UNIVERSIDADE ESTATUDAL DE CAMPINAS
PÓS-GRADUAÇÃO EM GEOCIÊNCIAS

APRESENTAÇÃO DE PLANO DE TRABALHO

# ESTUDOS DE SEDIMENTOLOGIA NO CANYON DO GUARTELÁ; CONTRIBUIÇÕES AO ESTUDO DE SISTEMAS FLUVIAS NO DEVONIANO, FORMAÇÃO FURNAS, BACIA DO PARANÁ, BRASIL

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## SUMÁRIO

# 1. INTRODUÇÃO

## 1.1 Motivos para o desenvolvimento do projeto de pesquisa

O *Canyon* do Guartelá é uma área escavada ao longo do leito do rio Iapó com aproximadamente 30 km de extensão na região denominada geomorfologicamente, como Segundo Planalto Paranaense (Guimarães *et al*. 2007). Uma área conhecida pelas belas paisagens, biodiversidade e principalmente pela geologia do local com afloramentos de rochas que tem a origem no Período Devoniano (Melo e Guimarães, 2012).

As rochas que afloram no Canyon do Guartelá representam parte de uma unidade sedimentar extensa por dezenas de quilômetros na Bacia do Paraná, conhecida como Formação Furnas. A Formação Furnas é constituída principalmente por arenitos quartzosos médios a grossos, (Assine *et al*.,1994; Assine,1999; Milani *et al*., 2007).

Assine (*et al*.,1994; 1999) e Bergamaschi, (1992) realizaram pesquisas na região do Canyon do Guartelá e descreveram e interpretaram uma variedade de fácies e ambientes continentais a transacionais para o período de deposição dessas camadas. Muitas das fácies continentais encontradas são atribuídas por Araújo (2016), a partir de pesquisas no Canyon do Guartelá, a ação de sistemas fluviais de canais entrelaçadas com grande quantidade de avulsão e submetidas a variações de descarga hidráulica e de sedimentos. No entanto a construção desse sistema deposicional apresenta lacunas que precisam respondidas, como por exemplo, a extensão desse registro de depósitos fluviais na Formação Furnas e consequentemente sua relação com outros sistemas deposicionais e ainda entender a forma como ocorriam os processos depocisionais no início do Período Devoniano, onde as plantas ainda estavam se estabelecendo na Terra (Long, 2011)

Este projeto visa dar continuidade as pesquisas realizadas e apresentadas na dissertação de mestrado de Araujo (2016) e tem como objetivo identificar as fácies, elementos arquiteturais e paleocorrentes presentes no Parque Estadual do Guartelá, essas informações serão usadas para caracterizar o sistema de deposição responsável pela formação dos extensos afloramentos encontrados na Formação Furnas.

## 1.2 Relevância do contexto científico

A Formação Furnas é uma complexa unidade sedimentar construída por diferentes processos de deposição (Milani *et al.* 2007). Alguns pesquisadores interpretaram a Formação Furnas como derivadas de sistema fluvial dominado por rios entrelaçados (Schneider *et al*.1974; Zalán *et al*. 1987) mas, outras pesquisas também indicam a existência de ambientes marinhos dominados por maré (Bergamaschi, 1992; Assine, 1999; Borghi, 2002).

Em vista disso a região do *Canyon* do Guartelá, próximo a Tibagi (PR), é um local importante para buscar entender a organização das sucessões sedimentares da Formação Furnas.

A importância de investigar a unidade Formação Furnas é buscar entender as principais características de um antigo sistema deposicional, no qual não existem modelos análogos para efeito de comparação que auxiliem a interpretação.

Ao final o estudo de unidades areníticas de grandes dimensões é sempre fundamental para a caracterização geológica de possíveis rochas reservatório de aquíferos e hidrocarbonetos além de trazer novos estudos sobre a geologia das rochas expostas ao longo do rio Iapó no Estado do Paraná.

# 2. ÁREA DE PESQUISA

## 2.1 Localização da área de estudo

Os afloramentos analisados estão distribuídos ao longo do Parque Estadual do Guartelá localizado na porção centro-leste do estado do Paraná, entre os municípios de Castro e Tibagi (Figura 1), mais especificamente na região do *Canyon* do Guartelá, uma garganta de 30 km de extensão e desnível de até 450 metros (Figura 2), que foi escavado ao longo do leito do rio Iapó, afluente do rio Tibagi que deságua no Paranapanema. O entalhamento do rio gerou escarpas sustentadas pelo Arenito Furnas além de apresentar exposições de outras sequências paleozóicas na Bacia do Paraná (Melo, 2002).

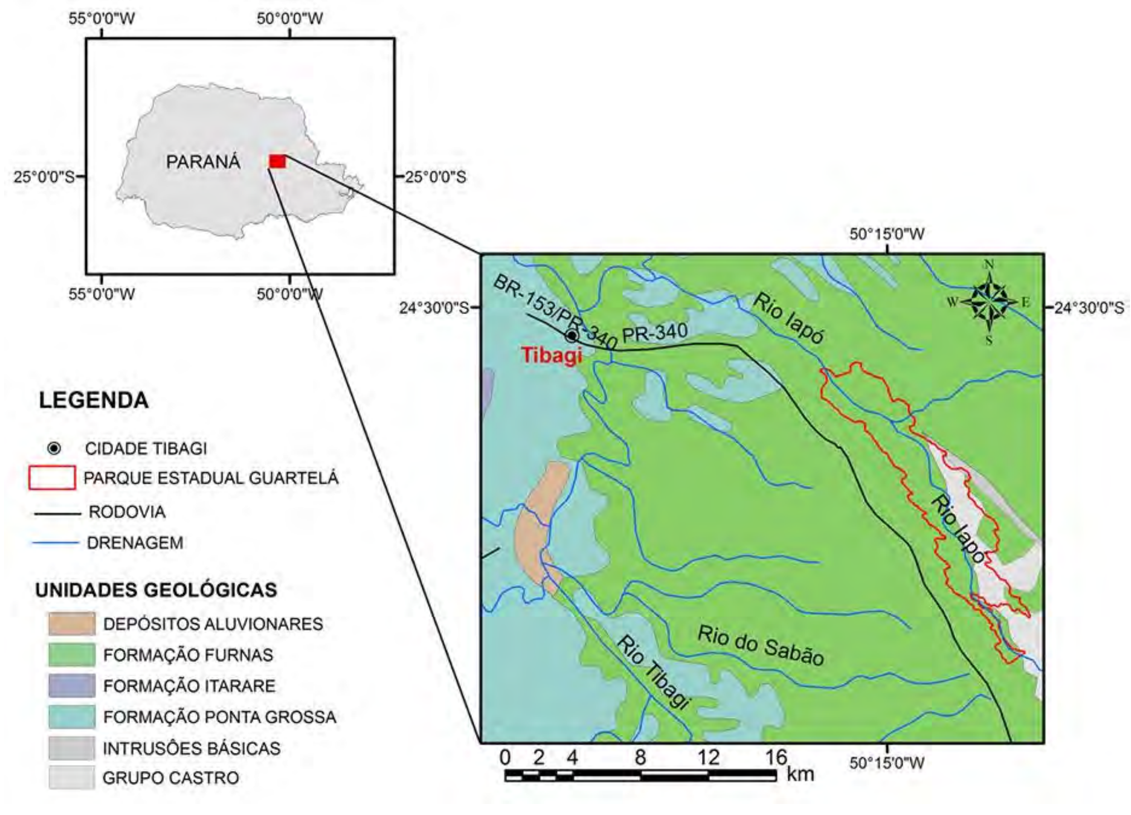

**Figura 1. Mapa de localização e mapa geológico da área de estudo (Base de dados CPRM, 2004).**

**Figura 2. Imagem do *Canyon* do Guartelá. O rio Iapó, ao fundo, escavou profundas escarpas exibindo extensões paredões das rochas de idade devoniana da Formação Furnas.**

## 2.2 Sequência Devoniana da Bacia do Paraná

As primeiras investigações científicas da sequência devoniana da Bacia do Paraná datam do final do século XIX, e desde cedo era claro o empilhamento estratigráfico de um pacote arenoso na base, Formação Furnas, e no topo um pacote pelítico, Formação Ponta Grossa, no entanto, só a partir dos trabalhos de Maack (1947) e Petri (1948). Lange & Petri (1967) denominaram essa sequência de Grupo Paraná, termo usado até os dias de hoje.

Somente a partir dos trabalhos de Dino & Rodrigues (1993), com datação de material palinológico em folhelhos basais da Formação Ponta Grossa, associado às pesquisas de Assine *et al.* (1994) e Milani *et al.* (1994), com coleta de dados de afloramentos, perfis petrofísicos e litológicos, foi possível verificar um contanto concordante entre Furnas e Ponta Grossa e estabelecer a idade do Grupo Paraná como pertencente ao Período Devoniano.

Assine (1996); Milani (1997) e Milani *et al.* (2007), demonstraram que o Grupo Paraná ou Supersequência Paraná, como também é chamada, está sobrepondo as rochas ordovício-silurianas do Grupo Rio Ivaí (Figura 3) ou diretamente assentada sobre embasamento pré-cambriano/paleozóico.

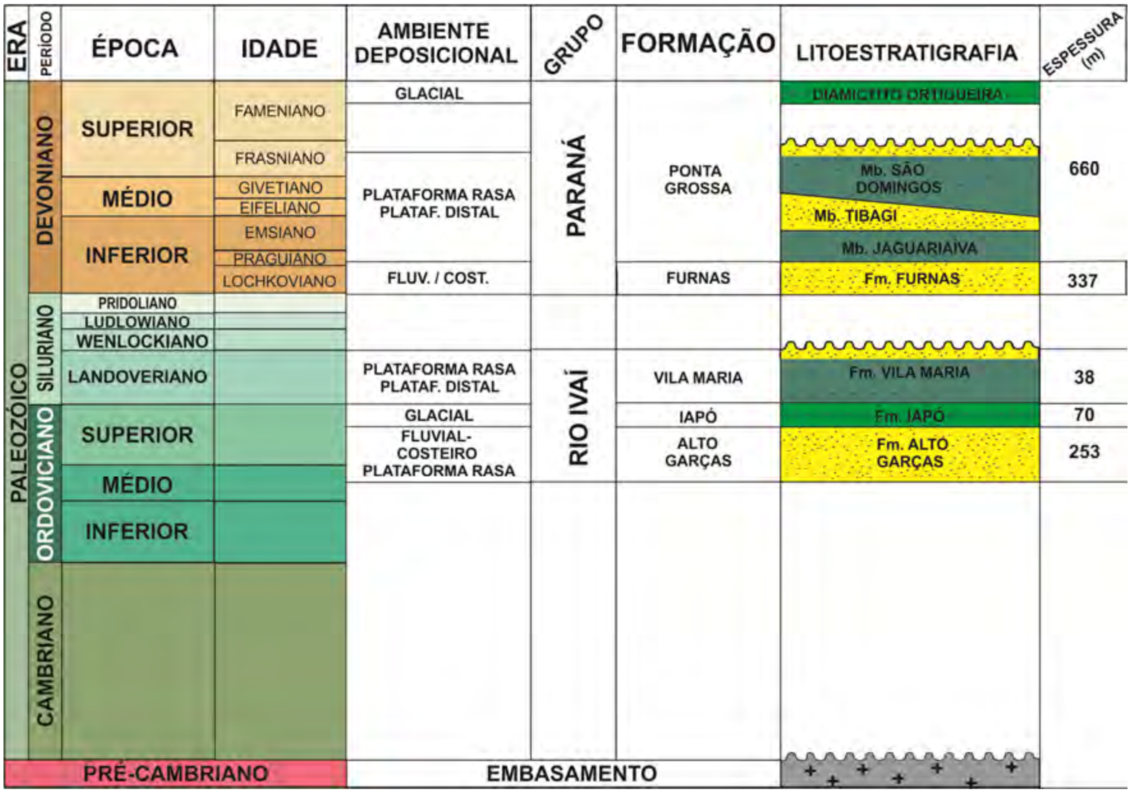

**Figura 3. Carta estratigráfica das sequências ordovício-siluriana e devoniana da Bacia do Paraná (Modificado de Milani *et al.*, 2007).**

## 2.3 Formação Furnas

A Formação Furnas é uma ampla unidade arenítica com aproximadamente 250 a 330 m de espessura (Milani *et al.*, 2007), que se distribui por uma grande área da Bacia do Paraná em torno de um eixo principal NW-SE; no entanto, a maior parte da unidade encontra-se em subsuperfície, com os principais afloramentos limitados a borda norte (MT, GO) borda noroeste (MT, MS) e borda sudeste (SP, PR) (Assine, 1996) (Figura 4).

Segundo a literatura a Formação Furnas é composta por arenitos quartzosos, cauliníticos médios a grossos, com estratificação cruzada, em menor quantidade apresenta camadas de conglomerados quartzosos e níveis micáceos a argilosos, (Assine *et al*.,1994; Assine,1999; Milani *et al.*, 2007). A deposição da Formação Furnas ocorreu aproximadamente no Devoniano Inferior no Lochkoviano (Dino & Rodrigues, 1993; Gerrienne *et al*. 2001)

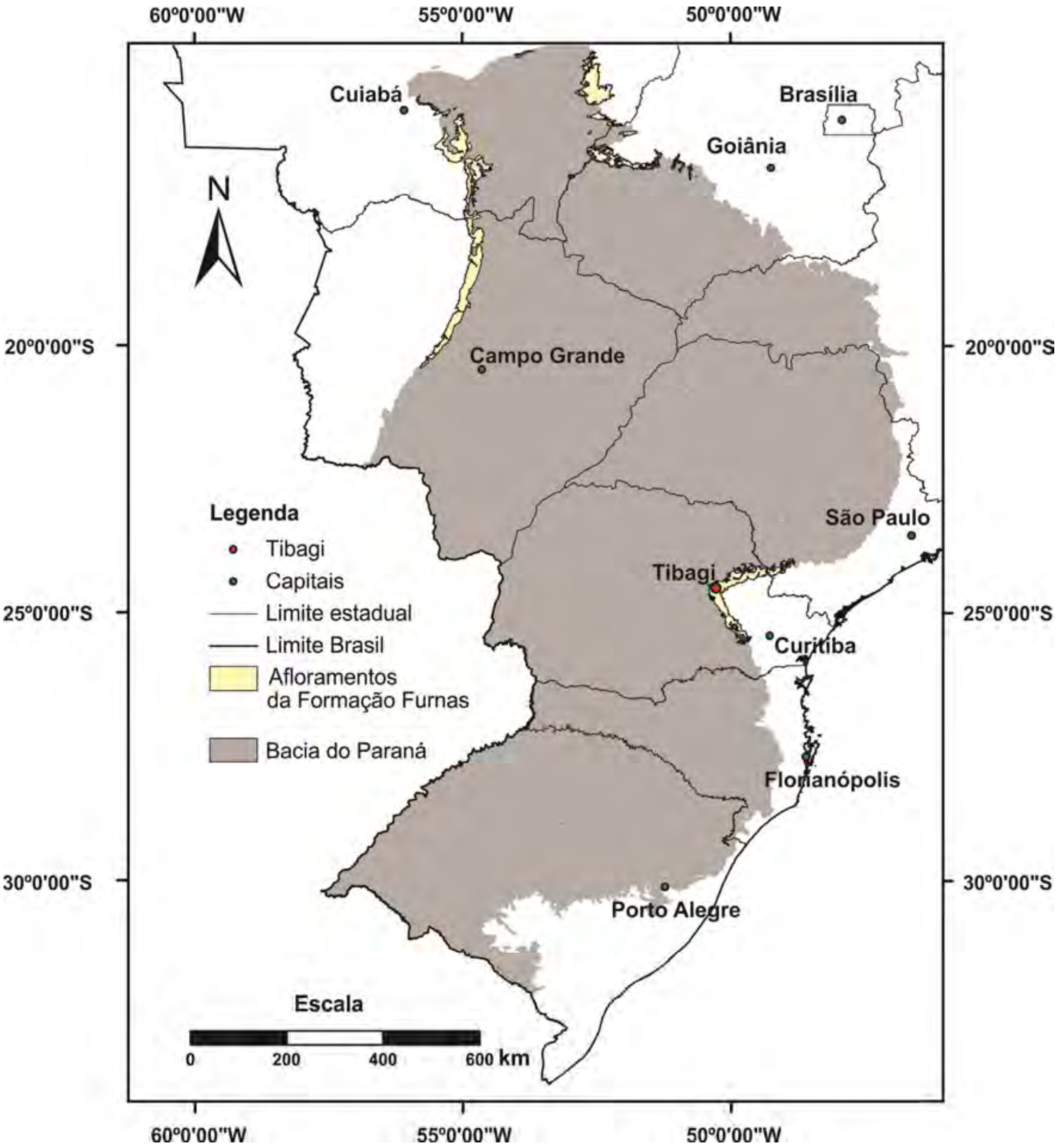

**Figura 4. Mapa da Bacia do Paraná com os locais de ocorrência dos afloramentos da Formação Furnas em vermelho na região da cidade de Tibagi (PR) onde está o Canyon do Guartelá (Base de dados CPRM, 2004).**

## 3. MÉTODOS DE ESTUDO UTILIZADOS EM CAMPO

Os dados serão adquiridos diretamente durante a análise de exposições de rochas facilmente acessíveis. Serão escolhidas as mais continuas lateralmente e verticalmente. Nessas exposições o estudo será efetuado mediante a descrição das características das rochas, a coleta de dados de paleocorrentes e a confecção gráfica e fotográfica de painéis bidimensionais.

A descrição das rochas sedimentares ocorrerá com base no método de análise de fácies. Este método consiste na descrição e interpretação de texturas sedimentares como composição, granulometria, seleção, trama (*fabric*) dos sedimentos, grau de arredondamento dos grãos de arenitos, estruturas sedimentares, superfícies limitantes, formas e dimensões das camadas, organização sequencial vertical (temporal) e horizontal (espacial) de diferentes ordens na sucessão sedimentar (Miall, 1984; 1999; Walker, 2006).

A análise de paleocorrentes consiste na coleta de vetores extraídos de feições sedimentológicas produzidos por fluxo de correntes subaquáticos, assim permitindo a reconstrução do sentido dos paleofluxos.

Os painéis gráficos e fotográficos serão utilizados para reconstruir a arquitetura deposicional do sistema sedimentar. No campo serão efetuados esboços gráficos e fotos de detalhe. No laboratório estes gráficos serão reconstruídos mediante o uso das imagens digitalizadas. Acima das imagens serão desenhados e classificados os vários tipos de superfícies limitantes que separam unidades litológicas. O estudo de arquitetura deposicional estabelece ordens de grandeza para as superfícies limitantes de acordo com a metodologia de Miall (1985). Posteriormente as superfícies delimitam corpos sedimentares com características específicas que são reflexo de um grupo de fácies geneticamente associadas, denominado por Allen (1983) "elemento arquitetural".

Se possível, seria auspiciosos coletar algumas amostras de rocha para análises petrográficas e microestruturais. As amostras, de dimensões máximas de (10x10x10) $cm^3$ e em número não superior a 15 seriam coletadas no chão já soltas sem romper as paredes de erosão natural. Contudo lembramos que a impossibilidade de coleta das amostras não invalida o projeto.

## 4. RESULTADOS

Os resultados obtidos serão redigidos na forma de Tese de Doutorado e apresentado ao Programa de Pós-Graduação em Geociências da Universidade Estadual de Campinas (UNICAMP). Posteriormente os resultados mais relevantes serão submetidos à publicação em revistas científicas com foco em geologia e ensino da historia evolutiva da Terra. Até o momento os resultados obtidos no mestrado de Araújo (2016) e proponente deste projeto serão apresentados logo abaixo como Anexo deste projeto. O objetivo aqui é demonstrar a importância e avanços nos estudos já realizados na região do Parque Estadual do Guartelá graças a parceria com o Instituto Ambiental do Paraná (IAP) que sempre auxilia esse tipo de pesquisa científica.

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# 6 ANEXO: ARTIGO A SER SUBMETIDO EM REVISTA CIENTÍFICA

## Furnas Formation, Ordovician sandstone of Guartelá Canyon, SE, Brazil: fluvial or tidal dominate system?

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### ABSTRACT

Sand-dominated fluvial and subtidal depositional systems may exhibit similar features:: (i) dominance of sand and subordinated gravel, (ii) high mineralogical maturity, (iii) medium to large cross bedding, (iv) tabular beds of variable thickness. The Furnas Formation is a sedimentary succession (Early Devonian) whose interpretation is controversial: some authors interpreted it as a fluvial braided system, while other considered its origin associated with coastal to shallow tidal-dominated sea. The Guartelá Canyon represents a key area of study of this unit where it shows excellent exposures from the base to the top. This paper deals with new arguments based on detailed facies analysis, architecture reconstruction and paleocurrents that allow considering the Furnas Formation here exposed in these areas as portion of a huge fluvial system. Five lithofacies were described and interpreted: large cross-bedded sandstone, small cross-bedded sandstone, low-angle laminated sandstone, low-angle stratified sandstone and conglomeratic sandstone. Large and small cross-bedded sandstone facies represents sandy dunes and downstream migrating sandy bars, respectively. Low-angle laminated and low-angle stratified lithofacies suggest the existence of bedforms produced under upper flow regime. Conglomeratic sandstone lithofacies constitutes thin and extensive beds, generally planar, which may represent the deposition of a sand-gravel mixture associated with discharge peaks during flow migration. These lithofacies result associates in four architectural elements: unit bars, amalgamated bars, channelized bodies and top bar. Erosive and concave bottom is related to the action of subaqueous channelized forms, which are common in fluvial deposits and are not found in subtidal settings as shallow seas. Minor channels commonly occur close to the top of unit and amalgamated bar, suggesting the presence of cross bar channels that cut across the bars top. Cross bar channels and upper flow structures developed on the top of bars suggest that the construction of the bars was related to relative variation of the water level due to the growing of the bar and the normal and flood flow alternance. Paleocurrents data indicate a dominant direction, thus suggesting a unidirectional flow, differently from tidal settings which show bidirectional current trends. This depositional model defined by detailed facies analysis suggests fluvial system for the southeastern part of the Furnas Formation in the Guartelá Canyon region.

**KEYWORDS:** FURNAS FORMATION, FLUVIAL SYSTEM, GUARTELÁ CANYON

## INTRODUCTION: TIDAL AND RIVERS SANDY DEPOSITS

Few sedimentary structures are really unique of tidally-influenced depositional environments. Most of the sedimentary structures present in this environment can be also founded in fluvial, deltaic, shallow marine or lacustrine environments (Davis, 2012). Bedforms and architectural elements produced by tidal-dominated shelves and large braided river system can be, in some ways, easily mistakable. Both the systems are dominantly sandy and most common sedimentary structure is cross-stratification, produced by migration subaqueous dunes and bars.

The Furnas Formation at the Guartelá Canyon (SE Brazil) displays a monotonous succession of cross-stratified sandstone (Melo, 2002). Many authors interpreted this cross-bedded succession formed by shallow-water coastline currents or as a tide-dominated shelf (Sanford & Lange, 1960; Bigarella *et al.*, 1966; Bergamaschi, 1992; Assine, 1999). Other studies used the presence of coarse sandstone, conglomerate beds, absence of glauconite and fossil assemblage as evidence of fluvial system dominated by braided rivers (Schneider *et al.* ,1974; Zalán *et al.*, 1987).

The published studies do not permit a clear understand of the sedimentary processes that generated the Furnas Formation, because these studies did not focus on the genesis and reconstruction of the sandstone bodies. This study was realized with purpose to analyze the depositional architecture of this unit likening to facies analyses, palaeocurrents. The main objective of this paper is define what hydraulic mechanisms were responsible for sand transport and construction of the architectural elements.

## GEOLOGICAL SETTINGS OF THE STUDY AREA

The study area is localized at Guartelá Canyon (Figure 1), which is a gorge with a maximum 450 m depth. carved out among Devonian rocks in Southeast Brazil, permitting an exposition of sedimentary unit knows as Furnas Formation, vertically, at the base to top, by approximately 30 km of extension in NW-SE direction in a region (Melo, 2002).

The Furnas Formation is part of the Paraná Basin, which is a large intracratonic basin implemented along N-S direction. The first sedimentary successions were deposited during Middle-Ordovician and accumulated until Middle-Silurian on marine conditions. During Early-Devonian another sequence called of Paraná Group started to be deposited and the basal sequence is the Furnas Formation (Milani, 1997; Milani *et al*., 2007) (Figure 2). The Furnas Formation is Lochkovian in age (Dino & Rodrigues, 1993; Gerrienne *et al*. 2001), is approximately 250 m thick and is composed of monotonous beds of sandstones predominantly quartz grains, with minor component of feldspars and horizontal extensive thin beds of conglomerate. Furnas Formation is overlain by muddy sandstone of the Ponta Grossa Formation. (Assine, 1999; Milani *et al*., 2007). Sanford & Lange (1960) interpreted the Furnas Formation as deposited in marine settings. Following this interpretation Bigarella et al. (1966) attributed the sedimentation of the Furnas Formation as product of longshore currents. Schneider *et al.* (1974) and Zalán *et al*. (1987) argued that the presence of cross-stratification, coarse to very coarse sandstone, conglomerates beds and absence of glauconite suggested that Furnas Formation was deposited in a fluvial system. More recently Assine (1999) reinterpreted Furnas Formation and suggested that this succession represented a transition from alluvial-coastal plain at the base to tidal-dominated marine shelf at the top.

## METHODS AND DATASET

Detailed facies analysis was realized in well-exposed outcrops that occur throughout the escarpment of Guartelá Canyon (Figure 3). Four outcrops were chosen into the measured section of 131 m of thickness in the medium to upper part of Furnas Formation (figura4).

In each photo-panel were designed sketches with the lines that represent the boundaries surface, which was taken into consideration the shape, the cutting links and lateral continuity of each line, useful parameters to studies of depositional architecture.

Facies analysis detail along each set of sedimentary structure realized at the centimeter to decimeter scale. The parameters analyzed were grain-size, sorting, roundness, compositional maturity, sedimentary structures, boundaring surfaces.

The data include also 57 palaeocurrents measurements, the mostly from cross-stratifications, which were plotted in rose diagrams using StereoNet software.

## FACIES ANALYSIS

Five lithofacies have been distinguished according to textural features. The sandbodies of the Furnas Formation consist predominantly of planar-cross-beds cosets, minor amounts of small cross-bedding, low-angle lamination and low-angle stratification. Elsewhere in the Furnas Formation, mainly in the upper part, the conglomeratic sandstone overlies the top of many surfaces of the sandbodies.

### Large cross-bedded sandstone

This lithofacies is represented by tabular 0.4 to 2 m thick sets of planar cross-bedding, which are composed of moderately-sorted, medium- to very coarse-grained sandstone with subangular grains. The foresets dip from 18 to 30 degrees and the are characterized by alternations of medium- to coarse-grained and coarse- to very coarse-grained sand (Figure 5A). Rarely some foresets are made up of granules and pebbles. .  (Figure 5B).

Bounding surfaces of the set are planar and, but some are inclined when they are limited by major surface. Generally display vertical agradation. Commonly, the bottom surface of the sets is marked by alignment of granules and pebbles (5 to 10 mm), which sometimes are covered by thin layers of fine sand, probably related to low-angle cross-laminated lithofacies described in item 0 (Figure 5C). Reactivation surfaces are common, often truncating one set repeatedly (Figure 5D). These erosion surfaces in some cases represent pebbles and granules accumulation zones

Interpretation: Large-scale cross-bedded sandstone is formed by migration of medium to large subaqueous 2D dunes (Ashley, 1990), without significant reverse flow reworking the base of the lee slope, so tangential contacts and small structures such as counter-current ripples are absents (Harms et al., 1975; Harms et al., 1982). Planar cross-beddings are also indicative that there are not important contributions of suspended sediment to form the foreset (Bridge, 2003). Avalanche processes are most relevant process that built the foresets on the dune lee side. This is responsible of alternating coarse and fine sediment and concentration of coarsest grains at the base of each set (High and Picard, 1974). The bimodal grain size in foreset results from presorting of sediment by small bedforms that climbing the upstream side of large bedforms, which is related to long-term flow unsteadiness (Smith, 1972; ReesinK and Bridge, 2007). Planar surfaces that limit the sets testify the absence of erosive scouring at the base of the set (McKee and Weir, 1953). Reactivation surfaces that cut cross-beds are indicative short-time changes in flow discharge, probably caused by fluctuations in the water level (Collinson, 1970) and/or slight foreset migration due to the dune or bar crest line variations (Haszeldine, 1983).

### Small cross-bedded sandstone

The small cross-bedded sandstone consists of two types tabular cross-beds: planar and tangential cross-bedded sandstone (**Erro! Fonte de referência não encontrada.**).

The planar cross-bedded sandstone is 0.06 to 0.1 m thick. It is formed by moderately to well-sorted sandstone, fine- to medium- and medium- to coarse-grained with subangular grains,. The foresets form a sharp angle at the base of the avalanche slope. Rarely pebbles (up to 7 mm) are founded on the foreset surfaces. The dip of these cross beds is 23 to 26 degree and usually the coarsest grains are observed at the base of the sets. The set boundaries are generally planar and quasi horizontal. The tangential cross-bedded sandstone is characterized by sets 0.1 m thick, well-sorted, very fine- to medium-grainedsandstone with subangular grains. The angle of dip of the foresets is 18 to 23 degree. Set bottom is planar and horizontal. The small cross-beds usually overlay the top of the large cross-bedded sandstone.

Interpretation: The small planar and tangential cross-beds represent, respectively, the migration of small 2D and 3D dune (Ashley, 1990). Main difference to the origin for these two types of dunes is that 2D dunes with straight crest are interpreted as produced from lower energy flows, with increasing flow velocity the straight ridge of dunes move to sinuous crest, yielding 3D dunes (Harms et al., 1982). In any case, the flow strength was not sufficient for generate scouring at the base of the set. Small 2D dunes are dominant avalanching processes, while 3D dunes may include intermittent saltation and suspension processes (Brigde, 2003).

### Low-angle laminated sandstone

The low-angle laminated sandstone consists in small sets in average 0.04 m thick composed of well-sorted fine-grained sandstone with subangular grains, . The laminations dip in angle 6 to 14 degrees. The shapes of the sets have slightly sigmoidal geometry. This lithofacies displays some parallel laminations overlaying small sets of low-angle lamination (Figure 7A, B). These small sets are found between major erosional surfaces (master surfaces, decribed in item 5.2) which limit the large sand bodies. The laminations are composed of thin layers and marked by the presence of millimeters muscovite clasts.

Interpretation: Low-angle laminated sandstone is interpreted as produced by deposition mechanisms in hydraulic conditions close to upper flow regime, at the transition between ripples stability field into upper plane bed field (Southard & Boguchwal, 1990).

Small ripples have the lee slope progressively diminish due to increase in current flow rate, so the foresets become sigmoidal in shape and if the conditions of flow velocity increases further, low-angle cross-laminations will pass to parallel laminations (Chakraborty & Bose, 1992), as it has seen in Figure 7C.

### Low-angle stratified sandstone

The low-angle stratified sandstone occurs in sets, 0.18 m to 0.3 m thick (Figure 8A, B). They are constituted of fine- to well-sorted, medium-grained sandstone with subangular grains,. The foresets sometimes have a sigmoidal shape and dipping values are on average 13 degrees. Laterally and toward the top the low-angle stratification are overlain by parallel lamination. These structures usually occur stacked in fining-upward cosets, 0.9 m thick.

Interpretation: Low-angle stratified sandstone is interpreted as washed out dunes produced by depositions mechanisms close to the transition into upper flow regime. With increasing flow strength the dunes become shorter and longer in their length. Therefore a similar interpretation to low-angle laminated sandstone.

Low-angle stratified shows a particular morphology similar to humpback dunes (Figure 8C) as described by Saunderson & Lockett (1983). This authors explain that in humpaback dunes the erosion of stoss side dune reaches a point of maximum height, where almost immediately deposition begins, forming low-angle cross-stratification to horizontal lamination extending over the avalanche face. However the avalanche faces is not a permanent feature, disappearing and reforming in this beds. Moreover, these bedforms are transitory and may display little different aspects from each other depending on how the energy flow evolves (Lang & Winsemann, 2013).

### Conglomeratic sandstone

This lithofacies consists of thin beds of conglomeratic sandstone (Figure 9A), 0.03 to 0.11 m thick and consist of pebbles and cobbles, with an average grains dimension of 21 mm and maximum dimension of 90 mm (Figure 9B). The clasts are well rounded, with oblate to spherical shapes, made up of fragments of quartz and quartzite (Figure 9C). The matrix consists of coarse- to very coarse-grained, well rounded sandstone and gives rise to conglomeratic sandstone, clast-supported and sometimes matrix-supported. The beds of conglomeratic sandstone are tabular and laterally extended more than 130 m (maximum lateral exposure of a single continuous bed). Only four thin beds were observed in a succession 3 m thick, at middle to upper portion of the Furnas Formation. Sometimes the conglomeratic sandstone occur interbedded with small to large cross-bedded sandstone 0.2 to 0.4 m thick (Figure 9D). The contact relationship with other beds of sandstone is abrupt (Figure 9E).

Interpretation: The conglomeratic sandstone was probably originated for deposition of sand-gravel mixture associated with dunes migration. The avalanche processes in lee-face dune results in a vertically sorting of the grains on the foresets of the dunes.  Associated to avalanching process, the bedload transports of deposits sand-gravel mixture can lead to formation of gravel lag deposits. During some discharge peak the largest grains are entrained in the flow and then deposited in waning discharge, while the smaller grains remain in movement, resulting in an accumulation of gravel lag without cross-bedding. This accumulation of gravel lag is the source to the next discharge peak (Kleinhans, 2001).

## DEPOSITIONAL ARCHITECTURE AND PALEOFLOW ANALYSIS OF FURNAS FORMATION

### Bounding surfaces and sandbody geometry

The sandstone geometry has tabular or wedge shapes that are 11 to 40 m in length and 3 to 6 m in height (Figure 11), and represents outcrops limits. These sandstone bodies are stacked vertically in several successions and separated one from another by marked master erosion surfaces that can be flat with subordinate smaller channelized forms.

Four order of bounding surfaces were distinguished within the Furnas Formation. The first-order represents the most simple surface that are foresets of cross stratifications, which result of migration of lee face of large, small or humpback dunes. The second-order surface is characterized by reactivation surfaces that cut across cross-strata and represent change in bedform orientation. The third-order surface represents the boundary of simple sets of cross-strata. These surfaces are flat and close to horizontal because of the absence of scouring in trough and they are laterally extensive (10-20 m). The fourth-order surface is a master surface up to 40 m in lateral extension. This surface delimits sandstone macroforms, which top often is flat and sub horizontal suggesting action of strong erosive processes. The bottom is in general concave-up and rarely horizontal. The geometry of these surfaces suggests that these macroforms are deposited by the high energy flows of the depositional system in channelized forms.

Three main exposures are studied with detail to show the facies organization, the architectural elements and the paleocurrents distribution of the sandbodies succession present in vertical log.

## Description of the sections and paleocurrents

### Section 1

The section 1 (Figure 12), the most basal, is 3 m thick. From the base upward, a representative facies succession is marked by small cross-bedding that are overlaid by an erosional surface. This erosional surface is 7,5 m in length and 1 m thick and exhibit a concave-up shape and its represent fourth-order bounding surface Within fourth-order surface occurs large scale cross-bedding, which shows variation in the angle foreset, from repose angle on one extremity to parallel lamination next to the other extremity. This channelized form cut across other beds with tabular cross-bedding. This succession is terminated by other four-order surface, which define a macroform. On the top of ancient deposits occurs small mesoforms with low-angle bedded sandstone that in turn exhibit incision of 0.6 m thick like-channelized fill. Paleocurrent measurements mainly of large scale cross-bedded sandstone and small cross-bedded sandstone indicate paleoflow toward SW.

### Section 2

The section 2 (Figure 13) in approximately middle of vertical log exhibits clearly lithofacies and boundaries surfaces. On the base of section occurs low-angle laminated sandstone facies, which passes abruptly to large scale planar cross-bedding 1.5 m thick, which this boundary represent a fourth-order surface . Often erosive surfaces, described as reactivation surfaces are present on large scale cross-bedded sandstone in a sequences of two overlapped beds, wherein into upper bed these reactivation surfaces are more frequently and the thickness is smaller than lower bed. Upward small cross-bedded sandstone occurs in a range 1.6 m thick. On the top of outcrop low-angle laminated sandstone were found and it lie on the master surface. Reactivation surfaces and master surfaces have been described as third-order and fourth-order surfaces respectively. Paleocurrent directions of this lithofacies are bimodal oblique; main flow direction is toward S and SW, with dominant component toward SW.

### Section 3

Above of gravel lag deposits is possible seen that the grains are coarser than in the section 1 and section 2. Section 3 (Figure 14) is composed of a group of large scale cross-bedded sandstone amalgamated in a succession 6 m thick, that are bounded by erosive surfaces interpreted as fourth-order surface. Almost all these erosive surfaces are flat and laterally extensive limited by outcrop edge. However it is also possible see one concave up surface into the base of one large scale cross-bedding. The paleocurrents show a bimodal patterns toward S and SW, but in this case mainly toward S.

### Section 4

This section (Figure 15) is localized close to the top of Furnas Formation deposits on the Guartelá Canyon. This is 5.6 m thick and in 28 m length. Large scale cross-bedded sandstone occurs at the base of the outcrop which passes vertically up into small cross-bedded sandstone. This succession is finished by incision of an overlying erosive form, which it is filled by large scale cross-bedding which in turn is overlaid by cross-bedding that are amalgamated to top. The paleocurrents often exhibit normal either parallel patterns regarding to section. It is confirmed for the bimodal spreading at the paleocurrent measurement, which is meanly to S and SW.

## Interpretation of architectural elements

Within the Guartelá Canyon four architectural elements were found, herein interpreted as unit bars, compound bars, channel fill deposits and top bars deposits (Figure 16).

### Unit Bars

The The most common element found is well exported  on section 2. Itwas interpreted as unit bar element as explained at the facies analysis the large-scale cross-bedding represents migration of lee slope bars (Allen, 1983; Bridge, 1983; Chakraborty, 1999). This process produces cross beddings large over many meters laterally. On the top of unit bars is possible see mesoforms that represents migration of superimposed bedforms interpreted as dunes. Some reactivation surfaces with convex-up shape that cut across dunes probably were generated by erosion in the troughs of superimposed bars (Reesink and Bridge, 2007).

### Compound bars

The second element has interpreted as compound bars, section 3, it is because the fourth-order surface represents erosion of incomplete succession of unit bars that are joined

### Channel fill deposits

The channels bars are visualized on section 1 and 4 the third element that has been described. The concave-up basal surface this element, overlain by large cross-bedded sandstone following the main palaeocurrent direction, was suggested as created by action of channelized forms, representing the base, which these bars are formed. The sets of large cross beds overlying by small cross beds interpreted as migrations of dunes, are stacked in an geometry that form the channels bars, where the bar grow vertically by accretion of deposits of smaller bedforms (Bridge, 2003)

### Top bars deposits

The last element has recognized in section 4 there is close relationship with channels bars. They represent small channel developed on top of bars. These minor channels have been interpreted like cross bar channels, where they cut across the bars top according to Bridge (2003).

## DISCUSSION;

### The Furnas Formation: fluvial vs tidal system

The study of depositional architecture revealed a series of contraries arguments to interpretation of a shallow marine environment in Furnas Formation. First the most of cross-stratifications, which represent the migration of sand dunes and bars show a angular contact with the base set, and the dip angle is larger than 18º, characteristics of fluvial systems. Unlike sandwaves formed in shallow sea, which cross stratification shows an angle around 15º at lee slope (Johnson & Baldwin 1996).

Assine (1999) suggests that the gravels found in Furnas Formation are lags deposits reworked by marine processes known as winnowing, which it removes the finer fractions and leaving gravels. However the amount of coarse sand matrix, which often characterize matrix-supported raises doubts with respect to these sedimentary processes. In addition, gravel lag deposits are not uncommon in fluvial facies successions, and its origin can be related to the formation of cross-stratification as shown in this study.

Assine (1999) described several cross-stratifications as produced by currents with opposite flow directions, based on the feature they display in sections on outcrops, but a detailed analysis reveals that the most of these structures is subject to section in which they found, giving to a idea that can be produced by bipolar currents. However the Palaeocurrent analysis shows that change in the direction in dunes migration is on average 35º with paleoflow toward S and SE.

The study of depositional architecture has revealed the existence of channelized forms, which occurs the main bedforms composed of planar cross-stratification with upward decrease in bed thickness associated with passage on the bars top of bedforms produced in upper flow regime, which is characteristics the construction of channels bars associated with developing of cross bar channels and shallow fast flow on the braid bars within a fluvial braided system.

Other structures attributed to tidal environments have not been found as mud drapes and tidal bundles, and other marine processes are also not present as wave ripples or hummocky cross-stratification generated by action of oscillatory waves.

### Depositional model; Braided bars and channels

The architectural elements (unit bar, amalgamated bars, channelized form and cross-bar channels) suggest depositional system dominated by a large braided river (**Erro! Fonte de referência não encontrada.**).

The bars, represent the depth of the channels. The vertical succession often shows systematic upward decrease in bed thickness. This feature indicate that the large dunes were formed in largest flow depth, while the small dunes it is possible that occurred in short flow, where the shear stress and sediment transport rate increase (Yalin, 1977).

Cross-bar channels are indicative that has been changed in water level on bars top which led to the formation of little channels cutting across the bars top (Bridge, 2003), Other sedimentary structures also suggest the occurrence of change in water levels (at least the top bars) is the presence of low-angle stratified sandstone , which origin, in this work, is related to migration of bedforms generated close to upper plane regime like small ripples passing to planar lamination and humpback dunes. The bedforms created in conditions near the transition from ripples or dunes to upper-stage plane bed are common in the upper part of sandy braid bars (Bristow, 1993; Bridge, 2003). Fielding (2006) argued that the preservation of upper flow regime like humpback dunes is associate an upper part of sedimentary units and controlled by abrupt drops in water level.

The reactivation surfaces found that cut the large cross-bedded sandstone are keys to understand the shape of the large dunes interpreted at the Furnas Formation. Many reactivation surfaces, separated by few meters each other, are recorded cutting repeatedly in a one set. In this way the dip directions these reactivation surfaces are slightly different from underlying foresets. These features are similar to the model purpose by Haszeldine (1983), for the origin of these structures, which the author explained that some reactivation surface may be generated by change in the position of the bedforms crestline. Therefore, it is likely that the reactivation surfaces that cut the sets of large cross-bedding were formed during periods of steady flow.

## CONCLUSION

The study of depositional architecture of the Furnas Formation has revealed the existence of unit bar, amalgamated bras and channelized forms, which occurs the main bedforms composed of planar cross-stratification with upward decrease in bed thickness associated with passage on the top these macroforms of bedforms produced in upper flow regime, which is characteristics of the construction of channels bars associated with developing of cross bar channels and shallow fast flow on the bars top, within a fluvial braided system.

## ACKNOWLEDGEMENTS

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## FIGURES

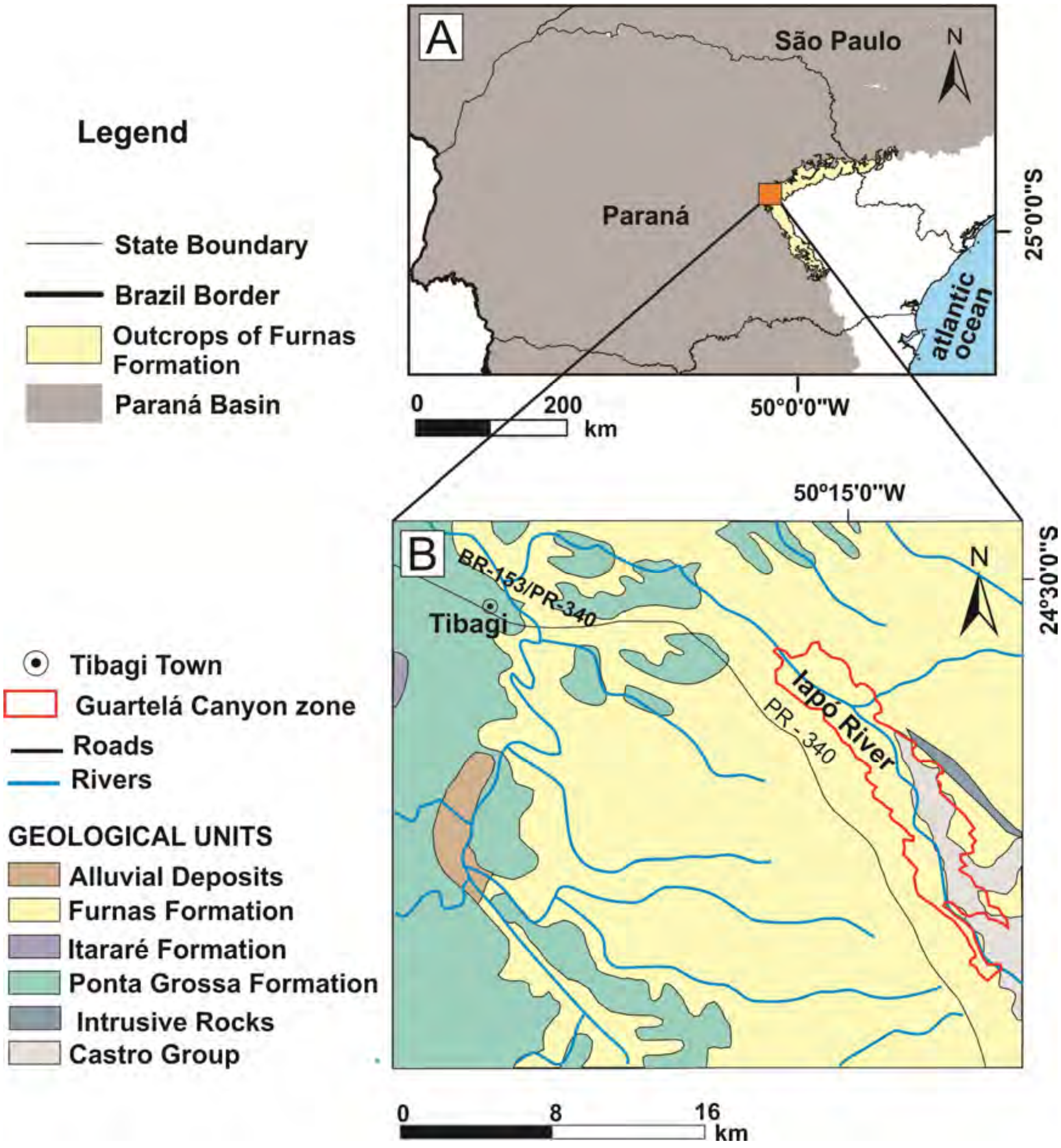

**Figure 1. A - Location of the Furnas Formation outcrops in Paraná Basin. B - In particular (red shape), the area canyon Guartelá (data base from CPRM, 2004).**

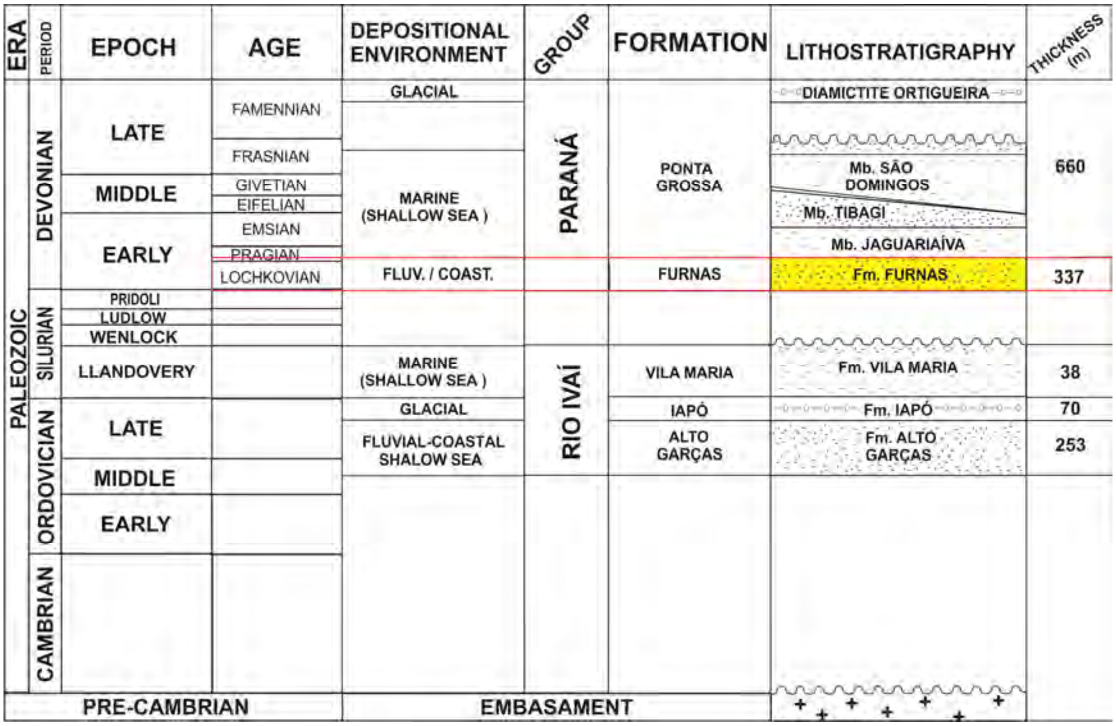

**Figure 2. The low part of the stratigraphic chart of the Paraná Basin with focus on location of the Furnas Formation deposited on Early Devonian.**

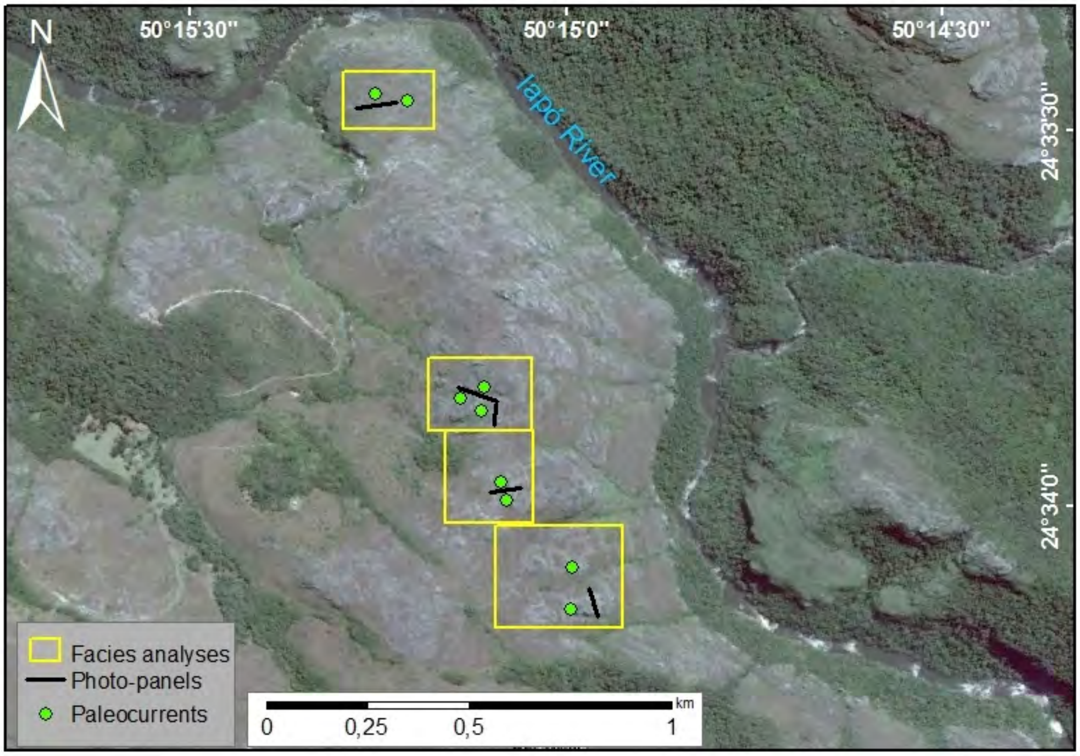

**Figure 3. Satellite image of the Guartelá Canyon with the localization, where was realized the field analysis**

**Figure 4. Vertical log through a representative of Furnas Formation, Guartelá Canyon. The roses diagram show measurement paleocurrents of four section studied in details.**

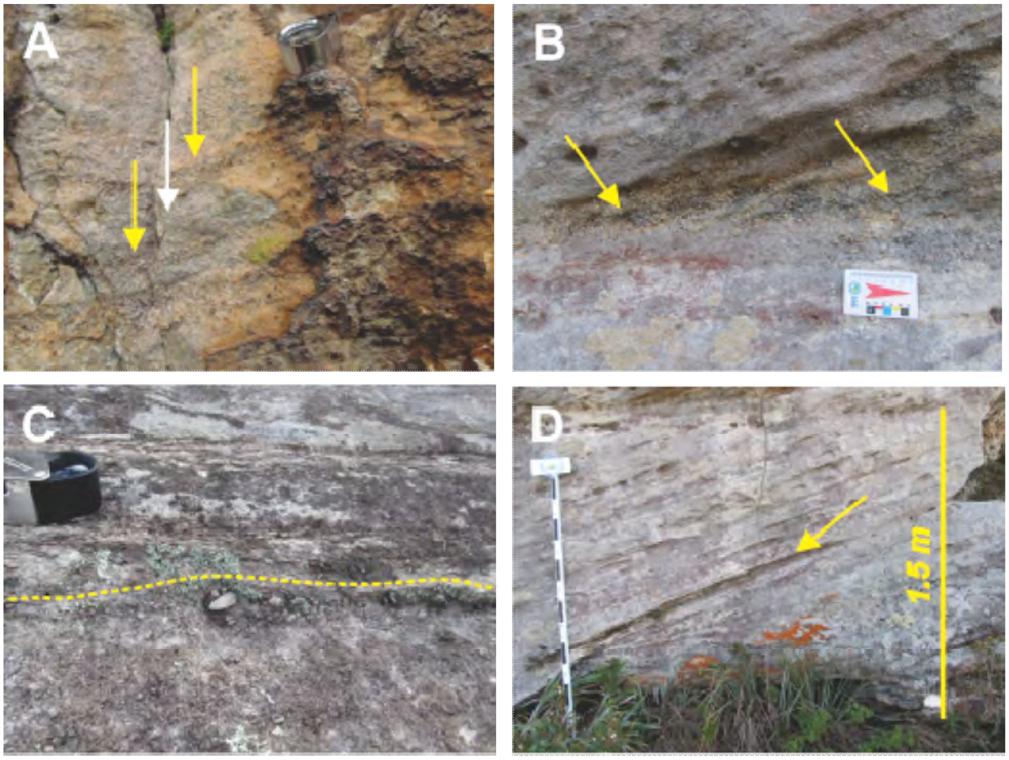

**Figure 5. Large scale cross-bedded sandstone. A - Alternation on the particle size on foreset, medium sand (white arrow) and coarse sand (yellow arrow). B - Accumulation of grains on the base of the foreset, (indicated by the yellow arrow). C - Some sets are bounded by granules and pebbles, covered with thin fine sand (above the dashed line). ). D - Large planar cross-bedding cut by a reactivation surface (indicated by the yellow arrow).**

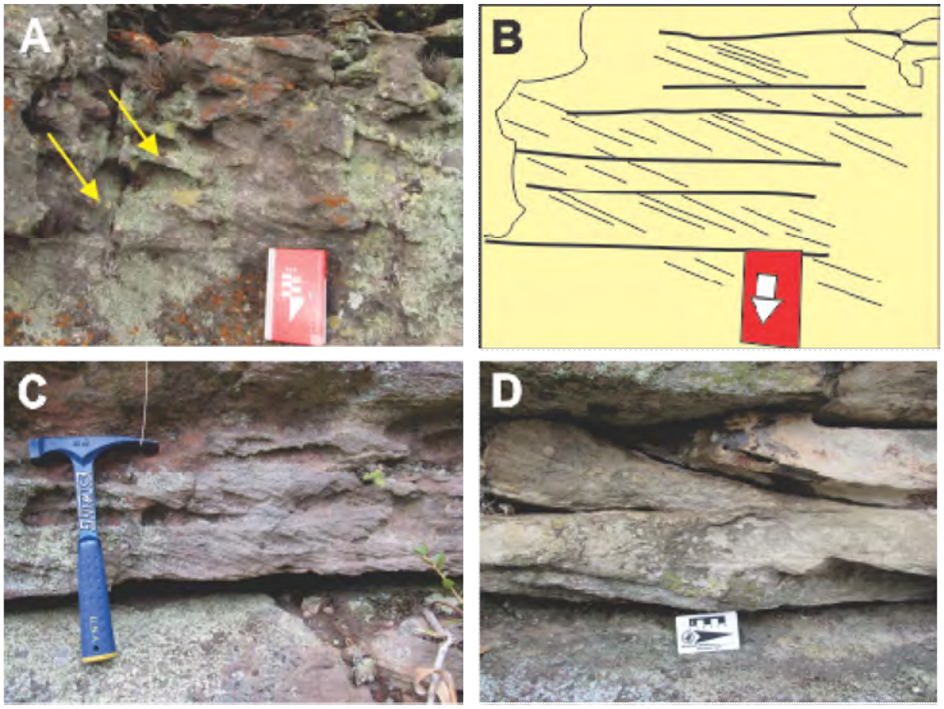

**Figure 6. Small cross-bedded sanstone. A - Sets of cross-beds with angular contact at the base. B – Sketch of picture A, exhibiting detail of sets up to 0.10 m thick. C – small crossbeds with 0.06 m thick. D – Detail of tangencial surface with erosinal surface.**

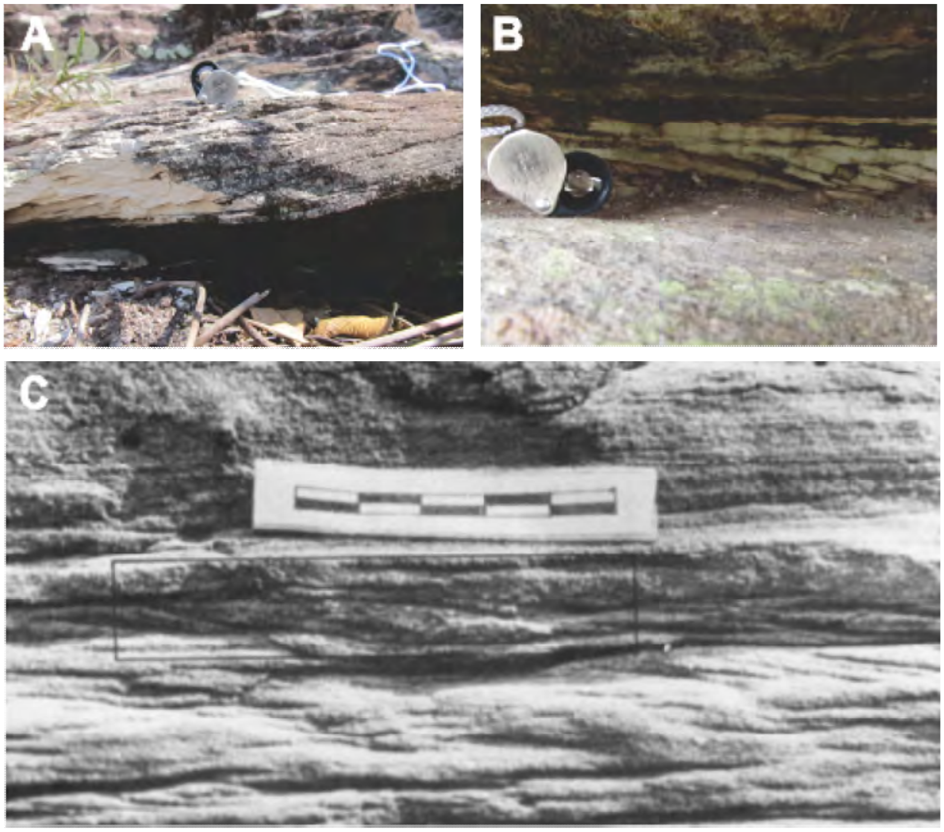

**Figure 7. Low-angle laminated sandstone. A and B - Simple set of low angle lamination with slightly sigmoidal shape, which occur between major surfaces bounding large sand bodies, usually the thin beds undergo faster erosion than other beds, and so are usually found in horizontal recesses in the rock. C - The detail in Picture shows a cross-lamination passing to parallel lamination (Chakraborty & Bose, 1992).**

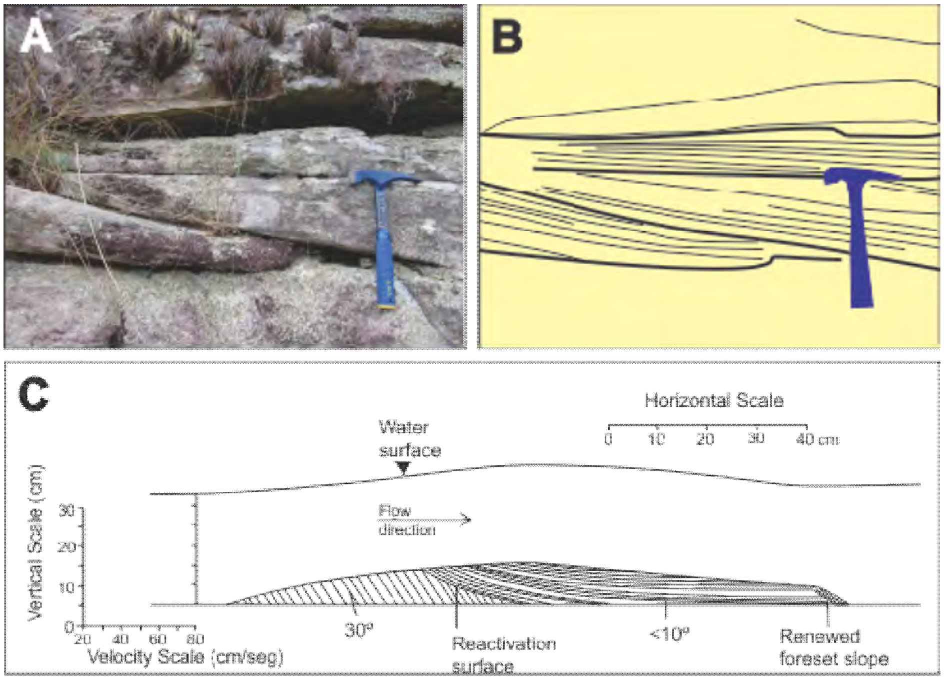

**Figure 8. Low-angle stratified sandstone. A - Low-angle layers passing to parallel-lamination layers of 0.18 to 0.30 m thick. B - Interpretive sketch from picture A where you can observe upward decrease of the slope angle of the foreset . C - Conceptual model of humpback dunes produced from flume experiments (modified after Saunderson & Lockett, 1983).**

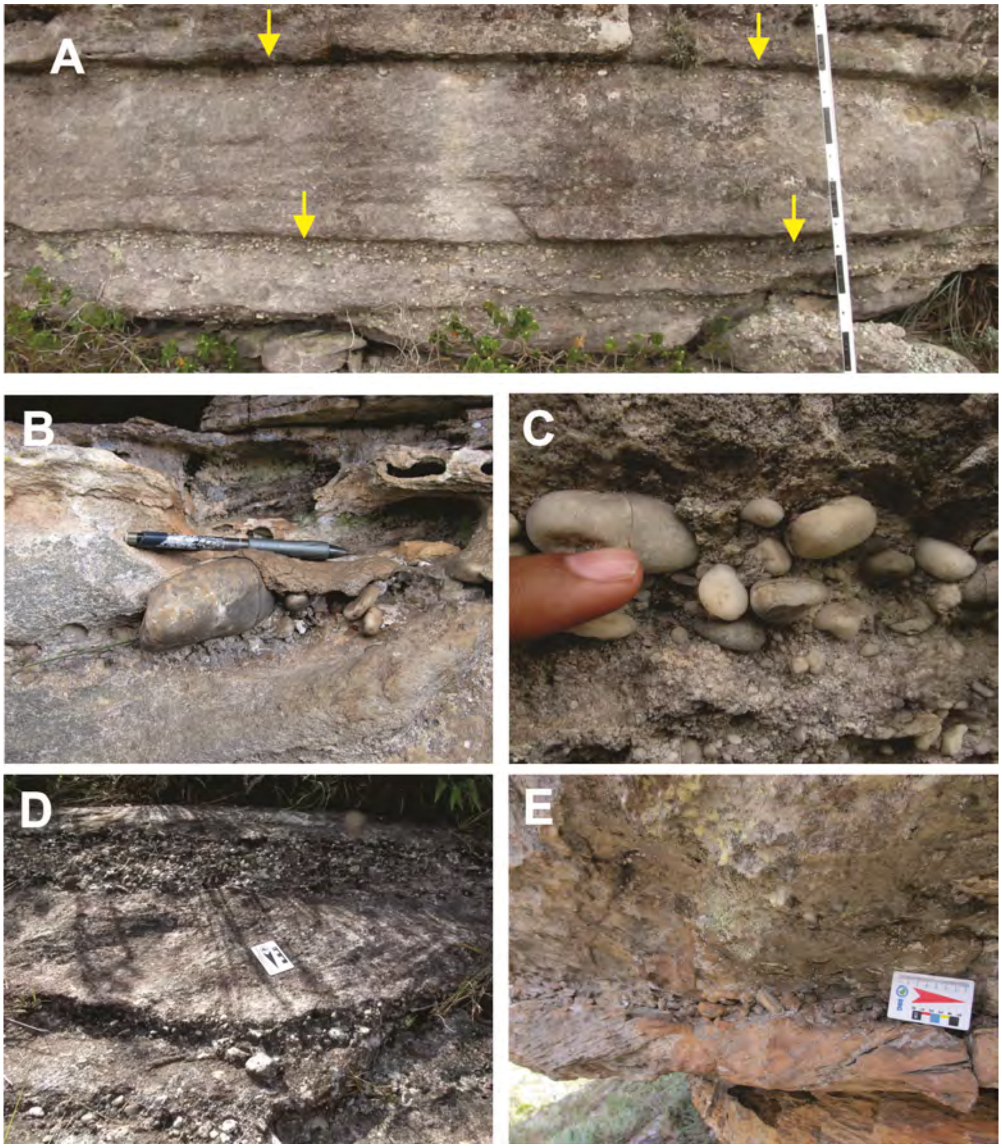

**Figure 9. Conglomeratic sandstone. A - Thin beds of conglomeratic sandstone (3 to 11 cm thick).The are interbedded with sets of cross beds (dip to the left) in range of 1 m thick. B - The center of the photo a clast 9 cm diameter recorded. C - Details of the well-rounded grains, and coarse very coarse sand matrix constituting clast-supported and matrix-supported. D - Conglomeratic sandstone occuring interbedded with small cross-bedded sandstone. E -. Conglomeratic sandstone representing abrupt surface.**

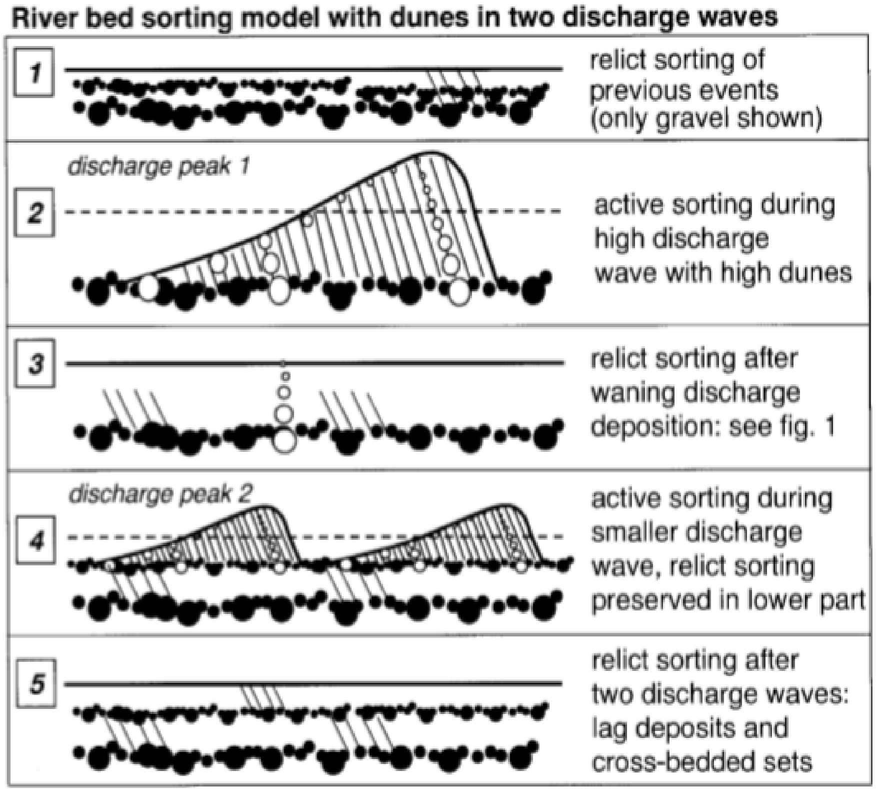

**Figure 10. Conceptual model of deposition and preservation of the gravel lag interbedded with cross-bedding (Kleinhans, 2001).**

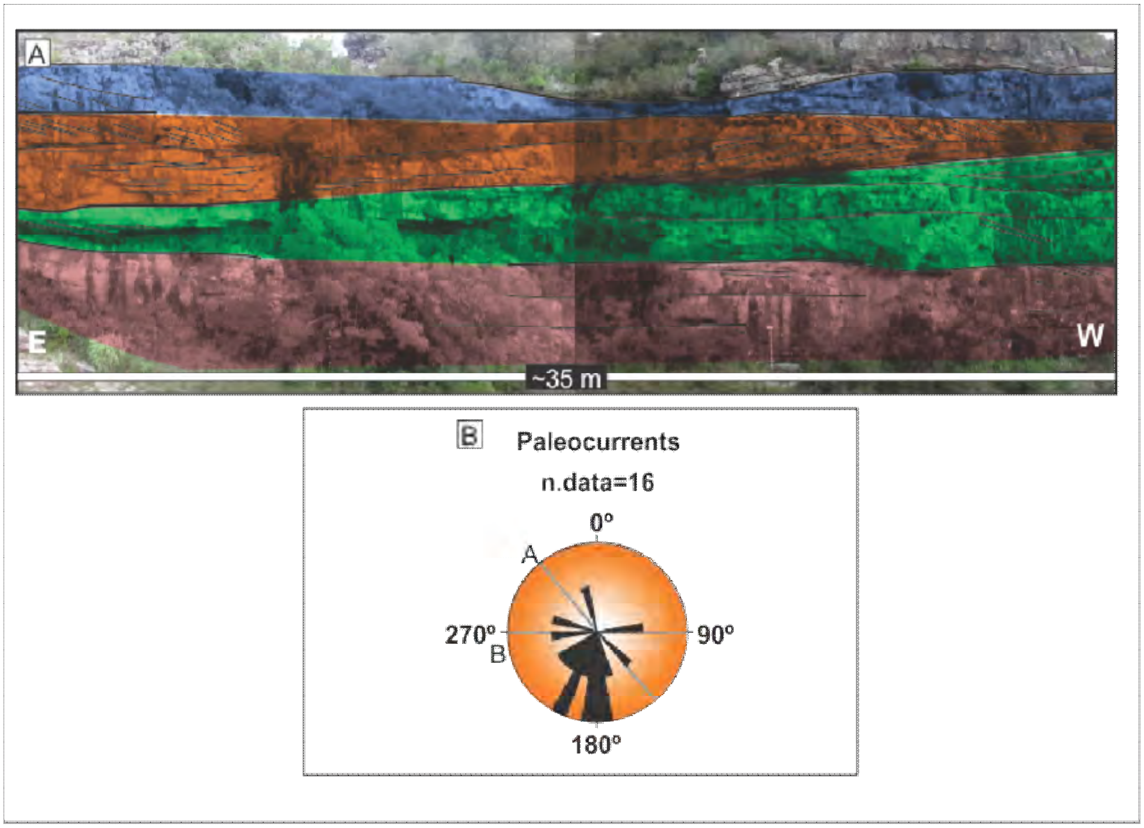

**Figure 11. A - Panoramic photo with boundaries surfaces and bed geometry interpreted which exhibit the tabular and wedge form at beds. B- Measured paleocurrents data from this large section**

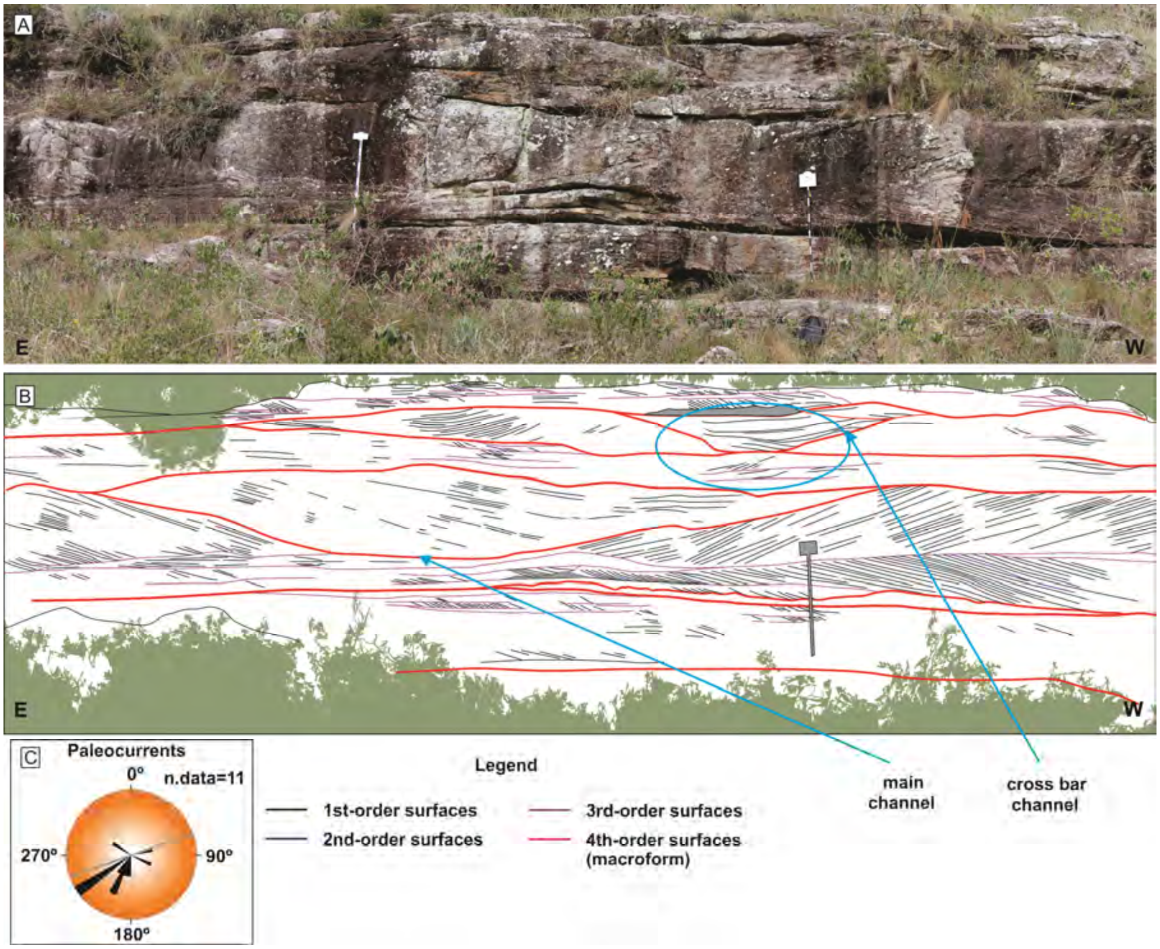

**Figure 12. Some little channels are found associated with the top of channels bars. C - In this section the palaeocurrents are dominantly to SW.**

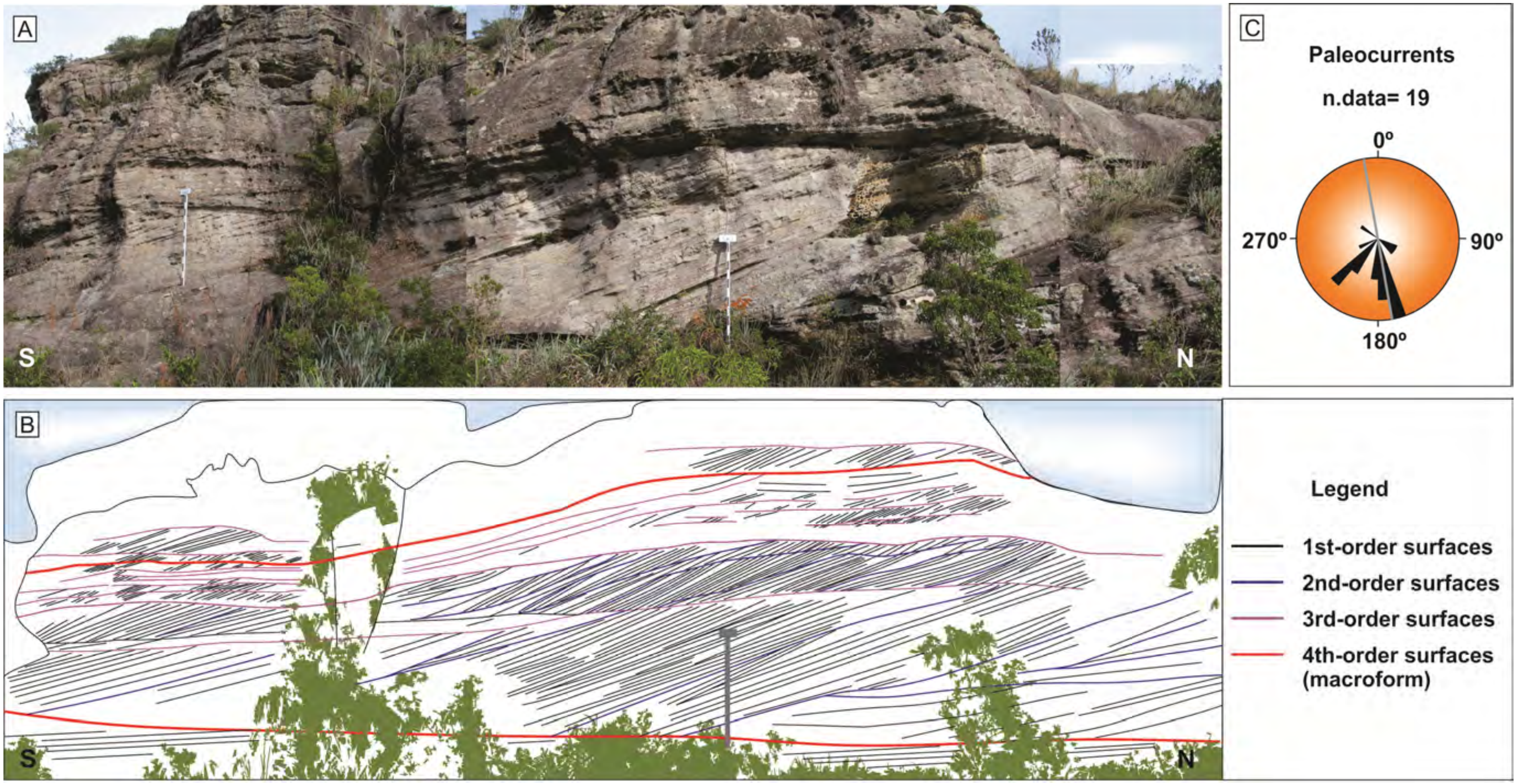

**Figure 13. A,B - Sketch produced from interpreted photomosaic with the main boundaries surfaces, the large cross beds overlain by small cross beds represents a macroform type nominated bar channel. C – The palaeocurrent direction is bimodal with S to SW.**

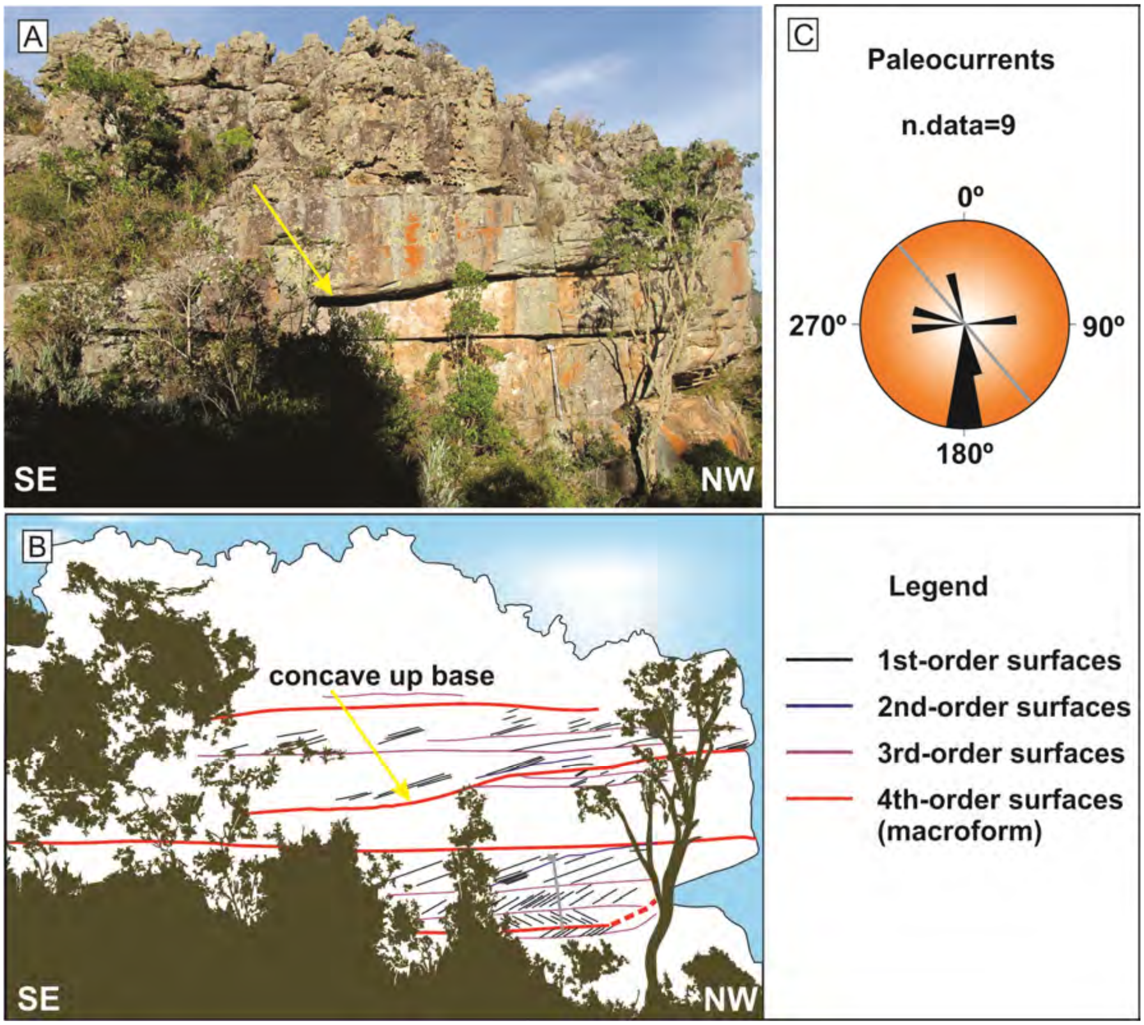

**Figure 14. Basal part of the 4th-order surface (indicated by the yellow arrow) with erosive concave shape. C – The main palaeocurrents to S direction. The Vertical line in the centre of the circle represents the section orientation.**

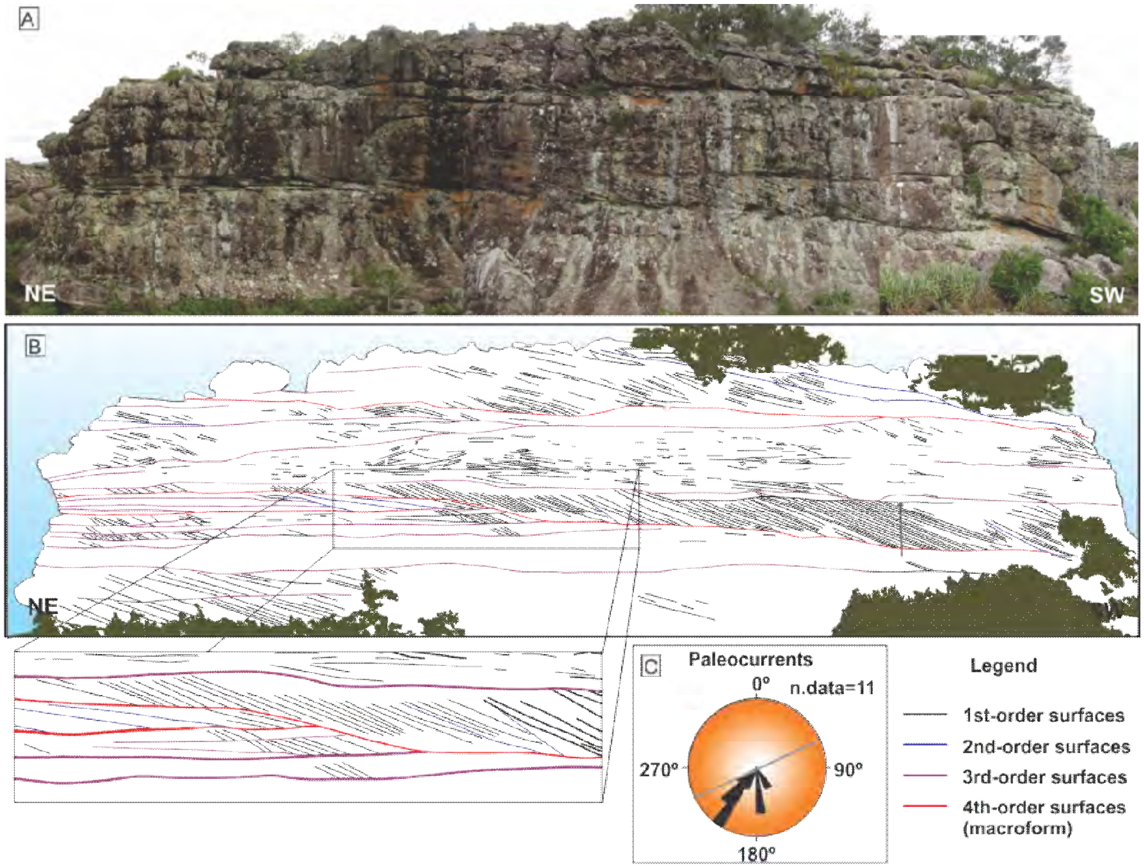

**Figure 15.A, B - Interpreted sketch showing the facies succession. The bar top made of small cross-bedded sandstone is covered by low-ange cross-strata then a new channel cut across the early bar as noted in the B detail of the drawing. C – Palaeocurrents to S to SW direction**

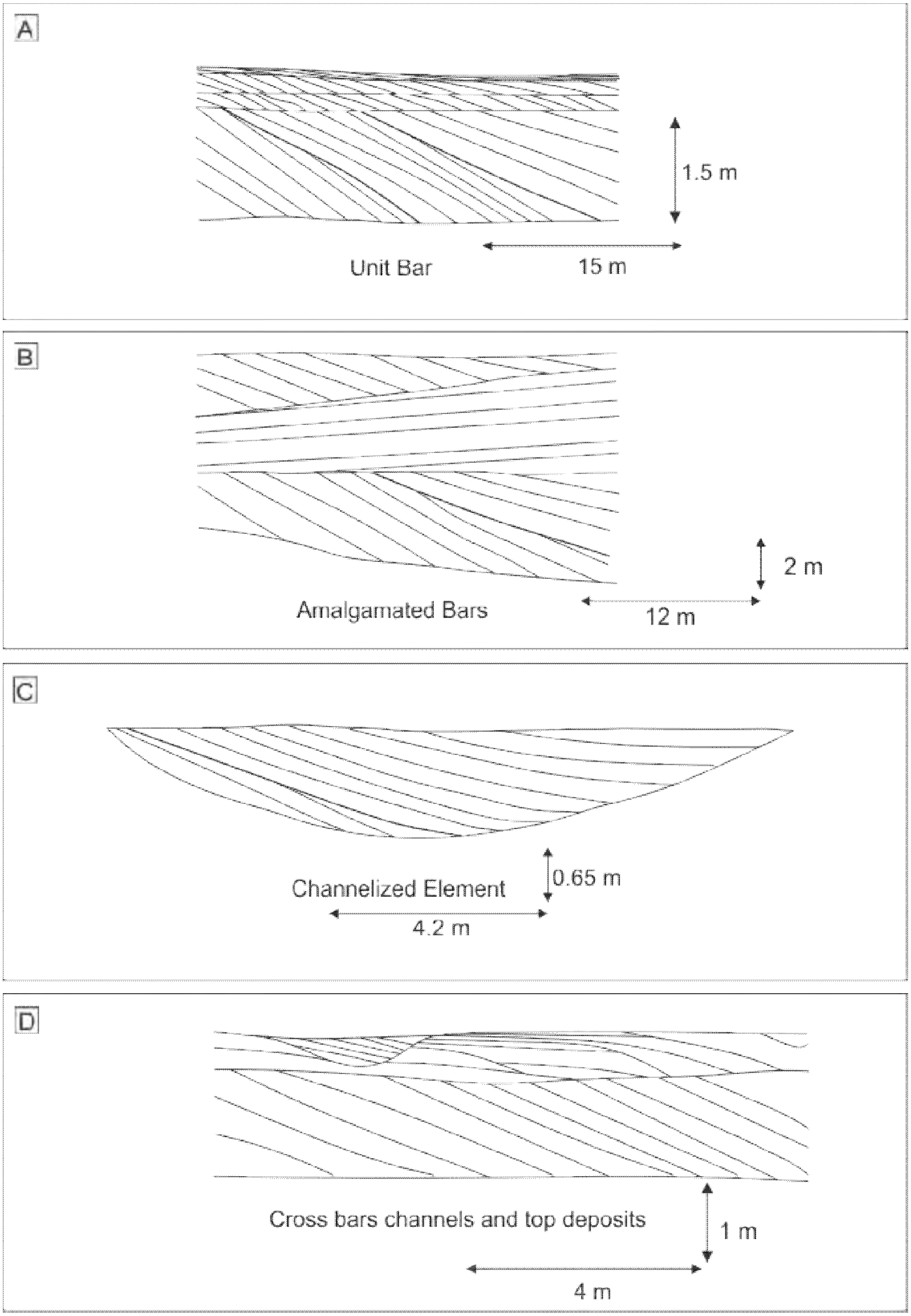

**Figure 16. Architectural elements found at the Furnas Formation around Guartelá Canyon that represent fluvial deposits.**

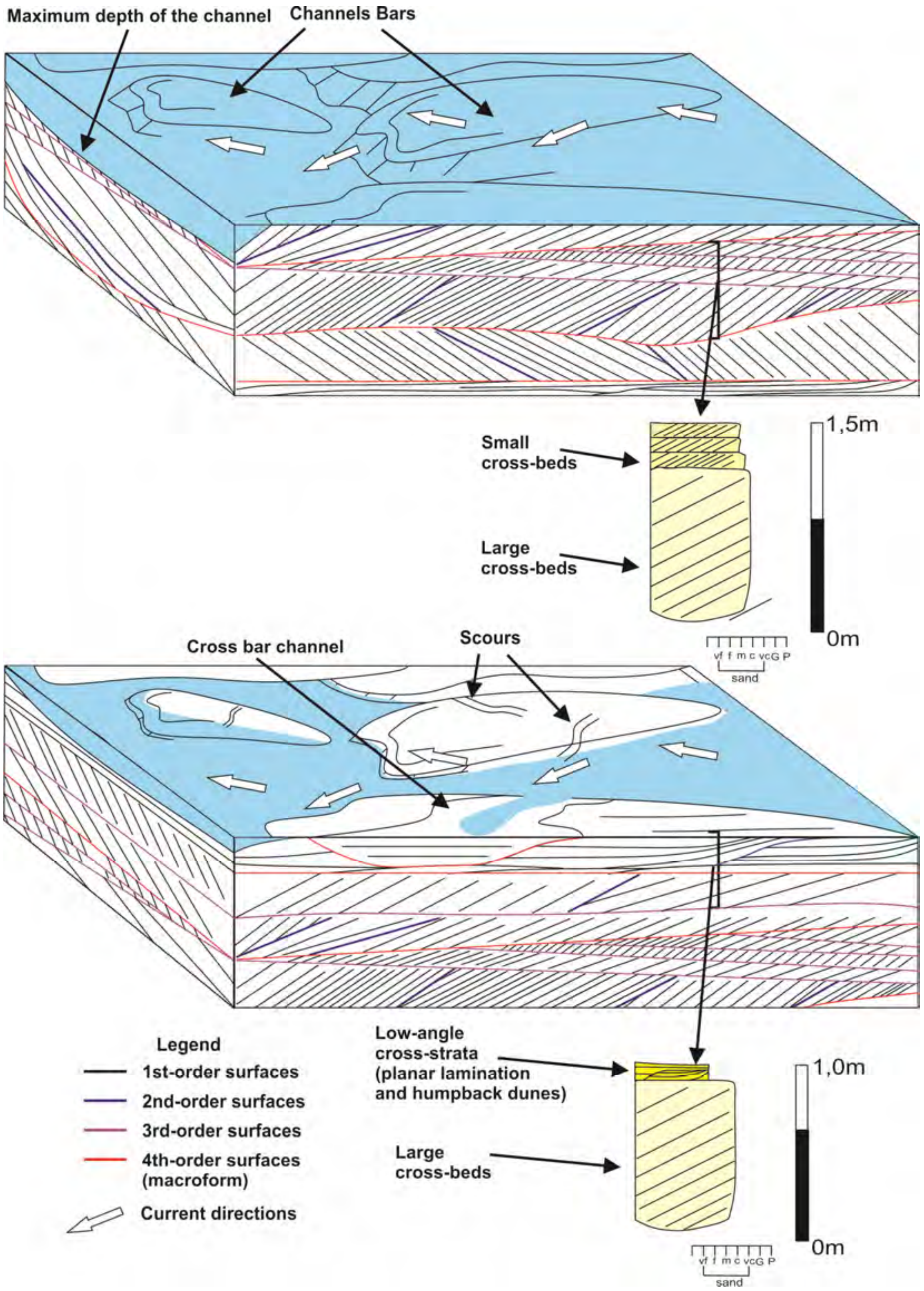

**Figure 17. The first example represents a braided system in high flow stage, which creates large dunes and close to the top small dunes in short water level. The second model is low flow stage, where the bar top is exposed, in shallow water the dunes become washed out with plane top and cross bars channels can be forms cutting across the upper part of the main bars.**