UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE GEOCIÊNCIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM GEOCIÊNCIAS

ARQUITETURA DE FÁCIES E EVOLUÇÃO ESTRATIGRÁFICA DA FORMAÇÃO TACUAREMBÓ, BACIA NORTE – UY

FRANCYNE BOCHI DO AMARANTE

ORIENTADOR – Prof. Dr. Claiton Marlon dos Santos Scherer

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RESUMO

A Formação Tacuarembó (Jurássico Superior – Cretáceo Inferior), subdividida em Membro Batoví e Membro Rivera, aflora na região norte do Uruguai, nos departamentos de Rivera e Tacuarembó. O objetivo principal deste trabalho é a análise sedimentológica e estratigráfica da Formação Tacuarembó, através da caracterização faciológica, a reconstrução dos modelos deposicionais e a definição das relações de contato entre os membros Batoví e Rivera. Para alcançar tal objetivo, foi realizado o levantamento, na escala 1:50, de um testemunho e de quarenta e uma seções colunares, estas divididas em sete transectas com base em sua distribuição espacial. Como resultado, foram detalhadas litofácies posteriormente agrupadas em diferentes associações de fácies. O Membro Batoví é constituído por associações de fácies de (1) dunas eólicas, (2) lençóis de areia eólicos, (3) canais fluviais efêmeros, (4) canais fluviais perenes entrelaçados e (5) deltas. O Membro Rivera, por sua vez, é constituído essencialmente por associações de fácies de dunas eólicas. A intercalação entre depósitos fluviais, eólicos e deltaicos, com predominância de associações fluviais sugere que o Membro Batoví representa o modelo deposicional de porção distal de um sistema fluvial distributário. Já o Membro Rivera caracteriza-se pelo sucessivo cavalgamento de dunas eólicas, sem a ocorrência de depósitos de interdunas úmidas ou encharcadas, definindo um sistema eólico seco. A mudança abrupta de sistemas deposicionais, marcada por uma superfície plana, por vezes com concentração de clastos, indica a existência de uma discordância entre os membros Batoví e Rivera. Aliado a isto, a mudança no modelo deposicional sugere uma alteração climática, passando de um clima arido a semi-árido durante a deposição do Membro Batoví, para um clima hiperárido ao longo da deposição do Membro Rivera.

Palavras-Chave: sistema deposicional fluvial distributário distal; sistema deposicional eólico; Membro Batoví, Membro Rivera; Bacia Norte.

ABSTRACT

The Tacuarembó Formation (Upper Jurassic - Lower Cretaceous), subdivided into Batoví Member and Rivera Member, crops in the northern region of Uruguay, in the Rivera and Tacuarembó departments. The main objective of the present work is the sedimentological and estratigraphic analysis of the Tacuarembó Formation, through the faciological characterization, reconstruction of the depositional models and definition of contact relations between the Batoví and Rivera members. To reach such objective, a well-log and forty-one columnar sections were surveyed in a scale 1:50, and later the columnar sections were divided into seven transects, based on their spatial position. As a result, lithofacies were detailed and later grouped in different facies associations.The Batoví Member consists of associations of facies of (1) eolian dunes, (2) eolian sand sheets, (3) ephemeral fluvial channels, (4) perennial braided fluvial channels and (5) deltaic. On the other hand, the Rivera Member, is essentially constituted by facies associations eolian dunes. The intercalation between fluvial, eolian and deltaic deposits, with predominance of fluvial associations, suggests that the Batoví Member represents the depositional model of the distal portion of a distributary fluvial system. Contrastingly, the Rivera Member is characterized by the successive eolian dunes climbing, without the occurrence of wet or damp interdunes deposits, defining a dry eolian system. The abrupt change of depositional systems, marked by a flat surface, sometimes with clasts concentration, indicates the existence of an unconformity between the members Batoví and Rivera. Allied to this, the change in the depositional model suggests a climatic change, going from arid to semi-arid climate during the deposition of the Batoví Member, to a hyperarid climate during the deposition of the Rivera Member.

Keywords: Distal distributary fluvial systems; eolian depositional systems; Batoví Member; Rivera Member; North Basin.

SUMÁRIO

1 INTRODUÇÃO

A base da sucessão Juro-eocretácea da Bacia Norte é definida pela Formação Tacuarembó, dividida em dois membros, o basal denominado de Membro Batoví e o superior, de Membro Rivera (Bossi, 1966; Perea *et al.*, 2009). O primeiro é caracterizado por associações de fácies fluvio-eólicas com corpos lacustres associados, enquanto que o Membro Rivera é composto por arenitos eólicos (Ferrando & Andreis, 1986).

Apesar de existirem estudos sedimentológicos da Formação Tacuarembó, estes são genéricos e não permitem uma reconstrução faciológica e paleogeográfica da bacia. Além disso, existem divergências quanto à natureza do contato entre o Membro Batoví e o Membro Rivera. Alguns autores consideram que existe uma transição entre os membros, sendo impossível separá-los com clareza, sugerindo que estes representam uma associação contínua de eventos e estão posicionados no mesmo contexto paleogeográfico (Sprechmann *et al*., 1981; de Santa Ana & Veroslavsky, 2003). Outros autores defendem a existência de uma discordância delimitando os membros, e inclusive os dividem em duas (Ferrando & Andreis, 1986) ou três (Ferrando *et al*., 1987; Bossi *et al*., 1998) formações distintas. A possível presença da discordância indica que os membros foram depositados em sistemas deposicionais distintos, o que pode implicar em mudanças climáticas e de paleofluxo na bacia.

É possível correlacionar os membros Rivera e Batoví da Formação Tacuarembó com formações aflorantes da Bacia do Paraná no Rio Grande do Sul. De acordo com a definição original de Falconer (1931), e levando em conta a subdivisão da Formação feita por Bossi (1966), os sedimentos do Membro Batoví são correlacionáveis aos da Formação Guará (Scherer & Lavina, 2006), enquanto que o Membro Rivera correlaciona-se com a Formação Botucatu (França *et al*., 1995).

Tendo em vista a carência de estudos detalhados da região, espera-se que o presente projeto contribua para agregar conhecimento e fortalecer os estudos faciológicos da Formação Tacuarembó, possibilitando um melhor entendimento da distribuição de sistemas deposicionais no tempo e espaço, e contribuindo na reconstrução paleogeográfica Juro-eocretácea da Bacia Norte.

Acredita-se que a partir da conclusão desta etapa de pesquisa seja possível o estabelecimento de um modelo faciológico integrado entre o Uruguai e o Rio Grande do Sul.

1.1 Objetivos

O objetivo geral do projeto é a análise sedimentológica e estratigráfica da Formação Tacuarembó da Bacia Norte nos departamentos de Tacuarembó e Rivera do Uruguai. Dentre os objetivos específicos, destacam-se:

- A caracterização faciológica detalhada e a reconstrução dos sistemas deposicionais dos membros Batoví e Rivera.
- Definição do arcabouço estratigráfico da Formação Tacuarembó, enfatizando as relações de contato entre seus membros.
- Contribuir para o conhecimento dos sistemas continentais Juro-eocretáceos da Bacia Norte (Bacia do Paraná).

1.2 Estado da arte: sistemas fluviais distributários.

Os sistemas fluviais distributários (SFD) são encontrados em uma ampla variedade de contextos climáticos e tectônicos na atualidade e, conforme demonstrado por Weissmann et al. (2010), ao analisar mais de 700 bacias sedimentares continentais ao redor do globo, compõe a maior parte de cobertura subaérea de sistemas fluviais em uma bacia sedimentar.

Os SFD são comumente classificados como leques aluviais, leques fluviais e mega leques na literatura, sendo que cada denominação apresenta características distintas (DeCelles & Cavazza 1999; Leier *et al*., 2005; Gibling 2006). Mega leques tipicamente cobrem áreas de 10^3 a 10^5 km², têm raio maior de 100 km, e apresentam gradiente de declividade menor de 0,1º. Leques aluviais geralmente cobrem uma área menor que 100 km², têm raio de 1 a 20 km, podendo atingir 30 km, e seu gradiente de declividade é, normalmente, >1º. Os mega leques são dominados por corpos de canais fluviais incisos em um aluvião de granulometria mais fina em suas partes distais, enquanto que os leques aluviais são dominados por sedimentos de granulometria mais grossa frequentemente depositados por fluxos gravitacionais. Os leques fluviais são formas com tamanho e gradiente intermediários entre os mega leques e os leques aluviais, e são dominados por corpos de canais fluviais assim como os mega leques. Este trabalho utiliza o termo sistema fluvial distributário (SFD) descrito por Weissmann *et al.* (2010), que abrange as três classificações descritas.

Os autores descrevem SFD como um padrão de depósitos de canais e planícies de inundação dispostos em forma radial a partir de um ápice, posição onde o sistema fluvial pode-se expandir lateralmente de uma área confinada para desconfinada (Hartley *et al.,* 2010). Utilizando o termo “distributivo”, implica-se que todos os canais não precisam estar ativos simultaneamente (Weissmann *et al*., 2010).

Hartley *et al.* (2010) compilaram uma base de dados com 415 exemplos de sistemas fluviais cuja planoforma apresenta um padrão de canais radial e distributivo, com comprimento maior que 30 km, para definir suas características, distribuição e controles do desenvolvimento. Os autores concluíram que os sistemas fluviais distributários e suas bacias hidrográficas não são restritos a um cinturão latitudinal específico, e se desenvolvem em todas as zonas climáticas, sendo dominantes (58%) em climas secos. Os estilos de geometria e planoforma de SDF estudados são variados, mostrando planoformas entrelaçadas, meandrantes ou transicionais, e são controlados por variações em: (1) descarga, relacionada ao clima e (2) suprimento sedimentar, que é função do clima, do tamanho e relevo da área de captação e da litologia da carga sedimentar. Os autores atestam que SFD ocorrem em todas as configurações tectônicas, sendo que os de maior comprimento estão restritos a bacias de antepaís periférico e cratônicas, pois têm um maior espaço horizontal de acomodação disponível. O SFD mais longo observado têm 704 km de comprimento, porém a maioria (72%) varia entre 30 e 100 km.

Nichols & Fisher (2007) descreveram os processos de formação de um leque de depósitos fluviais. Os autores afirmam que o sistema distributário é construído como uma série de unidades incrementais depositadas por rios individuais que se tornam desconfinados em um ponto na planície aluvial. A espessura dos depósitos diminui com a distância do canal alimentador conforme as inundações depositam sua carga perto dos bancos do canal, e ao longo do tempo haverá a construção de um corpo lobular de baixa amplitude no assoalho da bacia. As áreas adjacentes ao lóbulo estarão em uma elevação mais baixa e, consequentemente, haverá avulsão do canal ativo. A repetição deste processo resultará na migração do canal ativo para diferentes posições na planície aluvial ao longo do tempo, com cada avulsão redirecionando o rio para o curso em uma elevação mais baixa. A qualquer momento a maior parte do sistema ficará em áreas inativas, e estes setores abandonados estarão sujeitos à modificação pedogênica e retrabalhamento da superfície por escoamento local ou atividade eólica.

Sistemas fluviais distributários podem ser inferidos no registro baseados em tendências observadas com aumento da distância do ápice: (i) diminuição do tamanho de grão, (ii) diminuição na razão L/E dos corpos arenosos de canal, iii) redução na interconectividade dos canais, (iv) evidências de fracionamento da drenagem, (v) dispersão radial na paleocorrente (Friend, 1978; Horton & DeCelles; 2001, Nichols & Fisher, 2007, Weissmann, *et al*., 2013).

As associações de fácies de sistemas fluviais distributários são divididas com relação ao seu posicionamento espacial relativo ao ápice: proximais, intermediárias e distais. As associações de fácies proximais incluem os sedimentos de granulometria mais grossa e os canais mais profundos, sendo depósitos arenosos ou conglomeráticas com imbricação de clastos, estratificação cruzada tangencial e estruturas de barras (Nichols & Fisher, 2007). Além disso, nesta zona o sistema é relativamente estreito, se expandindo a partir do ápice, por isso o canal migra por uma área limitada, e conforme migra retrabalha o material de granulometria fina de planície de inundação (Weissmann *et al.*, 2013).

Na zona intermediária, as dimensões e granulometria das fácies de preenchimento de canais diminuem, e os canais tornam-se mais lateralmente estáveis (Nichols & Fisher, 2013). Nesta zona o SFD cobre uma área mais ampla, causando bifurcação dos canais, e sofre perda de água por infiltração ao longo da zona proximal, causando maior espaçamento entre os canais fliviais. Como conseqüência, mais material fino é depositado e tem o potencial de ser preservado (Weissmann *et al.,* 2013). Adicionalmente, como material mais grosso é depositado nos alcances proximais do SDF, menos estará disponível nesta zona (Strong *et al.,* 2005).

Os depósitos distais apresentam uma alta proporção de fácies de planície de inundação, com depósitos de preenchimento de canal compreendendo apenas uma porcentagem pequena dos estratos (Nichols & Fisher, 2007). Os canais presentes são rasos e fracamente canalizados em sua maioria, com corpos arenitos em forma de finos lençóis com base abrupta e algumas vezes erosiva, sugerindo canalização local do fluxo (Graham, 1983). Entre os corps tabulares arenosos, há o desenvolvimento de fácies lamosas com evidências de formação de solo (Sadler & Kelly, 1993).

Hartley et al (2010) reconhecem sete tipos de terminações de sistemas fluviais distributários: mudança na planoforma de um padrão distributivo para contributivo, terminação em sistema fluvial axial em campos de dunas eólicas, em playa lakes, lagos permanentes ou em pantanais. Já em climas áridos, existem duas terminações possíveis, apontadas por Nichols e Fisher (2007): *terminal splays*, quando não há lago presente, ou formação de um delta lacustre de planície de inundação (*floodplain lake delta*) quando o nível do lago está alto.

O termo *terminal splay* é análogo ao termo *terminal fan* utilizado por Kelly e Olsen (1993) para SFD que não findam em lago ou mar. Outro nome empregado para descrever este tipo de terminação é "*terminal floodouts*" elaborado por Tooth (1999 a,b) para terminações de rios efêmeros na árida Austrália Central, marcadas pela transição de fluxo canalizado para não canalizado. De acordo com o autor, esta feição pode medir de 1 a 1000 km² na forma de lençóis de granulometria fina.

Fisher *et al.* (2008) atestam que o local em que se forma o *terminal splay* é onde a forma do canal se perde completamente no ponto que o nível de base fluvial é igual à elevação da superfície, causando a transferência de água e sedimentos como inundações em lençol desconfinadas, as quais espalham sedimentos em uma área mais ampla. Os autores dividem os depósitos de *splay* em proximais, com dominância de carga de fundo, e distais, com a maior parte de depósitos gerados por carga em suspensão, marcando a desaceleração das inundações. Os depósitos arenosos de *terminal splay* proximal podem apresentam estratificação plano-paralela, marcas onduladas de corrente e, por vezes, estruturas de dunas subaquosas. (Fisher & Nichols, 2007).

Por outro lado, o sistema fluvial distributário em climas áridos pode terminar em um lago efêmero. Fisher *et al.* (2007) sugerem que durante períodos de trato de sistema de nível alto do lago, os canais dos sistemas fluviais fluem no corpo de água raso formando uma série de lobos deltaicos.

Além da tectônica, controladora do espaço de acomodação, o clima influencia no comprimento de um sistema fluvial distributário, pois controla os seguintes fatores: descarga do rio, suprimento sedimentar, balanço entre o suprimento de água, estes governados pelo clima na *hinterland*, e perda devido à evaporação/transpiração, controlada pelo clima na bacia e pela natureza do sedimento da planície de inundação, que afeta as taxas de infiltração. (Hartley *et al* 2010, Nichols e Fisher, 2007). Alterações no clima em variadas escalas de tempo resultarão na variação das distâncias entre o ápice do sistema e os *terminal splays* conforme o depósito é construído, com possíveis interdigitações entre zonas proximais e intermediárias, e intermediárias e distais (Nichols & Fisher, 2007).

Já a espessura da sucessão vai depender do espaço de acomodação da bacia e do suprimento sedimentar (Fisher & Nichols, 2007). A Bacia Munster, no sul da Irlanda, por exemplo, atinge mais de 6000 m de espessura (Graham, 1983).

A diminuição lateral da velocidade do fluxo (perpendicular à direção do fluxo) em lençol é interpretada como causa da variação no tamanho de grão em análogos no registro (Tunbridge, 1984; Beer & Jordan,1989; Cuevas Gozalo & Martinius, 1993). Isto implica que inundações em lençol e seus depósitos resultantes não são radialmente simétricos. Esta propagação assimétrica é promovida por uma sutil variação na superfície topográfica do fluxo, o que pode resultar na formação de um limite irregular do lobo terminal dos depósitos de *splay* (Tooth, 1999a,b; Tooth, 2005). Como consequência, em seção composta lateral, o *splay* será composto por numerosos depósitos individuais, os quais podem estar interconectados (no caso de *splay* proximal) ou separados por depósitos finos (Stear, 1983). Fischer et al 2008 demonstram quantitativamente a tendência de diminuição de espessura dos corpos de areia com aumento da distância da área-fonte, e a interpretam como resultado do espalhamento e desaceleração de eventos de inundações em lençol desconfinadas, o que é resultado em deposição em uma área continuamente mais ampla.

1.3 Sobre a estrutura desta dissertação

Esta dissertação de mestrado está estruturada em torno de artigo publicado submetido em periódico. Consequentemente, sua organização compreende as seguintes partes principais:

a) Introdução sobre o tema e descrição do objeto da pesquisa de mestrado, onde estão sumarizados os objetivos, o estado da arte sobre o tema de pesquisa.

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c) Comprovante eletrônico de submissão do manuscrito ao periódico.

d) Referências bibliográficas citadas no capítulo 1 desta dissertação.

2 ARTIGO

Facies architecture and stratigraphic evolution of the Tacuarembó Formation, Norte Basin – Uruguay.

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ABSTRACT

The Tacuarembó Formation (Upper Jurassic-Lower Cretaceous), subdivided into Batoví Member and Rivera Member, crops in the northern region of Uruguay, in a narrow strip with an average width of 35 km by 115 km in length, oriented north-south. The present work has as main objective the sedimentological and stratigraphic analysis of the Tacuarembó Formation, through the faciological characterization, reconstruction of the depositional models and definition of contact relations between the Batoví and Rivera members. From the survey of columnar profiles in the scale 1:50, elaboration of lateral sections through the preparation of photomosaic and data collection of paleocurrents, different facies associations were individualized. The Batoví Member consists of associations of facies of (1) eolian dunes, (2) eolian sand sheets, (3) ephemeral fluvial channels, (4) perennial braided fluvial channels and (5) deltaic. On the other hand, the Rivera Member is essentially constituted by facies associations eolian dunes. The intercalation between fluvial, eolian and deltaic deposits, with predominance of fluvial associations, suggests that the Batoví Member represents the depositional model of the distal portion of a distributary fluvial system. Contrastingly, the Rivera Member is characterized by the successive eolian dunes climbing, without the occurrence of wet or damp interdunes deposits, defining a dry eolian system. The abrupt change of depositional systems, marked by a flat surface, sometimes with clasts concentration, indicates the existence of an unconformity between the members Batoví and Rivera. Allied to this, the change in the depositional model suggests a climatic change, going from arid to semi-arid climate during the deposition of the Batoví Member, to a hyperarid climate during the deposition of the Rivera Member.

Keywords: distal distributary fluvial systems; eolian depositional systems; Batoví Member; Rivera Member; Norte Basin.

INTRODUCTION

In recent years, numerous studies have described and interpreted different fluvial-eolian units of the Lower Jurassic Upper-Cretaceous Gondwana Supercontinent (eg Mountney *et al.*, 1998; Veiga *et al.*, 2002; Scherer *et al.*, 2007; Scherer and Lavina, 2006; Peri *et al.*, 2016). During this period of time, paleogeographic and paleoclimatic changes occurred that generated alterations in the continental-scale depositional scenario (Kuchle *et al.*, 2011). Although there are studies superficially approaching stratigraphy and sedimentology, there is no detailed study of the facies architecture and high resolution stratigraphy of the Juro-Cretaceous succession of the Paraná Basin in Uruguay.

The present work has as main objective the sedimentological and stratigraphic analysis of the Tacuarembó Formation in the Rivera and Tacuarembó departments of Uruguay. As specific objectives can be highlighted: (i) detailed faciological characterization and reconstruction of the depositional systems of Batoví and Rivera members, (ii) definition of the stratigraphic framework of the Tacuarembó Formation, emphasizing the contact relations among its members and (iii) to contribute to the knowledge of the continental Southeastern Brazil-Paraná Basin systems.

GEOLOGICAL SETTING

The Norte Basin, equivalent to Uruguayan portion of the Paraná Basin (de Santa Ana, 1989), occupies about 100,000 square kilometers of the northern region of the country (Fig. 1A). It is composed by four sequences separated by regional unconformities: early Devonian, Permian-Eotriassic, Juro-Eocretaceous and Upper Cretaceous-Paleocene (de Santa Ana, 2004). The Paleozoic filling, composed by the first and part of the second sequences, represents transgressive-regressive cycles related to second order sea-level changes. The Mesozoic filling includes the latest sequences, and it’s marked by a continentalization of the basin, that caused an erosive process during the Triassic and part of the Jurassic Eras, generating an unconformity named “intra-gondwanic unconformity (Caorsi and Goñi, 1958; Padula and Mingramm, 1967; de Santa Ana, 2004). The Tacuarembó Formation accumulated in a continental context, corresponding to the basal portion of the first Mesozoic sequence (Juro-eocretaceous), (Bossi, 1966).

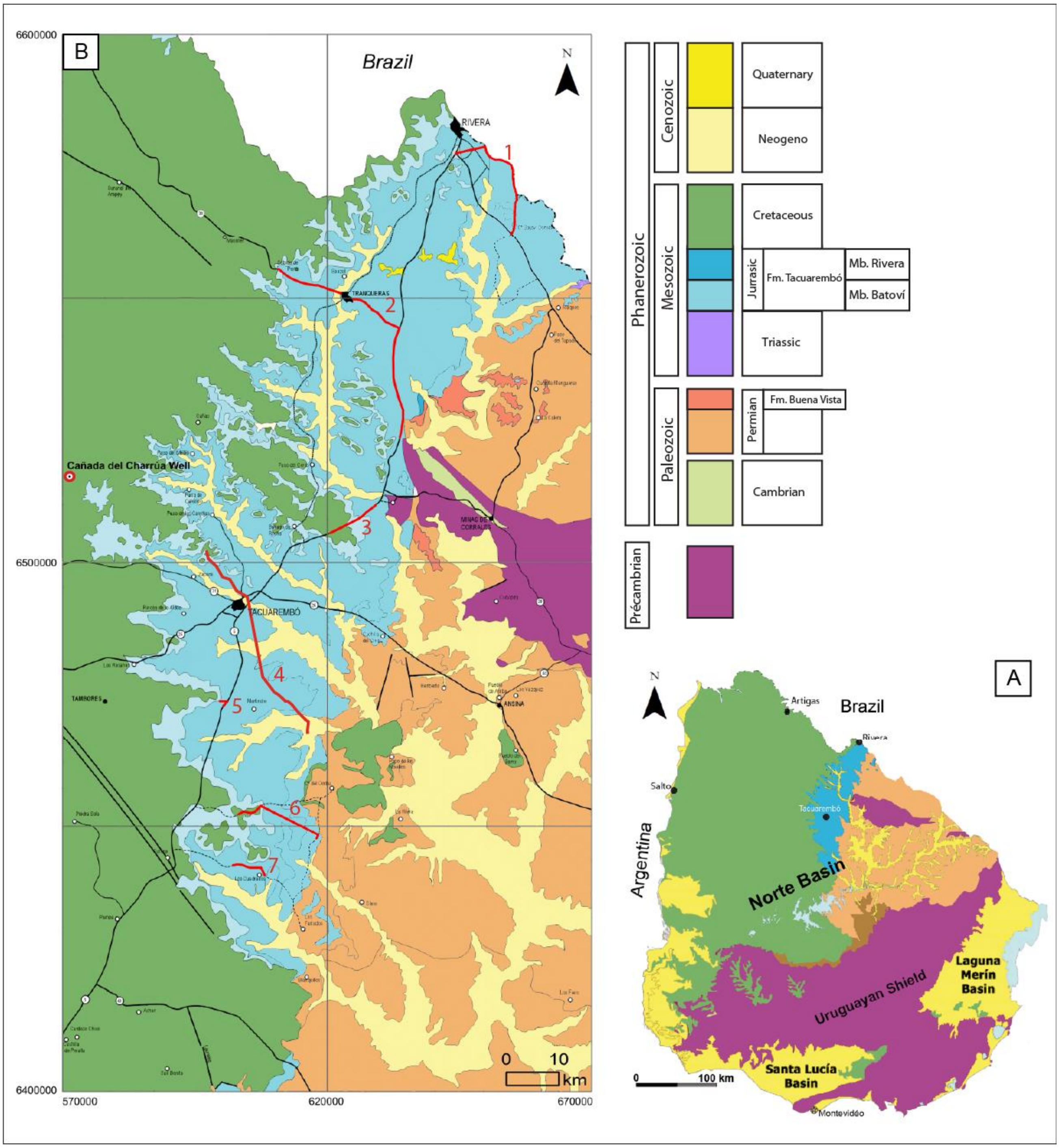


Fig. 1. (A) Geological map of Uruguay. Modified from Perea *et al.* (2009) (B) Geological map of northern Uruguay showing the cropping portion of the Tacuarembó Formation and its surroundings, containing the seven transects presented in Fig. 5-10 and 12, and the location of the well log Cañada del Charrúa, presented in Fig. 13. Modified from Bossi *et al.* (1998).

The Tacuarembó Formation, first identified and described by Walther (1919), and Falconer (1931), was lithostratigraphically named by Bossi (1966), which later recognized and defined two members, a lower and an upper member, to which Perea *et al.* (2009) attributed the names Batoví and Rivera, respectively. It is assigned to the Formation an age Late Jurassic - Early Cretaceous, dated by diverse fossil content of the Batovi Member, represented by gastropods, reptiles crocodilian, semionotiformes fish and conchostracans (Mones and Figueira, 1981; Ferrando *et al.*, 1987; Perea *et al.*, 2001; amongst others). The lower contact of the Tacuarembó Formation is marked by an unconformity with Permian Yaguarí and Buena Vista formations (de Santa Ana *et al.*, 2006).

Batoví and Rivera members have different lithological atributes. According to de Santa Ana and Verolavsky (2003), the Batovi Member is characterized predominantly by very fine to coarse sandstones, with a quartzitic composition, locally subarcoseous (subordinately subliticous), whitish in color, reaching purplish, greenish or red-orange shades; and massive or laminated mudstones. The sandstones present different sedimentary structures, including small to large scale planar and tangential cross bedding and horizontal to low-angle stratifications. The Batoví member is interpreted as fluvial-eolian deposits (Perea *et al.*,2009). Additionally, the authors state that the aqueous deposits dominate toward the top of the Batoví Member, suggesting progressively more humid climatic conditions, including the development of a more permanent river system.

The Member Rivera is composed by fine to medium-grained and well-selected, reddish to reddish-brown sandstones. It consists in two typical facies: the first, sandstones with large-scale, planar or through cross-bedding, internally with grainflow and grainfall structures, which is interpreted as deposits of eolian dune fields; the second, composed of sandstones with horizontal to with sub-horizontal laminations, internally with eolian ripple laminations, interpreted as sand sheet deposits. (Perea *et al.*, 2009).

The Rivera Member is overlapped and interdigitated by the Arapey Formation, which consists of Eocretaceous tholeiitic basalts stemming from the fragmentation of the Gondwana Supercontinent.

Regionally, the Tacurembó Formation is correlated with Mesozoic deposits of Argentina, represented by the formations San Cristóbal (Padula and Mingramm, 1969) and Solari (Santa Ana *et al.*, 2006), constituents of the Chaco-Paraná Basin. In Brazil, the correlation of the Rivera Member with eolian sandstones of the Botucatu Formation of the Paraná Basin is incontestable (France et al, 1995; Lavina and Scherer, 2006). On the other hand, the correlation of the Batovi Member with Brazilian deposits is unclear due to the divergence of opinions (Bossi, 1966; Ferrando and Andreis, 1986; Ferrando *et al.*, 1987; Bossi *et al.*, 1998). This paper takes into account the data from the latest study, conducted by Scherer and Lavina (2006), which correlates the Batovi Member of the Tacuarembó Formation with the fluvial-eolian deposits of Guará Formation of the Paraná Basin.

STUDY AREA AND METHODS

The Tacuarembó Formation crops out in northern Uruguay, in the Rivera and Tacuarembó Departments (Perea *et al.,* 2009); its outcrop belt is 35 km wide and 115 km long, in a N-S orientation (Fig. 1A). In this work forty-one outcrops and one well-log were described through sedimentological logs in scale 1:50, in which lithofacies were detailed, lithofacies associations were established and paleocurrent data was collected. Because of the vegetation and the attenuated relief of the region, most of the outcrops were vertically and laterally restricted, and kilometers or hundreds of meters separated, making it impossible to settle lateral correlation. The vertical analysis of the entire stratigraphic interval was made by the relative position of the outcrops in seven topography transects determined by the physical proximity of the outcrops (Fig. 1B), taking the structural data into account. The transects were made using the outcrops topographical position according to the software *Google Earth*.

BATOVÍ MEMBER FACIES ASSOCIATIONS

The lower member of the Tacuarembó Formation, known as Batoví Member, is composed by sixteen distinctive facies, summarized in Table 1, that occur within five facies associations: (i) eolian dunes, (ii) eolian sand sheets, (iii) perennial braided fluvial channels, (iv) ephemeral fluvial channels, (v) delta front (Table 2). Their relative proportion is shown in Figure 2.

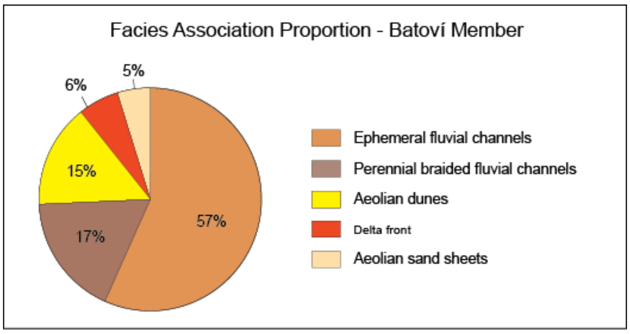


Fig. 2. Pie chart showing the relative proportions of the facies associations that compose the Batoví Member.

Eolian dunes facies association

Description. Fine- to medium- grained, light pink sandstones, with well-sorted, well-rounded, highly spherical quartz grains, arranged into sets of through cross-strata (St(e)) (Fig. 4A). Cross-bedding consists of grainflow strata in the steeper part of the foresets (up to 4 cm thick) which interfinger with inversely graded wind-ripple laminae down-dip. Internally to the sets, sometimes are found high-angle concave surfaces (18-20^o) that truncate lower strata, and dip in the same direction of the cross-bedding strata. Intercalation between wind ripple laminae and grain flow strata deposits is also commonly found. The average dip direction of the foresets is to 080^o, displaying a dip directional spread ranging mainly from 30° to 150° (Fig. 3). Individual sets range in thickness from 10 cm to 2.8 m, with multiple sets forming stacked cosets of up to 5 m thick. The upper and lower contacts of this unit are sharp and horizontal, with no erosional relief.

Interpretation. Well-sorted sandstones with highly spherical grains, presenting cross-stratification in sets up to 2.8 m thick and, composed by grainflow strata at the steeper part of the foresets and inversely graded wind ripple laminae at the base, indicate residual deposits of migrating eolian dunes (Hunter, 1977; Kocurek and Dott, 1981). The concave surfaces dipping towards the dipping direction of the foresets can be classified as reactivation surfaces (Kocurek, 1996). Reactivation surfaces and the alternation between packages of grain-flow and wind ripple laminae are formed from cyclical erosion of the lee face of the dunes during periods of reverse or oblique winds, followed by new deposition (Kocurek and Dott, 1981). This cyclicity is interpreted as seasonal changes in wind direction, and represents the annual migration rate of the eolian dunes. In the Batoví Member the maximum thickness of the one cycle is 1 m. The unidirectional highly dispersive paleocurrent of the through cross-strata indicates crescentic dunes with sinuous crestlines, migrating manly towards ENE.

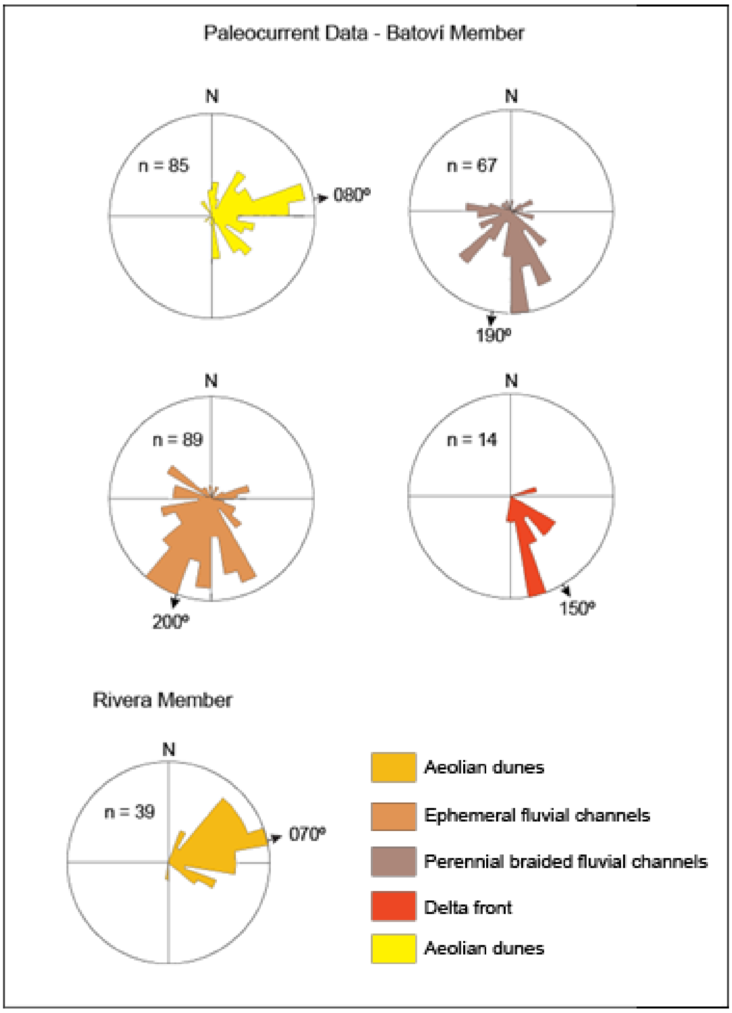


Fig. 3. Rose diagrams showing the paleocurrent data of each facies association of Batoví and Rivera members, with the number of paleocurrents measured and the mean vector indicated with an arrow.

Eolian sand sheets facies association

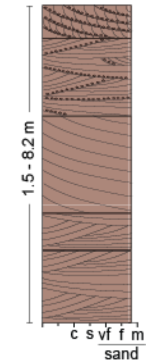
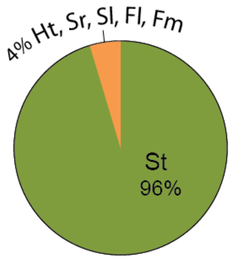
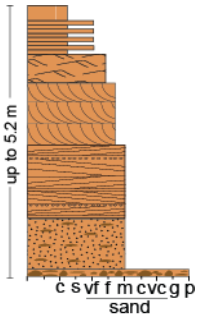
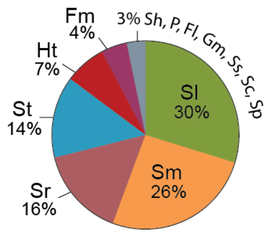
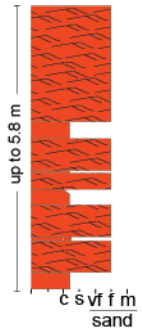
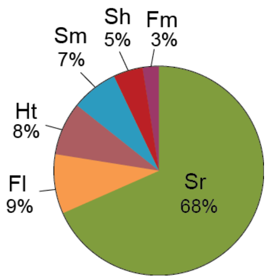
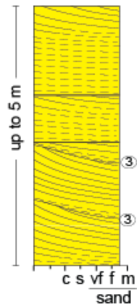
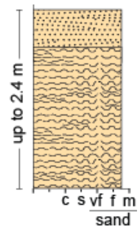
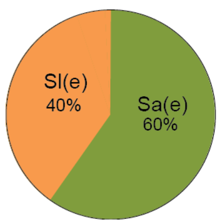
Description. Fine- to medium-grained, light pink sandstones, with well-sorted, well-rounded, highly spherical quartz grains, arranged into tabular bodies up to 2.4 m thick. Internally, these units are formed by 20 cm to 1.75 thick sets of horizontal to low-angle cross-stratification (generally <5^{o}) composed by inversely graded wind-ripple laminae (Sl(e)); or, more often, with horizontal to wavy lamination interlayed with irregular mudstone laminae, defining crinckled texture (Sa(e)) (Fig. 4F), disposed in beds from 20 cm to 2.25 m thick. It presents abrupt lower and upper contact with other facies association.

Interpretation. Packages of horizontal to low-angle cross-bedding, composed by well-sorted and highly spherical grains presenting inverse gradation, are interpreted eolian sand sheet deposits, formed by migration and subcritical climbing of wind ripples on dry depositional surfaces (Hunter, 1977). Beds containing

Table 1. Lithofacies that compose the Batoví Mb. and their description and interpretation.

Facies	Description	Depositional Process
Gm	Massive, sandy intraformational conglomerate with mud intraclasts <10 cm; the sand fraction varies from fine to medium; 10 to 20 cm thick beds.	Unidirectional high energy flow hyperconcentrated in sediments.
Sm	Fine- to coarse-grained sandstones; poorly- to well-sorted; massive; commonly with mud intraclasts; sometimes presenting erosive base with mud intraclasts; 10 cm to 1.90 m thick beds.2	Rapid deposition of hyperconcentrated flows, fluidization or intensive bioturbation.
St	Fine- to coarse-grained; poorly- to well-sorted; it may present clasts of quartz and mud intraclasts, both up to granule grain size, at the base of sets, parallel to stratification, or disperse; trough cross-stratification; 20 cm to 2 m thick sets.	3D subaqueous sandy dunes migration in a unidirectional low energy flow regime.
St(e)	Fine- to medium-grained sandstones, well-sorted, with well-rounded and highly spherical grains; large-scale cross stratification; 15 cm to2.8 m thick cross-strata sets; the base of the foresets consists of millimetrically spaced laminations with inverse grading, which interdigitates with wedges of massive sandstones up to 4 cm thick towards the top of the foresets; frequent presence of reactivation surfaces.	Residual deposits of eolian dunes, with wind ripple lamination to the base of the foresets that passes upward to grainflow strata. Dunes with well-developed slip face.
Sp	Fine-grained sandstones; moderately-sorted; planar cross-stratification; 25 cm thick set.	2D subaqueous sandy dunes migration in a unidirectional low energy flow regime.
Sr	Very fine- to fine-grained sandstone; moderately- to well-sorted; ripple cross-lamination, set thickness a few cm, forming up to 4,15 m thick cosets; supercritical to subcritical climbing angle.	2D- or 3D-ripples in a unidirectional low energy flow regime.
Sh	Fine- to medium-grained sandstones; poorly- to well-sorted; horizontal lamination; 10 to 110 cm thick beds.	Horizontally-bedded deposits originated via unidirectional upper flow regime.
Sl	Fine- to coarse-grained sandstones; poorly- to well-sorted; it may present granule and pebble of quartz and intraclasts parallel to stratification; intraclasts are also sometimes found in the base of the beds or disperse; low-angle cross-stratification; 15 cm to 5.25 m thick sets.	Unconfined lower- to upper-flow regime transitional bed form
Sl(e)	Fine- to medium-grained sandstones, well-sorted with well-rounded and highly spherical grains; horizontal to low-angle cross-stratification composed by millimetrically spaced laminations with inverse grading; tabular sets from 20 cm to 1.75 m thick.	Translatent strata produced by the migration and subcritical climbing of wind ripples on dry depositional surfaces; basal strata of wind dune (heavily truncated dune) or eolian sand sheet.
Sa(e)	Dominantly fine-grained sandstones, rarely medium-grained; well-sorted; horizontal to wavy lamination, interlayered with irregular mudstone laminae, defining a crinkled texture; 20 cm to 2.25 m thick beds	Adhesion structures originated from the adherence of dry sand grains that were carried to wet surfaces by the wind.
Ss	Fine-grained sandstone; moderately sorted; sigmoidal cross-bedding; 60 cm thick set.	Lower- to upper-flow regime transitional bedform.
Sc	Fine-grained sandstones; plastic deformation structures forming complex folding of lamination; 50 cm thick beds.	Plastic deformation of partially liquefied sediments; fluidization; differential overloading
Fl	Mudstones to very fine-grained sandstones; millimetric horizontal lamination; 5 to 75 cm thick beds.	Suspension settling in dominantly standing water.
Fm	Mudstones to very fine-grained sandstones; massive; sometimes fissile in weathered surfaces; 5 to 70 cm thick beds.	Lack of lamination due to (i) flocculation of clay suspension, or (ii) loss of lamination associated with fluidization or intensive bioturbation.
Ht	Millimeteric to centimetric heterolythic linsen to flaser bedding; intercalations of very fine to fine sandstones (massive, Sm, sometimes with ripples, Sr), mudstones, claystones and siltstones, laminated (Fl) or massive (Fm); commonly presenting bioturbation and plastic deformation structures, which breaks the lamination; 15 cm to 2.15 m thick packages.	Deposition by decantation of suspended load alternating with bed load or rapid deposition of hyperpycal flow in a flow regime very close to zero. Plastic deformation due to fluidization and overloading.
P	Mudstones to very fine-grained sandstones; mottle and block structures; root traces; red colored with diffuse horizons of color variations; 15 cm to 1.2 m thick beds.	Suspension settling of sediment subject to desiccation, oxidation and soil development.

Table 2. Facies associations of the Batoví Mb. and their general vertical log, description, relative proportion of lithofacies and interpretation.

Facies association	Vertical log	Description	Lithofacies proportion	Interpretation
PERENNIAL BRAIDED FLUVIAL CHANNELS		Mudstones and fine to medium-grained sandstones, 1.5 - 8.2 m thick sandbodies; sometimes presenting basal erosional surface of 2 m relief at most; composed by downstream accretion macroforms and sand bedform.		Channelized, low-sinuosity perennial fluvial channel.
EPHEMERAL FLUVIAL CHANNELS		Intraformational conglomarates, fine to coarse-grained sandstones and mudstones; tabular bodies up to 5.2 m thick; sometimes presenting basal erosional surface of 1.5 m relief at most.		Unconfined to poorly channelized, ephemeral sheetflood.
DELTA FRONT		Mudstones and fine- to medium-grained sandstones; tabular bodies composing coarsening and thickening-upward successions up to 5.8 m thick.		Terminal splay lacustrinedelta front.
EOLIAN DUNES		Fine- to medium-grained sandstones with trough cross-bedding; sets up to 5 m thick; the cross-beds are composed by gainflow strata that interlay down-dip with wind ripple laminae.	100% St(e)	Crescentic dune fields in a dry eolian system.
EOLIAN SAND SHEETS		Fine- to medium-grained sandstones; tabular bodies up to 2.4 m thick.		Wet and dry eolian sand sheets.

irregular horizontal to wavy lamination composed by alternating sandstone and mudstone laminae, classified as adhesion structures caused by the adherence of sand grains on humid surfaces (Kocurek and Fielder, 1982), are interpreted as wet eolian sand sheet deposits. The intercalation between dry eolian ripple strata and adhesion strata reflects changes in the substrate wetness associated with either modifications of the rate of water table fluctuation or dry sand availability (McKee, 1979; Chakraborty and Chaudhuri, 1993; Scherer and Lavina, 2005).

Perennial braided fluvial channels facies association

Description. Fine- to medium-grained sandstones, poorly- to moderately-sorted, sometimes with clasts of quartz and/or mud intraclasts<6 cm disperse or following the stratification, organized in amalgamated sand bodies 1.5 to 8.2 m thick. The sand bodies are composed mainly by through cross-bedding sets (St) up to 2 m thick. Subordinately, it can occur fine- to medium-sandstones with ripple cross-lamination (Sr) or with low-angle cross-stratification (Sl). Sometimes, lenticular package, 5 to 70 cm thick, compound by massive, (Fm) and laminated (Fl) mudstones to very fine-grained sandstones or hetherolitic bedding (Ht) can occur intercalated with sandstone bodies. These fine deposits are truncated to some extent by the sandstone bodies.

Architectural elements include simple and composite downstream accreting macroforms (DA) and, dominantly, sandy bedforms (SB). Composite DA elements are 0.4 to 1.5 m thick, composed by a coset marked by the superposition of trough cross-strata sets (St) of 0.15 to 0.25 m thick separated by slightly concave, low-angle surfaces (dipping less than 12^o), oblique (20^o to 40^o) to the direction of the cross-strata dip. Simple DA elements consist in isolated, large trough cross-strata sets (St), with thickness varying from 1 to 2 m (Fig. 4C). SB elements, can reach up to 8 m and are composed by isolated sets of trough cross-strata sets (St), 20 to 90 cm thick.

Lower contacts are sharp, horizontal to deeply erosive, with erosional surface of 2 m relief at most, commonly presenting coarser grain size (from coarse sand to pebble).

The paleocurrent data indicates paleoflow with a mean vector to 190^o, highly dispersive, varying manly from SSW to SSE (Fig. 3).

Interpretation. The dominance of beds of through cross-bedding, composed by poorly- to moderately-sorted grains, with grain size reaching granule, occasionally presenting basal scours, classifies this unit as fluvial channels deposits. The cross-strata arranged into SB and DA architectural elements, associated to rare occurrence of fine-grained lithofacies, points to a fluvial system with low-sinuosity and bedload transport dominated (Miall, 1996), interpreted as braided fluvial channels. The predominance of through-cross bedding indicates that discharge was relatively steady, carried by a perennial flow. However, there were fluctuations in the flow regime and/or sediment concentration during the flood events, demonstrated by the subordinate presence of sandstones with low-angle and ripple cross-stratifications (Allen *et al.*, 2014). The rare occurrence of heterolytes indicate that overbank area was poorly developed or that channel avulsion were frequent, eroding fine deposits (Nichols and Fisher, 2007; Weissmann *et al.*, 2013).

Ephemeral channels facies association

Description. Fine- to coarse-grained, poorly- to well-selected, quartzitic sandstones bodies, arranged in tabular sets of 10 cm to 5.25 m thick, mainly with low-angle cross-strata (Sl), trough cross-strata (St), ripple cross-lamination, or structureless, massive (Sm) (Fig. 4D). Subordinately, fine- to medium-grained sandstones present horizontal lamination, planar or sigmoidal cross-bedding, or convolute strata. Clasts of quartz and/or mud intraclasts, <6 cm, disperse or following the stratification are common.

Frequently, the sand bodies are capped by lenticular beds of mudstones to very fine-grained sandstones, composing fining-upward successions. The mudstones to very fine-grained sandstones are laminated, in beds up to 75 cm thick, or present mottle and block structures, root traces and diffuse horizons of color variations, with thickness varying from 15 cm to 1.2 m (Fig. 4E).

Subordinately, the base of the successions presents massive, sandy intraformational conglomerates with mud intraclasts<10 cm, with the sand fraction fine to medium-grained, in beds 10 to 20 m thick (Fig. 4D).

Rarely, it can occur linsen to flaser hetherolitic bedding composed by massive, (Fm) and laminated (Fl) mudstones intercalated with fine- to very fine-grained sandstones, massive (Sm) or with ripple cross-lamination (Sr), in beds 15 cm to 2.15 m thick.

The lower contact of the unit is sharp and generally planar. Less commonly, the contacts undulated to deeply erosive, with basal scour of 1.5 m relief at most, and rarely does it present granules and pebbles. The paleocurrent of the through and ripple cross-bedding sets has a vector mean pointing to 200°, and it is highly dispersive, varying mainly from SSE to SSW (Fig. 3).

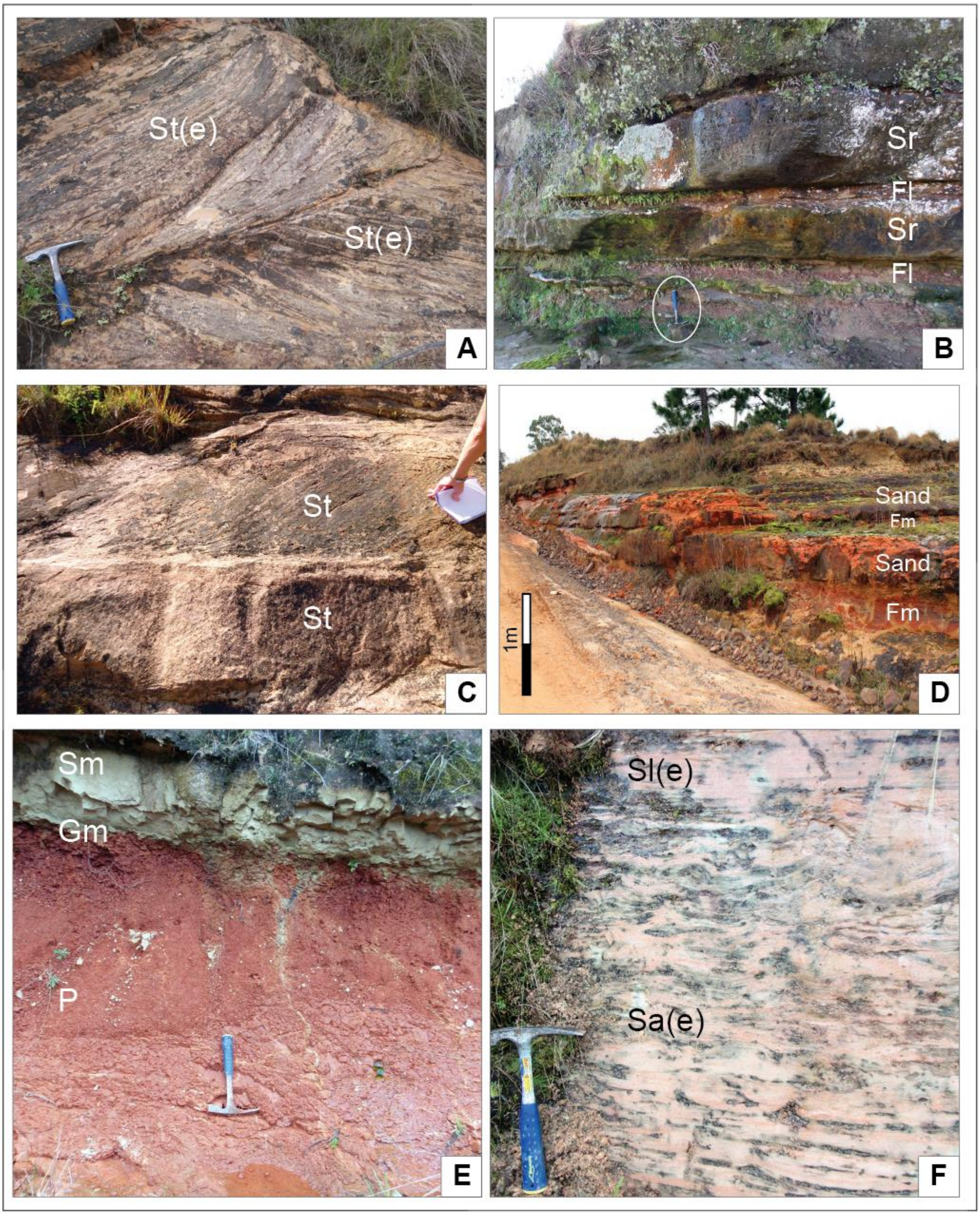


Fig. 4. Photos of the facies associations that compose the Batoví Mb. (A) Superposition of eolian dunes characterizing the eolian dunes facies association; (B) Delta front pointed by thickening-upward successions; (C) Simple accretion bars characterizing the perennial braided fluvial channel facies association; (D) Tabular shape of the ephemeral fluvial channels facies association; (E) Ephemeral fluvial channels association in detail; (F) Sand sheet facies association characterized by adhesion structures and low-angle cross strata.

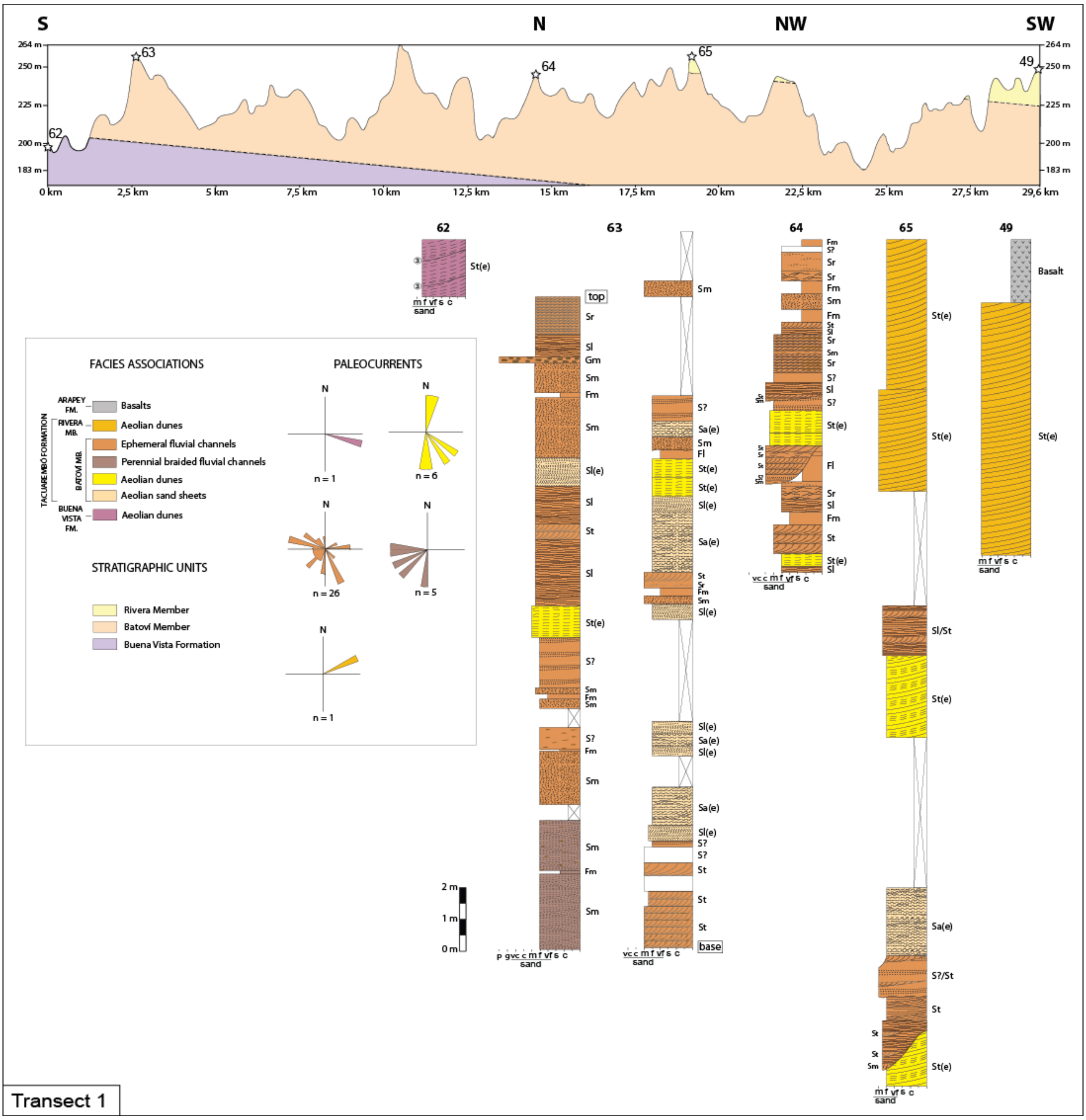


Fig. 5. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 1, and the paleocurrent data of each facies association present.

Interpretation. The relatively high occurrence of trough (St) and low-angle (Sl) cross-bedded and ripple-laminated sandstones (Sr) indicates that bed load is a significant depositional mechanism in this facies association (Fisher *et al*., 2008). The alternation between these lithofacies, plus the presence of fine-grained lithofacies, is interpreted as resulting from fluctuation in flow magnitude during a flood event. The erosive base of the beds, along with the presence of intraformational conglomerates, suggests that, at least initially, the flux was relatively powerful. The low-angle cross-bedded sandstones represent the intermediate magnitude of the flow, and as its magnitude decreases, it deposits trough cross-bedded sands and then ripple-laminated sandstones. The lowest flow energy is represented by the deposition of fine-grained sediments. This succession represents the carrying capacity decrease of the flow over time (Fisher *et al*., 2008).

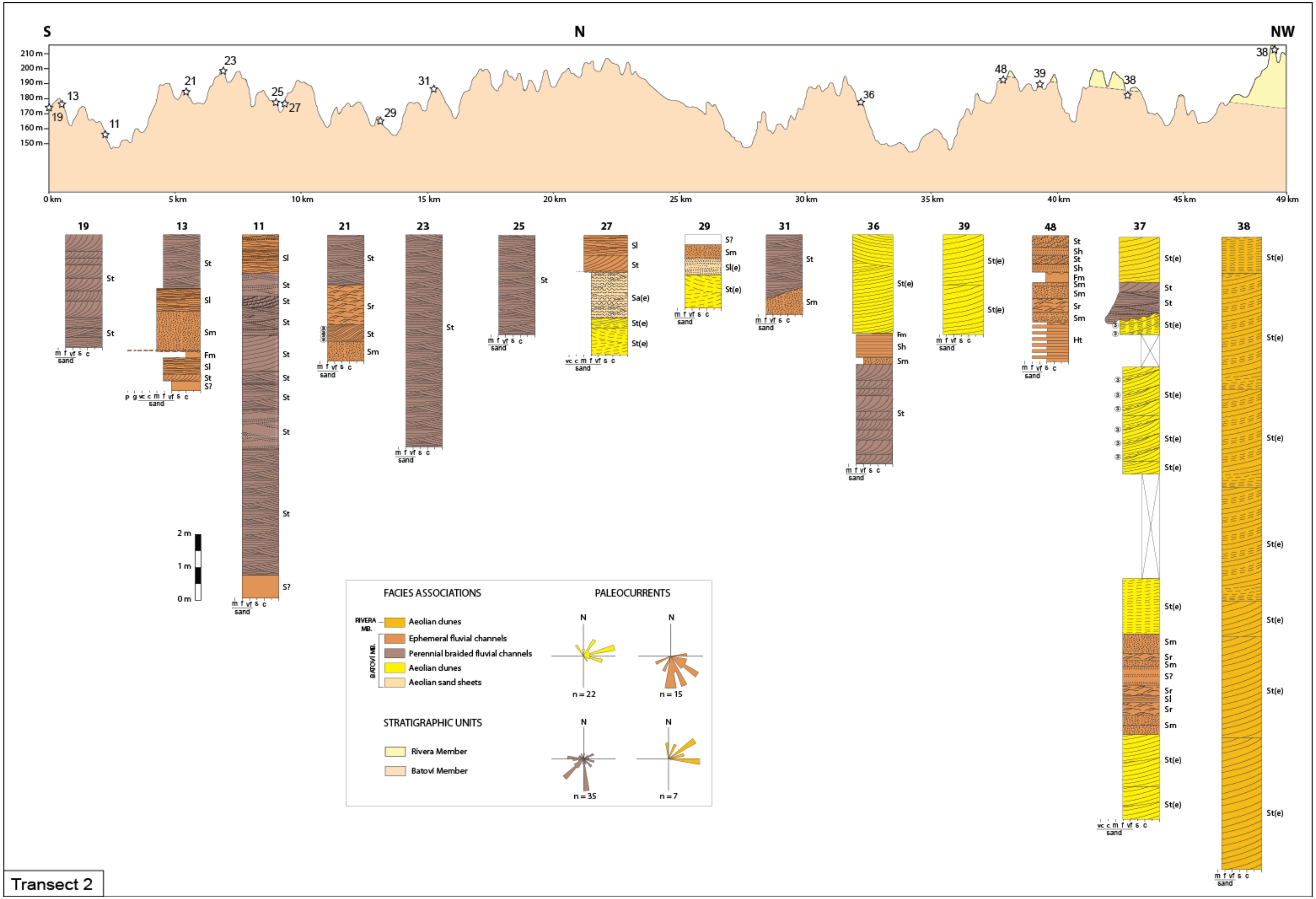


Fig. 6. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 2, and the paleocurrent data of each facies association present.

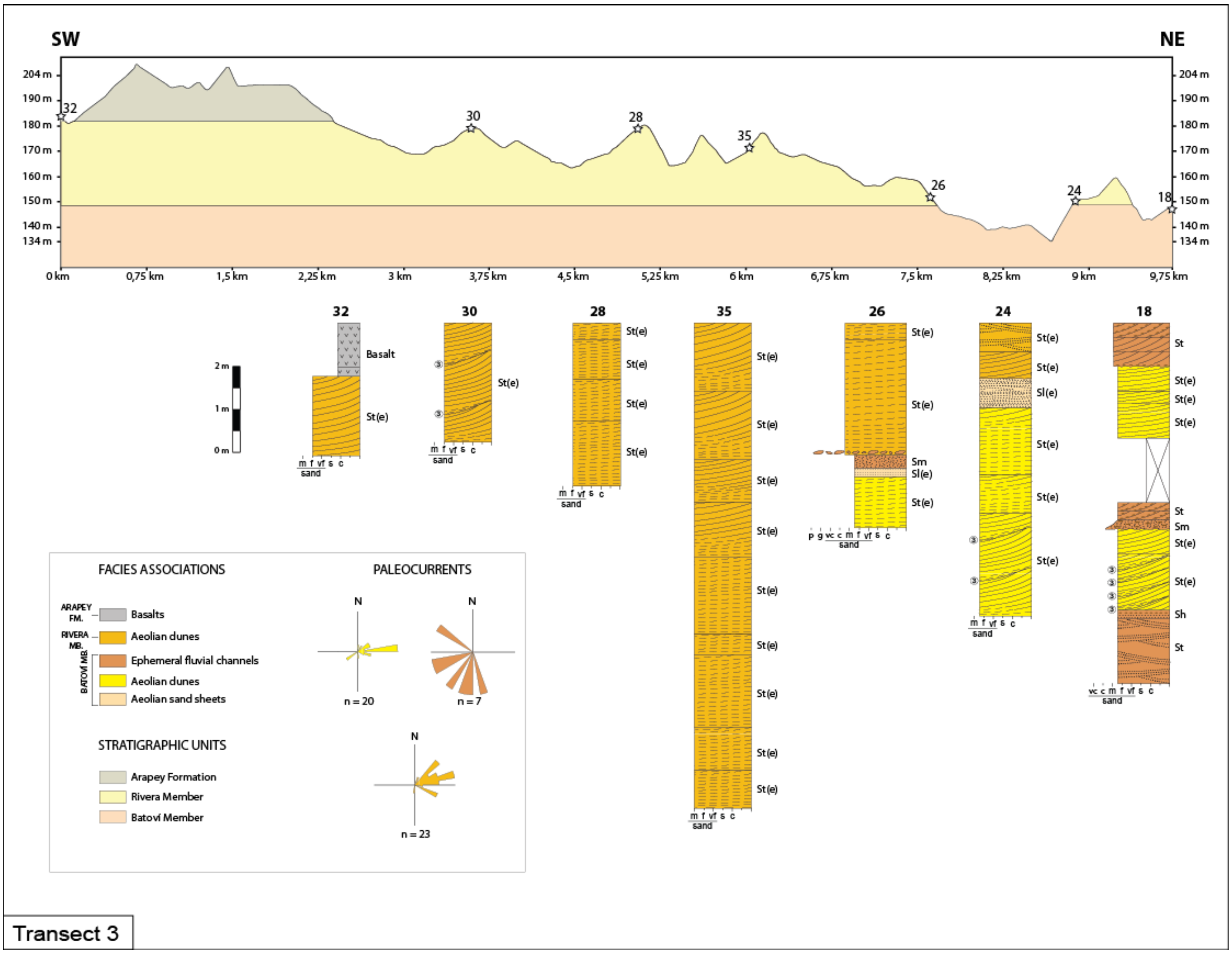


Fig. 7. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 3, and the paleocurrent data of each facies association present.

The presence of mudstones or very fine-grained sandstones draped bounding surfaces or "pause planes" (Dreyer, 1993) within the channel fill indicates deposition from multiple fluvial events that were interrupted by periods of relative quiescence (Love and Williams, 2000; Bridge, 2003). This 'pulsed' delivery of water and sediment is characteristic of ephemeral fluvial systems (Nanson *et al.*, 2002), formed during flash flood events, that is, events of short duration and high intensity, with rapid deceleration (Miall, 1996).

Separation of sandy lithofacies by discontinuous layers fine-grained sediments is thought to result from the persistence of small pools and semi-permanent ponds following major flood events (Fisher *et al.*, 2008). In some cases the period of fluvial inactivity was long enough to allow development of paleosols (Fisher *et al.*, 2007), which indicates periods of subaerial exposure.

The linsen to flaser hetherolitic bedding either represent distal deposits of the ephemeral fluvial systems, or mark lateral splays of the channel body.

Fluvial systems face fluctuations in discharge because of seasonal rainfall variations in the hinterland catchment area (Nichols and Fischer, 2007), hence the flash flood events record rainy, more humid seasons.

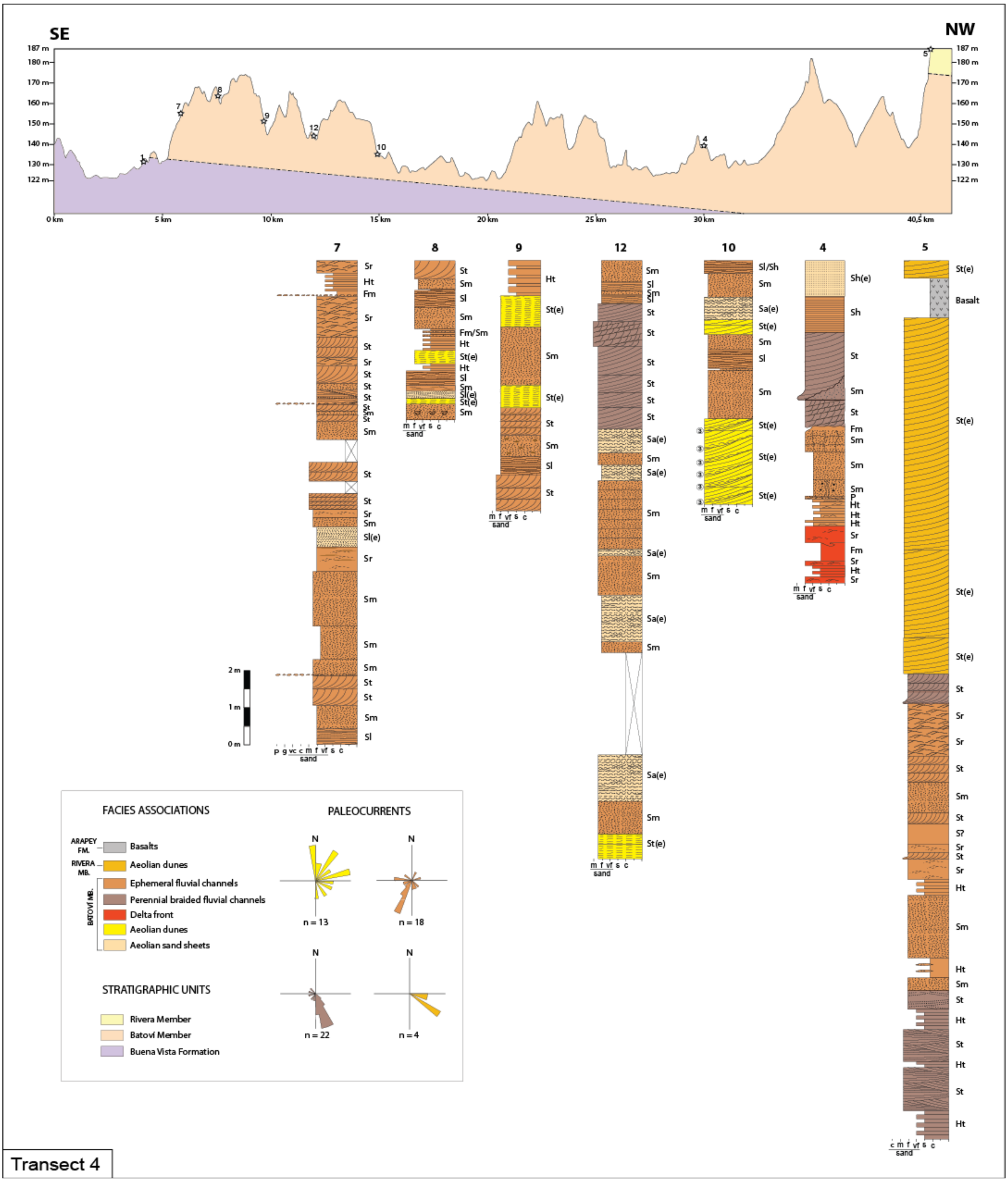


Fig. 8. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 4, and the paleocurrent data of each facies association present.

Delta front facies association

Description. This facies association is organized in coarsening- and thickening-upward successions, with variant sizes reaching up to 5.8 m thick (Fig. 4B). The base of the succession is composed by hetherolitic bedding (Ht) or decimetrical (15 to 40 cm) intercalation of the massive (Fm) or laminated mudstones (Fm) and well sorted, fine-grained sandstones, massive (Sm) or with ripple cross-lamination (Sr). The top of the cycles is characterized by amalgamated, well sorted, fine- to medium grained sandstones, massive (Sm) or with subcritical to supercritical, ripple cross-laminated sets (Sr). Horizontal to low-angle cross-stratification (Sl) are rare. The lower and upper contacts of this unit are planar and sharp. The paleocurrent acquired from ripple cross-stratification points to a mean vector of 150°, with little variation along the SE quadrant (Fig. 3).

Interpretation. Successions of coarsening- and thickening-upward beds, with intercalation of mudstones and sandstones are characterized as delta front deposits (Battacharyya, 2010). The base, where there is a prevalence of mudstones and heterolythes, is the distal delta front; whereas the top of the successions, with amalgamated sandstone beds, is defined as proximal delta front. The assemblage of lithofacies points that the sandstone beds were deposited mainly by quasi-steady hyperpycnal turbidity currents, formed when sediment-laden fluvial flood discharges entered standing, lower-density water bodies (Mulder and Alexander, 2001; Zavala *et al.*, 2006). Sandstone beds with climbing ripple lamination suggest secondary currents reworked fine sand deposits (Sáez *et al.*, 2007).

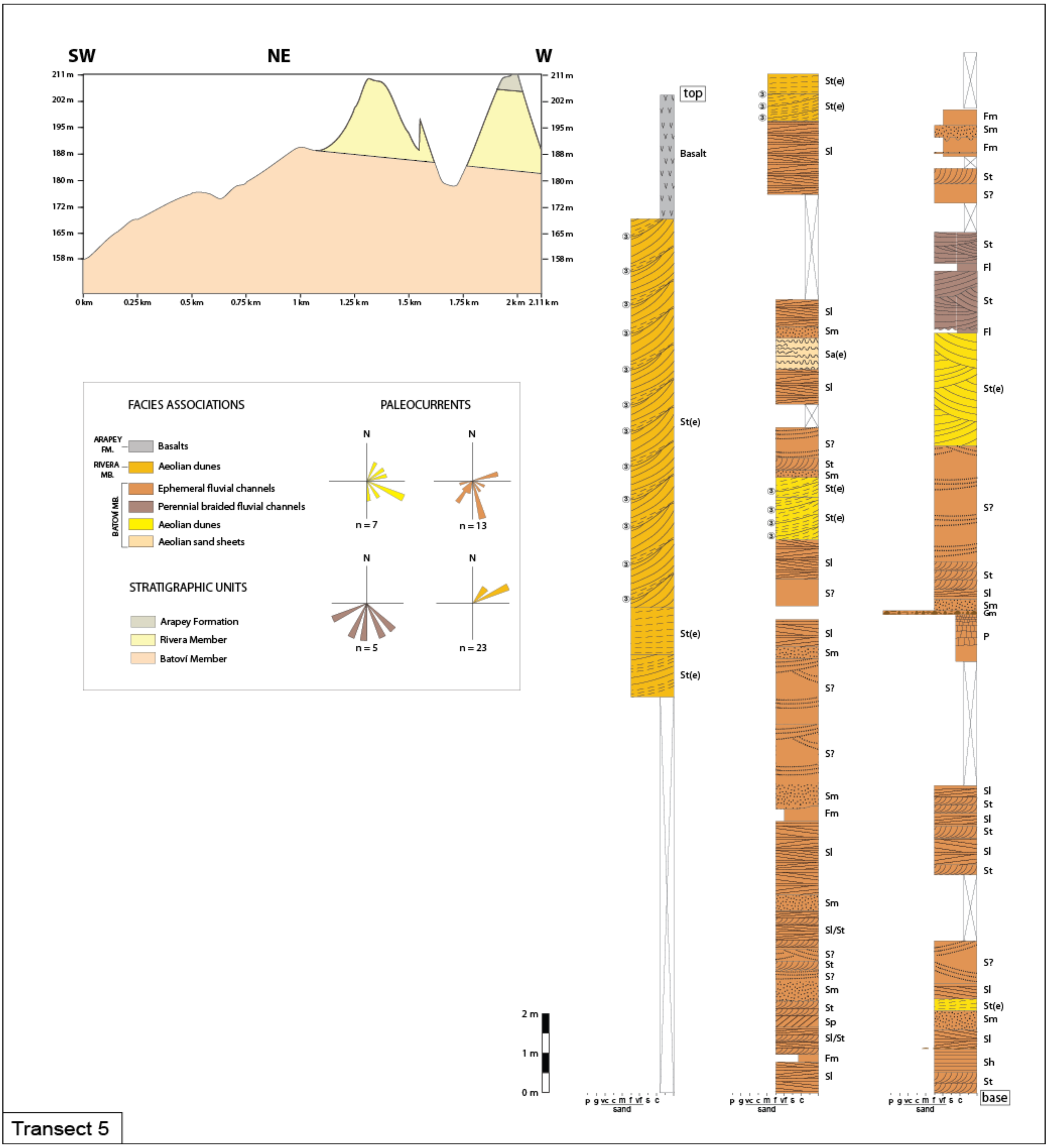


Fig. 9. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 5, and the paleocurrent data of each facies association present.

The progradational successions are irregular due to water depth and fluvial discharge variations (Battacharya, 2010).

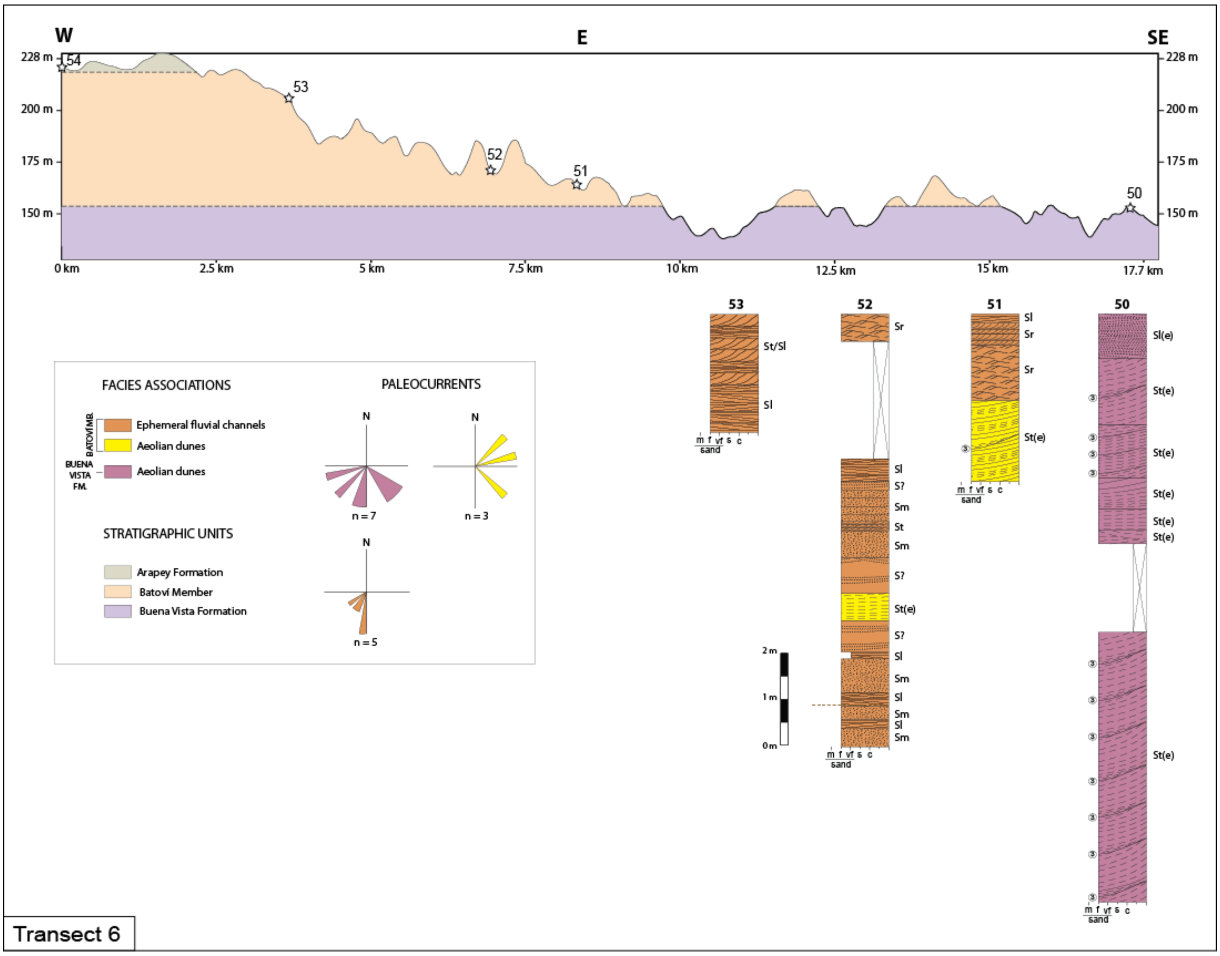


Fig. 10. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 6, and the paleocurrent data of each facies association present.

RIVERA MEMBER FACIES ASSOCIATION

The Rivera Member, upper member of the Tacuarembó Formation, is composed by one lithofacies (St(e)), and its vertical stacking composes the eolian dunes facies association.

Eolian dunes facies association

Description. Fine- to medium- grained, orange sandstones, with well-sorted, well-rounded, highly spherical grains composed mainly by quartz and K-feldspar, arranged into sets of large through cross-strata (St(e)) from 10 cm to 13 m thick (Fig. 11A). Cross-bedding consists of grainflow strata in the steeper part of the foresets (up to 4 cm thick) which interfinger with inversely graded wind-ripple laminae (Fig. 11B) down-dip. Internally to the sets, sometimes are found high-angle concave surfaces (18-20^{o}) that truncate lower strata, and dip in the same direction of the cross-bedding strata. Intercalation between wind ripple laminae and grain flow strata deposits is also commonly found. The average dip direction of the foresets ranges mainly from 20^{o} to 130^{o}, being the mean vector to 070^{o} (Fig. 3). Multiple sets forming stacked cosets of up to 25 m thick. The upper and lower contacts of this unit are sharp and horizontal to sub-horizontal, with no erosional relief. The lower contact sometimes presents faceted quartz clasts <3 cm.

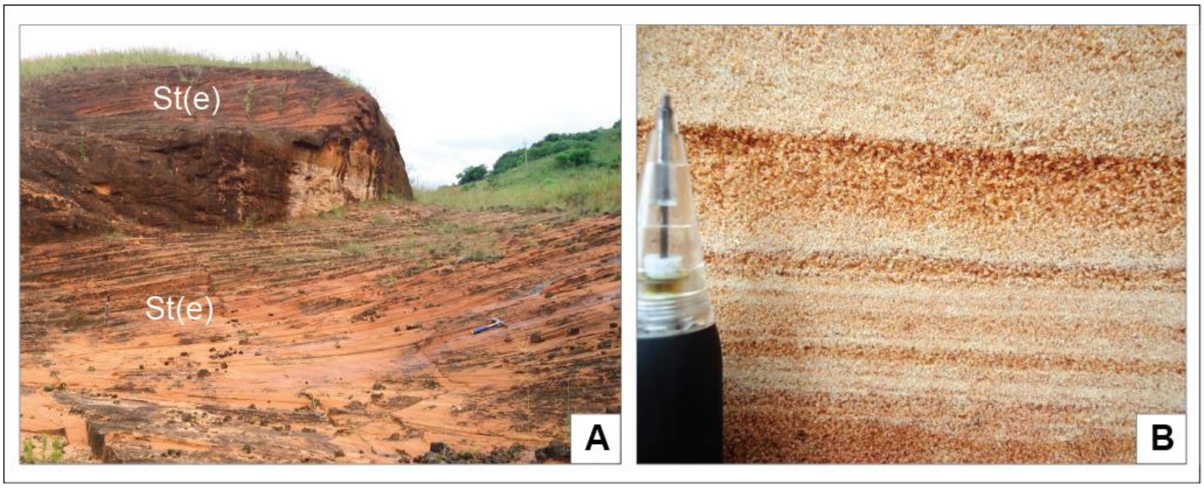


Fig. 11. Photos of the facies association that composes the Rivera Mb. (A) Superposition of eolian dunes characterizing the eolian dunes facies association; (B) Lithofacies St(e) detail, showing the inverse grading within the laminae.

Interpretation. As mentioned for the eolian dunes facies association of the Batoví Member, well-sorted sandstones with highly spherical grains, presenting cross-stratification in sets up to 13 m thick and, composed by grainflow strata at the steeper part of the foresets and inversely graded wind ripple laminae at the base, indicate residual deposits of migrating eolian dunes (Hunter, 1977; Kocurek and Dott, 1981). The low dispersion and unidirectional sense of dip of the large scale cross stratification indicates straight to slightly undulated eolian crescentic dune crests.

The concave surfaces dipping towards the dipping direction of the foresets can be classified as reactivation surfaces (Kocurek, 1996).The cyclicity represented by this feature marks the annual migration rate of the eolian dunes (Kocurek and Dott, 1981). In the Rivera Member the maximum thickness of the one cycle is 2 m. The unidirectional highly dispersive paleocurrent of the through cross-strata indicates crescentic dunes with sinuous crestlines, migrating manly towards ENE.

BATOVÍ MEMBER DEPOSITIONAL MODEL

The Batoví Member is composed mostly (74%) by fluvial deposits, being that 57% is attributed to ephemeral fluvial systems and 17% to perennial ones. The eolian dunes represent 15% of the unit, while eolian sand sheets correspond to 5%. The deltaic deposits are rare, representing 6% of the total. The contacts between all facies associations are abrupt and sharp, typically with no significant relief. The fluvial paleocurrents shows a highly dispersive pattern with mean vector pointing to SSW (Fig. 3), which indicates catchment area located NE; while eolian dunes paleocurrent points mainly to ENE (Fig. 3), indicating dominant winds coming from SW. The deltaic paleocurrents have little variation around the mean vector that points to SSE. The composition and texture of the sediments are similar between the facies association. The sandstones are fine to very fine-grained, primary quartzose.

The abrupt contact and lack of interdigitation evidences between the facies associations imply that they didn’t overlap each other at a relatively short time period; rather there was a lateral alternation and coexistence (Fig. 5-10, 12-13). The opposite trend of fluvial and eolian paleocurrent is another evidence of non-contemporaneity and points to the fact that the fluvial system settled on a flat surface, with no presence of an eolian dune field conditioned to the drainage network. Even though the water flow and dominant wind bring sediments from different, opposite locations, the grain size and composition of sediments both systems carry are the same, excluding fine-grained fluvial lithofacies and exceptions in some fluvial sandstones, which present a certain content of granules and pebbles. This suggests that the sediment that composes eolian lithofacies is brought by the fluvial systems. During periods of fluvial activity decrease in the area, there is an increase in dry sand availability, favoring the eolian dunes and sand sheets construction.

The facies association setting suggests that Batovi Member represents a distal portion of a distributary fluvial system (DFS) (Friend, 1978). Distributary fluvial systems can be inferred in rock record based mainly on trends in an increasing distance from the apex: (i) decrease in grain size, (ii) radial dispersion of the paleocurrent, (iii) increase in fine-grained lithofacies proportion (Friend 1978, Horton and DeCelles, 2001, Nichols and Fisher, 2007, Weissmann *et al.*, 2013). As a result, it is necessary to analyze works made on the Batoví

Member continuation in Brazilian territory, where it is called Guará Formation, to confirm this depositional model for the Batoví Member. Reis (2016) identified the north portion of the Guará Formation as composed by fluvial sandstones deposits, arranged in two different fluvial styles: (1) deep perennial braided rivers and (2) weakly-channelized ephemeral braided rivers. Scherer and Lavina (2005) described the south of the Guará Formation in Brazil, located near Uruguayan territory, as constituted by fluvial and eolian facies associations that include crescentic, simple to locally composite eolian dunes, eolian sand sheets, fluvial channels and distal flow deposits. The perennial fluvial channels described by Scherer and Lavina (2005) and Reis (2016) have dominant grain size varying from medium to very coarse-grained, while in the Batoví Member, fluvial sandstones are typically fine to medium-grained, with highly dispersive paleocurrent showing a radial drainage network. Also, there is an increase in the fine-grained lithofacies, from 5% in the north of the Guará Formation (Reis, 2016) to 9% in the Batoví Member.

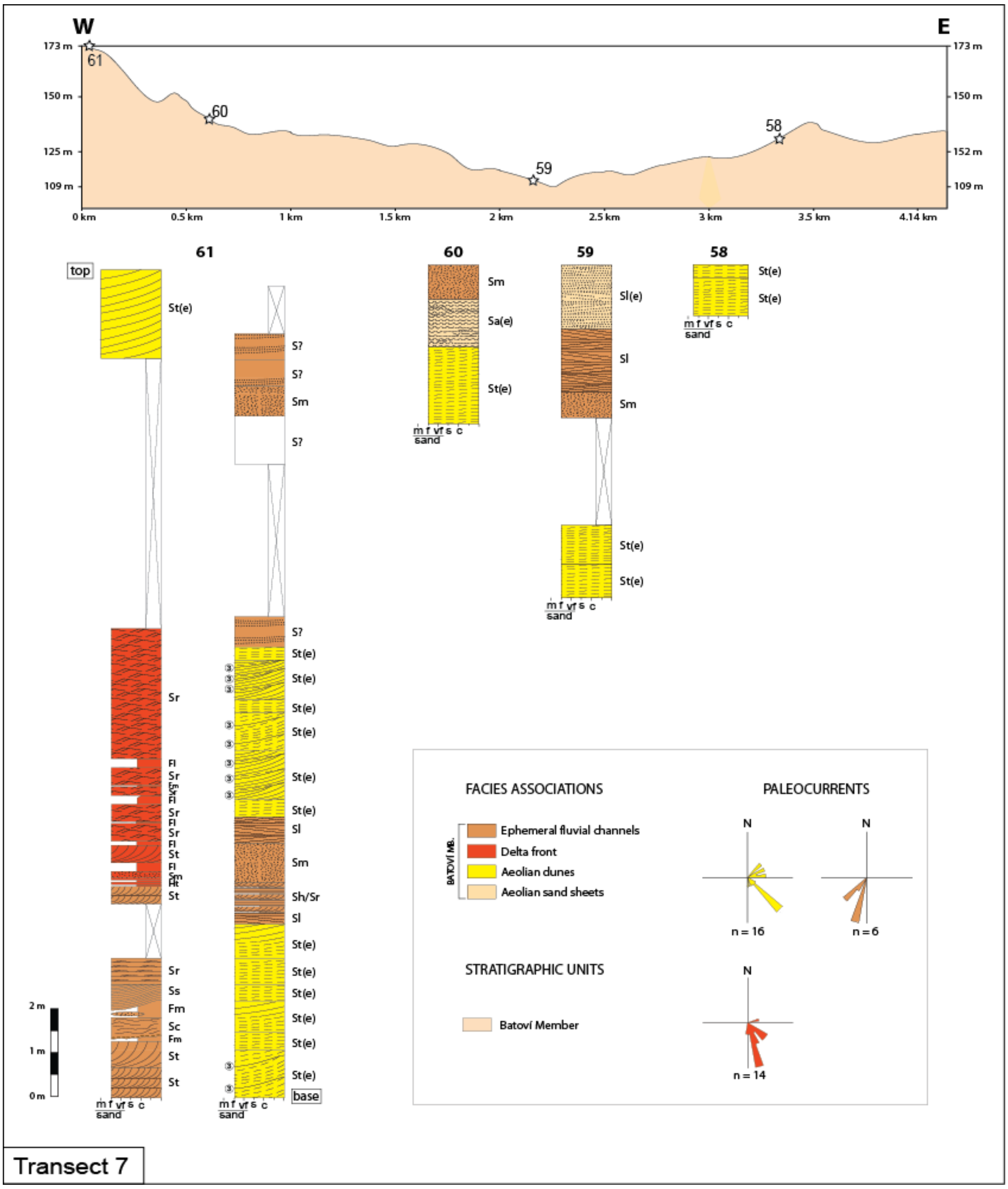


Fig. 12. Columnar sections and the vertical topographic positions of the outcrops that compose the transect 7, and the paleocurrent data of each facies association present.

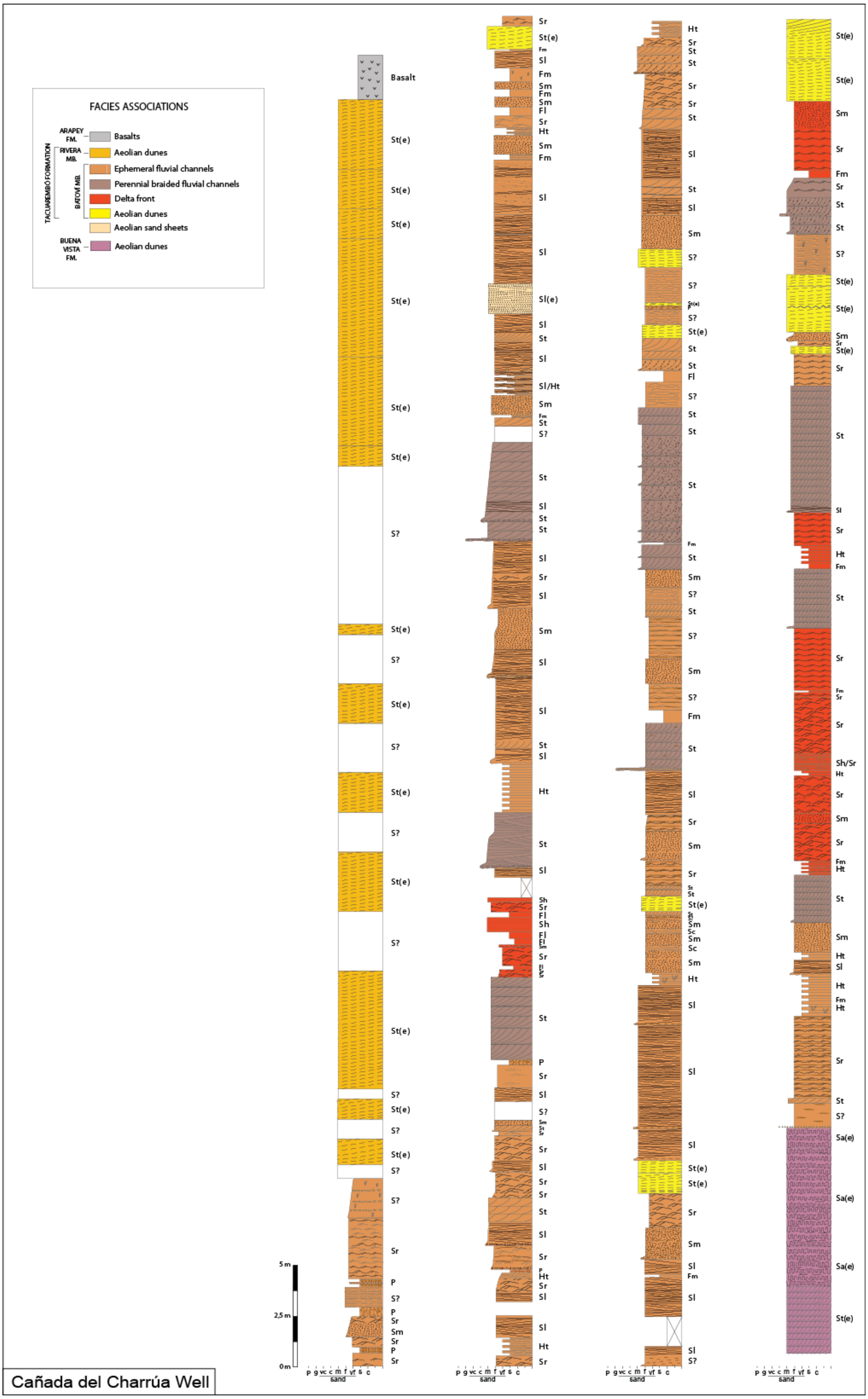


Fig. 13. Columnar section of the Cañada del Charrúa well log.

Therefore, the Batovi Member must represent the distal part of the large distributary fluvial system (Fig. 14). The dominance of shallow and weakly channelized ephemeral channels, arranged in sheet-shaped sandstones bodies with abrupt, sometimes erosive base, is characteristic of a distal DFS (Graham, 1983). Besides, the fluvial and eolian interaction can be observed in such systems, as observed in the Corblets Sandstones of the Alderney Sandstone Formation, located in the Channel Islands (UK), as described by Ielpi and Ghinassi (2016). Another evidence that can be considered is the presence of the deltaic deposits, which suggests the development of lakes, similar to what is observed in the distal portions of the Luna and Huesca DFS located in the Ebro Basin, northern Spain (Fisher *et al.*, 2007). However, the presence of prodelta musdstones with no correlation between the transects, indicates the lakes were small, originated from pools and ponds where water accumulated forming, in which fine-grained sediment was deposited by suspension. During periods of high level of the lakes, the fluvial channels flow into the body of water forming a series of deltaic lobes (Fisher *et al.*, 2007).

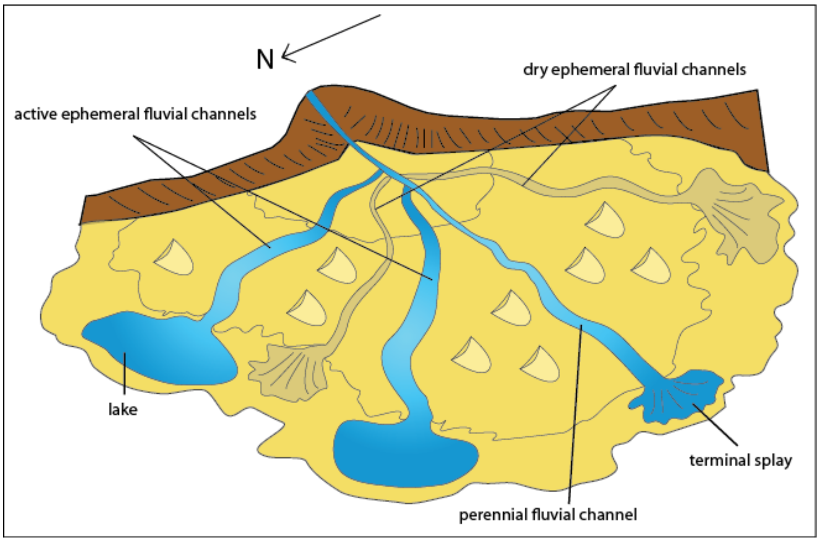


Fig. 14. Schematic illustration of the depositional model attributed to Batoví Mb.

RIVERA MEMBER DEPOSITIONAL MODEL

The Rivera Member is characterized by the superimposition of trough cross-strata sets, generated by climbing of the crescentic eolian dunes. The absence of adhesion strucures and other records indicating the presence of damp points to a dry eolian system that formed in an arid to hyper-arid climatic context, in which the water table was below the depositional surface (Kocurek and Havholm, 1993). Also, there isn't record of dry interdune facies, such as low-angle cross-bedded sandstones interdigitating with trough cross-strata upwards, indiciating that the dry interdunes were little expressive, discontinuous and disconnected (Fig. 15). The paleocurrent pattern of the crossed eolian strata points mainly to the ENE quadrant, indicating dominant winds coming from SW. The Rivera Member can be correlated to Botucatu Formation of the Paraná Basin, representing a wide erg developed in the beginning of the Cretaceous (Scherer, 2000; 2002; Scherer and Goldberg, 2007).

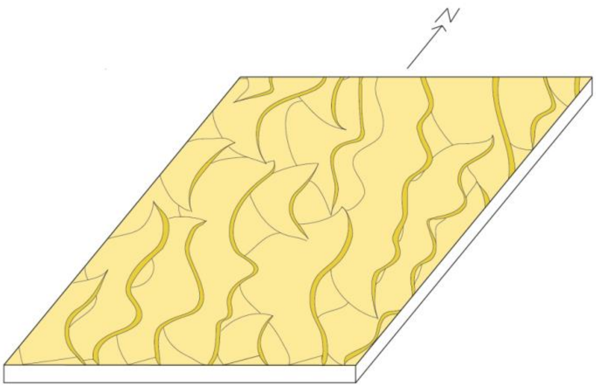


Fig. 15. Schematic illustration of the depositional model attributed to the Rivera Mb.

BOUNDING SURFACE BETWEEN BATOVÍ MEMBER AND RIVERA MEMBER

The bouding surface between the two members is characterized by a sub-horizontal (dipping less than 3º) surface, which is traceable throughout almost the entire studied area (almost 100 km). This surface is abrupt, flat or slightly irregular and sometimes it contains faceted quartz clasts measuring <3 cm.

The presence of a flat to slightly irregular surface that can be covered by granules and pebbles of faceted quartz, plus its remarkable lateral extent, suggests that the contact represents an unconformity formed by eolian deflation (Kocurek, 1981). The faceted quartz clasts are the main evidence of eolian deflation for they represent ventifacts formed by continuous eolian abrasion, produced by the impact of sand-sized particles transported by the dominant wind, which generates abrasion facies in sediments greater than granules (Laity, 2009).

CONCLUSIONS

The Tacuarembó Formation registers two different continental depositional systems marking significant paleoenvironmental changes in the basin.

The Batoví Mb. is composed by the alternation of ephemeral channels, perennial braided channels, eolian dunes, eolian sand sheets and deltaic facies associations. The predominance of fluvial facies association, mostly being ephemeral channels, with radial paleocurrent, suggests a distal distributary fluvial system. The terminations of the deposits is given mainly by terminal splays, and by small lake deltas.

The Rivera Mb. is constituted by successive eolian dunes cross-strata, with no record of humid or damp interdunes, suggesting a dry eolian system (Scherer 2000, 2002). In this time of eolian system, the water table is permanently below the depositional surface, indicating that the only sedimentation controls were the dry sand availability, the eolian transport capacity and the sand saturation in the winds.

The contact between its two members is characterized by a slightly irregular, sub-horizontal surface, that sometimes contains faceted quartz clasts measuring <3 cm, and it's traceable for at least 100 km. This surface is defined as a supersurface, which denotes a period of eolian deflation and non-deposition (Stokes, 1968), and denotes a change in the depositional style of the basin. While the Batoví Mb. registers distal fluvial distributary system deposits, in an arid to semi-arid environment, the Rivera Mb. accumulated a dry eolian dune field, indicating a hyperarid climatic context. The eolian paleocurrents pattern of both members points to ENE quadrant, indicating that there wasn't a significant variation in the dominant winds direction.

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Facies architecture and stratigraphic evolution of the Tacuarembó Formation, Norte Basin – Uruguay.

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Abstract

The Tacuarembó Formation (Upper Jurassic-Lower Cretaceous), subdivided into Batoví Member and Rivera Member, crops in the northern region of Uruguay, in a narrow strip with an average width of 35 km by 115 km in length, oriented north-south. The present work has as main objective the sedimentological and stratigraphic analysis of the Tacuarembó Formation, through the faciological characterization, reconstruction of the depositional models and definition of contact relations between the Batoví and Rivera members. From the survey of columnar profiles in the scale 1:50, elaboration of lateral sections through the preparation of photomosaic and data collection of paleocurrents, different facies associations were individualized. The Batoví Member consists of associations of facies of (1) eolian dunes, (2) eolian sand sheets, (3) ephemeral fluvial channels, (4) perennial braided fluvial channels and (5) deltaic. On the other hand, the Rivera Member is essentially constituted by facies associations eolian dunes. The intercalation between fluvial, eolian and deltaic deposits, with predominance of fluvial associations, suggests that the Batoví Member represents the depositional model of the distal portion of a distributary fluvial system. Contrastingly, the Rivera Member is charac-terized by the successive eolian dunes climbing, without the occurrence of wet or damp interdunes deposits, defining a dry eolian system. The abrupt change of depositional systems, marked by a flat surface, sometimes with clasts concentration, indicates the existence of an unconformity between the members Batoví and Rivera. Allied to this, the change in the depositional model suggests a climatic change, going from arid to semi-arid climate during the deposition of the Batoví Member, to a hyperarid climate during the deposition of the Rivera Member.

Taxonomy

South American Stratigraphy, Siliciclastic Environments

Keywords

distal distributary fluvial systems; eolian depositional systems; Batoví Member; Rivera Member; Norte Basin.

3 REFERÊNCIAS BIBLIOGRÁFICAS

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4 HISTÓRICO ESCOLAR

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Aluno

FRANCYNE BOCHI DO AMARANTE

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Lista das atividade de ensino do aluno avaliadas pelo curso.

HISTÓRICO CURSO
GEOCIÊNCIAS - Mestrado Acadêmico - 01/03/2016

Período Letivo	Código	Disciplina	Cré-ditos	Con-ceito	Situação
2016/02	GEP00091	Ambientes deposicionais clásticos costeiros	5	-	Matriculado
2016/02	GEB00053	Evolução Costeira	4	-	Matriculado
2016/02	GEP00033	Geologia do Quaternário Costeiro do Rio Grande do Sul	5	A	Aprovado
2016/01	GEB00046	Análise estratigráfica	6	A	Aprovado
2016/01	GEB00044	Estratigrafia Avançada	4	A	Aprovado
2016/01	GEB00045	Fácies e Sistemas Deposicionais	5	A	Aprovado
		Inglês em 13/05/2016	-	-	-

Totais

Créditos Matriculados neste Ingresso:	9
Créditos Cursados com Aprovação neste Curso:	20
Total:	29

5 PARECERES DA BANCA EXAMINADORA