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A field guide to the sand-rich turbidite systems of the Taciba Formation, Itararé Group, Paraná basin, Brazil

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Abstract

This field guide provides a detailed outcrop logistics, access and description of the sand-rich turbidite deposits of the Taciba Formation (Rio do Segredo Member), the uppermost unit of the Pennsylvanian Itararé Group (Paraná Basin), which crops out in the Santa Catarina State, southern Brazil. This area has become a classic destination for professional' field courses and students interested in outcrop analogous to offshore turbidite reservoirs. Although some of the outcrops have been widely described, some localities remain unexplored. These turbidite systems are here subdivided on the basis of their degree of confinement, relative to the Precambrian basin floor topography. The bedrock morphology was shaped during the Late Paleozoic Ice Age. Advance and retreat phases of glaciers are represented by superficial scouring into the crystalline basement. This glacially-carved topography in turn controlled the subsequent sedimentation by forming a basal nonconformity in the Taciba Formation. Thus, the turbidity currents and their deposits, exposed in three main areas along the eastern margin of the Paraná basin, were classified as confined and/or unconfined. This field guide is also valuable for nourishing the ongoing debate on the turbidity currents interpretations based on sedimentological descriptions of the main localities and their major features. Field guides are quite popular in North America and Europe, among other places, but not so popular in Brazilian literature. The present contribution aims to bring details on some little known turbidite-outcropping localities of the Taciba Formation. It also intends, through its format, to attract interest of national and international geologists on Brazilian key outcrops and offer a synthesis and a starting point for teaching purposes and future studies.

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1. Introduction

The eastern margin of the Paraná Basin, in southern Brazil, offers spectacular outcrops related to gravitational flows deposits (Gama et al. 1992; Eyles et al. 1993; Vesely and Assine 2002; D'Ávila et al. 2008; Suss et al. 2014; Aquino et al. 2016; Carvalho and Vesely 2016; Fallgatter and Paim 2019; Rodrigues et al. 2021; Vesely et al. 2021; Fallgatter et al. 2023). There, turbidites of the Itararé Group present a variety of features that can be associated with glacially induced sea-level fluctuations during the Late Paleozoic Ice Age (LPIA). The Itararé Group contains a well-known turbidite interval, a long-time recognized unit (Salamuni et al. 1966; Castro 1980) that is informally subdivided into thin- and thick-bedded or into mud- and sand-rich turbidites. Salamuni et al. (1966) recognized, for the first-time, sandstone beds related to the deposition from turbidity currents in the Brazilian sedimentary basins, through extensive mapping of the Permo-Carboniferous rocks of the Itararé Group in the south of the Paraná and north of the Santa Catarina states. Although the authors were referring to the thin-bedded turbidites that dominate the upper portion of the Taciba Formation, the paper is considered the seminal work on the research of turbidites in Brazil (see Vesely et al. 2021). This field guide comprises the lower portion of the Rio do Sul Formation of Schneider et al. (1974), or the Rio do Segredo Member of the Taciba Formation of França and Potter (1988). It follows the deposition of a black shale interval, a well-known stratigraphic marker in the Itararé Group recognized as the Lontras Shale that is frequently used for regional correlations. These deposits are related to a forced regressive phase that follows a major flooding event, recorded by the abrupt superposition of long-lived, flood-derived hyperpycnal underflow deposits and short-lived, surge-type turbidites (Kneller 1995; Mulder and Alexander 2001; Meiburg

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and Kneller 2010) above the Lontras Shale (i.e., correlative conformity; Puigdomenech et al. 2014; Valdez-Buso et al. 2019; Fallgatter et al. 2023).

This field guide presents three main areas (Fig. 1) exposing turbidity systems deposited under distinct degrees of confinement. The Vidal Ramos and Rio dos Cedros areas show turbidites confined to a pre-existing topography, whereas the Doutor Pedrinho/Benedito Novo area shows an unconfined character. The control on deposition from gravity-driven flows in confined settings is provided by the interactions between flow efficiency, size and morphology of the receiving basin (Kneller 1995; Prather et al. 1998; Kneller and McCaffrey 1999; Sinclair and Tomasso 2002). In confined settings, depositional architecture of turbidite systems depend on the available space and sediment supply (Kneller 1995; Patacci et al. 2015). Thus, there is no absolute size that defines confinement and whether the flows are going to reach the margin or not will depend on their efficiency (Kneller 1995). In the present outcrops, the confinement conditions were created by ice advance over the Precambrian bedrock resulting in glacially-carved lows preserved as narrow troughs. Therefore, the succeeding subglacial and deglacial sedimentation were mainly controlled by these relatively confined depositional settings.

In areas where turbidity currents are unconstrained by pre-existing topography, their deposits are quite extensive and crops out for more than 1000 km^2, so there must be many outcrops that are not covered in this guide (see Vesely et al. 2021 for additional outcrops). In fact, we recommend further investigations in Dona Emma, Presidente Getúlio, Vitor Meireles, José Boiteux, Ascurra and Barra do Prata municipalities where the same succession crops out (Fig. 1). This field guide is not intended to make extensive discussions and interpretations about the processes involved in the deposition of turbidity currents, but rather to provide descriptive and illustrative details of some of the key localities in these regions. The outcrops are in a suggested order to follow, making it easier to understand the depositional systems.

2. Logistics and recommendations

Two main airports are relatively close to the outcrops: the Hercílio Luz International Airport in Florianópolis and the Navegantes International Airport (Fig. 1). The best way from the Hercílio Luz International Airport is to take the BR 101 highway to Palhoça. From there, take the BR 282 road and drive west about 90 km to Alfredo Wagner. If you have time, interesting deposits related to the theme crops out close to this locality (for more details see Rocha-Campos et al. 1988 and Fallgatter and Paim 2019). From Alfredo Wagner, take the SC 350 road and drive northwest about 30 km, turn right at the junction, to follow the SC 281 road for about 14 km. At the next junction, turn right and take the BR 486/SC 416 road for more 12 km to Vidal Ramos, the first main city to start the field trip.

The best way from the Navegantes International Airport (Fig. 1) is to take the BR 470 and drive west about 73 km to Indaial. Turn right at the roundabout and drive north about 9 km to Timbó. Here you have two options: keep driving north for another 9 km to Rio dos Cedros or turn left and take the BR 477 for more 30 km to Doutor Pedrinho/Benedito Novo. Vidal Ramos, Rio dos Cedros and Doutor Pedrinho cities have some facilities such as hotels, inns, campsites, hospitals, gas stations, restaurants and supermarkets and serve as a

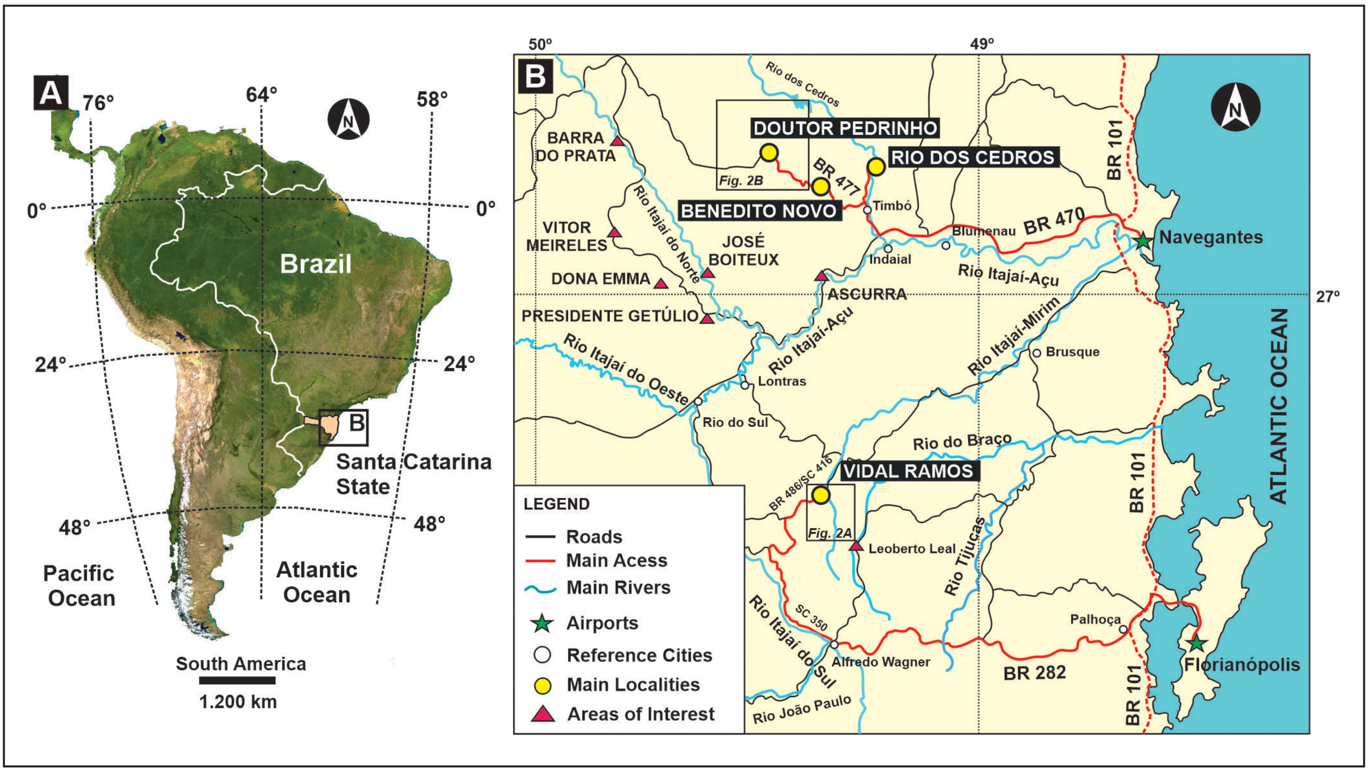

FIGURE 1 - Location of the areas of interest. A) Location of Santa Catarina State in southern Brazil. B) Road map of part of the eastern portion of the Santa Catarina State showing main access to the areas. The map also includes other areas of interest (see text for details). Black boxes indicate the areas covered by the geological maps in figure 2.

local base to move to nearby outcrops. Booking in advance is always recommended.

The eastern region of the Santa Catarina State is covered by the Atlantic Forest, a dense vegetation that can be cold and wet during the winter and hot and humid during the summer. Climatic conditions are instable and can change very fast, so visitors should be prepared. Most of the outcrops are situated along river margins, caves and waterfalls, thus the best time to visit some of the localities is during the summer (November to March) when the rainy season declines and river levels are lower, allowing for better exposures. Always bring a first aid kit, repellent and sunscreen. Beware of snakes (the most common and dangerous species is *Bothrops jararaca*), spiders and scorpions and always remember to let someone know where you are going and when you will be back. It is highly recommended to visit the outcrops in groups to reduce the risks. Bring snake gaiters protection and always check the availability of antiophidic serum in nearby hospitals. When visiting the outcrops, ask consent to property owners if needed and show respect to local people.

3. Geological Setting

The Itararé Group is a significant depositional interval of the Paraná basin, providing important evidences for glacial paleogeographic reconstructions over the Gondwana. The Paraná Basin is a northeast-southwest oriented, elongate intracratonic basin settled on the South American platform. The Pennsylvanian Itararé Group (late Bashkirian to late Moscovian; Souza 2006; Cagliari et al. 2016) records a prolonged interval of glacial influence in the basin and comprise the record of the Late Paleozoic Ice Age (LPIA). It encompasses several subglacial features (striated pavements, gouges and troughs), dropstone-bearing intervals and deglacial deposits relative to waxing and waning phases of glaciers.

Reconstructions of the glacial paleogeography during the Itararé Group deposition are mostly based on subglacial erosion features and the subsequent deposits. Ice motion mainly headed to the north and northwest (Rosa et al. 2016 and references therein). A source of ice in South Africa thus may represent the spreading center from which glaciers flowed out to reach the eastern margin of the Paraná Basin. Restoring the positions of South America and southern Africa during the Late Paleozoic, an ice center located in the Huab and Kunene areas of western Namibia (the Windhoek Ice Cap; Santos et al. 1996) can be identified as the most probable source of ice. Grounded on these reconstructions, late Paleozoic glacial deposits in the eastern Paraná Basin have been ascribed to the advance and retreat of an ice sheet (Bigarella et al. 1967; Crowell and Frakes 1970), to large glacial lobes (Santos et al. 1996), multiple, minor ice lobes (Vesely et al. 2015) or to topographically controlled ice corridors (Fallgatter and Paim 2019). Considering that deposition was partially confined to glacial troughs, ice that reached the eastern rim of the Paraná basin can be ascribed to topographically-controlled ice streams (Fallgatter and Paim 2019) flowing out from continental ice masses (Bigarella et al. 1967). However, glacial lobes may have occurred at the termini of ice streams (Santos et al. 1996; Vesely et al. 2015), where the ice was free to propagate. In light of a probable link between the southeastern margin of Brazil and southwestern margin of Africa during the LPIA, an accurate paleogeographic scenario should contain elements from several of the models stated above. The ubiquitous NW trend of ice movement in the Itararé Group is probably a result of the position of the Paraná Basin depocenter, and the ice carved troughs may have been facilitated by pre-existing NW-oriented tectonic lineaments in the Precambrian bedrock (Zalán et al. 1990; Fallgatter and Paim 2019; Fallgatter et al. 2023).

Based on outcrop sections along the eastern margin of the basin, Schneider et al. (1974) divided the Itararé Group into the Campo do Tenente, Mafra and Rio do Sul formations. Later, França and Potter (1988), working largely with subsurface data, subdivided the Itararé Group into three major fining-upward glacial-deglacial cycles, named Lagoa Azul, Campo Mourão and Taciba formations. The subdivision of França and Potter (1988) is here used and is quite similar to the divisions proposed by Schneider et al. (1974). The Rio do Segredo Member of the Taciba Formation comprises the sand-rich, thick-bedded turbidite systems that abruptly overlain the Lontras Shale (Fig. 2), a fossiliferous, quite diverse unit encompassing both terrestrial and aquatic groups, including marine organisms (Neves et al. 2014, Wilner et al. 2016; Mouro et al. 2020; Saldanha et al. 2023). The Taciba Formation represents the last glacial record of the Paraná Basin (Mottin and Vesely 2021).

4. Vidal Ramos area

All the suggested outcrops to visit near Vidal Ramos are of easy access. The turbidite deposits are confined to a glacially-carved low over the Precambrian metamorphic bedrock (Brusque Metamorphic Complex), preserved as a wide, NNW-SSE oriented trough (Fig. 2; Fallgatter et al. 2023). This partially exhumed paleotrough extends further south for about 35 km to the Alfredo Wagner area where similar deposits crop out (Fallgatter and Paim 2019). This connection is proposed by the relative positions of the two localities, the alignment of glacial striations (Rocha-Campos et al. 1988; Puigdomenech et al. 2014; Rosa et al. 2021), and the similar facies distribution (Fallgatter et al. 2023). Further north, a connection between the paleotrough and the Rio do Sul embayment (Canuto 1993; Santos et al. 1996; Fallgatter and Paim 2019; Schemiko et al. 2022) cannot be discarded.

The turbidite system that fills this glacial trough consists of three sand-rich units (Ts1 to Ts3 stages), intercalated with three thin-bedded packages (F1 to F3), defined by an abrupt change in grain size and bed thickness (see Fallgatter et al. 2023). These units are easily recognizable and mappable when present in the study area. The Ts1 may reach up to 9 m thick in the trough axis, thinning-out to 1 m near the trough flanks. In the trough axis, the initial deposition of Ts1 erodes previous deposits of the F1 unit. The Ts2 shows an increase in individual bed thickness and is up to 7 m thick along the trough axis and thins out to about 3 m close to the trough margins. Deposits of Ts2 erodes F2 beds. The Ts3 stage is up to 9 m thick close to the trough axis and thins out to 1 m towards the glacial trough flanks. Unlike Ts1 and Ts2 stages, deposits of Ts3 erodes previous sandstone beds of Ts2 and are interfingered with F3. All stages show an overall lenticular geometry, thinning-out towards the trough flanks where the individual sandstone beds pinch-out and onlap the Precambrian bedrock. Paleocurrents taken on

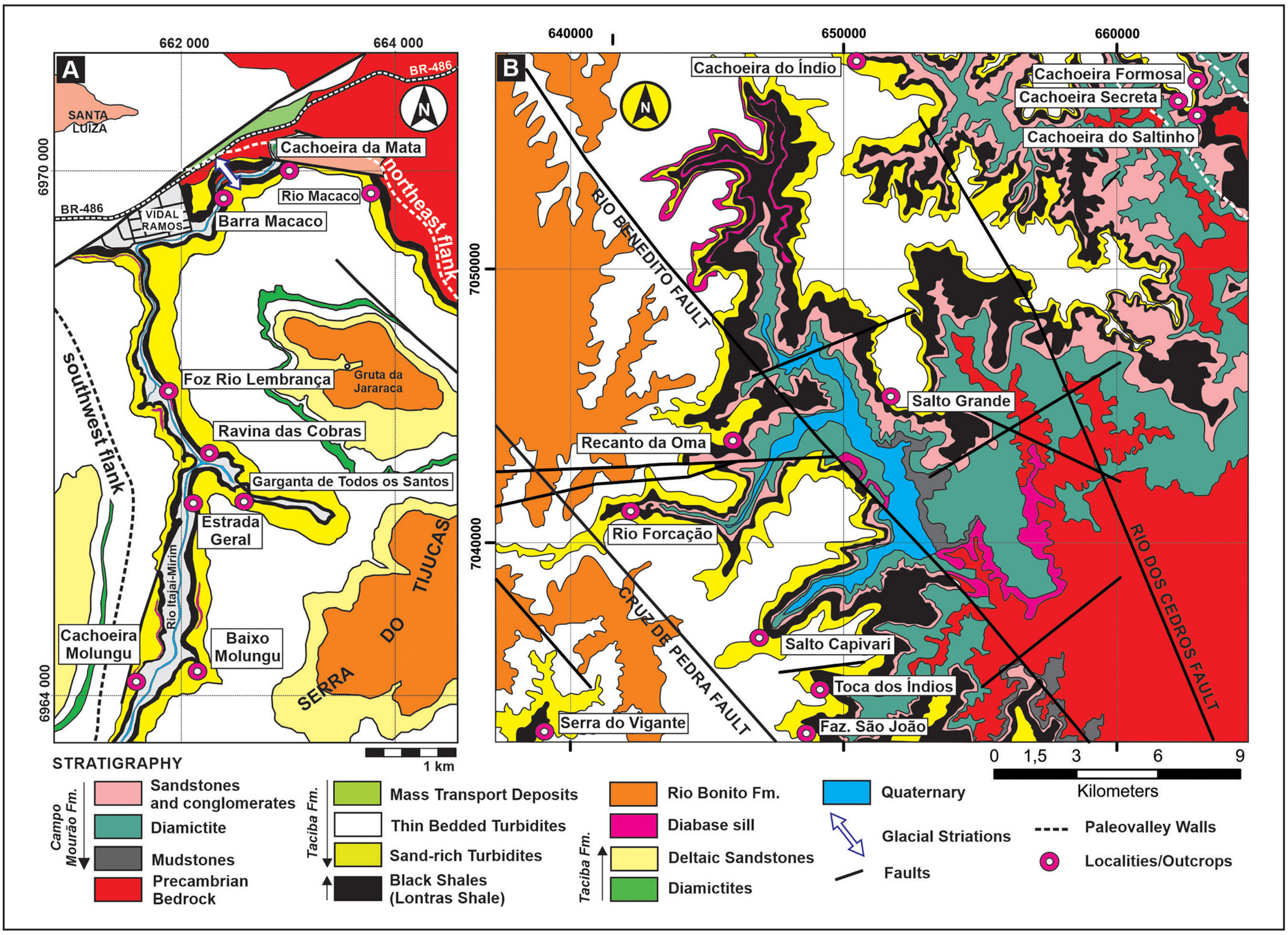

FIGURE 2 - Geological maps showing the localities/outcrops covered in this field guide. A) Geological map of the Vidal Ramos area. B) Geological map of the Doutor Pedrinho/Benedito Novo and Rio dos Cedros areas. Map A was slightly modified from Fallgatter et al. (2023) and map B was modified from D'ávila (2009) after Aquino (2015).

sole marks and ripple cross-laminations show a transport trend to the northwest, compatible with the glacial striations carved into the basement and the general orientation of the trough. These sand-rich turbidite systems are ascribed to sinuous, laterally extensive channelized bodies (Fallgatter et al. 2023). The lower portion of each stage represent the channel-axis deposition, characterized by its scour into previous deposits and coarser grain size (medium-to-coarse grained sand and eventual granule to pebble size clasts). The deposition of this basal interval is followed by an aggradational phase where sandstone beds amalgamation dominates. The F1, F2 and F3 intervals consist of normally graded couplets of very fine-grained sandstone to mudstone showing abundant planar-bedded and ripple-cross laminated intervals. Close to the northeast flank of the trough, the F1 and F2 units display abundant dropstones and a few thin slumped intervals that are absent along its southwest margin. In turn, close to the southwest flank the deposits are more extensively bioturbed, mainly by feeding traces. Paleocurrents readings from ripple cross-laminations of F1, F2 and F3 show scattered directions, while those taken in sole marks shows a transport trend to north-west. These deposits are interpreted as levee or overbank sedimentation taking place during the successive passage of turbidity currents (Fallgatter et al. 2023).

4.1. Barra Macaco outcrop
Coordinates: UTM 22J 662409.00/6969814.00

In Vidal Ramos, take the BR 486/SC 416 road to northeast and turn right at the gas station, go down the Avenida Gilberto Comandolli for about 550 meters until the junction with Brusque Road and turn left. Continue on this unpaved road for more 400 meters, turn right at the junction, cross the bridge over the Itajaí-Mirim river and park the vehicle. Go up a path behind the house to the Barra do Macaco outcrop but ask permission before. Just in front of this outcrop, behind the houses, on the margins of the Itajaí-Mirim river, there are glacial striations described by Puigdomenech et al. (2014) and Rosa et al. (2016).

Sandstone beds at the base of Ts1 show lenticular geometry (Fig. 3A) and consist of medium-grained, moderately sorted sandstones with rare, dispersed small pebble-size clasts (Fig. 3B). These beds are sandwiched by chaotic deposits showing rip-up mudstone clasts and rare metamorphic pebbles dispersed in a silt-rich matrix (Figs. 3C and D). These deposits resemble turbidites with linked-debrites (hybrid beds of Haughton et al. 2009) and suggest more than one type of flow rheology acting during the same depositional event (see Fallgatter et al. 2023). The base of Ts1 erodes the thin, fine-grained sand-to-mud beds of

F1. As you walk along the outcrop, notice the thickening upward trend of Ts1 and the common presence of intra-bed scours (Fig. 4A). This suggest either a discharge fluctuation on long-lived flows (Mulder and Syvitski 1995; Mulder et al. 2003; Plink-Björklund and Steel 2004; Zavala et al. 2006) or a waxing depletive flow (Kneller 1995; Kneller and Buckee 2000). This interval is ascribed to the channel-axis deposition (Fallgatter et al. 2023).

As you follow the outcrop from the side and reach its uppermost part, you will come across a well exposed package of fine-grained, thin sand-to-mud couplets of F2. These deposits show plane-bedding, ripple cross-lamination and contain scattered, granule- to -pebble-size dropstones (Fig. 4B). Also note the occurrence of thin, up to 1 m thick intervals of slumped deposits (Fig. 4C). Paleocurrents within F2 show scattered directions, suggesting reflections and deflections against the margins and/or multiple sources, which is unlike. These deposits are abruptly overlain by thick, medium-grained sandstone beds of the Ts2 stage (Fig. 4C), which also contain chaotic beds similar to the base of Ts1 (channel-axis deposits). The upper part of the succession consists of massive beds that pass upwards to plane-bedded, and ripple cross-laminated sandstone followed by mudstone.

4.2. Cachoeira da Mata outcrop
Coordinates: UTM 22J 662909.68/6970340.88

From the previous stop, keep following the Brusque Road along the east side of the river for another 800 m. This point is before the road makes a sharp turn to the left and can be hard to find. On your right, look for a small opening in the woods where a small stream flows. There are no paths. Climb up for a few meters following the stream to get to a small waterfall.

In the Cachoeira da Mata outcrop you will see boulder- and pebble-size dropstones within F1 interval (Fig. 5A), which also shows thin sandstone beds with abundant planar bedding and ripple cross lamination (Fig. 5B). The latter indicates scattered transport directions. F1 is deposited over black shales ascribed to the Lontras Shale that crops out in this section and show rare granule-size dropstones.

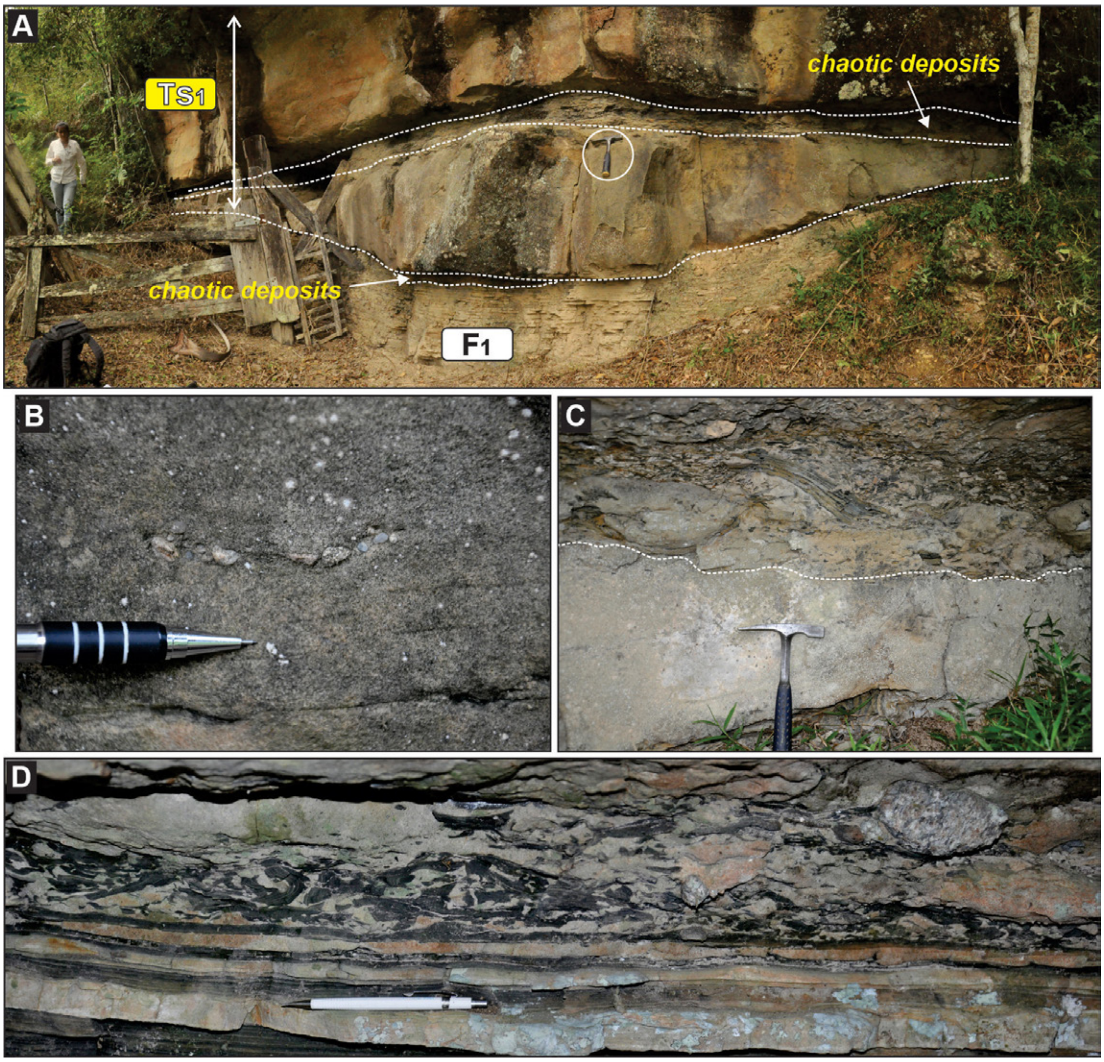

FIGURE 3 - The Barra Macaco outcrop. A) Lenticular sandstone beds of Ts1 showing erosive contact into thin bedded, sand-to-mud deposits of F1. Circled hammer (30 cm long) for scale. B) Detailed on dispersed, pebble-size clasts. C) and D) Chaotic intervals consisting of deformed sand patches, granule to pebble-size mudstone clasts and rare metamorphic clasts within a silt-rich matrix.

FIGURE 4 - Details of the Barra Macaco outcrop. A) Moderately sorted, sandstone beds with intra-bed scours. B) Pebble-size dropstone within F2 showing disruption of surrounding laminae. C) General view of the dropstone-bearing F2 sharply overlain by thick sandstone beds of Ts2. Note minor slumped interval within F2.

Sandstone beds of Ts1 and Ts2 are normally graded and include, from base to top, massive, plane-bedded and ripple cross-laminated intervals capped by mudstones related to suspension fallout. These beds are likely related to short-lived, surge-type turbidity currents (Lowe 1979; Kneller 1995; Mulder and Alexander 2001; Meiburg and Kneller 2010). As you go up in stratigraphy, note the lenticular sandstone beds at the base of Ts3. These beds consist of coarse-grained, poorly sorted sandstones sandwiched between chaotic, coarse-grained sandstones bearing mudstone clast (Figs. 5C, D and E). Both the lenticular sandstone beds and the chaotic deposits may be attributed to hybrid beds (Haughton et al. 2009). They are similar to those exposed in the Barra Macaco outcrop and represent the channel-axis deposition (Fallgatter et al. 2023).

4.3. Rio Macaco outcrop
Coordinates: UTM 22J 663254.50/6970838.20

From the previous stop, keep following the Brusque Road along the east side of the river for another 480 m to the next bifurcation. Turn right and drive for a few more meters until you reach a gate and park the vehicle. The gate will probably be closed. This area belongs to the company Votorantin Cimentos. It is prudent to ask for permission before entering in this private property. After crossing the gate, continue walking for a few more meters until you find an opening in the woods to your right where a small stream flows. There are no paths. Follow the stream to get to a small waterfall. At the beginning of the climb there is a large hollow tree that serves as a landmark.

Rio do Macaco is the closest outcrop to the northeast flank of the paleotrough (Fig. 2). Here it is important to note a decrease in the overall thickness of the F1 and F2 relative to the previous points (Fig. 6). These deposits show pebble-size dropstones and minor slumped intervals. It also contains abundant thin, plane-bedded and ripple cross-laminated sandstones. Ts1 and Ts2 consist of mostly massive, sand-to-mud sandstone beds ascribed to short-lived, surge-type turbidity currents (Lowe 1979; Kneller 1995; Mulder and Alexander 2001; Meiburg and Kneller 2010). Also note the lateral thinning-out of individual beds as you approach the basin margin.

4.4. Foz Rio Lembrança outcrop
Coordinates: UTM 22J 662999.59/6967560.19

From the previous stop, go all the way back until the junction of Brusque Road with Avenida Gilberto Comandolli. From there, drive southwest for about 1 km, turn left and

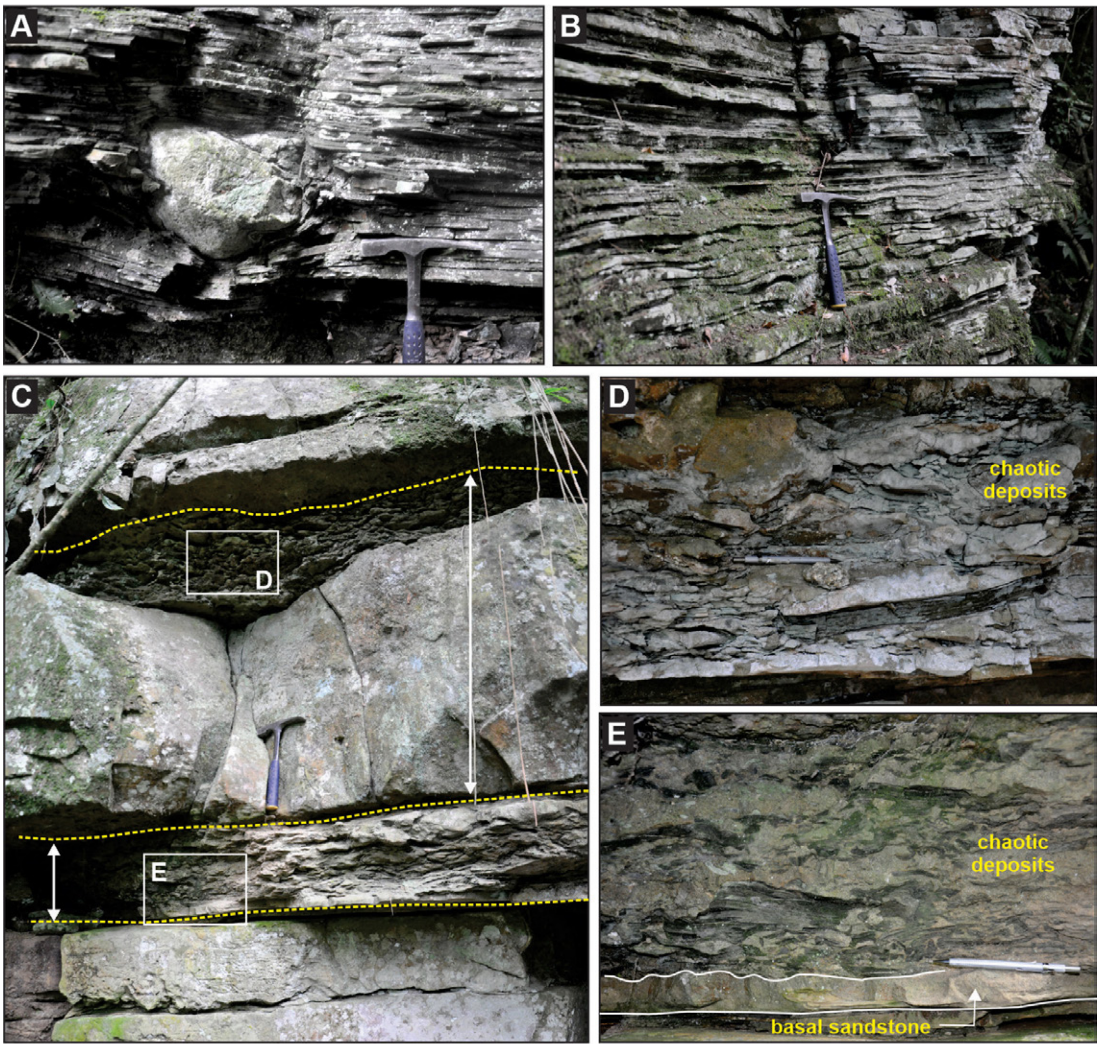

FIGURE 5 - The Cachoeira da Mata outcrop. A) Boulder-size dropstone. B) Thin bedded, normally graded sand-to-mud couplets showing abundant planar-bedding and ripple cross-laminations within F1. C) Coarse-grained, lenticular sandstone beds of Ts2 sandwiched by chaotic intervals that may be attributed to hybrid flows. D) and E) Details of the chaotic intervals.

cross the bridge. Keep driving south on Nicolau Petri Street for 1.8 km until you cross a bridge over a small stream (Rio Lembrança) and park your vehicle (only the first part of the road is paved and it runs along the west side of the Itajaí-Mirim river). On your left, on the banks of the Itajaí-Mirim river, you will find the Foz Rio Lembrança outcrop. Along this road, there are many thick diabase sills that may resemble sandstone beds.

From this outcrop onwards you start following the southwest flank of the glacial trough. Note that the thicknesses of F1, Ts1 and Ts2 decrease dramatically. The initial deposition of Ts1 shows two amalgamated sandstones beds bounded by an erosional contact consisting of a mud clasts-rich interval (Fig. 7A and B). Sandstone beds occur either amalgamated or interbedded with mudstones and exhibit lenticular geometry. It consists of normally graded, moderately sorted beds with a massive base followed by plane-bedded and ripple cross-laminated intervals. These beds are interpreted as surge-type, short-lived turbidity currents. The massive interval results from frictional freezing of a basal, high-density layer developed below a fully turbulent, low-density flow. Mudstone beds of F1 display feeding traces, unknown footprints (Fig. 7C) and sole marks (mainly flute casts).

4.5. Ravina das Cobras outcrop
Coordinates: UTM 22J 663645.00/6967184.00

Continue driving southeast on the same road for about 300 m until the first junction. Turn left, cross the bridge over the Itajaí-Mirim river, and turn right at the next junction. Go to the houses, park the vehicle, ask the owner for permission, and walk a few more meters along a path to the Ravina das Cobras outcrop. Be careful with snakes.

Here, the Ts1 unit does not crops out but you will see the well exposed F2 (Fig. 8A). The latter consists of thin bedded, normally graded sand-to-mud couplets composed of very fine-grained sandstone beds, often displaying plane-bedding and ripple-cross lamination, followed by massive mudstones. These structures indicate northwestward, axial transport along the trough. Ts2 sandstone beds are relatively thin and show soft sediment deformation such as balls and pillows and flame structures (Fig. 8B). Also note a hybrid bed (Haughton et al. 2009) within the Ts3 stage (Fig. 8C). This hybrid bed shows evidence of more than one type of flow rheology acting during the same depositional event, comprising a deposit that forms a pair related to non-cohesive and cohesive flows superimposed.

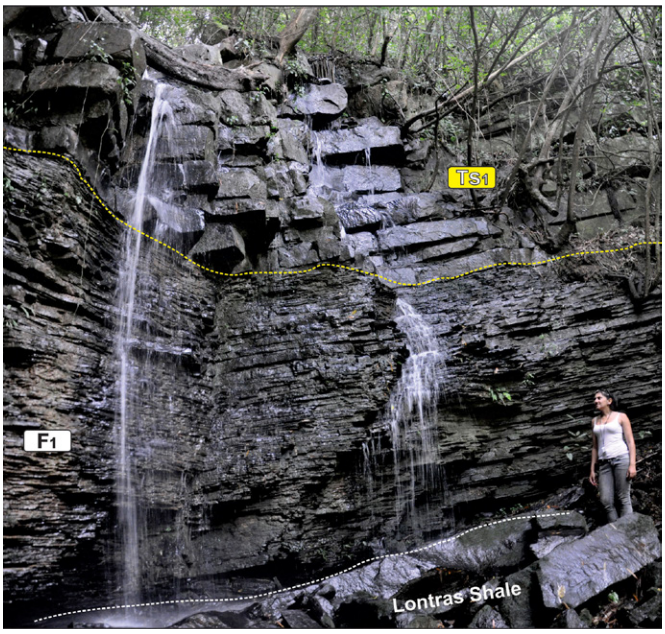

FIGURE 6 - The Rio Macaco outcrop. Note a decrease in thickness of the F1 relative to the previous points and sandstone beds of Ts1 thinning-out as it approaches the northeast trough wall.

4.6. Garganta de Todos os Santos outcrop Coordinates: UTM 22J 664356.00/6966950.00

Return to the main road and keep driving southeast for another 650 m. Turn left at the church and continue for another 860 m to a small group of houses and park the vehicle. Ask the owners for permission and follow an upstream path along the margins of the Todos os Santos creek behind the houses. Be careful with snakes.

From this outcrop onwards, Ts2 and Ts3 disappear. Here you will see a thin, F1 interval deposited above black shales (Lontras Shale) and overlain by Ts1 deposits (Fig. 9A). Ts1 increases in thickness (Fig. 9B; the outcrop is closer to the trough axis). Moderately to well sorted sandstone beds of Ts1 show soft sediment deformation (balls and pillows and flame structures) and occur either amalgamated (Fig. 9C) or interbedded with mudstones. Thicker sandstone beds are mostly massive, with only their upper parts showing plane-bedded and ripple cross-laminated intervals (delayed grading; Lowe 1982). These beds are ascribed to deposition from surge-type, short-lived low density waning flows eventually deformed by vertical shear from escaping interstitial fluid.

4.7. Estrada Geral outcrop Coordinates: UTM 22J 663996.44/6966233.68

Return to the church point and continue driving southeast for another 800 m. From the church onwards, this same road is called Estrada Geral Molungu. The outcrop will be on the

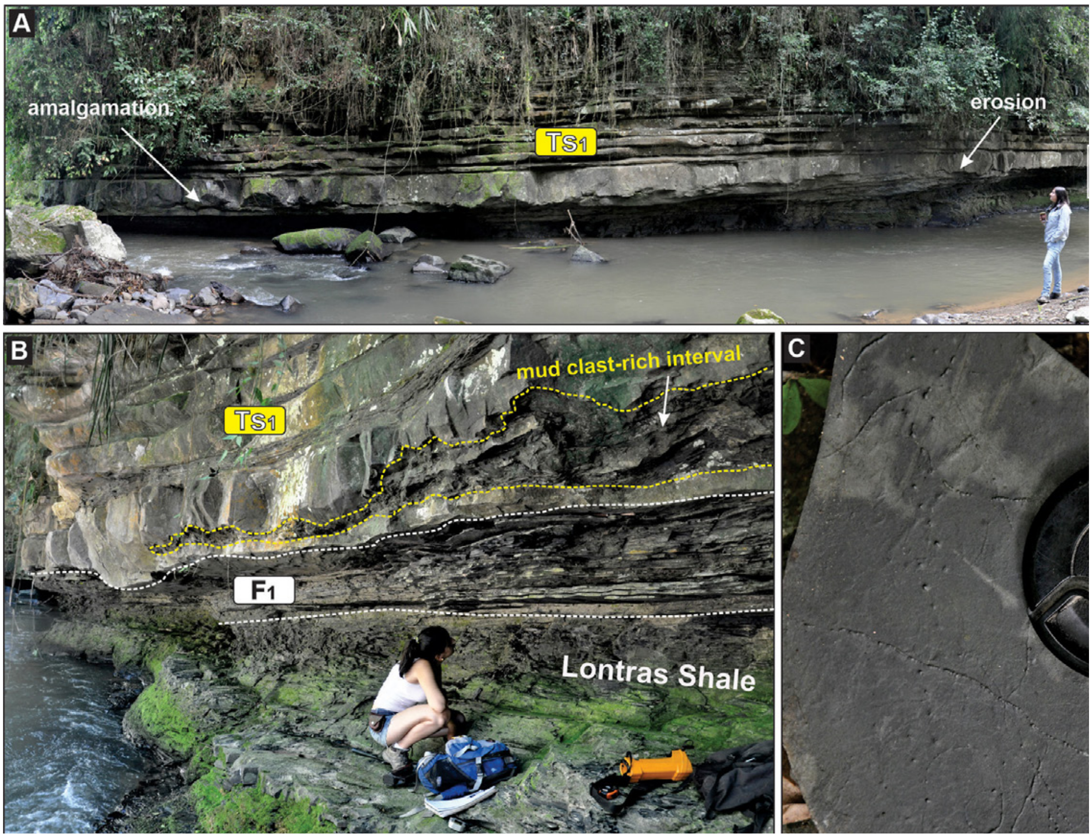

FIGURE 7 - The Foz Rio Lembrança outcrop. A) Erosion and amalgamation at the interface of sandstone beds of Ts1. B) Detail of the erosional surface consisting of chaotically distributed mudstone clasts within a very fine-grained matrix. Also note the decrease in thickness of F1 relative to the previous stops. C) Feeding traces and unknown tracks in mudstone layers of F1.

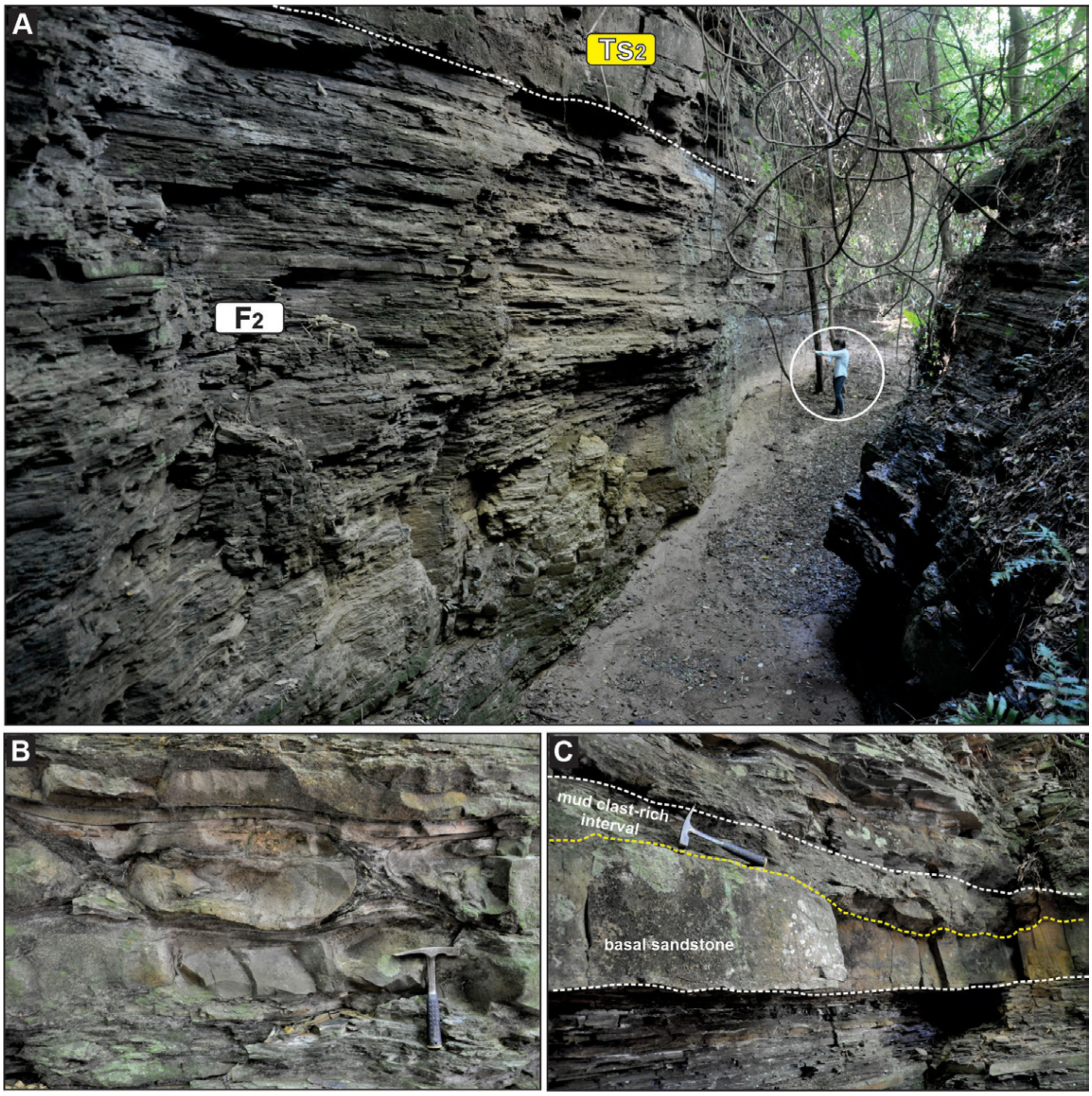

FIGURE 8 - The Ravina das Cobras outcrop. A) Thin, normally graded sand-to-mud couplets of F2. Circled person for scale (ca 1,7 m tall). B) Soft sediment deformation (balls and pillows) and C) turbidite with linked-debrite (hybrid bed) within Ts3.

left side of the road and is easy to find. Park the vehicle and walk straight ahead for a few more meters to a bus stop. Behind the bus stop there is a path that leads to the upper parts of the outcrop.

The Estrada Geral outcrop is closer to the southwestern flank of the trough, relative to the previous stops. Note that the sandstone beds of Ts1 are thinner (Figs. 10A and B). They consist of very fine-grained, well sorted sandstones displaying ripple cross laminations with transport direction to northwest, parallel to the trough orientation. Here, thin, normally graded sand-to-mud couplets of F1 show abundant feeding traces and sole marks, such as flute, prods, grooves and bounce casts (Fig. 10C).

4.8. Baixo Molungu outcrop
Coordinates: UTM 22J 664774.00/6965037.00

From the last stop, continue driving south for another 1.3 km to the entrance of a “farm” inn (Sítio do Vô Bubi). This is a recreation and accommodation place for families and kids during weekends and holidays. Ask the owner for permission at the entrance and park the vehicle inside the property. From there, follow a path that leads to a waterfall. Along the way, there is a good exposure on your right, just before reaching the waterfall (Fig. 11A).

Here, sandstone beds of F1 show abundant ripple cross laminations indicating a downward transport along the trough (Fig. 11B). Note also that individual sandstone beds increase in thickness as you get closer to the trough axis and move away from the basin margin (Fig. 11A). Sandstone amalgamation is common within Ts1 and often marked by flames and load structures at the bedding boundaries. Fine- to very fine-grained, well sorted sandstones present plane-bedding and ripple cross-lamination (Fig. 11C). These beds show abundant sole marks, such as flutes, grooves, prod and bounce casts. These structures indicate axial transport to the northwest.

4.9. Cachoeira Molungu outcrop
Coordinates: UTM 22J 664236.00/6964669.00

Return to the road and head south for another 750 m until the entrance to an abandoned leisure park on your right

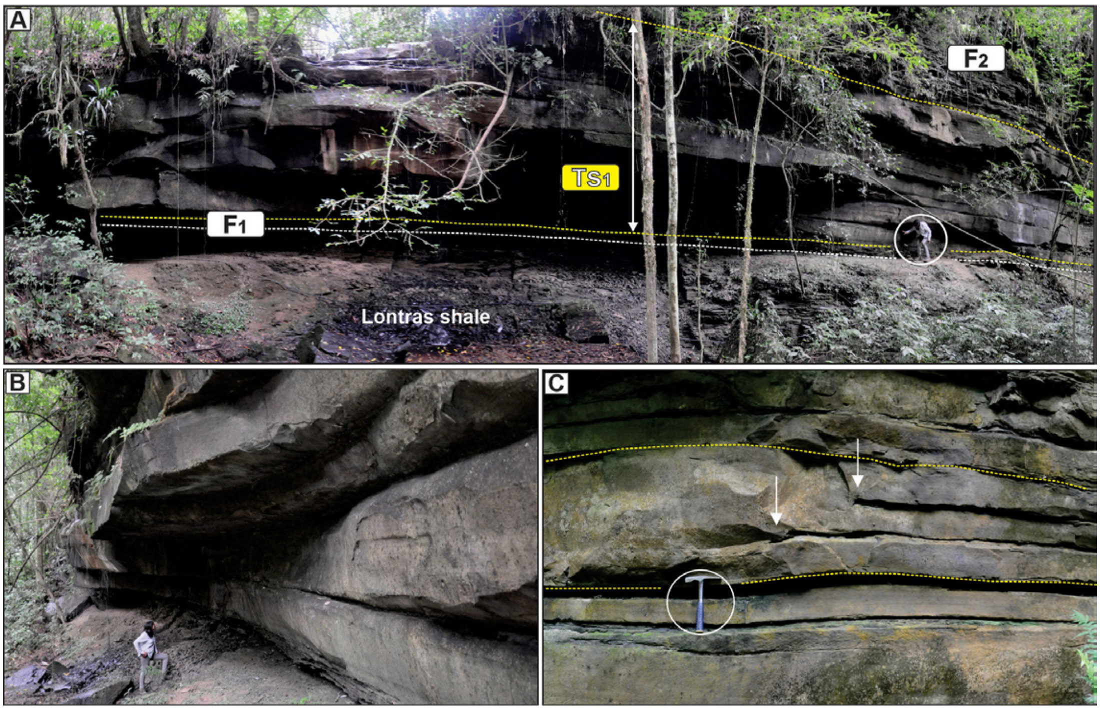

FIGURE 9 - The Garganta de Todos os Santos outcrop. Circled person for scale (ca 1,7 m tall). A) and B) Thick, moderately to well sorted and mostly massive sandstone beds of Ts1. C) Sandstone beds amalgamation (arrows). Circled hammer (30 cm long) for scale.

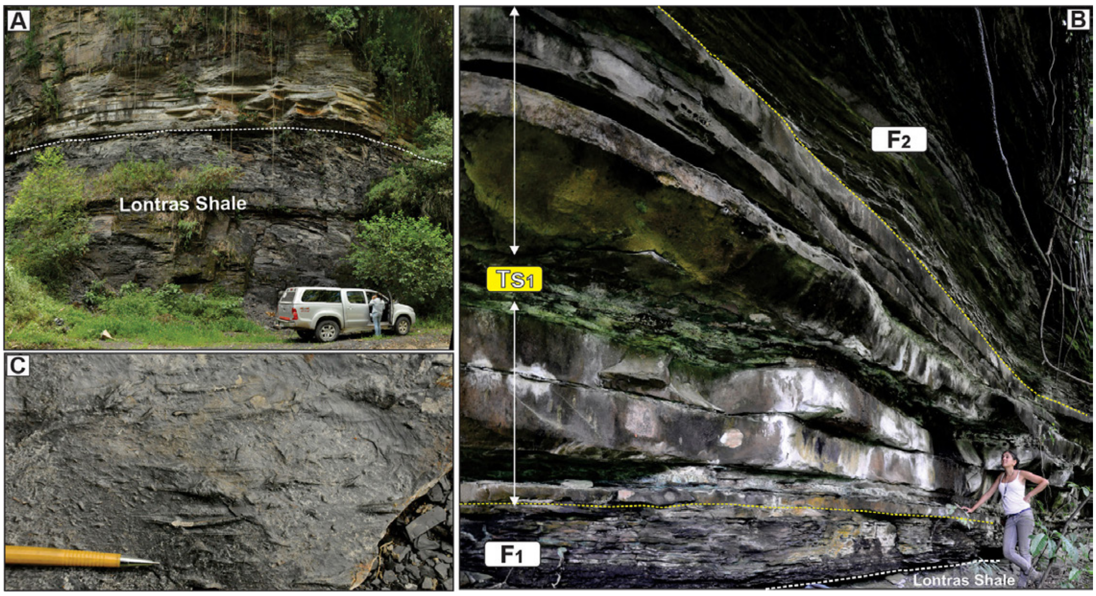

FIGURE 10 - The Estrada Geral outcrop. A) and B) Details of the outcrop showing relatively thinner sandstone beds relative to the previous stop as you approach the southwest basin margin. C) A variety of sole marks (mainly bounce and prod casts) at the bottom of F1 beds.

(Parque Paraíso). Enter the park and keep left down a road for another 200 m to a house and ask permission to the owner. Follow the road for another 300 m to the waterfall and park the vehicle. Note that a thick, up to 3 m diabase sill is emplaced within the succession.

In this outcrop you can see how the Ts1 decreases in thickness as it approaches the basin margin (9 m-thick vs. 1.5 m-tick; Fig. 11D). Individual sandstone beds are thinning-out towards the southwest flank of the trough. Sandstone beds of Ts1 are normally graded, very fine-grained and include plane-bedded and ripple cross-laminated intervals.

5. Doutor Pedrinho/Benedito Novo area

Doutor Pedrinho and Benedito Novo are small towns, some outcrops are a bit far and others are difficult to access. The indication of how to get to the outcrops will use the Doutor Pedrinho town hall as a starting point, which is easy to find.

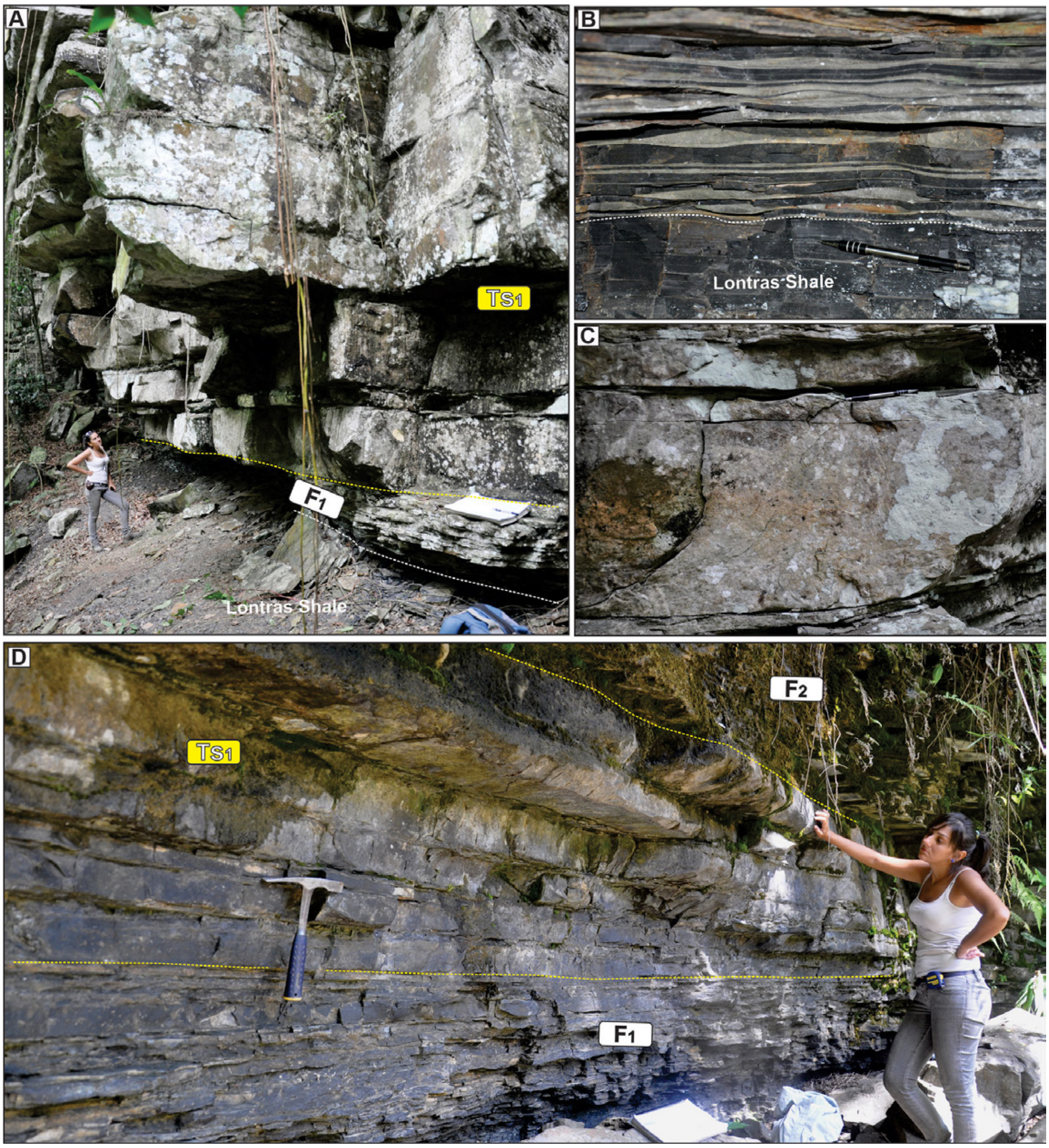

FIGURE 11 - The Baixo Molungu outcrop. A) Individual sandstone beds showing an increase in thickness (relative to the previous point) as you move away a little from the basin margin. B) Thin sandstone beds of F1 interval showing abundant ripple cross laminations. C) Sandstone beds of Ts1 showing a massive base followed by plane-bedding and ripple cross-lamination. D) A section of the Cachoeira Molungu outcrop showing sandstone beds of Ts1 decreasing in thickness and thinning-out towards the southwest flank of the trough.

Here, the depositional physiography controlled the deposition of a loosely confined turbidite system filling a broader and gentler depression (Fig. 2) relative to the Vidal Ramos and Rio dos Cedros areas. There is no evidence that turbidite deposits are confined to the Doutor Pedrinho/Benedito Novo area. D'Ávila (2009) proposes 4 depositional sequences separated by discontinuities for the Itararé Group in Doutor Pedrinho area. Later, Aquino (2015), through new mapping data, suggested the subdivision in 3 sequences, with the turbidite deposits recorded at the base of the Sequence 3 (Valdez-Buso et al. 2019). Paleocurrents are relatively different from one locality to another, showing a radial dispersion trend and suggesting more than one input point of sediments into the basin. However, a source to the east and southeast of the area seems to have been dominant, indicating the deposition of fan shaped lobes (Fallgatter 2015).

In Doutor Pedrinho/Benedito Novo area, the turbidite succession is approximately 30 m thick in total, and is subdivided into five, sand-rich stratigraphic units (Ts1 to Ts5). These units are not present everywhere and somehow difficult to identify. Individual sandstone beds are truncated, thinning and pinching out, making them hard to correlate between the localities, which may suggest that lateral/compensational stacking patterns dominate (Fallgatter 2015). Compensational stacking is usually related to deposition of consecutive lobes in topographic lows between preceding lobes (Straub and Pyles 2012; Prélat and Hodgson 2013). It is likely to be generated by lobe switching, and can occur on a range of scales (Piper et al. 1999; Deptuck et al. 2008; Prélat et al. 2009; Prélat and Hodgson 2013). Furthermore, the succession exposed in Doutor Pedrinho area is characterized by small packages of thickening- and subtle coarsening-upward trends within

FIGURE 12 - The Fazenda São João outcrop. A) Laterally continuous, thick tabular sandstone beds of the Ts2 and Ts3. Circled person for scale (ca 1.8 m tall). B) Bidirectional ripple cross-laminations within Ts1. C) Thin, normally graded sand-to-mud beds showing abundant planar-bedding and ripple cross laminations. Circled hammer (30 cm long) for scale.

each of the stratigraphic units (Ts1 to Ts5). This signature may result from lobe progradation followed by avulsion or abandonment. Considering this information, it seems that in each unit, lobe progradation dominates over lateral stacking, increasing rates of sedimentation due to a delta front advance. Although this interpretation is speculative, the turbidite system exposed in Doutor Pedrinho area may contain elements of both compensational stacking (Hodgson et al. 2006; Prélat et al. 2009; Prélat and Hodgson 2013) and lobe progradation (Grundvåg et al. 2014).

5.1. Fazenda São João outcrop
Coordinates: UTM 22J 648418.00/7027237.00

Departing from the Doutor Pedrinho town hall, take the BR 477 road and drive south for about 10 km until you cross the bridge over the Benedito River. Turn right and follow the road that runs parallel to the São João stream for about 16 km. At the end of the road, you will arrive at the Fazenda São João (São João Farm). Just before arriving, on the last sharp curve to the left, there is a place to park the vehicle. Next to this parking area there is a poorly marked path that goes for about 50 m to a waterfall. A few meters from the beginning of the path, look to your left for an opening in the woods that leads to a small "cave" where a well exposed part of the succession crops out. Once you reach the waterfall (Fig. 12A), cross the stream and reach the outcrop on the right side of it. Be careful as it is quite slippery and full of snakes.

This outcrop has some peculiarities. The base of Ts1 consist of thin, very fine-grained sand-to-mud beds with abundant asymmetrical ripple-cross laminations showing bidirectional paleocurrents (Fig. 12B). This may indicate reflection and deflection of the currents against basin floor irregularities, thus some sort of confinement in the initial deposition of Ts1 unit. These deposits correspond to the thinner sandstone beds in the succession and may represent lobe off-axis to fringe settings (Fig. 12C). Beds of Ts2 and Ts3 are mostly massive and amalgamated, consisting of thick, up to 2 m, well sorted, fine-grained sandstones with load and flame structures. It eventually shows flute casts and grooves at the base of beds. Thicker and laterally-extensive individual sandstone beds of Ts2 and Ts3 point to larger volume flows and may be ascribed either to the vertical-stacking of the sandstone beds or to successive lobe progradation followed by

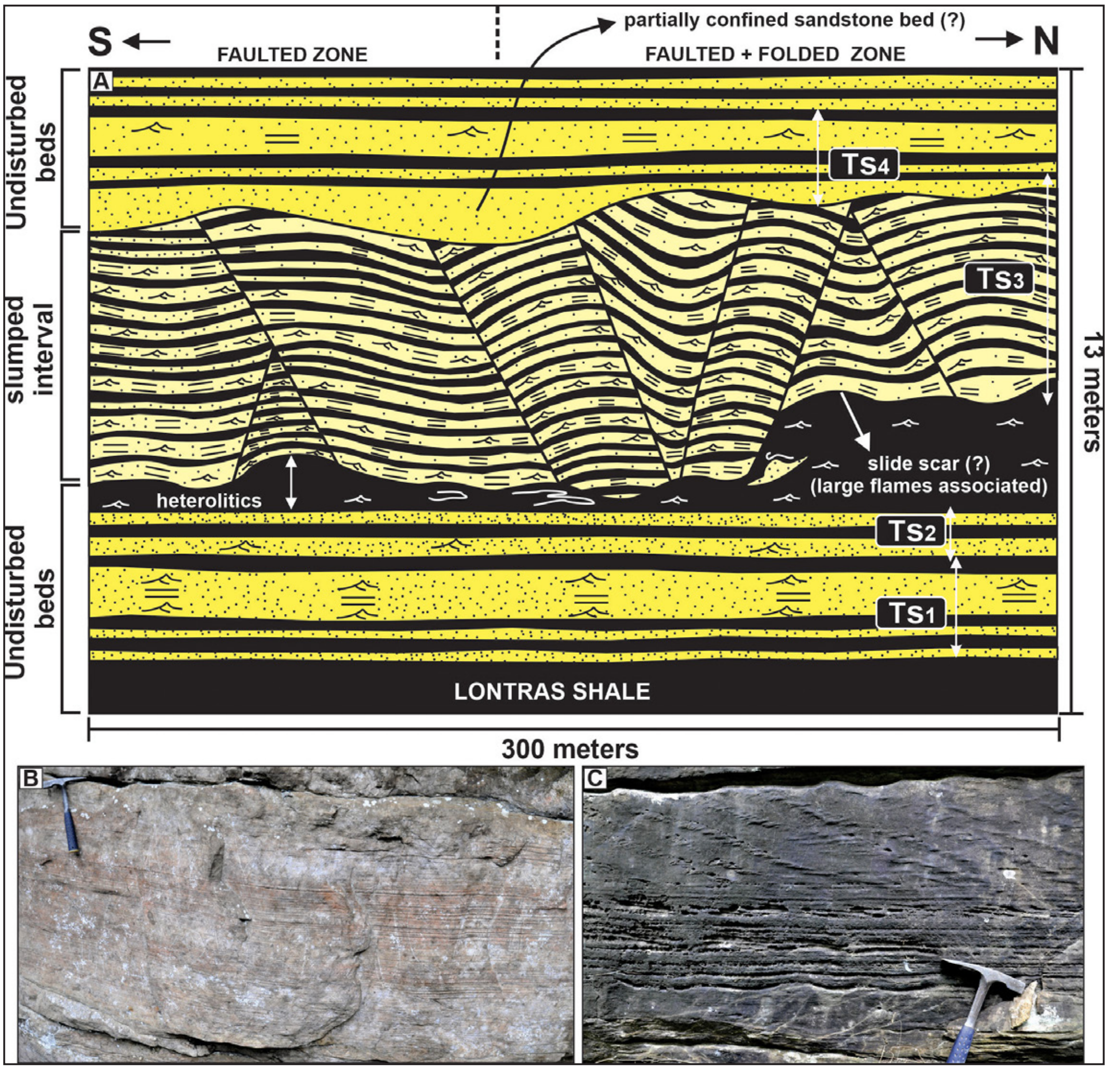

FIGURE 13 - The Toca dos índios outcrop. A) Schematic view of the Toca dos Índios outcrop showing a slumped interval sandwiched between undisturbed beds. B) Sandstone beds presenting planar-bedding. C) Sandstone beds showing vertical alternation of ripple-cross lamination, plane-bedding and climbing ripple cross-lamination.

avulsion or abandonment (compensation cycles). Sandwiched between the thick sandstone beds of Ts2 and Ts3 is a fine-grained interval. It consists of normally graded, sand-to mud beds with planar-bedding and ripple cross laminations, the latter indicating transport to WNW and may represent lobe off-axis deposits.

5.2. Toca dos Índios outcrop
Coordinates: UTM 22J 648180.77/7029789.52

Go back along the road from the previous stop for about 5 km and turn left at the junction. There are road signs indicating this location. You passed this junction on the way to the Fazenda São João outcrop. Continue for 600 m until the next junction. Here you have two options: on the right, at 400 m, there is an outcrop called Arroio Piloto, whereas on the left, for another 1 km, you will find the main outcrop (Toca dos Índios). The two outcrops are part of the same depositional context. We suggest to first visit the Toca dos Índios outcrop and then the Arroio Piloto one. The Toca dos Índios outcrop is a private property that works as an inn and can be a good option for accommodation. Remember to ask the owner for permission first. There is a well-marked path that leads to the outcrop.

This is certainly the most interesting outcrop in the area. It is laterally extensive, exposed over more than 300 m in a depositional dip direction and consists of a thick unit of disturbed beds sandwiched between thick intervals of undisturbed beds (Fig. 13A). The entire succession is sharply deposited on the Lontras Shale. The lower and upper intervals of undisturbed beds consist of fine- and very fine-grained, well sorted, tabular sandstone layers showing flute and groove casts that indicate transport to west-southwest and west-northwest. It also contains planar-bedded sandstones (Fig. 13B). Bed amalgamation is common and often marked by small flames and load structures. Some of the thicker beds show abrupt grain size and bedform changes (alternation of plane-bedding, ripple- and climbing-ripple cross laminations) within the same bed (Fig. 13C), suggesting recurrent pulses of acceleration and deceleration of the flow during the same event. This sort of evidence points to a direct connection between fluvial floods and gravity flows, thus long-lived, hyperpycnal turbidites (sustained flows; Mulder and Syvitski 1995; Mulder et al. 2003; Plink-Björklund and Steel 2004;

FIGURE 14 - Details of the Toca dos Índios outcrop. Sandstone beds associated with brittle (A and B) and brittle + ductile (C and D) deformation. E) Base of the slumped interval at the northern end of the outcrop showing a well-exposed slide scar cut into thin bedded, normally graded sand-to-mud couplets. Note also a deformed sandstone block.

Zavala et al. 2006; or waxing-to-waning depletive flows of Kneller 1995; Kneller and Buckee 2000).

The disturbed interval is up to 6 m thick and consist of a large scale, slumped sandstone beds showing brittle-to-ductile deformation (Fig. 13A). The southern half of the interval is dominated by faults (Figs. 14A and B) whereas its northern half comprises faults and folds (Figs. 14 C and D). This interval consists of deformed, fine- to very fine-grained sandstones showing abundant plane-bedding and ripple cross lamination. This deformed succession slipped on heterolithic deposits. At the northern end of the outcrop, a slide scar is well exposed (Fig. 14 E) associated with large flames and ball and pillows structures (see Arroio Piloto outcrop).

Returning back along the road, you have access to the Arroio Piloto locality, where the same deformed succession crops out (Fig. 15A). This is a road cut outcrop exposed in a depositional strike direction. Note within the succession some pairs of unusual, sheared flame structures (Fig. 15B). Here, the sliding surface records large flame and ball and pillow structures (Fig. 15C). Note that these deformed beds preserve their primary sedimentary structures, mainly in the form of planar-bedding and ripple cross lamination.

5.3. Salto Capivari outcrop Coordinates: UTM 22J 645939.26/7035686.03

The Salto do Capivari outcrop is also known as Cachoeira Paulista (Paulista waterfall; see Vesely et al. 2021). From the last point, go back to the main road that runs parallel to the São João stream. Continue back along this road for another 1.6 km to the church you passed on the way to the previous outcrops. A few meters before reaching the church, turn left at the junction and continue for about 7 km to Salto Capivari. The conditions on this road are not the best, be careful. Another possibility is to go back to BR 477 and follow the road back to Doutor Pedrinho. From the bridge over the Benedito River, drive for 5 km to the junction that leads to the Salto Capivari (Cachoeira Paulista). There are road signs pointing the way. This outcrop is located in an outdoor activity center and there is an option for camping. Once you are there, there is a path that leads to the base of the waterfall (Fig. 16A).

At the foot of the waterfall, note that the base of sandstone beds within Ts1 show abundant sole marks (Fig. 16B), mainly flutes and groove casts, which show sediment transport to north-northwest. Sandstone amalgamation is common. Also

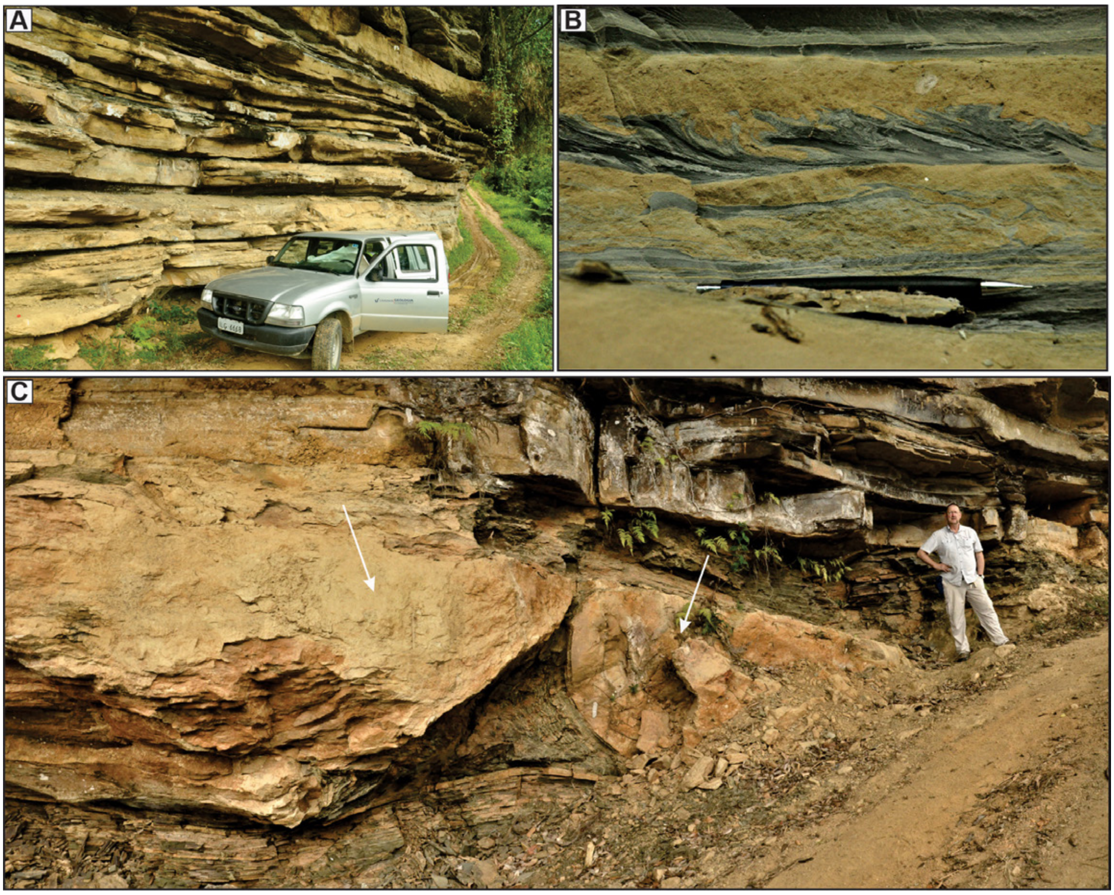

FIGURE 15 - The Arroio Piloto outcrop. A) This outcrop shows the same deformed strata in a strike view, relative to the Toca dos Índios outcrop. B) Detail of sheared flame structures. C) Large-scale ball and pillow structures (indicated by arrows) and associated flame structure at the base of the slumped interval.

note an intraformational conglomerate consisting of fine-grained sandstone with dispersed mudstone clasts (Fig. 16C). On the wall, near the waterfall, are deformed beds showing large-scale, soft sediment deformation (Fig. 16D) originated by upward interstitial fluid escape. Some of the thicker beds include plant debris and coarser grains laminae within fine-grained sandstones which may suggest river floods peaks, hence long-lived, hyperpycnal turbidites. The presence of plant fragments indicates fluvial erosion of a vegetated landscape, suggesting that an outwash plain and delta developed between the margin of the retreating ice and the sea.

On the way up to the parking area, note an up to 1 m thick hybrid bed (Haughton et al. 2009) within Ts2 (Fig. 17). This deposit suggests evidence of a more complex flow rheology, behaving as non-cohesive and cohesive flows in a single depositional event, interpreted as a vertical succession of turbidity current and debris flow couplets (Fig. 17). It is completely distinct from the surrounding strata in terms of inferred depositional process. Its lower half consists of fine-grained, moderately sorted sandstone showing planar bedding and mudstone clasts with their long axis parallel to bedding. Its upper part comprises an ungraded, matrix-supported conglomerate whose matrix is composed of mud-rich sandstone containing deformed sand patches, cohesive rafts of thin sand-to-mud beds and muddy slabs. The entire bed is interpreted as high density turbidite with linked-debrite, the latter produced by an increase in mud content within the turbulent flow inducing a change from Newtonian to non-Newtonian fluids.

5.4. Recanto da Oma outcrop
Coordinates: UTM 22J 642981.03/7043140.15

From the last point, go back to Doutor Pedrinho. From the town hall, follow the main road to the west for about 10 km to a small locality called Ribeirão São Paulo (notice the road signs). Turn right at the junction and continue for another 3 km to the Recanto da Oma. This is a private property, ask permission first. The place serves excellent meals, but it is necessary to make a reservation in advance. Once you are there, there is a path behind the houses that leads to a small waterfall. Keep going downstream until you reach the top of another waterfall. In some parts it is necessary to walk through the water. Go down the waterfall along a slippery path on your right. Be careful with snakes.

When you are at the base of the waterfall, note some thick, tabular sandstone beds (Fig. 18A) showing flute and groove casts at the bottom, which indicate transport to northwest and west-northwest. Some of the thicker beds consist of fine-grained, moderately sorted sandstones showing intra-bed scours and subtle inverse to normal grading. They also display a vertical alternation of plane-bedded and ripple cross-laminated intervals within the same deposit. This sort of evidence suggests long-lived flows with waning and waxing pulses ascribed to flood-driven hyperpycnal flows (Mulder and Syvitski 1995; Mulder et al. 2003; Plink-Björklund and Steel 2004; Zavala et al. 2006) or waxing, depletive flows (Kneller 1995; Kneller and Buckee 2000).

FIGURE 16 - The Salto Capivari outcrop. A) Thickening upward cycles indicated by arrows (Ts2 to Ts4) possibly related to successive episodes of lobe progradation and avulsion. B) Groove casts at the bottom of sandstone beds of Ts1. C) Mudstone-rich intraformational conglomerates. D) Disturbed sandstone beds (indicated by arrow) related to large-scale soft sediment deformation.

On the way back, when you go up the waterfall, note some beds that may suggest deposition from hybrid sediment gravity flows within Ts2 (turbidites with linked debrites; Haughton et al. 2009). There is also a level of thin, deformed and folded beds of very fine-grained sandstone beds that represent a minor slumped interval (Figs. 18B, C and D). Next to that level, note the lateral thinning- and pinching-out of thin, fine-grained sandstone beds. These sets of evidence may suggest lobe off-axis to fringe settings.

5.5. Rio Forcação outcrop
Coordinates: UTM 22J 638966.00/7040005.00

Return to the junction with the main road in Ribeirão São Paulo. Turn right and head west for another 4 km until you reach the outcrop in the locality of Rio Forcação (notice the road signs). This outcrop is a road cut easy to find. It is also available on google street view. Next to the outcrop there are two waterfalls where the turbidites are also exposed.

This is the best-known outcrop in the area (D'Ávila et al. 2008, D'Ávila 2009, Fallgatter 2015, Vesely et al. 2021, Schemiko et al. 2022). The most prominent feature is a mud diapir from the Lontras shale (Fig. 19A), with sandstone beds thinning- and pinching-out towards its walls (Fig. 19B). The diapir originates by sediment load and overweight. This sort of evidence is suggested by large-scale load cast and mud injections that occur in the basal sandstone beds of Ts1 (Fig. 19C), laterally close to the mud diapir. Up in the stratigraphy, note a slumped interval consisting of folded sandstone beds associated with large-scale flame structures. Some of the thicker, tabular sandstone beds show large mudstone chips at the base. Flutes and groove casts are common and show sediment transport to north and north-northwest. Well sorted, fine-grained sandstones beds with ripple-cross lamination indicate transport to west

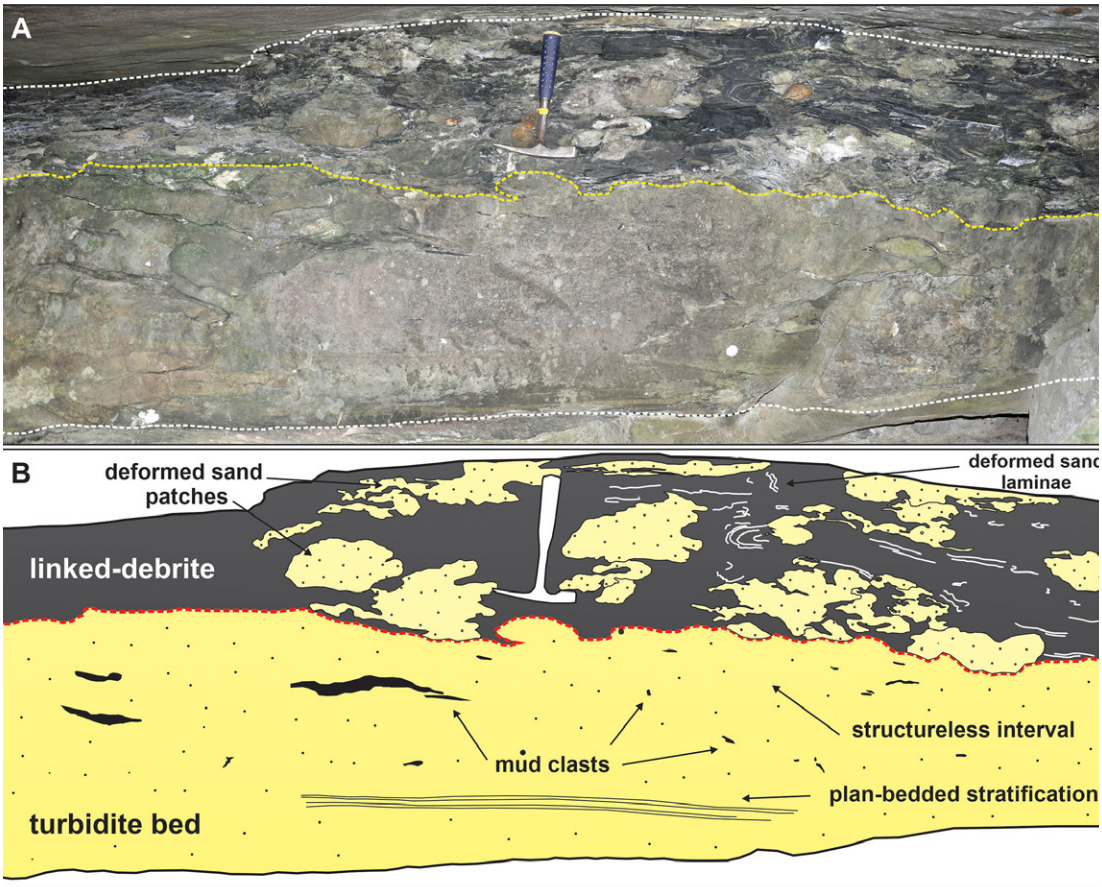

FIGURE 17 - Hybrid bed of the Salto Capivari outcrop. A) General view of the deposit. B) Line drawing of (A) showing a bipartite structure consisting of a basal turbidite followed by a linked, debrite interval. The lower division show incipient planar-bedded stratification and large mud clasts aligned parallel to bedding. The upper division show deformed sand patches and sand laminae within a mud-rich matrix.

and west-northwest. Note a level rich in plant- and coal-debris within Ts1. Plant debris within sandstone beds has been ascribed to gravity-flow deposits derived from river floods (Plink-Björklund and Steel 2004).

5.6. Serra do Vigante outcrop
Coordinates: UTM 22J 636106.86/7029766.52

From the last stop, keep following westwards along the main road for about 8 km until a well-marked junction. Turn left and you will be entering into an indigenous reserve. Be respectful as they may not be very friendly. Follow this road for about 22 km to the outcrop. This outcrop is an extensive, easy-to-find road cut (Fig. 20A). Here you have a thick exposure of the Lontras Shale as well. When you pass the indigenous reserve area, the road will continue alongside the Wiegand river. In the Alto Vigante locality, there are two nearby waterfalls where the succession also crops out.

The succession starts with normally-graded, thin-to-medium thick, tabular sandstone beds of Ts1. The sandstone beds show a massive base followed by plane-bedded and ripple cross-laminated intervals (Fig. 20B). These features indicate deposition from surge-type, short-lived, low density waning flows (Kneller 1995). Flute casts, grooves and other types of sole marks are quite common in these beds and present a paleocurrent trend to north-northwest and west. Beds that resemble those with hybrid origin (Haughton et al. 2009) are also present. Altogether, these characteristics suggest lobe off-axis to fringe settings. Up in the stratigraphy, tabular sandstone beds show a thickening- and subtle coarsening-upward trend suggesting a progradational signature of the lobes (Fig. 20C).

Sandstone amalgamation is common and often marked by load casts and flame structures. Up in the stratigraphy, note that individual sandstone beds increase in size within Ts2 and Ts3. They consist of moderately sorted, fine-grained tabular sandstones showing vertical alternation of plane-bedded and ripple cross-laminated intervals. This signature suggests long-lived, flood-driven hyperpycnal underflows, representing waning and waxing stages of probably meltwater derived river floods (Mulder and Syvitski 1995; Kneller 1995; Kneller and Buckee 2000). Some up-side down fallen beds show abundant tridimensional ripples and extensive groove casts.

5.7. Salto Grande outcrop
Coordinates: UTM 22J 651641.00/7046125.00

From the last stop, return to the Doutor Pedrinho town. This outcrop is part of an extensive escarpment, visible from any point in Doutor Pedrinho when looking east (Fig. 21A). From the town hall, take the side street at the junction and cross the bridge over the Benedito River. Turn left and follow for 1.5 km until the next junction (“Móveis Viki” as a reference). Turn right and continue for another 1.3 km to the first village

FIGURE 18 - The Recanto da Oma outcrop. A) Thick sandstone beds of Ts1. It usually displays flutes and groove marks at the base. Circled person for scale (ca 1,8 m tall). B) Contorted, folded and deformed thin, sand-to-mud couplets. C) and D) details of (B).

in the Salto Grande farm. Before entering, remember to ask for permission. On your right, inside the property, there is a path that leads close to the outcrop. Follow this path for about 600 m and park the vehicle. From this point, there is a poorly marked trail that leads to the base of the escarpment. This trail is very little used and it is possible that it is completely closed by the bush, maybe you have to make way. Be careful, high risk of snakes.

Here you will see interlayered fine-grained and sand-rich intervals (Fig. 21A). They consist of thin, normally graded, sand-to-mud beds showing planar-bedding and ripple cross laminations that indicate transport to south-southwest and west-southwest. Individual sandstone beds of Ts1 present mudstone clasts concentrated near the top. Eventual mud clasts content on their top indicates erosion along the current head and ensuing layer-by-layer deposition from non-cohesive flows (Mulder and Alexander 2001). Flutes and groove casts are common and show transport to southwest and west. Few beds showing hybrid character are also present. Soft sediment deformations are common. Tabular sandstone beds within Ts2 and Ts3 are mostly massive and present a coarsening- and thickening upward trend (Figs. 21A, B and C). This signature may result from lobe progradation due to a delta front advance.

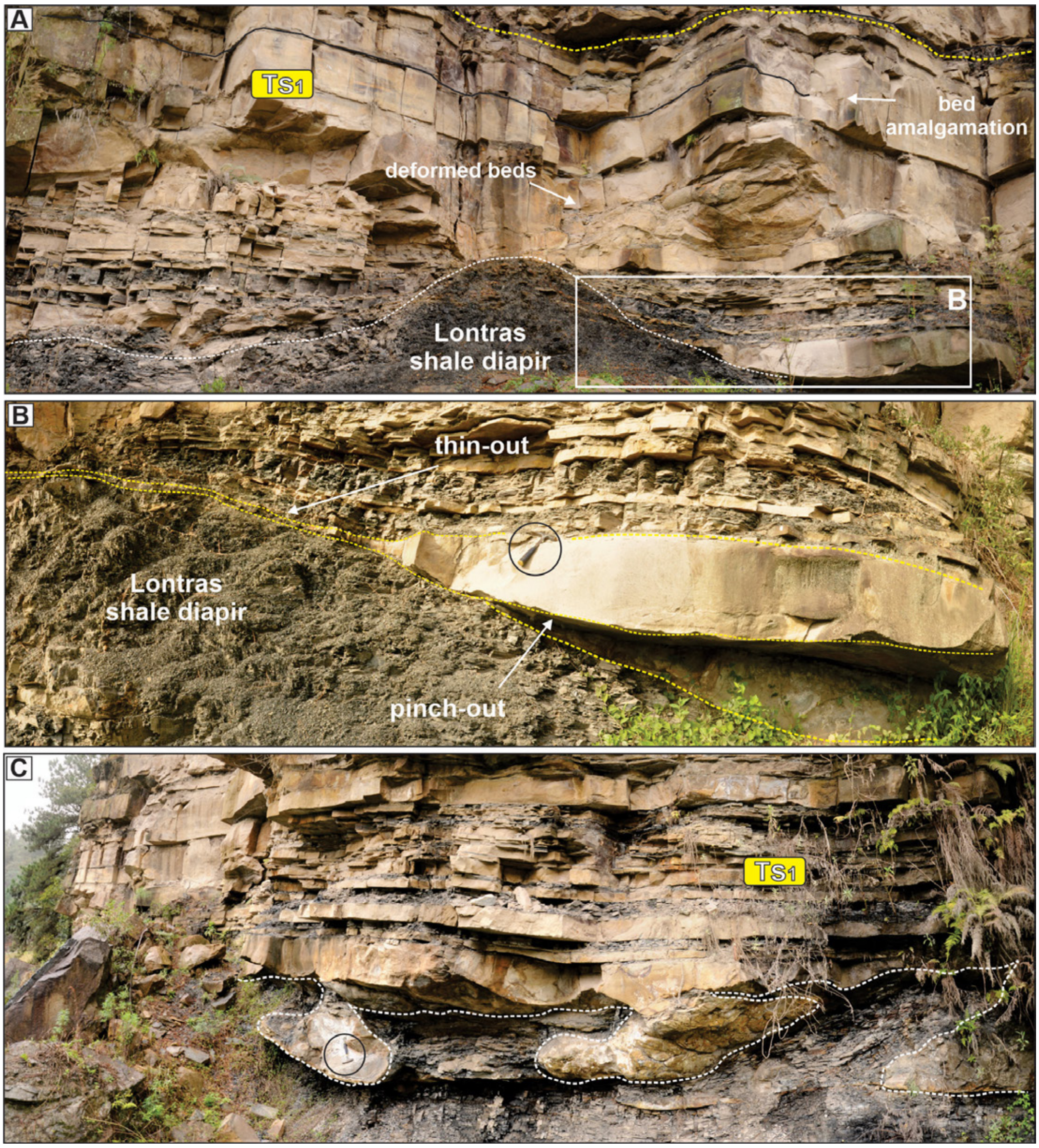

FIGURE 19 - The Rio Forcação outcrop. A) Base of the outcrop showing the Lontras shale diapir, amalgamated and deformed sandstone beds. B) Detail of (A) showing thin- and pinch-out of sandstone beds towards the Lontras shale diapir. Circled hammer (30 cm long) for scale. C) Base of Ts1 unit consisting of large-scale soft sediment deformation such as load casts and mud injections. Circled hammer (30 cm long) for scale.

5.8. Cachoeira do Índio outcrop
Coordinates: UTM 22J 646720.00/7061052.00

From the last stop, return to the Doutor Pedrinho town hall and head west again on the main road for about 700 m. Turn right and cross the bridge (this is also an alternative route that leads to the Recanto da Oma outcrop, notice the road signs), then turn right again at the next junction. Follow this road for about 25 km until the first well-marked junction. Turn right and drive for 4 km to a group of houses. There are road signs indicating the way. Park the vehicle and follow the path behind the houses to the waterfall. This is a camping area and may be a good alternative for accommodation.

When you are at the base of the waterfall, note that the tabular sandstone beds are mostly massive. However, some beds show plane-bedded stratification followed by ripple cross laminated intervals, which indicate westward transport. Small flame structures and load casts are common at the interface of the amalgamated sandstone beds. Note the thickening-upward nature of each Ts unit that indicate progressively larger flows and may be associated with a vertically-stacked pattern. There is a path to the other side of the waterfall that goes behind the water curtain. There, thicker sandstone beds show subtle grain-size changes and dewatering structures. Bioturbation is common. Up in the stratigraphy, flutes and groove casts at the bottom of beds show transport to north and northwest. A diabase sill, up to 1 m thick and emplaced between the turbidite layers, disturbs the succession.

6. Rio dos Cedros area

Rio dos Cedros is the closest town to the outcrops of this area. Here, the turbidite deposits are also confined to a glacially-carved low scoured into the Precambrian bedrock.

FIGURE 20 - The Serra do Vigante outcrop. A) Thick exposure of the Lontras shale. B) Thin-to-medium thick bedded, normally graded sandstone beds of Ts1 ascribed to lobe off-axis to fringe deposits. C) Thickening upward trend of sandstone beds within Ts2. Circled hammer (30 cm long) for scale.

FIGURE 21 - The Salto Grande outcrop. This escarpment can be seen from any point at the Doutor Pedrinho town. A) Tabular sandstone beds. B) and C) Thickening upward trends within Ts1 and Ts2 which may denote lobe progradation. Note a person for scale (ca 1,8 m tall).

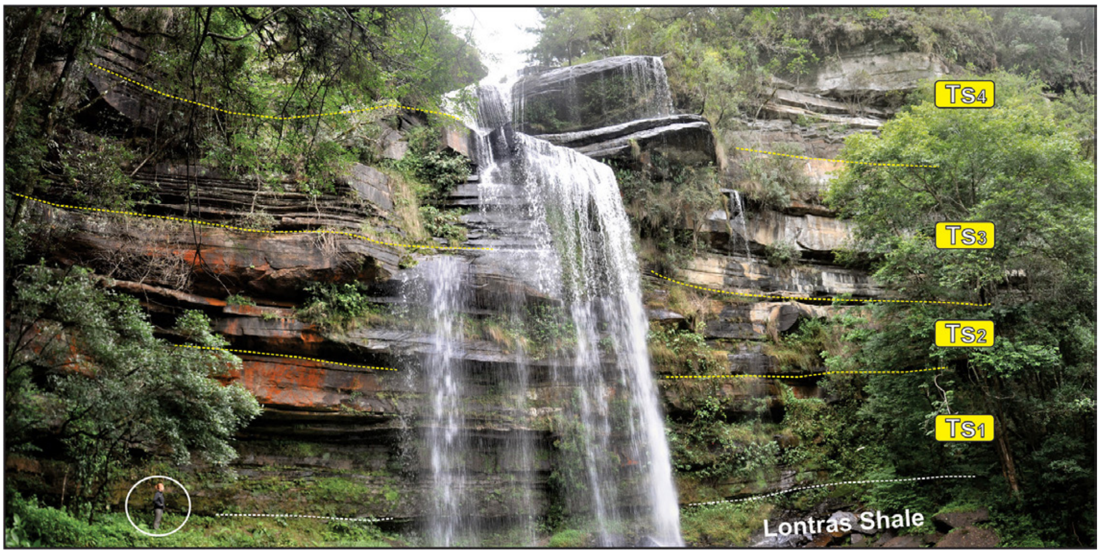

FIGURE 22 - General view of the Cachoeira dos Índios outcrop showing massive, mostly amalgamated sandstone beds. Note that Ts units present thickening- and subtle coarsening-upward trend possibly associated with progressively larger flows. Circled person for scale (ca 1,7 m tall).

FIGURE 23 - The Cachoeira do Saltinho outcrop. A) Thickening-upward trend of individual sandstone beds of Ts3. B) Mud clasts-rich sandstone. C) Sole of a sandstone bed showing fragments of plant leaves.

It comprises an extensive, NNW-SSE oriented, partially exhumed trough (Fig. 2). The Precambrian bedrock consists of protomylonitic to mylonitic monzogranite of the Rio da Luz Suite (Santa Catarina Granulitic Complex). This glacial trough is estimated to be up to 7 km wide and 20 km long where up to 70 m of Carboniferous strata are partially exposed. A basement high to the ENE is believed to represent the eastern side of the trough. Unfortunately, due to the regional dip of the Parana Basin to the west, its western margin is covered by younger strata, and poorly crops out in a few locations. Deposits of the Lower Taciba Formation in the Rio dos Cedros area rests directly on Precambrian basement rocks, defining a nonconformity that is thought to represent a scouring surface like the Vidal Ramos one.

The turbidite succession is approximately 30 m thick and lies directly over black shales (Lontras Shale). It does not show a clear subdivision as in Vidal Ramos, being more similar to the Doutor Pedrinho area. One of the main characteristics of these confined systems is that they show dropstones within the succession, which in turn does not occur in unconfined settings (e.g. Doutor Pedrinho/Benedito Novo area). Paleocurrents indicate a consistent northwest transport, compatible with the general direction of the glacial trough.

6.1. Cachoeira do Saltinho outcrop
Coordinates: UTM 22J 662982.29/7059967.90

In the Rio dos Cedros downtown, take the main street heading north (Avenida Tiradentes). This is the same road that follows along the banks of the Cedros river and passes through the localities of Alto Cedros and Rio Rosinha, which are geographical references in this region, until reaching the Rio Bonito/Palmeiras dam. Continue driving along the left side of the dam lake. From the starting point you will drive about 30 km to the outcrop, which is located at the north end of the dam lake. This outcrop is a road cut, has a small waterfall on the side and is easy to find (Fig. 23A).

Here you have a partial exposure of the succession, with sandstone beds of Ts3 cropping out. Note some thick, fine-grained tabular sandstones that are moderately sorted and mostly massive. Thinner beds are mud clasts-rich (Fig. 23B) and consist of massive intervals that pass upwards to plane-bedded and ripple cross-laminated sandstone. Ripple-cross lamination indicates transport to northwest, which is consistent with the glacial trough orientation. Note a fallen block of sandstone showing abundant fragments of plant leaves (Fig. 23C).

6.2. Cachoeira Secreta outcrop
Coordinates: UTM 22J 662020.20/7060397.21

From the last point, head west along the same road for another 1.2 km until you reach a group of houses. Pay attention as you will cross over a small creek and park your vehicle.

FIGURE 24 - Details of the megaturbidite of the Cachoeira Formosa outcrop. A) General view of the megaturbidite sharply deposited over de Lontras Shale. B) The lower interval of the megaturbidite consisting of abundant dish structures and deformed sand patches. C) Detail of the lower interval. D) Granules to pebble-size clasts at the base of the megaturbidite bed. E) Detail of the thick mud cap. F) Boulder-size, basement-affinity dropstone within the mudstone cap.

Follow this creek downstream for a few meters until you reach the top of a waterfall. On your right there is a path that leads to the base of the waterfall. This is a private property, therefore ask permission before.

As in the previous point, here you have a partial exposure of the succession, with sandstone beds of Ts2 and Ts3 units cropping out. Sandstone beds show subtle grain-size changes and are mostly massive. Amalgamation is common and usually displays flame structures and load cast at the interface of sandstone beds. Up in the stratigraphy, note a few tabular beds of fine-grained sandstones with ripple-cross lamination. Intervening fine-grained intervals often show bioturbated surfaces.

6.3. Cachoeira Formosa outcrop Coordinates: UTM 22J 662158.83/7061265.50

This is the main outcrop of this area. From the last point, follow the same road for about 2.5 km until the entrance of a farm on your right. There should probably be a road sign indicating it. This is a private property, so ask permission first. Follow this road to the house for about 1 km and park the vehicle. There is a path that leads to the base of the waterfall, but its access is difficult and dangerous. A rope will be probably necessary. The path is slippery and passes through a small "cave" (a group of fallen rocks). After this part, the path leads to the waterfall, but you turn to your left, following the wall of the escarpment. Be very careful with snakes.

The most prominent feature here is a megaturbidite bed presenting a sharp contact with the underlying Lontras Shale (Fig. 24A). It consists of an up to 5 m thick, sand-to-mud graded bed including a basal, ≤ 0,5 m thick interval presenting abundant dish structures and deformed sand patches (Figs. 24B and C). This interval may suggest an intense upward fluid escape taking place during the run-out of the turbidity current. Its base also includes granule to pebble-size clasts (Fig. 24D) and groove casts that indicate a transport to northwest, consistent with the glacial trough orientation. The basal unit is overlain by structureless, fine- to very fine-grained sandstone displaying sparse mudstone clast concentrations. Mudstone clasts are aligned parallel to the bedding, not imbricated, and notably concentrated at the top of the sandstone. This sandstone grades upwards to an up to 3 m thick siltstone/mudstone cap (Fig. 24E) that include granule- to boulder-size, basement-affinity dropstones showing disruption of surrounding laminae (Fig. 24F). Dropstones within the mud cap indicate the presence

FIGURE 25 - Details of the Cachoeira Formosa outcrop. A) Thick, amalgamated sandstone beds of Ts2 unit. B) Granules and pebble-size clasts and (C) extensive groove casts at the sole of sandstone beds. D) Bioturbated surfaces (feeding traces).

of floating ice derived from a calving tidewater glacier, probably associated with a glacial outburst event that originates the anomalous, mega turbidity flow. In addition, this thick siltstone/mudstone cap may indicate a situation where the confinement is higher and the residual cloud of the turbidity current was not free to spread in such settings.

Up in the stratigraphy, note some thick, amalgamated and moderately sorted, fine-grained sandstone beds of Ts2 unit (Fig. 25A) showing granule- to pebble-size clasts (Fig. 25B) and long groove casts at their bottoms (Fig. 25C). Individual sandstone beds are up to 2,5 m thick and mostly massive, with only their upper 20 to 10 cm showing normal grading (delayed grading, Lowe 1982). Sandstone beds of Ts3 unit show planar-bedding and ripple cross lamination, which indicate transport towards northwest. Bioturbation is common (Fig. 25D).

7. Final Remarks

This outcrop-based study deals with most of the main localities where turbidite systems of the Itararé Group crops out in the Santa Catarina State, southern Brazil. It allowed us to present some key features of each outcrop and briefly discuss involved depositional processes and degree of confinement of the related turbidity systems.

The presence of deglacial deposits filling up glacially-carved structures as well as broader and gentler depressions strongly suggests that deposition of the Itararé Group was largely controlled by basin floor topography. It is important here to make a distinction between the degree of confinement experienced either by individual flows or by the depositional system as a whole. The first will determine the stacking and internal architecture of the turbidite systems whereas the second is controlled by the basin size and geometry that determine the overall architecture of the turbidity systems.

The outcrops exposed in all three areas are considered coeval. They lie just above a correlative conformity that delineates the boundary between the underlying Lontras Shale, a regional maximum flooding marker, and the overlying turbidites. Beds related to the deposition from surge-type, short-lived low density waning flows are rarer than those related to the deposition from long-lived, flood-driven hyperpycnal underflows. The catastrophic failure of previous slope deposits is a usual trigger mechanism for surge-type, short-lived turbidity currents. On the other hand, those related to long-lived flows represents waning and waxing stages of probably meltwater derived river floods or jets from the grounding line. The coexistence of both suggests the base of delta slopes as a logical setting for the herein described turbidity systems.

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Authorship credits

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DMS						

A - Study design/ Conceptualization **B** - Investigation/ Data acquisition
C - Data Interpretation/ Validation **D** - Writing
E - Review/Editing **F** - Supervision/Project administration

References

Aquino C.D. 2015. Sedimentação deglacial em ambientes confinados e desconfinados: estudo comparativo de exposições das bacias de Paganzo (SJ, Argentina) e Paraná (SC, Brasil). PhD Thesis, Universidade do Vale do Rio dos Sinos, São Leopoldo, 168 p.

Aquino C.D., Valdez V.B., Faccini U.F., Milana J.P., Paim P.S.G. 2016. Facies and depositional architecture according to a jet efflux model of a late Paleozoic tidewater grounding-line system from the Itararé Group (Paraná Basin), southern Brazil. Journal of South America Earth Science, 67, 180-200. https://doi.org/10.1016/j.jsames.2016.02.008

Bigarella J.J., Salamuni R., Fuck R.A. 1967. Striated surfaces and related features developed by Gondwana ice sheets (State of Paraná, Brazil). Palaeogeography, Palaeoclimatology, Palaeoecology 3, 265-276. https://doi.org/10.1016/0031-0182(67)90019-3

Cagliari J., Philipp R.P., Valdez B.V., Netto R.G., Hillebrand P., Lopes C.R., Basei M.A.S., Faccini U.F. 2016. Age constraints of the glaciation in the Paraná Basin: evidence from new U–Pb dates. Journal of the Geological Society, 173, 871-874. https://doi.org/10.1144/jgs2015-161

Canuto J.R. 1993. Facies e ambiente de sedimentação da Formação Rio do Sul (Permiano), Bacia do Paraná, na região de Rio do Sul, Estado de Santa Catarina. PhD Thesis, Universidade de São Paulo, São Paulo, 184 p. https://doi.org/10.11606/T.44.1994.tde-17072013-144504

Carvalho A.H., Vesely F.F. 2016. Facies relationship recorded in a Late Paleozoic fluvio-deltaic system (Paraná Basin, Brazil): insights into the timing and triggers of subaqueous sediment gravity flows. Sedimentary Geology, 352, 45-62. https://doi.org/10.1016/j.sedgeo.2016.12.004

Castro J.C. 1980. Fácies, ambientes e sequencias deposicionais das formações Rio do Sul e Rio Bonito, leste de Santa Catarina. In: Congresso Brasileiro de Geologia, 31, 283-299. Available on line at: https://www.sbgeo.org.br/home/pages/44

Crowell J.C., Frakes L.A. 1970. Phanerozoic glaciation and the causes of ice ages. American Journal of Science, 268(3), 193- 224. https://doi.org/10.2475/ajs.268.3.193

D'Ávila R.S.F., Arienti L.M., Aragão M.A.N.F., Vesely F.F., Santos S.F., Voelcker H.E., Viana A.R., Kowsmann R.O., Moreira J.L., Coura A.P., Paim P.S.G., Matos R.S., Machado L.C.R. 2008. Ambientes de água profunda. In: Silva A.G., Aragão M.A.N.F., Magalhães A.J.C. (eds). Ambientes de sedimentação siliciclástica do Brasil: São Paulo, Beca. p. 246-300.

D'Ávila R.S.F. 2009. Seqüencias deposicionais do Grupo Itararé (Carbonífero e Eopermiano), Bacia do Paraná, na área de Dr. Pedrinho e cercanias, Santa Catarina: turbiditos, pelitos e depósitos caóticos. PhD Thesis, Universidade do Vale do Rio dos Sinos, São Leopoldo, Brasil, 233p. http://www.repositorio.jesuita.org.br/handle/UNISINOS/9698

Deptuck M.E., Piper D.J.W., Savoye B., Gervais A. 2008. Dimensions and architecture of late Pleistocene submarine lobes of the northern margin of East Corsica. Sedimentology, 559(4), 869-898. https://doi.org/10.1111/j.1365-3091.2007.00926.x

Eyles C.H., Eyles N., Franca A.B. 1993. Glaciation and tectonics in an active intracratonic basin: the Late Paleozoic Itararé Group,

Paraná Basin, Brazil. Sedimentology, 40(1), 1-25. https://doi.org/10.1111/j.1365-3091.1993.tb01087.x
Fallgatter C. 2015. Confined to unconfined deep-water systems of the Paraná (Brazil) and Paganzo (Argentina) basins. PhD Thesis, Departamento de Geologia, Universidade do Vale do Rio dos Sinos, São Leopoldo, Brasil, 208 p.
Fallgatter C., Paim P.S.G. 2019. On the origin of the Itararé Group basal nonconformity and its implications for the Late Paleozoic glaciation in the Paraná Basin, Brazil. Palaeogeography, Palaeoclimatology, Palaeoecology, 531(B), 108-225. https://doi.org/10.1016/j.palaeo.2017.02.039
Fallgatter C., Paim P.S.G., Silveira D.M., Valdez-Buso V., Aquino C.D. 2023. Confined turbidite system of the upper Paleozoic Itararé Group, Paraná Basin, Brazil: beyond the topographic control paradigm. Sedimentary Geology, 457, 106512. https://doi.org/10.1016/j.sedgeo.2023.106512
França A.B., Potter P.E. 1988. Estratigrafia, ambiente deposicional e análise de reservatório do Grupo Itararé (Permocarbonífero), Bacia do Paraná (parte 1). Boletim de Geociências da Petrobrás, 2, 147-191.
Gama Jr. E.G., Perinotto J.A.J., Ribeiro H.J.P.S., Pádula E.K. 1992. Contribuição ao estudo de ressedimentação do Subgrupo Itararé: trato de fácies e hidrodinâmica deposicional. Revista Brasileira de Geociências, 22, 228-236. https://doi.org/10.25249/0375-7536.1992228236
Grundvåg S.A., Johannessen E.P., Hansen W.H., Bjorklund P.P. 2014. Depositional architecture and evolution of progradationally stacked lobe complexes in the Eocene Central Basin of Spitsbergen. Sedimentology, 61(2), 535-569. https://doi.org/10.1111/sed.12067
Haughton P., Davis C., McCaffrey W., Barker S. 2009. Hybrid sediment gravity flow deposits: classification, origin and significance. Marine and Petroleum Geology, 26(10), 1900-1918. https://doi.org/10.1016/j.marpetgeo.2009.02.012
Hodgson D.M., Flint S.S., Hodgetts D., Drinkwater N.J., Johannessen E.P., Luthi S.M. 2006. Stratigraphic evolution of fine-grained submarine fan systems, Tanqua depocenter, Karoo Basin, South Africa. Journal of Sedimentary Research, 76(1), 20-40. https://doi.org/10.2110/jsr.2006.03
Kneller B. 1995. Beyond the turbidite paradigm: physical models for deposition of turbidites and their implication for reservoir prediction. In: Hartley, A. J. and Prosser, D. J. (eds). Characterization of Deep Marine Clastic Systems. Geological Society Special Publication, 94, 31-49. https://doi.org/10.1144/GSL.SP.1995.094.01.04
Kneller B.C., McCaffrey W. 1999. Depositional effects of flow non-uniformity and stratification within turbidity currents approaching a bounding slope. Deflection, reflection and facies variation. Journal of Sedimentary Research, 69(5), 980-991. https://doi.org/10.2110/jsr.69.980
Kneller B.C., Buckee C. 2000. The structure and fluid mechanics of turbidity currents; a review of some recent studies and their geological implications. Sedimentology, 47(1), 62-94. https://doi.org/10.1046/j.1365-3091.2000.047s1062.x
Lowe D.R. 1979. Sediment gravity flows: their classification and some problems of application to natural flows and deposits. In: Doyle L.J., Pilkey O.H. Geology of continental slopes. Society for Sedimentary Geology, 27. https://doi.org/10.2110/pec.79.27.0075
Lowe D.R. 1982. Sediment gravity flows II: depositional models with special reference to the deposits of high-density turbidity currents. Journal of Sedimentary Research, 52(1), 279-297. https://doi.org/10.1306/212F7F31-2B24-11D7-8648000102C1865D
Meiburg E., Kneller B. 2010. Turbidity currents and their deposits. Annual Review of Fluid Mechanics, 42, 135-156. https://doi.org/10.1146/annurev-fluid-121108-145618
Mottin T.E., Vesely F.F. 2021. Formação Taciba: última manifestação glacial no Paraná. Boletim Paranaense de Geociências, 78, 65-82. http://dx.doi.org/10.5380/geo.v78i0.79352
Mouro L.D., Pacheco M.L.A.F., Ricetti J.H.Z., Scomazzon A.K., Horodysky R.S., Fernandes A.C.S., Carvalho M.A., Weinschutz L.C., Silva M.S., Waichel B.L., Scherer C.M.S. 2020. Lontras Shale (Paraná Basin, Brazil): insightful analysis and commentaries on paleoenvironment and fossil preservation into a deglaciation pulse of the Late Paleozoic Ice Age. Palaeogeography, Palaeoclimatology, Palaeoecology 555, 109850. https://doi.org/10.1016/j.palaeo.2020.109850
Mulder T., Syvitski J.P.M. 1995. Turbidity currents generated at river mouths during exceptional discharges to the world oceans. The Journal of Geology, 103(3), 285-299. https://www.jstor.org/stable/30071222
Mulder T., Syvitski J.P.M., Migeon S., Faugeres J.C., Savoye B. 2003. Marine hyperpicnal flows: initiation, behavior and related deposits. A review. Marine and Petroleum Geology, 20(6-8), 861-882. https://doi.org/10.1016/j.marpetgeo.2003.01.003
Mulder T., Alexander J. 2001. The physical character of sedimentary density currents and their deposits. Sedimentology, 48(2), 269-299. https://doi.org/10.1046/j.1365-3091.2001.00360.x
Neves J.P., Anelli L.E., Simoes M.G. 2014. Early Permian post-glacial bivalve faunas of the Itarare Group, Parana Basin, Brazil; Paleoecology and biocorrelations with South American intraplate basins. Journal of South American Earth Science 52, 203-233. https://doi.org/10.1016/j.jsames.2014.03.001
Patacci M., Haughton P.D.W., McCaffrey W.D. 2015. Flow behavior of ponded turbidity currents. Journal of Sedimentary Research, 85(8), 885-902. https://doi.org/10.2110/jsr.2015.59
Piper D.J.W., Cochonat P., Morrison M.L. 1999. The sequence of events around the epicentre of the 1929 Grand Banks earthquake: initiation of debris flows and turbidity current inferred from sidescan sonar. Sedimentology, 46(1), 79-97. https://doi.org/10.1046/j.1365-3091.1999.00204.x
Plink-Björklund P., Steel R.J. 2004. Initiation of turbidity currents: outcrop evidence for Eocene hyperpycnal flow turbidites. Sedimentary Geology, 165(1-2), 29-52. https://doi.org/10.1016/j.sedgeo.2003.10.013
Prather B.E., Booth J.R., Steffens G.S., Craig P.A. 1998. Classification, lithologic calibration, and stratigraphic succession of seismic facies of intraslope basins, deep-water Gulf of Mexico. American Association of Petroleum Geology Bulletin, 82, 701-728. https://doi.org/10.1306/1D9BC5D9-172D-11D7-8645000102C1865D
Prélat A., Hodgson D.M., Flint S.S. 2009. Evolution, architecture and hierarchy of distributary deep-water deposits: a high-resolution outcrop investigation from the Permian Karoo Basin, South Africa. Sedimentology, 56(7), 2132-2154. https://doi.org/10.1111/j.1365-3091.2009.01073.x
Prélat A., Hodgson D.M. 2013. The full range of turbidite bed thickness patterns in submarine lobes: controls and implications. Journal of the Geological Society, 170, 209-214. https://doi.org/10.1144/jgs2012-056
Puigdomenech C.N., Carvalho B., Paim P.S.G., Faccini U.F. 2014. Lowstand turbidites and delta systems of the Itararé Group in the Vidal Ramos region (SC), southern Brazil. Revista Brasileira de Geociências, 44(4), 529-544. https://doi.org/10.5327/Z23174889201400040002
Rocha-Campos A.C., Machado L.C.R., Santos P.R., Canuto J.R., Castro J.C. 1988. Pavimento estriado da glaciação Neo-Paleozóica em Alfredo Wagner, SC, Brasil. Instituto de Geociências da Universidade de São Paulo, 19, 39-46. https://doi.org/10.11606/issn.2316-8986.v19i0p39-46
Rodrigues M.C.N.L., Trzaskos B., Vesely F.F., Mottin T.E. 2021. Diversidade de estilos estruturais e processos de deformação em depósitos de transporte em massa. Boletim Paranaense de Geociências, 78, 83-109. http://dx.doi.org/10.5380/geo.v78i0.79402
Rosa E.L.M., Vesely F.F., França A.B. 2016. A review on late Paleozoic ice-related erosional landforms in the Parana Basin: origin and paleogeographical implications. Brazilian Journal of Geology, 46(2), 147-166. https://doi.org/10.1590/2317-4889201620160050
Rosa E., Vesely F.F., Isbell J., Fedorchuk N. 2021. As geleiras carboníferas no sul do Brasil. Boletim Paranaense de Geociências, 78, 24-43. http://dx.doi.org/10.5380/geo.v78i0.78669
Salamuni R., Marques-Filho P.L., Sobanski A.C. 1966. Considerações sobre turbiditos da Formação Itararé (Carbonífero Superior), Rio Negro-PR e Mafra-SC. Boletim da Sociedade Brasileira de Geologia, 15, 1-19.
Saldanha J.P., Mouro L.D., Horodyski R.S., Ritter M.N., Neto H.S. 2023. Taphonomy and paleoecology of the Lontras Shale Lagerstätte: detailing the warming peak of a Late Paleozoic Ice Age temperate fjord. Palaeogeography, Palaeoclimatology, Palaeoecology, 609, 111326. https://doi.org/10.1016/j.palaeo.2022.111326
Santos P.R., Rocha-Campos A.C., Canuto J.R. 1996. Patterns of late Palaeozoic deglaciation in the Paraná Basin, Brazil. Palaeogeography, Palaeoclimatology, Palaeoecology, 125(1-4), 165-184. https://doi.org/10.1016/S0031-0182(96)00029-6
Schemiko D.C.B., Vesely F.F., Rodrigues M.C.N.L. 2022. Late Paleozoic glacial to postglacial stratigraphic evolution of the Rio do Sul depocenter, Itararé and Guatá groups, Pennsylvanian-Cisuralian, southern Brazil. Brazilian Journal of Geology, 52(4), 1-22. https://doi.org/10.1590/2317-4889202220220027

Schneider R.L., Muhlmann H., Tommasi E., Medeiros R., Daemon R.F., Nogueira A.A. 1974. Revisão estratigráfica da Bacia do Paraná. In: Congresso Brasileiro de Geologia., 28, 1, 41-65.

Sinclair H.D., Tomasso M. 2002. Depositional evolution of confined turbidite basins. Journal of Sedimentary Research, 72(4), 451-456. https://doi.org/10.1306/111501720451

Souza P.A. 2006. Late Carboniferous palynostratigraphy of the Itararé Subgroup, northeastern Paraná Basin, Brazil. Review of Palaeobotany and Palynology 38(1), 9-29. https://doi.org/10.1016/j.revpalbo.2005.09.004

Straub K.M., Pyles D.R. 2012. Quantifying the hierarchical organization of compensation in submarine fans using surface statistics. Journal of Sedimentary Research, 82(11), 889-898. https://doi.org/10.2110/jsr.2012.73

Suss J.F., Vesely F.F., Santa Catharina A., Assine M.L., Paim P.S.G. 2014. O Grupo Itararé (Neocarbonífero-Eopermiano) entre Porto Amazonas (PR) e Mafra (SC): sedimentação gravitacional em contexto marinho deltaico com influência glacial. Geociências, 33(4), 701-719. Available on line at: https://www.periodicos.rc.biblioteca.unesp.br/index.php/geociencias/article/view/9515

Valdez-Buso V., Aquino C.D., Paim P.S.G., Souza P.A., Mori A.L.O., Fallgatter C., Milana J.P., Kneller B. 2019. Late Palaeozoic glacial cycles and subcycles in western Gondwana: correlation of surface and subsurface data of the Paraná Basin, Brazil. Palaeogeography Palaeoclimatology Palaeoecology, 531(B), 108435. https://doi.org/10.1016/j.palaeo.2017.09.004

Vesely F.F., Assine M.L. 2002. Superfícies estriadas em arenitos do Grupo Itararé produzidas por gelo flutuante, sudeste do Estado do Paraná. Revista Brasileira de Geociências, 32, 587-594. Available on line at: https://ppegeo.igc.usp.br/portal/wp-content/uploads/tainacan-items/15906/44717/9856-12388-1-PB.pdf

Vesely F.F., Trzaskos B., Kipper F., Assine M.L., Souza P.A. 2015. Sedimentary record of a fluctuating ice margin from the Pennsylvanian of western Gondwana: Paraná Basin, southern Brazil. Sedimentary Geology, 326, 45-63. https://doi.org/10.1016/j.sedgeo.2015.06.012

Vesely F.F., Kraft R.P., Mattos T.R., Schemiko D.C.B., Berton F., Monteiro L.B., Yamassaki H.S. 2021. Os primeiros turbiditos do Brasil. Boletim Paranaense de Geociências, 78, 110-129. http://dx.doi.org/10.5380/geo.v78i0.79539

Wilner E., Lemos V.B., Scomazzon A.K. 2016. Associações naturais de conodontes Mesogondolella spp., Grupo Itararé, Cisuraliano da Bacia do Paraná. Gaea 9 (1), 30-36. https://doi.org/10.4013/gaea.2016.91.02

Zalán P.V., Wolff S., Astolfi M.A.M., Vieira I.F., Conceição J.C.J., Appi V.T., Cerqueira J.R., Marques A. 1990. The Paraná basin, Brazil. In: Leighton M., Kolata D.R., Oltz D.F., Eidel J.J. (eds.). Interior cratonic basins. Tulsa, Association of American Petroleum Geologists Bulletin. p. 681-708. https://doi.org/10.1306/M51530

Zavala C., Ponce J.J., Arcuri M., Drittanti D., Freije H., Asensio M. 2006. Ancient lacustrine hyperpycnites: a depositional model from a case study in the Rayoso Formation (Cretaceous) of West-Central Argentina. Journal of Sedimentary Research 76(1), 41-59. https://doi.org/10.2110/jsr.2006.12