 1982; Bridge and Best, 1988).
Sr	Fine to coarse sandstones with ripple cross-lamination (Fig. 5E and F).	Migration of unidirectional subaqueous 2D or 3D in lower flow regime (Allen, 1963; Miall, 1977).
Ss	Very coarse-grained sandstone with sigmoidal cross stratification.	Migration of subaqueous dunes with rapid aggradation combining traction and suspension in lower- to upper-flow regime (Wizevich, 1992).
Fl	Gray-purple, laminated mudstone (Fig. 6D).	Deposition of suspended load by settling in standing water (Miall, 1977; Turner, 1980; Jo and Chough, 2001).
Botucatu Formation		

St(e)	Fine- to medium-grained sandstone, moderately to well-sorted, trough cross-stratified in large scale sets (0.8-6 m thick, Fig. 5F and G) formed by inversely graded foresets with millimetric pin stripe lamination or massive strata (1.5 cm thick).	Sinuous-crested (3D) aeolian dunes, alternating grainflow and translatent subcritical wind ripple migration in the lee side (Hunter, 1977; Hunter and Rubin, 1983).
Sp(e)	Fine- to medium-grained sandstone, moderately to well-sorted, trough cross-stratified in large scale sets (2-6 m thick) formed by inversely graded foresets formed by millimetric pin stripe lamination or massive strata (1.5 cm thick).	Straight-crested (2D) aeolian dunes alternating grainflow and translatent subcritical wind ripple migration in the lee side (Hunter, 1977; Hunter and Rubin, 1983).
Sl(e)	Fine- to medium-grained sandstone, well-sorted, low-angle lamination formed by millimetric pin stripe inversely graded laminae (Fig. 4H).	Translatent subcritical wind ripple migration over a quasi-plane surface (Kocurek, 1981).

Figure 4. Details of Section 1 (Fig. 3). See Table 1 for facies code. A) Large scale cross strata of aeolian dune (facies St(e); person for scale 1.65 m high) and B) plane-parallel crenulated

adhesion structures (facies Sa(e); hammer length = 28 cm) from Pirambóia Formation. C) Sharp bounding surface (dashed line) marking the unconformity between Pirambóia and Guará Formations. D) Very coarse-grained cross-stratified sandstone (facies St, white dashed lines), with mudstone lithoclast or intraclast (limited by the red dashed line) and sandstone lithoclast (limited by the yellow dashed line) at the over an erosive surface representing the base of a fluvial channel. Each white or black bar on the scale has 1 cm. E) Detail of a medium-grained sandstone lithoclast at the base of a channel. F) Composite coset of trough cross stratification (facies St) compounding a downstream accretion element (DA). White dashed lines highlighting the sets and foresets. G) Sharp bounding surface (white dashed line) on the unconformity between Guará and Botucatu Formations. H) Detail of translatent wind ripple lamination (facies Sl(e); pencil tip = 2 cm).

5. Facies Associations

5.1. Pirambóia Formation

5.1.1. Aeolian dune facies association

This facies association comprises fine-grained, well-sorted, white sandstones that form large scale trough cross-stratified sets (St(e), Fig. 3, Section 1, Fig. 4A). Set thickness varies from 0.8 m to 3.0 m, and length around 2 m in outcrop, superimposed or in abrupt contact with aeolian sandsheet and ephemeral fluvial deposits. The stratification of foresets is constituted by millimetric laminae that exhibit an upward change from very fine- to fine-grained sandstone defining inverse grading, formed by the migration of translatent subcritical wind ripples. The measured azimuths of foresets indicate palaeowind to SSE (as show the rose diagram in Fig. 3).

Interpretation

Well-sorted, fine-grained sandstones arranged in large scale trough cross-stratified sets composed of wind ripple lamination suggest aeolian dune deposits (Hunter 1977, Kocurek, 1991, Scherer et al. 2007). The exclusive presence of wind ripple lamination may represent: (a) a severely truncated dune set, where the lee slipface is not preserved; (b) a dune type or portion of the dune where the slipface is absent; or (c) a low relief dune without slipface (Kocurek, 1991).

5.1.2. Aeolian sandsheet/interdune facies association

This facies association comprises fine-grained well-sorted white sandstones arranged into two distinct structures (Fig. 3, section 1): (1) Low-angle to horizontal millimetric lamination (Sl(e)/Sh(e)), with inversely graded laminae, formed by migration of translatent subcritical wind ripples over a plane or quasi-plane surface; (2) crenulated plane-parallel lamination (Sa(e); Fig. 4B) originated by adhesion of dry sand transported by wind in a wet substrate. The upward transition from facies Sl(e)/Sh(e) to Sa(e) is gradual. These facies are disposed in tabular packages 0.4 m to 1.4 m thick when in abrupt contact with aeolian dune facies association, or in thicker packages (4.6 m), directly in contact with ephemeral fluvial deposits.

Interpretation

Tabular packages of wind ripples and adhesion structures are characteristic of deposits of aeolian origin (Kocurek and Nielson, 1986; Clemmensen and Dam, 1993; Chakraborty and Chakraborty, 2001; Scherer and Lavina, 2005). The low-angle to horizontal wind ripple lamination was generated when dry sand was not sufficiently available for aeolian dune formation (Kocurek and Nielson, 1986; Clemmensen and Dam, 1993). The high water table intercepting the depositional surface is a significant mechanism that restricts dry sand supply (Kocurek and Nielson, 1986). Presence of adhesion structures testifies a moisturized substrate. Capillarity moisture was responsible for “freezing” and preserving wind ripple lamination (Kocurek and Nielson, 1986). In the Pirambóia sedimentary succession, there is a gradual transition from low-angle/horizontal wind ripple lamination to adhesion lamination, suggesting an increase in the humidity and local rise of the water table (Fig. 3, Section 1).

Tabular packages with horizontal lamination of aeolian origin can be formed in two different depositional settings: (a) metasaturated interdune areas located between aeolian dunes (e.g. Herries, 1993; Mountney & Thompson, 2002; Uličný, 2004); or (b) aeolian sandsheets, in context of low dry sand availability, inhibiting the construction of aeolian dunes (e.g. Trewin, 1993; Veiga et al., 2002; Biswas, 2005). For Pirambóia Formation deposits, both interpretations are possible. Horizontally-laminated aeolian deposits occur separating dune deposits and isolated between ephemeral fluvial deposits (Fig. 3, Section 1).

The interference of fluvial deposition in an aeolian system is also an important mechanism that controls dry sand supply (Kocurek and Nielson, 1986). Pirambóia Formation deposits present an interaction between ephemeral fluvial deposits and aeolian deposits, which indicates that fluvial activity has critical importance in the generation of aeolian sand sheets (Clemmensen and Dam, 1993; Chakraborty and Chakraborty, 2001; Scherer and Lavina, 2005).

5.1.3. Ephemeral fluvial deposits facies association

These deposits congregate facies resulting from subaqueous processes. Fine- and fine- to medium-grained white sandstone, moderately- to poorly-sorted, represents the main lithology (Fig. 3, section 1). The most recurrent structure in these deposits is subaqueous ripple lamination (Sr)arranged in a 3.6 m thick bed. Low-angle lamination formed in transitional flow (Sl) and massive (Sm) sandstones also occur. These facies together constitute a tabular sandbody 5 m thick, succeeding an aeolian sandsheet deposit, with sharp abrupt contact (Fig. 3, Section 1). In an alternative context, a single normal graded trough cross-bedded sandstone bed, representing a 3D subaqueous dune, occurs over an aeolian sandsheet deposit, whit an erosive contact, and preceding aeolian dune strata (Fig. 3, Section 1).

Interpretation

Moderately to poorly-sorted sandstones displaying ripple lamination, low-angle cross-stratification, trough-cross stratification and massive structure suggest fluvial deposition in a highly variable energy flow context. Massive sandstones are generated by deposition under upper flow regime conditions hyper-concentrated in sediments (Miall, 1978, 1996). Low-angle cross-stratification represents accelerant or waning flow within a transitional stage between subcritical and supercritical flow regimes (Harms et al., 1982; Bridge and Best, 1988). On the other hand, ripple lamination and subaqueous 3D dunes can also be products of unidirectional current under lower flow regime conditions (Allen 1963; Miall, 1977; Collinson et al, 2006). Such variation in flow energy suggests deposition in poorly-confined to unconfined ephemeral streams. The relationship of these deposits with aeolian sheets and aeolian dunes demonstrates fluvial-aeolian interactions, where fluvial transport and deposition invade the interdune area or cover aeolian sandsheets in periods of flash discharge, possibly at the border of aeolian system (Langford & Chan, 1989; Mountney and Jagger, 2004; Scherer and Lavina, 2005).

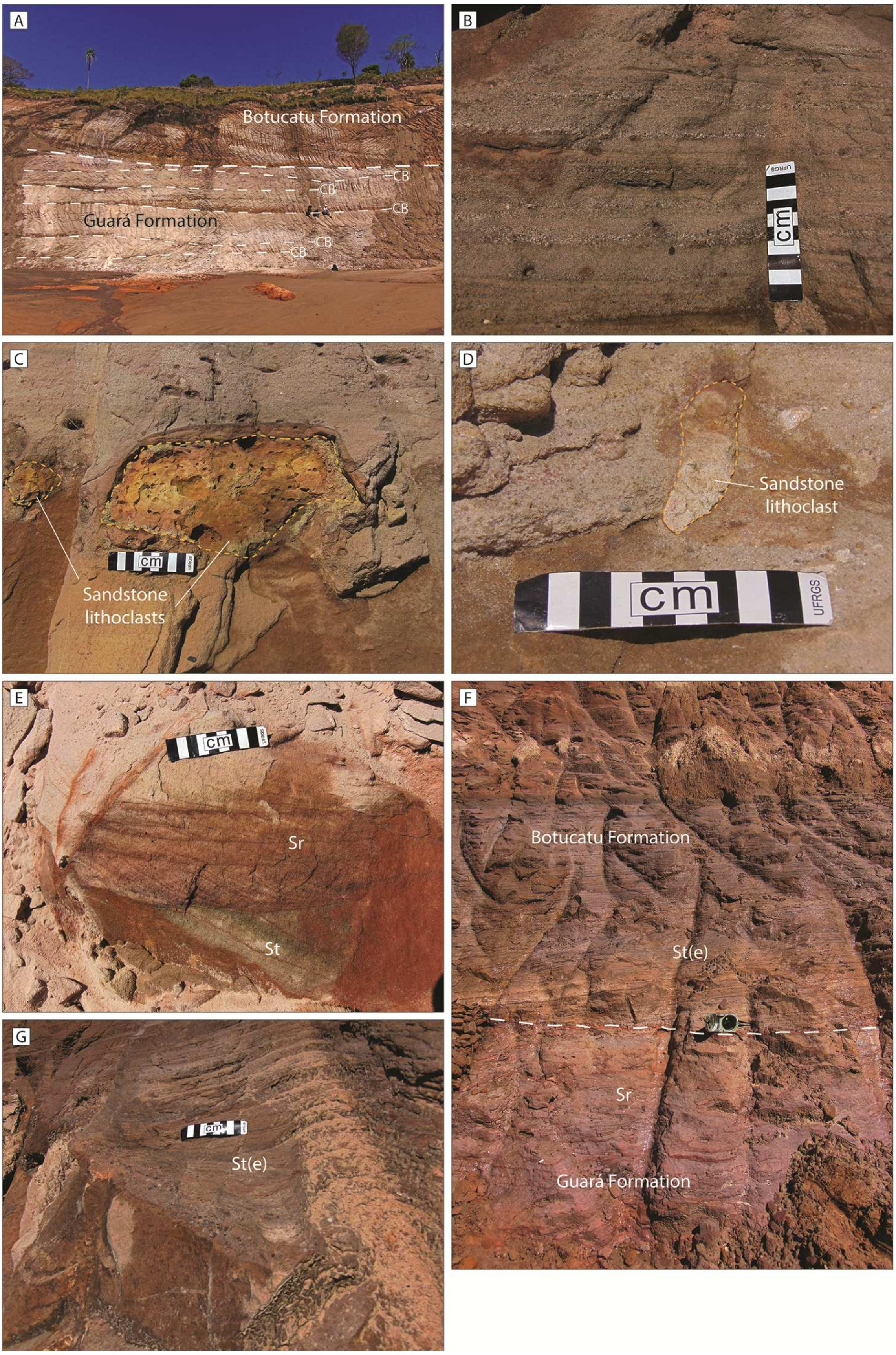
5.2. Guará Formation

5.2.1. Multistorey fluvial facies association

The deposits of Guará Formation are significantly composed of lithofacies that represent dune migration (e.g. St and Sp isolated sets; Fig. 3, Fig. 4D, 6C and E) and bedload or residual deposits that are deposited upon erosive surfaces (i.e. Gm; Fig. 3, Fig 4D, E and F). Simple and compound elements such as downstream accretion (DA, Fig. 3, 6F) are represented by large scale (0.8 to 1.9 m thick) cross-stratified sets and cosets (Sp and St). In compound elements, individual sets are bounded by low-angle inclined surfaces, dipping in the same direction of the intraset cross strata (Fig. 4F, Fig. 6F). In general, these facies are organized as fining upwards packages with massive conglomerates (facies Gm) at the base, composed by pebble to boulder sandstone clasts, granule to boulder mud clasts and granule to pebble quartz grains. The packages rest upon sharp erosive surfaces overlain by cross-stratified sets and cosets (Fig. 3, Fig. 4D, Fig. 5A, C and D, Fig. 6B). Foresets and cross-strata sets are commonly normally graded, with quartz granules and pebbles dispersive or marking the foresets and set bases (Fig. 5B).

Other sandstone lithofacies have very subordinated occurrence, including low-angle cross stratified sets (Sl), subaqueous ripple cross lamination (Sr; Fig. 5E), sigmoidal cross-stratified sets (Ss) and massive sandstones (Sm). The minor record of fine lithofacies (Fl) deserves special attention (Fig. 6D).

Paleocurrent measurements are concentrated in southwestern quadrant (Fig. 3). The mean vectors vary from 230° to 248°. Only in Section 3 there is a deviation to south, with mean vector to azimuth 179° (Fig. 3).

336 

337 **Figure 5.** Details of Section 2 (Fig. 3). A) Photo of Section 2. Amalgamated channel bodies
338 (thin white dashed lines) below unconformity (thick white dashed line) that separates Guará and

Botucatu Formations, the latter represented by a large-scale cross-stratified set of aeolian dune. B) Normal-graded foresets that form the trough cross-stratification (facies St). C) Fine-grained sandstone lithoclasts aligned over erosive surface and D) medium-grained sandstone lithoclast (highlighted by the yellow dashed line), at the channel bases. E) Coset of ripples cross-lamination (facies Sr) above cross-stratified set of subaqueous dune (facies St). F) Sharp surface boundary (white dashed line) between fluvial deposits of Guará Formation (facies Sr) and large scale trough cross strata of aeolian dunes of Botucatu Formation (facies St(e)). Compass for scale over the surface = 15 cm width. G) Detail of large-scale cross stratified set (facies St(e)) of aeolian dune, Botucatu Formation.

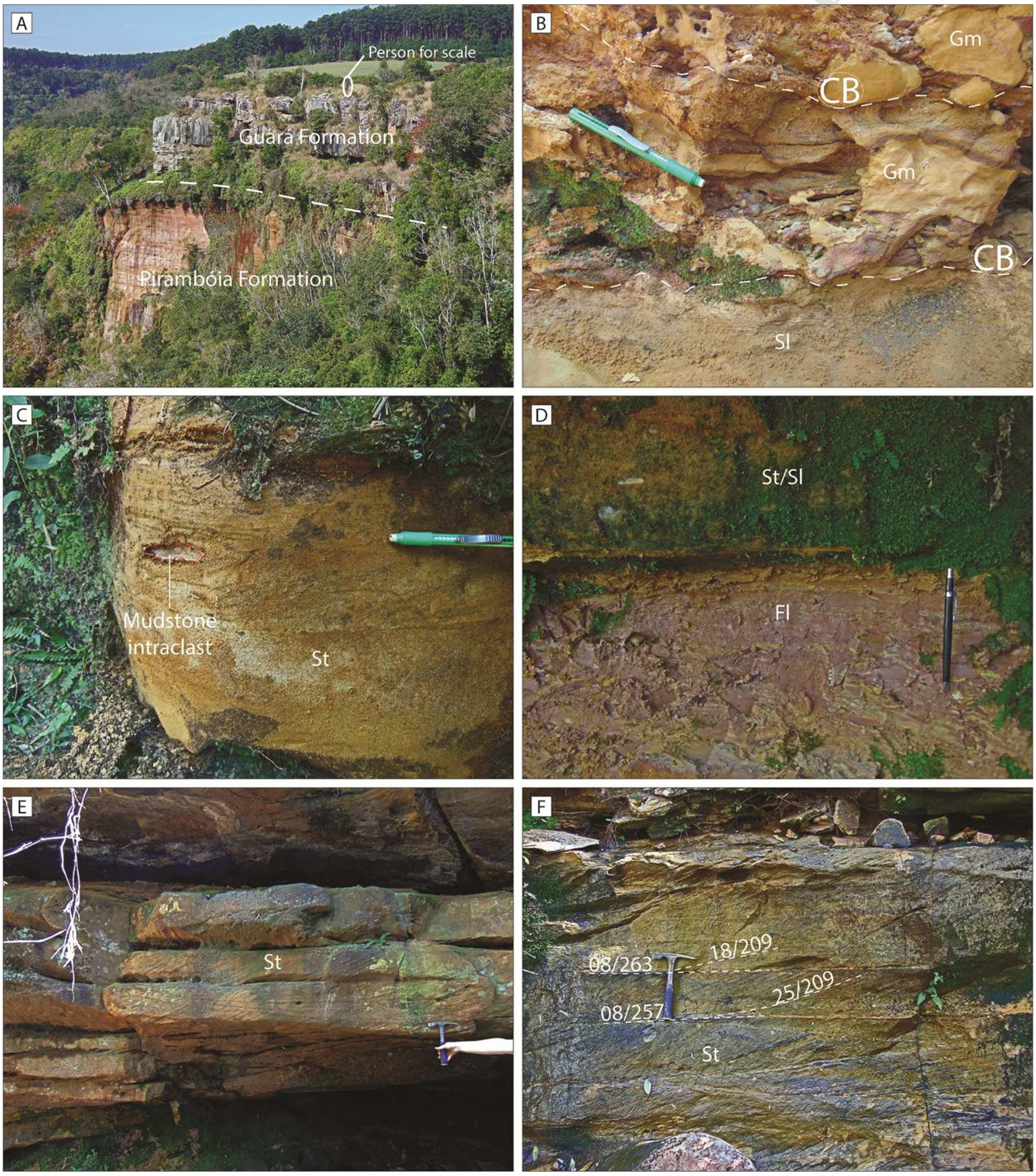


Figure 6. Details of Section 3 (Fig. 3). A) The unconformity between Pirambóia and Guará Formations, in a view of the landscape near Section 3. B) Intraformational massive conglomerates (facies Gm) over channel basal surfaces of two highly amalgamated channels. Pen length = 15 cm. C) Cross-stratified sandstone with mud clast (facies St). D) Sharp erosive surface of the channel base overlying the single floodplain mudstone (facies Fl) of the four sections studied. E) Cross-stratified isolated sets (facies St; hammer length = 28 cm). F) Composed coset (facies St) of a compound downstream accretion element (DA). The basal surfaces of the sets represent the accretion surfaces, dipping gently downstream (measures in horizontal numbers). The inclined truncated lines are the dunes foresets migrating in the front side of the bar element (paleocurrent measures in inclined numbers).

Interpretation

The fining-upward packages, the normal grading in foresets and sets, the presence of mud clasts associated with numerous erosive surfaces are characteristics of fluvial deposits (Collinson, 1996). The predominance of cross-stratified sets representing subaqueous dunes suggests perennial fluvial channels (Miall, 1996; Allen et al., 2013). The occurrence of downstream accretion elements, representing mid-channel and transverse bars migration, together with narrow dispersion of paleocurrents, points to a low sinuosity perennial fluvial system with considerable channel depth (Miall, 1996; Chakraborty, 1999; Scherer et al., 2015). The near absence of mudstones representing overbank deposits (notable in the logs of Fig. 3) in contrast with recurrence of mud clasts over erosive surfaces indicates a highly amalgamated and strongly erosive system that cannibalized overbank deposits. This amalgamation is a signal of low accommodation/supply ratio (Martinsen et al. 1999). All these characteristics indicate that Guará Formation represents highly amalgamated multistorey fluvial deposits in braided-channel belts.

5.3. Botucatu Formation

5.3.1. Aeolian dune facies association

Aeolian deposits of Botucatu Formation comprises fine- to medium-grained, moderately to well-sorted sandstones, with well-rounded grains. These sandstones constitute three lithofacies (Fig. 3): large scale trough cross-stratified sets (St(e); Fig 5A, F and G), large-scale planar cross-stratified sets (Sp(e)) and low-angle cross-stratification (Sl(e), Fig. 4H).

Cross-stratification foresets are exclusively formed by translatent subcritical wind ripples in millimetric inversely graded lamination (see facies St(e) and Sp(e) in Table 1). In the studied area, 3 to 5 cm thick massive inversely graded strata were generated by grainflow in the lee side of the dunes (Fig. 5A, F and G); or in 15 cm thick cycles alternating both wind ripples and grainflow strata. Sets from 1.5 to 6 m thick occur superimposed, bounded by planar sharp truncating surfaces, or separated by packages of low-angle cross-stratified sandstones. Dip-direction of foresets of these cross-strata shows a large dispersion between NW and SE (rose diagrams in Fig. 3). Low-angle cross-stratified sets are constituted by the migration of translatent subcritical wind ripples resulting in millimetric inversely-graded lamination (Table 1, Fig. 4H).

Interpretation

The presence of fine to medium-grained sandstones, with well-sorted and well-rounded grains arranged in cross-strata sets composed of wind ripples and grainflow strata suggest aeolian dune deposits (Hunter, 1977; Kocurek, 1981, 1991, 1996; Uličný, 2004). Trough cross stratification allied to high dispersion in the direction of curved foresets indicates crescent dunes with a sinuous crestline (e.g. 3D dunes). However, expressive sets of planar cross stratification demonstrate the occurrence of straight-crested transversal dunes (2D dunes).

The presence of cycles alternating grainflow strata and ripple laminae indicates the occurrence of intervals during which the dunes had well-developed slipfaces that alternated with periods during which part of the lee face was covered by wind ripples (Kocurek, 1991). This cyclic strata pattern suggests to seasonal changes in wind direction (Loope et al., 2001; Scherer and Goldberg, 2010).

Horizontal to low-angle stratification characterizes both sandsheet and dune-plinth deposits (Fryberger et al., 1979; Kocurek and Nielson, 1986). In relation to sandsheets, dune plinths tend to be finer-grained and are more often associated with aeolian dune cross-stratified beds (Eriksson and Simpson, 1998). Due to the homogeneity in sedimentary structures (exclusively wind-ripple lamination, Fig. 4H), the absence of sedimentary structures that character moisture during deposition in addition to the relation with aeolian dune cross-strata suggest that the packages of low-angle stratification of Botucatu Formation are the record of aeolian dune plinths.

6. Bounding surfaces

The contact between Pirambóia and Guará Formation in Paraná State is sharp contact with regional significance (Fig. 3, Fig. 4C, Fig. 6A), marking an abrupt lithological shift from arkose and subarkose fine-grained sandstone, massive, to quartzose coarse-grained gravelly sandstone with trough cross stratification (Fig. 4C). This surface represents a change from a wet aeolian system whit ephemeral fluvial influence to a perennial braided fluvial system (Fig. 3 and 4).

The transition from Guará Formation to Botucatu Formation is a regionally-correlated sharp surface (Fig. 3, Fig. 4G, Fig 5A and F) that represents the abrupt lithological transition between quartzose, coarse-grained gravelly sandstones, trough cross-stratified and arkose, fine to medium-grained sandstones, from a braided fluvial system to a dry aeolian depositional system.

7. Depositional systems

The relation between aeolian dunes and aeolian sandsheets and interdunes under water table influence points to a wet aeolian system. Additionally, the influence of ephemeral fluvial deposits in aeolian sedimentation characterizes the Pirambóia Formation succession as a fluvial-wet aeolian depositional system. A similar interpretation was accomplished by Wu and Caetano-Chang (1992) and Caetano-Chang and Wu (1994) to Pirambóia Formation in São Paulo State.

The multistorey, unidirectional and highly erosive features of fluvial deposits of the Guará Formation indicate an amalgamated perennial braided fluvial system. The fluvial origin of Guará Formation deposits was identified in other regions of the basin (Scherer and Lavina, 2005, 2006; Reis, 2016)

The dominance of dune deposits, without interdune preservation, indicates that the deposits of Botucatu Formation are part of a dry aeolian system. This point of view is in accordance with previous (Bigarella and Salamuni, 1961; Soares, 1975; Scherer, 2000, 2002; Scherer and Lavina, 2006).

8. Discussion

8.1. Stratigraphic Evolution

The regional stratigraphic logging and facies analysis allowed the recognition of five facies associations as part of three depositional systems, each corresponding to one independent stratigraphic unit. The units are: (i) a fluvial influenced wet aeolian depositional system in Pirambóia Formation; (ii) a perennial braided fluvial system in Guará Formation; and (iii) a dry aeolian system corresponding to Botucatu Formation.

Using sequence stratigraphy, large scale interpretations are limited. The volume of data recorded from Pirambóia and Botucatu Formation are not representative of their regional significance. These formations are not the main focus of this study, and although the collected data does not cover their full vertical successions, it is possible to make an evaluation of their stratigraphic evolution based on the herein described outcrops.

The record of Pirambóia Formation shows the interaction of aeolian dunes and interdunes or wet aeolian sandsheets with ephemeral fluvial processes. The studied succession has two portions separated by a gap of 15 m (Fig. 3, Section 1). In the first portion, a succession of cross-stratified sets of aeolian dunes is recognized, separated by low-angle to horizontally stratified strata of aeolian origin and a small subaqueous dune. The position of these horizontally stratified strata, between large scale aeolian cross strata, suggests the preservation of interdune deposits. The small scale subaqueous dunes demonstrate the invasion of interdune space by fluvial streams.

The second portion of Pirambóia Formation starts with 3 m of aeolian facies (low-angle strata formed by wind ripple migration and adhesion lamination), succeeded by facies of fluvial origin (low-angle cross stratification, current ripples and a massive bed), with no recurrence of aeolian facies up to the boundary with Guará Formation facies (Fig. 3, Section 1). Here, the aeolian portion demonstrates an increase of humidity influencing the aeolian transport, in the transition from wind ripples to adhesion lamination (Fig. 3, Section 1, Fig. 4B). The absence of aeolian dunes covering these beds suggests that these successions record a wet aeolian sandsheet.

The record of Pirambóia Formation in Section 1 (Fig. 3) shows a transition from facies of dry aeolian processes (aeolian dunes and dry aeolian sandsheets) passing through aeolian facies influenced for the water table (wet aeolian sandsheet, facies Sa(e)) and ending ephemeral fluvial deposits (facies St, Sl, Sm and Sr). This vertical facies succession represents the increase in humidity in the aeolian system along time, in a wetting-upward trend. The increase in humidity induced by the rise of the phreatic water table, reduced gradually the supply of dry sand, inhibiting the aeolian dune formation until the ephemeral fluvial processes prevailed.

The sharp bounding surface separating the units can be classified as an unconformity, marked by abrupt facies shift between Pirambóia and Guará Formations (Fig. 3, Fig. 4C, Fig. 6A), including color (from white yellowish to orange brownish), grain size (from fine- to coarse-grained), detrital composition (from arkose/subarkose to quartzarenite) and sedimentary structures (from massive to trough cross-stratified). This facies change represents an abrupt contact between ephemeral fluvial deposits of the Pirambóia Formation and multistorey fluvial channels of the Guará Formation, marking a major transition from a wet aeolian depositional system to a perennial braided fluvial system. Besides that, this surface has regional significance, correlated for nearly 100 km between Sections 1 and 3 (Fig. 3, Fig. 4C, Fig. 6A). The hiatus represented by this surface is unknown because the age of Pirambóia Formation is undetermined. The absence of pedogenic features below the unconformity may be explained by the erosive character of channelized fluvial deposits of Guará Formation, which probably caused the erosion of the superficial layer of pre-existent rocks. The presence of sandstone pebble to boulder lithoclasts concentrated over erosive surfaces in Guará Formation deposits (Fig. 4D and E, Fig. 5C and D) is diagnostic of the erosion of pre-existent consolidated sedimentary rocks. By context, these lithoclasts represent the original rocks of Pirambóia Formation. If the deposits of Pirambóia Formations were consolidated by diagenesis during the activity of Guará Formation fluvial channels, then a time hiatus would be assumed between the two units.

The composition and texture of the sandstones of the Guará Formation – well-rounded quartzarenites – are a strong characteristic of recycled sedimentary rocks, in other words, formed by sediment eroded from previous sedimentary rocks (Garzanti, 2016). The diagenesis and re-exposure to weathering, erosion and transport processes tend to concentrate quartz, a more resistant component in relation to feldspars and metamorphic/plutonic lithoclasts (Garzanti, 2016). The presence of gravel-sized sandstone clast, especially concentrated over scouring channel basal surfaces presumes the erosion of consolidated sandstones (Fig. 4D and E, Fig. 5C and D). This hypothesis is reinforced by the location of the study area and the paleocurrent patterns to SSW which suggest sediment transport from a source area located in northeastern Paraná Basin.

In the four studied sections, the Guará Formation is marked by the predominance of cross strata generated by subaqueous dune migration. In three of the sections studied (sections 1, 2 and 3, Fig. 3), the presence of large cross strata is notable, both simple and composed, representing downstream accretion elements (Fig. 3, 4F, 5F). These architectural elements are the typical unit of construction and migration of mid-channel fluvial bars (Miall, 1985; Wizevich, 1992; Bridge, 1993; Miall, 1996; Jo and Chough, 2001; Scherer et al., 2015). The mudstone bed (facies Fl, Fig. 3, section 3) represents overbank deposits in low energy floodplains and the recurrence of gravel-sized mud clasts over scour surfaces at the base of cross-stratified sets signal the low preservation potential of these deposits, frequently eroded by new channels (Miall, 1977; Ramos et al., 1986; Wizevich, 1992; Jo and Chough, 2001). The high number of channel boundaries (multistorey) identified in relatively thin successions, associated with low preservation of overbank deposits, is characteristic of braided rivers in the context of low vertical accommodation space (Shanley and McCabe, 1993; Wright and Marriot, 1993; Martinsen et al. 1999; Scherer et al., 2015).

The contact between Guará and Botucatu Formations is a sharp surface (Fig. 5A), marked by an abrupt facies shift where multistorey fluvial channel deposit of a perennial braided fluvial system of Guará Formation is overlain by superimposed sets of aeolian dunes of the Botucatu Formation. The Guará-Botucatu unconformity was described in detail in southern Paraná Basin (Scherer and Lavina 2006; Amarante et al., 2019). In the Rio Grande do Sul State, Scherer and Lavina (2006) mapped this unconformity for a 170 km long outcrop belt, identifying features of time hiatus as polygonal fractures and calcrete clasts at the base of Botucatu Formation. Amarante et al. (2019) recognized the surface in northwestern Uruguay, highlighting the shift of depositional systems trough it. The substantial climatic change necessary to recover a perennial river system by a hyper-arid aeolian deposit (Scherer, 2000; Scherer and Lavina, 2006, Amarante et al. 2019) is significant evidence of a sequence boundary. This change was also observed in this study in Paraná state.

The time of this boundary could be supposed by relative datation. Studies about the palaeofauna and palaeoichnofauna purpose Upper Jurassic age to Guará Formation (Scherer and Lavina, 2005; Dantzien Dias at al., 2007; Perea et al., 2009). Francischini et al. (2015) point to a significant difference in the dimensions in the dinosaur palaeofaunas between Guará and Botucatu Formation, suggesting that the Botucatu aridization reduced the size of the species. The age of Botucatu Formation final deposition is directly related with volcanic floods of Serra Geral Formation, dated in Valanginian (Renne et al., 1992; Thiede and Vasconcelos, 2010; Rossetti et al., 2017). In this sense, between Upper Jurassic and Valanginian we can attribute at least 5 million years of hiatus to the Guará-Botucatu unconformity, following the International Stratigraphic Chart (Cohen et al., 2013).

The Botucatu Formation succession shows large scale trough cross stratified sets with thicknesses varying from 1.5 to 6 m composed by wind ripple lamination and grainflow stratification. The sets dominated by wind ripples appear to be concentrated at the base, while the grain flow strata arise late in the vertical facies succession. This indicates upward increase in dune size, permitting the development of a slipface in the lee side of the dunes (Kokurek, 1991, 1996). The non-preservation of interdune deposits corroborates the interpretation of a dry aeolian system for the Botucatu Formation, in which the dunes climbed each other without the formation of interdune deposits due to lack of influence of phreatic water table (Mountney, 2012).

8.2. The Guará Formation in Gondwana context

The Guará Formation's braided fluvial deposits in Paraná state represents the proximal area of a wide depositional basin. Regional correlation integrating Scherer and Lavina (2006) and Amarante (2019) shows that Guará Formation constitutes the record of continental depositional systems in an area >800 km in north-south extension (Fig. 7). The facies and facies associations distribution also shows downstream shifting in depositional systems of Guará Formation, starting with fluvial systems, grading to fluvial-aeolian and ending in fluvial ephemeral and terminal distal sheetfloods. The paleocurrent patterns are similar in all sections, preferentially to SSW (see rose diagrams in Fig. 7). There is a reduction of general grain size of the deposits to the southwest direction, following the paleocurrent trend, starting with conglomeratic sandstones and conglomerates in Paraná up to fine-grained sandstones in Uruguay. The extension, the shifting depositional system and the reduction in grain size along the paleocurrent trend reinforce the proposition of Amarante et al. (2019) that Guará and Tacuarembó Formations constitute a big distributive fluvial system, following the models purposed by Hartley et al. (2010), Weissmann et al. (2010), Owen et al. (2015) and Owen et al. (2018).

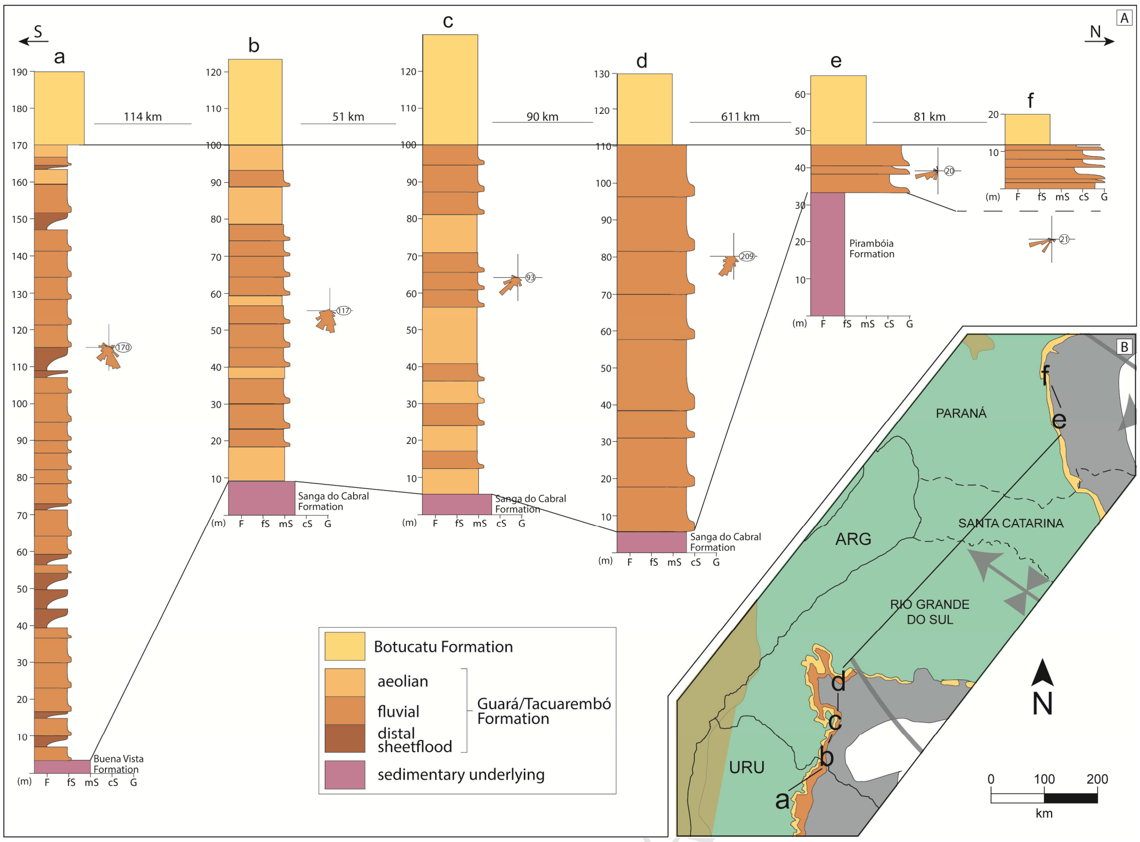


Figure 7. A) Regional correlation and cross-section through the Guará Formation occurrence area between the southern portion (section a) and the central portion (section f) of Paraná Basin. Section "a" has been adapted from Amarante et al. (2019). Sections "b" and "c" from Scherer and Lavina (2005, 2006). Section "d" from Scherer and Lavina (2006) and Reis (2016). Sections "e" and "f" from this study. B) Indicates the location map the cross-section, as a detail of Fig. 1B.

The Guará Formation as outlined by depositional model allows Southwestern Gondwana palaeoenvironmental reconstructions. The model suggests that Paraná Basin was dominated by fluvial and fluvial-aeolian systems in Upper Jurassic. The paleoflow points to a depocenter somewhere near the Argentina-Uruguay border, a unique condition in Paraná Basin history, in which the depocenter was located in the central portion of the basin. The distribution of the depositional systems points to an endorheic shallow basin.

The basal portion of the Twyfelfontein Formation in Namibia, southern Africa, is another example of an Upper Jurassic fluvial-aeolian succession (Fig. 8), designated by Mountney (1998) as Khrone Member (alluvial) and Mixed Unit (fluvial-aeolian)which precedes the Main Aeolian Unit (continuity of Botucatu Formation in African continent). Although the stratigraphic position of the Mixed Unit is the same as Guará Formation, below the Botucatu

Formation, detailed studies were not done to understand the stratigraphic relation between the units.

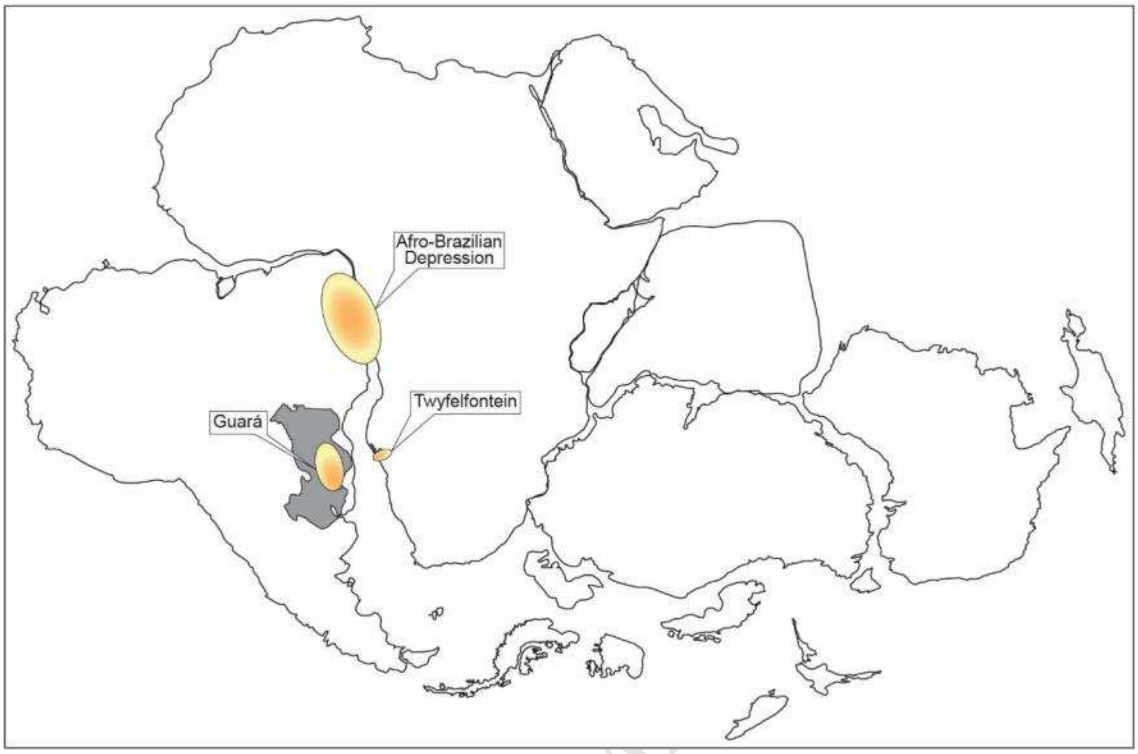


Figure 8. Upper Jurassic fluvial-aeolian occurrences in southwestern Gondwana: orange oval areas indicate the estimated extension and position inside Gondwana of the systems of Afro-Brazilian Depression, Guará Formation (Brazil) and Twyfelfontein Formation (Namibia). Gondwana reconstruction based on Schmitt and Romeiro (2017). Grey outlined areas = Paraná Basin and Huab Basin.

Similar depositional systems are found in reconstructions of Upper Jurassic Afro-Brazilian Depression setting (Fig. 8; Kuchle et al., 2011). These authors proposed that a fluvial, aeolian and lacustrine succession was deposited in a broad shallow endorheic basin occurring between Northeastern Brazil and Western Africa. These records and Guará model point to the existence of two Neo-Jurassic broad endorheic shallow basins in Gondwana (Fig. 8). Morley (2002) purposed the Early Rift Stage as a wide shallow basin formed by the aggregation of small slip faults in a region. This basin would occupy an area much bigger than the subsequent rift valleys (Morley, 2002). Kuchle and Scherer (2010) purposed a stratigraphic classification to this sedimentation: Rift Initiation Tectonic System Tract.

Different paleogeographic models predicted tectonism in the southwestern part of Gondwana in pre break up stages. The palaeomagnetism based model of Seton (2012) purposed transcurrent movements in the region of Chaco-Paraná around 150 Ma (Tithonian) that the authors attributed to the individualization of “Paraná subplate”. Salomon et al. (2017) analyzed the extensional structures of the conjugated margin of southern Brazil-Namibia and purposed a progressive rotation of southern South American Plate generated extension in a vast in a wide region around the future South Atlantic Rift. Is plausible to suppose that this tectonism promoted subsidence and sedimentation after the culmination of Gondwana break-up later in Lower Cretaceous.

9. Conclusions

The Upper Jurassic Guará Formation is recognized in the northern portion of Paraná Basin (Paraná state, Brazil). The formation records multistorey channels of a braided fluvial system. Sedimentological features and stratigraphic position allow the distinction of Guará Formation from Pirambóia and Botucatu formations (respectively underlying and overlying units). Fluvial paleocurrent pattern to SSW and detrital composition points to ancient stratigraphic units of Paraná Basin as sedimentary source area.

The spatial area covered by Guará Formation is thus expanded to a >800 km area with an overall north to south extension (Fig. 1, Fig. 7). This new fact points to a special geotectonic context for the Paraná Basin in Upper Jurassic, where a broad distributive fluvial system flowing from NE to SW interacted in distal portions with aeolian systems filling an endorheic basin. Fluvial-aeolian sedimentation is found in other parts of southwestern Gondwana in Upper Jurassic, as Huab Basin in Namibia and Afro-Brazilian Depression. These sedimentary successions are the record of the early stages of Gondwana break-up.

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Highlights

- The area of Guará Formation (Upper Jurassic) is expanded to the central part of Paraná Basin.
- The Guará Formation is correlated in >800 km long dip section through southern Brazil and northwestern Uruguay.
- Decreasing in grain size and changes in depositional systems along the section point to a big distributive fluvial system with aeolian influence.
- The Guará Formation is the record of a wide endorheic basin related with the first tectonic efforts of Gondwana break-up