UNIVERSIDADE ESTADUAL DE CAMPINAS
INSTITUTO DE GEOCIÊNCIAS

EMERSON FERREIRA DE OLIVEIRA

RELAÇÕES ENTRE OS PROCESSOS PALEOPEDOGENÉTICOS E SEDIMENTARES NA FORMAÇÃO MARÍLIA DA SERRA DE ECHAPORÃ (GRUPO BAURU, CRETÁCEO SUPERIOR)

CAMPINAS
2016

EMERSON FERREIRA DE OLIVEIRA

RELAÇÕES ENTRE OS PROCESSOS PALEOPEDOGENÉTICOS E SEDIMENTARES NA FORMAÇÃO MARÍLIA DA SERRA DE ECHAPORÃ (GRUPO BAURU, CRETÁCEO SUPERIOR)

DISSERTAÇÃO APRESENTADA AO INSTITUTO DE GEOCIÊNCIAS DA UNICAMP COMO PRÉ-REQUISITO PARA OBTENÇÃO DO TÍTULO DE MESTRE EM GEOCIÊNCIAS NA ÁREA DE GEOLOGIA E RECURSOS NATURAIS

ORIENTADOR: PROF. DR. GIORGIO BASILICI

ESTE EXEMPLAR CORRESPONDE À VERSÃO FINAL DA TESE DEFENDIDA PELO ALUNO EMERSON FERREIRA DE OLIVEIRA E ORIENTADO PELO PROF. DR. GIORGIO BASILICI

CAMPINAS
2016

Agência(s) de fomento e nº(s) de processo(s): FAPESP, 2014/13297-4

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca do Instituto de Geociências
Cássia Raquel da Silva - CRB 8/5752

OL4r	Oliveira, Emerson Ferreira, 1986- Relações entre processos paleopedogenéticos e sedimentares na formação Marília da Serra de Echaporã (Grupo Bauru, Cretáceo Superior) / Emerson Ferreira Oliveira. – Campinas, SP : [s.n.], 2016. Orientador: Giorgio Basilici. Dissertação (mestrado) – Universidade Estadual de Campinas, Instituto de Geociências. 1. Paleopedologia. 2. Sedimentos (Geologia). 3. Rochas - Formação. I. Basilici, Giorgio,1959-. II. Universidade Estadual de Campinas. Instituto de Geociências. III. Título.

<u>Informações para Biblioteca Digital</u>

Título em outro idioma: Relations between paleopedogenetics and sedimentary processes in Marília formation of the Echaporã Saw (Bauru Group, Upper Cretaceous)
Palavras-chave em inglês:
Paleopedology
Sediments
Rocks - Formation
Área de concentração: Geologia e Recursos Naturais
Titulação: Mestre em Geociências
Banca examinadora:
Giorgio Basilici [Orientador]
Alexandre Campane Vidal
Geraldo Norberto Chaves Sgarbi
Data de defesa: 26-02-2016
Programa de Pós-Graduação: Geociências

UNICAMP

UNIVERSIDADE ESTADUAL DE CAMPINAS

INSTITUTO DE GEOCIÊNCIAS

PÓS-GRADUAÇÃO EM GEOCIÊNCIAS NA

ÀREA DE GEOLOGIA E RECURSOS NATURAIS

AUTOR: Emerson Ferreira de Oliveira

"Relações entre processos paleopedogenéticos e sedimentares na formação Marília da Serra de Echaporã (grupo Bauru, Cretáceo Superior)".

ORIENTADOR: Prof. Dr. Giorgio Basilici

Aprovado em: 26 / 02 / 2016

EXAMINADORES:

Prof. Dr. Giorgio Basilici – Orientador

Prof. Dr. Alexandre Campane Vidal

Prof. Dr. Geraldo Norberto Chaves Sgarbi

A Ata de Defesa assinada pelos membros da Comissão Examinadora, consta no processo de vida acadêmica do aluno.

Campinas, 26 de fevereiro de 2016.

Dedico à minha mãe Rosidelma de Fátima Ferreira e à minha avó Carminda Batista Ferreira pelas suas simples palavras que me dão tanta força e nos momentos difíceis sempre estenderam a mão com carinho, amparo e preocupação.

Que a universidade pública, gratuita e de qualidade se democratize cada vez mais, com acesso a extensão, ensino e pesquisa de qualidade, e principalmente, que a classe trabalhadora tenha acesso as ciências, ao conhecimento das evoluções da Terra e Humana para compreendermos nossa realidade e tentarmos modificá-la para melhor.

AGRADECIMENTOS

Agradeço a todos que de maneira direta ou indireta contribuíram para a realização desse trabalho.

Ao professor Dr. Giorgio Basilici pelas contribuições, críticas e sugestões agregando muito para meu amadurecimento na pesquisa, pela persistência e acreditar em meu trabalho.

À Escola de Capoeira Angola Resistência - Núcleo Moradia nas figuras do professor Luis Fernando Gastaldi e Mariana de Sousa Lima que contribuíram muito para minha permanência em Campinas ao longo desses dois anos.

À todos colegas do Laboratório de Arquitetura Deposicional pelas conversas e contribuições nos trabalhos e no dia a dia.

À Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP pela concessão da bolsa de estudos (Processo nº 2014/13297-4).

EMERSON FERREIRA DE OLIVEIRA

Nascido em 28 de outubro de 1986, na cidade de Ituiutaba-MG, ingressou no curso de Geografia em 2009 na Universidade Federal de Uberlândia, depois de ter frequentado escolas públicas no ensino fundamental e médio. Obteve o título de Licenciatura e Bacharel em Geografia em dezembro de 2013, sendo seu Trabalho de Conclusão de Curso orientado pelo Prof. Dr. Carlos Roberto dos Anjos Candeiro com o título: Caracterização estratigráfica do Grupo Bauru no município de Ituiutaba – MG: Estudo de Caso do Morro Residual "Serra do Corpo Seco". No início de 2014 ingressou no curso de mestrado no Programa de Pós-Graduação em Geociências pela Universidade Estadual de Campinas, com orientação do Prof. Dr. Giorgio Basilici. Atualmente é aluno de doutorado do Programa de Pós-graduação em Geociências da Universidade Estadual de Campinas, que também está sob orientação do Prof. Dr. Giorgio Basilici e co-orientação do Prof. Dr. Patrick Francisco Fuhr Dal' Bó (UFRJ). Seus interesses de pesquisa são relacionados à pedologia, paleopedologia e sedimentologia. Para mais informações dos produtos de suas pesquisas acessar no sítio:

http://buscatextual.cnpq.br/buscatextual/visualizacv.do?id=K4439710J9

RESUMO

Paleossolos são representados por um corpo geológico que se encontra nas sucessões sedimentares e corresponde a um solo enterrado coberto por rochas ou por outros paleossolos mais recentes. A Formação Marília (Grupo Bauru) é constituída por uma porção relevante de perfis de paleossolos, em alguns afloramentos a espessura dos paleossolos supera 95% da sucessão. A alternância entre os processos paleopedogenéticos e sedimentares é um dos fatores fundamentais de controle para o desenvolvimento dos paleossolos. Esta pesquisa tem como objetivo a interpretação paleoambiental da porção superior do Grupo Bauru na região dos municípios de Marília e Echaporã do estado de São Paulo. Durante o trabalho de campo os paleossolos foram identificados e separados dos sedimentos mediante observação e descrição das estruturas pedogenéticas, horizontes, marcas de raízes, mosqueamentos e ausências de estruturas sedimentares. Os sedimentos foram identificados mediante a presença de estruturas sedimentares. Análises geoquímicas possibilitaram caracterizar os diferentes tipos de horizontes como Bw, Bk e Btk, o material de origem, hidrólise, calcificação e lixiviação. Os perfis de paleossolos analisados indicam condições ambientais de clima semiárido, com pouca vegetação. A maioria dos perfis de paleossolos são poucos desenvolvidos e possuem estruturas incipientes, alguns outros possuem estruturas pedogenéticas mais evidentes e contém um bom grau de desenvolvimento. O paleoambiente é identificado como clima semiárido, caracterizado pela alternância cíclica temporal entre depósitos subaquáticos não confinados.

Palavras-chave: paleossolos, sedimentos, paleoambiente, Grupo Bauru.

ABSTRACT

Paleosols are represented by a geological body that is found in sedimentary successions and corresponds to a buried ground covered by rocks or other newer paleosols. The Marília Formation (Bauru Group) is composed of a relevant portion of paleosols profiles, in some outcrops of paleosols the thickness exceeds 95% of the sequence. Switching between paleopedogenetics and sedimentary processes were fundamental in the development of paleosols. This research aims to make paleoenvironmental interpretation of the upper portion of the Bauru Group in the area of the cities of Marilia and Echaporã the state of São Paulo, analyzing the builders factors of geological bodies. During fieldwork for the identification and description of the structures of paleosols, horizons, roots traces, mottling. sedimentary structures of absences. The sediments were identified by the presence of sedimentary structures. Geochemical laboratory made it possible to characterized the different types of horizons as Bw, Bk and Btk, provenance, hydrolysis, calcification and leaching. The analyzed profiles indicate conditions in an environment with semiarid climate, with little vegetation. Some profiles are few developed and have few incipient structures, others have more obvious structures and contains a good level of development, in all. The paleoenvironment is identified as desert, with semi-arid climate, characterized by temporal cyclical alternation between unconfined underwater.

Keywords: paleosols, sediments, paleoenvironment, Bauru Group.

SUMÁRIO

1. ORGANIZAÇÃO DA DISSERTAÇÃO

A presente dissertação é composta por uma introdução sobre os paleossolos seguida por uma fundamentação teórica, descrição dos objetivos e dos métodos utilizados e um parágrafo dedicado ao contexto geológico da área de estudo.

Logo em seguida é apresentado um artigo elaborado para a submissão em revista científica arbitrada. No artigo é descrito e discutido uma seção com cinco perfis de paleossolos alternados com depósitos sedimentares. No texto são apresentados e discutidos os fatores que deram origem a tais paleossolos.

Posteriormente é apresentado em anexo outro artigo no qual o autor dessa dissertação colaborou com a sua realização.

2. INTRODUÇÃO

Paleossolos são classificados como solos de uma paisagem pretérita não mais existente nos dias atuais. Eles podem preservar interessantes registros de determinados períodos como o clima, temperatura, geomorfologia, fauna e flora, além de ser bons indicadores para análises estratigráficas constituindo superfície discordâncias. Em geral, os paleossolos são um importante objeto de estudos para auxiliar a compreensão dos processos evolutivos da Terra. Nas sucessões sedimentares os paleossolos representam uma fase de estabilidade da superfície deposicional. A indisponibilidade de sedimentos aliado com o desenvolvimento de uma cobertura vegetal, podem levar à ausência de processos de sedimentação e de erosão e formar processos pedogenéticos. Os principais paleossolos observados na porção setentrional do Grupo Bauru são Aridissolos, Alfissolos, Entissolos e Vertissolos (Basilici *et al*. 2009, Dal' Bó *et al*. 2010). Os primeiros dois representam longas interrupções na sedimentação, enquanto Entissolos, menos difundidos, representam curtos períodos de interrupção da sedimentação (Basilici *et al*. 2009, Dal' Bó *et al*. 2010). Os Vertissolos não dependem do fator tempo como os outros tipos.

A Bacia Bauru se formou a partir do processo termo-litostático ocorrido após acúmulo de quase 2.000 m de derrames basálticos da Formação Serra Geral, essa bacia sedimentar ocupa uma área de aproximadamente 370.000 km², se distribuindo no centro-oeste do estado de São Paulo, partes dos estados de Mato Grosso do Sul, Mato Grosso, Goiás, Minas Gerais e Paraná (Fernandes & Coimbra 1996, Riccomini 1997, Fernandes & Coimbra 2000).

Na referida bacia é possível encontrar diversos afloramentos de paleossolos, em especial na unidade litoestratigráfica denominada Formação Marília, que constitui a parte superior do Grupo Bauru. Em alguns locais os perfis de paleossolos representam cerca de 90% da sucessão sedimentar. Paleossolos podem ser representados por um corpo geológico que se encontra nas sucessões sedimentares e corresponde a um solo enterrado coberto por rochas ou por outros paleossolos mais recentes (Catt 1990, Retallack 2001). Nos últimos anos veem aumentando os estudos sobre paleossolos no Brasil, em especial na porção superior do

Grupo Bauru, no entanto ainda são poucos os trabalhos relacionados à paleopedogênese aliados a sedimentação tanto a nível internacional como a nível nacional. O presente trabalho pretende contribuir com os conhecimentos aplicando estudos de campo e geoquímicos, com o intuito de realizar uma reconstrução paleoambiental e paleoclimática do Grupo Bauru na área de estudos. As características sedimentológicas e paleopedogenéticas das unidades litoestrátigráficas do Grupo Bauru possuem informações paleoambientais que podem auxiliar em estudos do Cretáceo Superior sendo possível inferir aspectos como paleoprecipitação, paleotemperatura, comunidades biológicas que viveram em tal ambiente a fim de reconstituir o paleoambiente e poder realizar estimativas da evolução climática e geológica na parte centro-sul do Brasil.

3. FUNDAMENTAÇÃO TEÓRICA

Na Bacia Bauru já é possível encontrar alguns trabalhos referentes à gênese dos paleossolos em climas áridos e semiáridos da formação Marília e seu grau de desenvolvimento aliado com a sedimentação (Dal Bó 2009, Basilici 2010).

Para desenvolver um bom grau de estruturação interna (agregados, cutículas, horizontes, etc.) um paleossolo precisa formar-se, em geral, entre um período de 10^3 a mais de 10^6 anos. Durante este longo período de tempo o paleossolo se comporta como um sistema aberto, que tem a possibilidade de registrar todas as condições ambientais que ocorreram acima ou pouco abaixo da sua superfície e as relativas mudanças. Além disso, as relações de interestratificação vertical e horizontal entre paleossolos e sedimentos podem dar importantes informações de variações regionais ou locais das condições paleoambientais. Muitas das sucessões sedimentares formadas em ambientes continentais são caracterizadas por uma interestratificação vertical e horizontal de paleossolos e sedimentos. Os paleossolos se desenvolveram nos sedimentos apenas depositados quando condições climáticas, geomorfológicas, biológicas, de estabilidade topográfica (ausências de deposição e erosão) e temporais o permitiram (Kraus 1999).

Os paleossolos podem ser modificados por animais, penetrado por raízes e outras alterações como o soterramento por deposição sedimentar e erosão, com isso as marcas do registro sedimentar original são progressivamente destruídas. Algumas estruturas sedimentares podem ser preservadas em um paleossolo pouco desenvolvido ou nos seus horizontes inferiores (Retallack 2001). Antes de o paleossolo ser totalmente soterrado seus horizontes superiores frequentemente são truncados por erosão, isso pode ocorrer devido ao fato dos horizontes superiores serem frágeis e suscetíveis a erosão subaquosa ou eólica (Catt 1990).

Dixon (1994) afirma que solos áridos exibem uma variedade de características físico-químicas, biológicas e morfológicas distintas. Entre estes estão a presença de superfícies de cascalho e o desenvolvimento de crostas superficiais. Esses solos são caracterizados pela formação de uma diversidade de horizontes subsuperficiais diagnósticos, incluindo câmbicos, argilosos, petrocálcicos, gipsicos, petrogipsicos, natricos, salicos e horizontes duripan .

Solos áridos são tipicamente finos, dominados por sais e possuem pouca matéria orgânica. Os processos responsáveis pelo desenvolvimento destes solos são distintos e também resultam no desenvolvimento de um conjunto de características morfológicas diferenciadas (Dixon 1994).

4. OBJETIVOS

Essa dissertação de mestrado teve como objetivo principal realizar uma interpretação dos mecanismos que permitiram a construção dos corpos geológicos e dos paleoambientes que constituem a porção superior do Grupo Bauru (Membro Echaporã) no estado de São Paulo a partir de informações de estudos de paleossolos e o processo de sedimentação.

Os objetivos secundários foram a realização, a análise e interpretação dos paleossolos e depósitos sedimentares a partir de:

- Identificar, caracterizar e classificar os paleossolos.
- Identificar os processos controladores da evolução dos paleossolos: clima, tempo, material parental, associação biológica, morfologia, aporte sedimentar e erosão.
- Caracterizar os sedimentos e interpretar os processos deposicionais e os fatores de controle das fácies sedimentares.
- Definir as inter-relações entre os paleossolos e sedimentos.

5. MÉTODOS

Para a realização dos estudos foram necessárias etapas de pesquisas bibliográficas, trabalhos de campo, trabalhos laboratoriais e elaboração dos dados obtidos.

1. Pesquisas bibliográficas foram realizadas em busca de temas e de assuntos sedimentológicos e paleopedológicos relativos a sucessões sedimentares similares a área de estudo, assim como trabalhos específicos da área.

2. Foram realizados três trabalhos de campo nos respectivos meses de Janeiro, Julho e Agosto de 2015 para aquisição de dados, identificação e descrição de sedimentos e paleossolos nas áreas de estudos escolhidas.

2a. Na primeira fase de campo foi necessário o reconhecimento de perfis de paleossolos nas sucessões estratigráficas medidas, em particular, foram distintos paleossolos de depósitos. Formas macroscópicas típicas dos paleossolos foram usados para uma apropriada distinção. Entre os aspectos típicos foram procurados: marcas de raízes, agregados (*peds*), películas (*cutans*), níveis ou faixas com diferentes características cromáticas, concentração de minerais em nódulos, mosqueamentos (*mottling*) e bioturbações.

2b. Na segunda fase de campo os perfis de paleossolos foram descritos e medidos com análise de detalhe do topo para a base da seção estudada. Os dados de paleossolos foram coletados de acordo com os manuais de paleopedologia (Catt 1990, Retallack 1991, 1994, 2001) e pedologia (Dos Santos *et al.* 2005, IBGE 2007), excluindo devidamente todos os aspectos mascarados ou alterados pela diagênese. Os dados adquiridos durante esta fase são: granulometria (usando comparadores de bolso); cor (a definição é feita mediante a Carta de cores de Munsell); presença e tipo de películas (*cutans*); estrutura dos paleossolos, presença, tipo e dimensões de agregados (*peds*); presença, tipo, dimensões e concentração de nódulos ou concreções; concentrações de $CaCO_3$ com o auxílio de HCl à 10%; tipo, forma e percentual de marcas de raízes; bioturbações; presença, dimensões e difusão de gleização (*gleying*); presença e dimensões de superfícies de fricção (*slickensides*); espessura e desenvolvimento lateral dos horizontes; tipo de contatos entre os horizontes; tipo de contato dos perfis de paleossolos com os sedimentos.

2c. Os depósitos foram descritos e interpretados mediante o método de análise de fácies. As litofácies foram diferenciadas de acordo com as características litológicas (granulometria, textura, estruturas sedimentares e geometria das camadas) e relações de contato. A aquisição de dados em campo foi efetuada mediante medida e análise de perfis estratigráficos e observações verticais e horizontais dos afloramentos. Observações em afloramentos pontuais foram feitas. Na área a WSW de Marília foram identificados cinco perfis de paleossolos com detalhe à escala centimétrica. Nesses perfis foram coletadas 32 amostras para análises químicas.

3. A atividade de laboratório consistiu em análises geoquímicas de fluorescência de raios X, essas análises foram fundamentais para identificar e caracterizar os elementos químicos de cada horizonte trabalhado e através dos mesmos realizar os cálculos geoquímicos para obter resultados como hidrólise, calcificação, teor de argila, proveniência e lixiviação (Sheldon & Tabor 2009) e inferir qual ambiente que possibilitou a formação e desenvolvimento dos paleossolos e realizar comparações com os dados de campo obtendo assim resultados mais fiéis para as interpretações.

6. CONTEXTO GEOLÓGICO

A Bacia Bauru se formou acima de efusões basálticas (Formação Serra Geral) e é considerada ligada à subsidência termo-litostática por causa da enorme espessura dos basaltos, sendo que a parte mais espessa da sucessão é localizada em cima do depocentro da Formação Serra Geral (Riccomini 1997).

A sucessão estratigráfica que constitui a Bacia Bauru é formada prevalentemente por arenitos, de muito finos a médios, apresentando diferentes graus de cimentação. Na Formação Marília (Membro Echaporã) camadas de conglomerados areníticos ocorrem de forma localizada e não constituem mais de 5% da espessura total da sucessão. Sutis e descontínuas camadas de pelitos areníticos ocorrem por vezes interestratificadas com os arenitos, mas não constituem mais de 2% da espessura total (Fernandes & Coimbra 1996, Riccomini 1997, Fernandes & Coimbra 2000). Estudos paleontológicos de restos de vertebrados (Bertini *et al.* 1993, Santucci & Bertini 2001) e de microfósseis (Dias-Brito *et al.* 2001) indicam, porém sem muita certeza, que a sucessão sedimentar desta bacia se desenvolveu entre o Coniaciano e o Maastrichtiano. A Bacia Bauru é dividida em dois grupos: Grupo Caiuá e Grupo Bauru. O Grupo Caiuá aflora na porção oeste da bacia e, segundo alguns autores, (Fulfaro *et al*. 1999) é colocado estratigraficamente abaixo do Grupo Bauru do qual é separado por uma discordância estratigráfica denominada de geossolo Santo Anastácio (Fulfaro *et al.* 1992).

A ordenação estratigráfica da Bacia Bauru até os dias atuais ainda é discutida, cuja resolução consensual ainda parece muito longe. Um dos trabalhos mais antigos sobre a caracterização estratigráfica da Bacia Bauru é de Soares *et al.* (1980). Estes autores reconheceram quatro unidades, da base para o topo: Formação Caiuá, Formação Santo Anastácio, Formação Adamantina e Formação Marília. Fernandes & Coimbra (1996) reavaliaram a distribuição estratigráfica das unidades da Bacia Bauru. Estes autores dividiram a sucessão sedimentar em dois grupos: Caiuá e Bauru. O Grupo Caiuá é constituído pelas formações Rio Paraná, Goio Erê e Santo Anastácio. O Grupo Bauru é constituído pelas formações Uberaba, Adamantina, Marília e pelas rochas extrusivas alcalinas chamadas de Analcimitos Taiúva.

Uma visão diferente da organização estratigráfica, em parte similar ao modelo inicial de Soares *et al.* (1980), se observa em (Batezelli, 2003, Fulfaro *et al.* 1999, Paula & Silva *et al* .2003, 2005, 2006, 2009). Milani *et al.* (2007) interpreta a Bacia Bauru como sendo uma Supersequência da Bacia do Paraná, tendo uma espessura máxima preservada de cerca de 300 m e área de ocorrência de 370.000 km^2, com contato basal discordante. A Supersequência Bauru é formada pelos grupos cronocorrelatos Caiuá e Bauru. Os limites da Bacia Bauru são caracterizados por processos erosivos e/ou tectônicos (Batezelli 2010). O clima da época de sua formação foi proposto como árido/semiárido (Batezelli 2003). Com base em seu conteúdo fossilífero a formação Marília é considerada de idade Maastrichtiana (Dias-Brito *et al*. 2001, Santucci & Bertini 2001). Ela é a unidade do topo do Grupo Bauru, consiste essencialmente de arenitos maciços e, em menor quantidade, de conglomerados cimentados por calcita, conferindo à paisagem um característico relevo de platôs.

Na área de estudos a Formação Marília, unidade a qual são desenvolvidas as pesquisas deste trabalho é exposta por uma espessura maior de 110 m, na mesma os paleossolos são predominantes (95%).

7. RESULTADOS

Apresentação do Artigo

No artigo abaixo são apresentados parte dos resultados obtidos em campo e as análises em laboratório. A partir da correlação entre ambos os resultados foi definido os tipos de perfis e seus respectivos horizontes. Em laboratório foram realizadas análises geoquímicas e foi possível obter resultados como a hidrólise, teor de argila, calcificação, proveniência, lixiviação e índices de alteração química.

Os perfis de paleossolos analisados indicam condições ambientais de clima semiárido, com pouca vegetação. A maioria dos perfis de paleossolos são poucos desenvolvidos e possuem estruturas incipientes, alguns outros possuem estruturas pedogenéticas mais evidentes e contém um bom grau de desenvolvimento. O paleoambiente é identificado como clima semiárido, caracterizado pela alternância cíclica temporal entre depósitos subaquáticos não confinados.

Artigo

PALEOENVIRONMENTS OF MARILIA FORMATION IN THE ECHAPORÃ RANGE BASED ON PALEOPEDOLOGICAL AND SEDIMENTARY RECORDS (BAURU GROUP, LATE CRETACEOUS)

Emerson Ferreira Oliveira, Giorgio Basilici

Departamento de Geologia e Recursos Naturais, Instituto de Geociências, Universidade Estadual de Campinas

ABSTRACT

Paleosols are represented by geological bodies that are found in sedimentary successions and correspond to old soils overlaid by deposits or other younger paleosols. The Echaporã Member (Marília Formation, Upper Cretaceous) is almost entirely composed of a paleosol profiles. This research has as objective to reconstruct the paleoenvironmental conditions of formation of the Echaporã Member in the area close to the cities of Marilia and Echaporã, analyzing the controlling factors that generated the sedimentary succession. The methods used were: identification and description of paleosols and facies analysis of the deposits and geochemical analyses in laboratory. The studied profiles of the paleosols indicate development in semiarid climate. Most of the paleosols profiles display low grade of development, because they are represented by incipient structures and poor carbonate concentration. The paleoenvironment of the Echaporã Member is identified as a distal portion of a distributary fluvial system in semi-arid climate, characterized by occasional unconfined subaqueous flows that constituted the sediment supply and the parent material of the paleosols.

Key words: paleoenvironment, paleosols, sediments, Marília Formation, Upper Cretaceous.

INTRODUCTION

Paleosols is a buried soil formed in a past time. In paleosols some preserved aspects can record original features of the ancient climate, geomorphology, parental material, fauna and flora, depositional processes and time of formation. Paleosols are commonly found in continental sedimentary successions, where they may be covered by deposits or younger paleosols (Catt 1990, Retallack 2001). In sedimentary successions the paleosols represent a phase of stability of the topographic surface. In continental areas, the lack of availability of sediment, yield for example by absence of fluvial source, combined with the development of vegetation coverage may lead to periods of no sedimentation and no erosion and pedogenesis.

To develop internal structure (peds, cutans) and to be organized in horizons a paleosols need a period from 10^3 to 10^6 years. During this time the paleosol is an open system that has the possibility to record all environmental conditions that occur above or just below its surface and relative changes. Moreover, the relations of interestratification vertical and horizontal betwen paleosols and sediments can provide important information of regional or local variations of paleoenvironmental conditions.

Although in last years the interest on paleosols grew in Brazil (Dal Bó 2009, Basilici 2010), detailed studies on sedimentary successions abundant in paleosols are yet few if related with the international literature. The sedimentological and paleopedological features of the Bauru Group give paleoenvironmental information that can help in studies of the Upper Cretaceous allowing to infer aspects as paleoclimate, paleotopography, paleobiology and relationships with sedimentary processes. Thus, the objective of this work is to describe and interpret the paleosols and sedimentary deposits of the Echaporã Member of Marília Formation, in order to contribute to the understanding of the development of paleoenvironments and part of the geology of Bauru Group in southeastern Brazil.

GEOLOGICAL SETTING

The Bauru Basin formed from a isostasy process occurred after the accumulation of almost 2000 m of basaltic lavas of the Serra Geral Formation. This sedimentary basin covers an area of more than 350.000 km², occupying the central-western portion of the State of São Paulo, and part of the states of Mato Grosso do Sul, Mato Grosso, Goiás, Minas Gerais and Paraná (Riccomini 1997, Fernandes and Ribeiro 2015). The stratigraphic succession of the Bauru Basin consists predominantly of very fine- to medium-grained sandstones. Conglomeratic sandstone does not constitute more than 5% of the total thickness of the succession. Subtle and discrete layers of sandy pelites sometimes occur interstratified with sandstones; they constitute no more than 2% of the total thickness (Riccomini 1997, Fernandes and Coimbra 2000). Paleontological studies of vertebrate remains (Bertini *et al.* 1993, Santucci and Bertini 2001) and microfossils (Dias-Brito *et al.* 2001) indicate that this sedimentary succession developed between the Coniacian and Maastrichtian. The stratigraphic ordering of Bauru Basin to the present day is also discussed, whose consensual resolution still seems far away. Soares *et al.* (1980) recognized four units, from bottom to top: Caiuá fm, Santo Anastacio fm, Adamantina fm and Marília formations. Fernandes and Ribeiro (2015) reassessed the stratigraphic distribution of units of the Bauru Basin. These authors divided the sedimentary succession into two groups: Caiuá and Bauru. The Caiuá group consists of the Paraná River fm, Goio Ere fm, Santo Anastacio fm and Presidente Prudente formations. The Bauru Group consists of formations Araçatuba, Marília, São José do Rio Preto, Uberaba, Vale do Rio do Peixe and the extrusive alkaline rocks called Analcimitos Taiúva (Fernandes and Ribeiro, 2015, see their Fig. 2). A different view of the stratigraphic organization, similar in part to the initial model of Soares *et al.* (1980), observed in (Batezelli 2015, see his Fig. 2). Marília formation was interpreted as a vast alluvial fan, dominated by braided rivers and small lakes (Fernandes and Coimbra 2000). However, Basilici *et al*. (2009) interpreted this formation as a eolian sand sheet area, dominated by alternation between the deposition of wind-ripples, pedogenesis and some ephemeral channels. This new interpretation is due to the emphasis on the study of paleosols region, together with the sandstone deposit and wind ephemeral streams. The main paleosols observed in Bauru Group are Aridisols and Alfisols, representing long breaks in sedimentation, while Entisols, less abundant, represent short periods of interruption of sedimentation (Dal Bó *et al.* 2010). The studies were conducted in Marilia municipality region which has several outcrops of Marília formation (Figure 1).

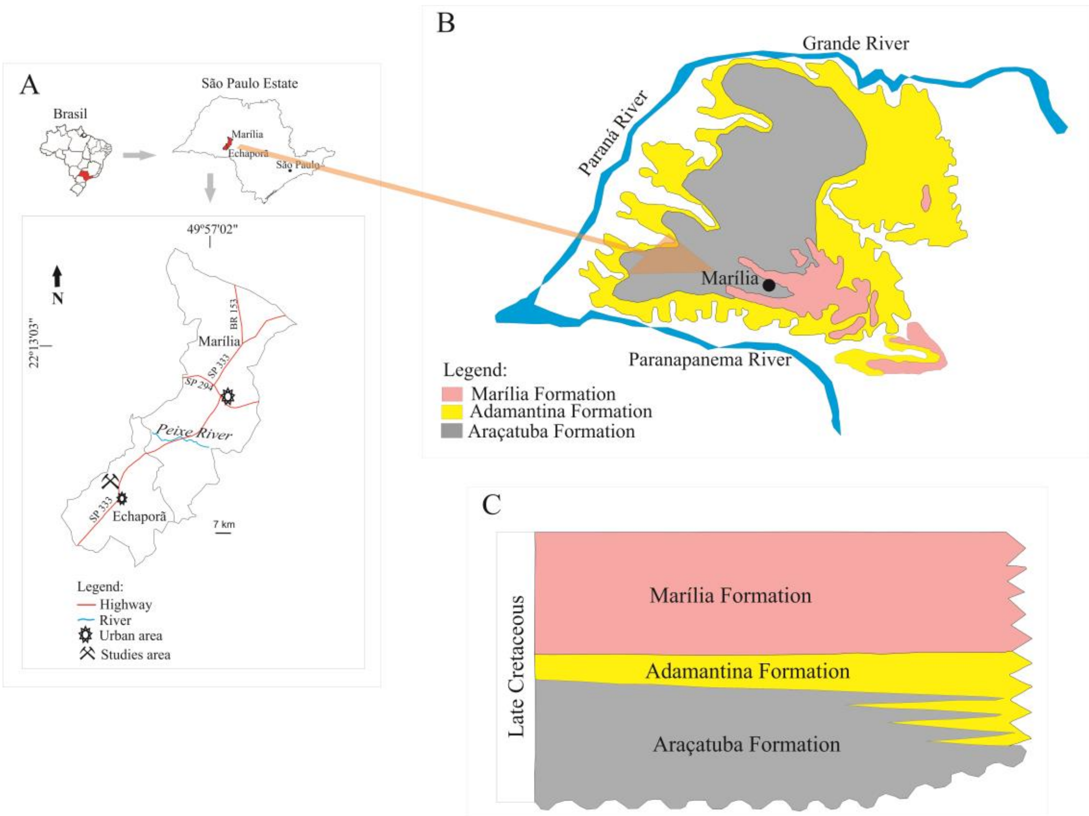


Figure 1: A - Location of the study área. B – Geological map of Bauru Group in São Paulo state, adapted from Batezelli 2015. C – Lithostratigrapy of the Bauru Group in São Paulo state, adapted from Batezelli 2015.

METHODS

In this present work paleosols were identified and analyzed in the field and laboratory analyses.

Firstly, we recognized the paleosols profiles in the stratigraphic succession measures, in particular separating paleosols from sedimentary deposits. Root marks, peds, cutans, horizons with different colors, concentration of minerals in nodules, mottling and bioturbation are used as macroscopic aspects to distinguish paleosols.

Secondarily, we produced a description and measurement of paleosol profiles from the top to the bottom. The paleosol data were collected according to the paleopedology manuals (Catt 1990, Retallack 1991, 1994, 2001). In this phase we collected these data: particle size; color; type and dimension of the structures (peds and cutans); presence, type, size and concentration of nodules or concretions; $CaCO3$ concentrations; type, form and percentage of root marks; bioturbation; presence, size and distribution of gleying; presence and dimensions of the slickensides; thickness and lateral development of horizons; types of contacts between the horizons and with deposits.

Facies analysis methods were used to describe and interpret the deposits. They were differentiated according to the lithologic characteristics (particle size, texture, structure and geometry of the sedimentary layers) and bounding surfaces.

Laboratory activity consisted in chemical analysis of X-ray fluorescence, that identified and quantified the chemical elements of each horizons. By means these analyses we calculated the Weathering Molar Ratios of hydrolysis, calcification, clay content, source, and leaching (Sheldon & Tabor 2009).

RESULTS

Five paleosol profiles were described: Profile 1 with Bk and R horizons; Profile 2 with the A, Bw1, Bw2 and Bk horizons; Profile 3, divided between Bw1, Bw2, Btk, Bw3, C and R; Profile 4, divided between the Bw and C; Profile 5 horizons, divided between Btk1, Bw1, Btk2, Bw2, Bk and C (Figure 2).

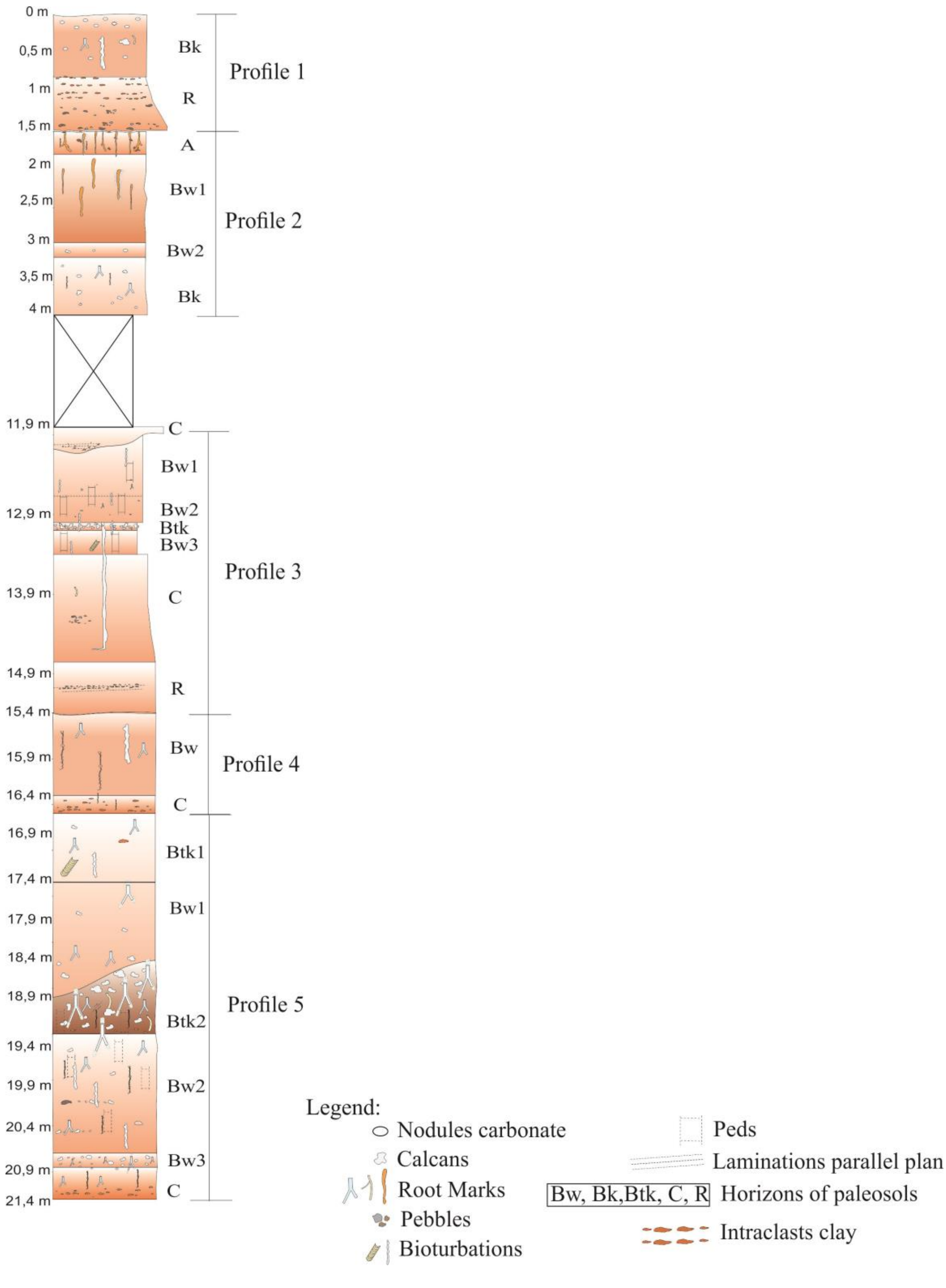


Figure 2: Stratigraphic measured section with interpreted paleosol horizons.

The top and bottom of the profiles are characterized by planar erosive surfaces identifiable by the presence above this surface of intraformational mudstone and small pebbles of metamorphic or magmatic rocks. Overall, the paleosol profiles consist of fine to medium-grained sandstone in upper part of the profile and coarse-grained sandstone in the lower portion. In C horizons, it is possible observe remains of sedimentary structures that consist in weakly horizontal laminations and horizontal accumulations of intraformational mudstone clasts. R horizon is the original parent material, is below described as deposit.

Description of horizons

The horizon A consists of medium- to fine-grained sandstone, moderate- to well-sorted. Predominant color is orange (2,5YR6/6), however there are mottling bright reddish brown (2,5YR5/8). There is no reaction in the test with 10% Hcl. The horizon A contain often tubular structures (rizotubules), vertical and 0.5 m length, filled with sandstone of different particle size. These marks are very common between 0-0.3 m. Some branching tubules show, the diameter is generally about 0.2 m and tapering down with a 5-7 mm diameter, filled sandstone is light gray with black spots linked to manganese, thick, poorly sorted and small pebbles (Figure 3 A).

The Bw horizons consist of medium- to fine-grained, moderately sorted sandstone. The sandstone grains show apparent surface microtexture to wind transport. The predominant color is orange (2,5YR6/8) and reddish brown (2,5YR5/8). Roots marks are present, but not so abundat as in A horizon. The transition from the lower limit is 60 mm (gradual) and is characterized by an increase of cementation (Figure 3 B).

Figure 3: A - roots marks vertically with ramifications, coin with 20 mm in diameter. B - Peds separated by calcans, horizon structures Bw, coin with 21 mm in diameter.

The horizon Bk consists of fine- to medium-grained sandstone, cemented and moderately sorted. The predominant color is orange (2.5YR6/6). The upper contact has transition 20-30 mm (abrupt). The nodules are widespread on the surface of the vertical section by up to 20%. The reaction with HCl produces bubbles to 4 mm demonstrating high content of calcium carbonate. The lower limit transition has around 60-70 mm (gradual), indicated by the progressive reduction of nodules. The nodules have size ranging from 10 mm to 30 mm and irregular shape. Some nodules show dark spots of manganese (Figure 4 A). Reddish orange surfaces (2.5YR7/3) are present and may indicate calcans. Small radial structures recognized as rizotubules (coated calcite esparítica) are frequent (Figure 4 A and B).

Btk horizons is light reddish orange (2,5YR7/4) with light gray (5Y8/1) mottling, that can indicate conditions of temporary stagnation of water within the soil. This horizon is characterized by higher values molar ratio of $Al_20_3/Si0_2$ (clay content) if compared with the adjacent horizons, probably indicating accumulation of clay (Figure 4 C and D).

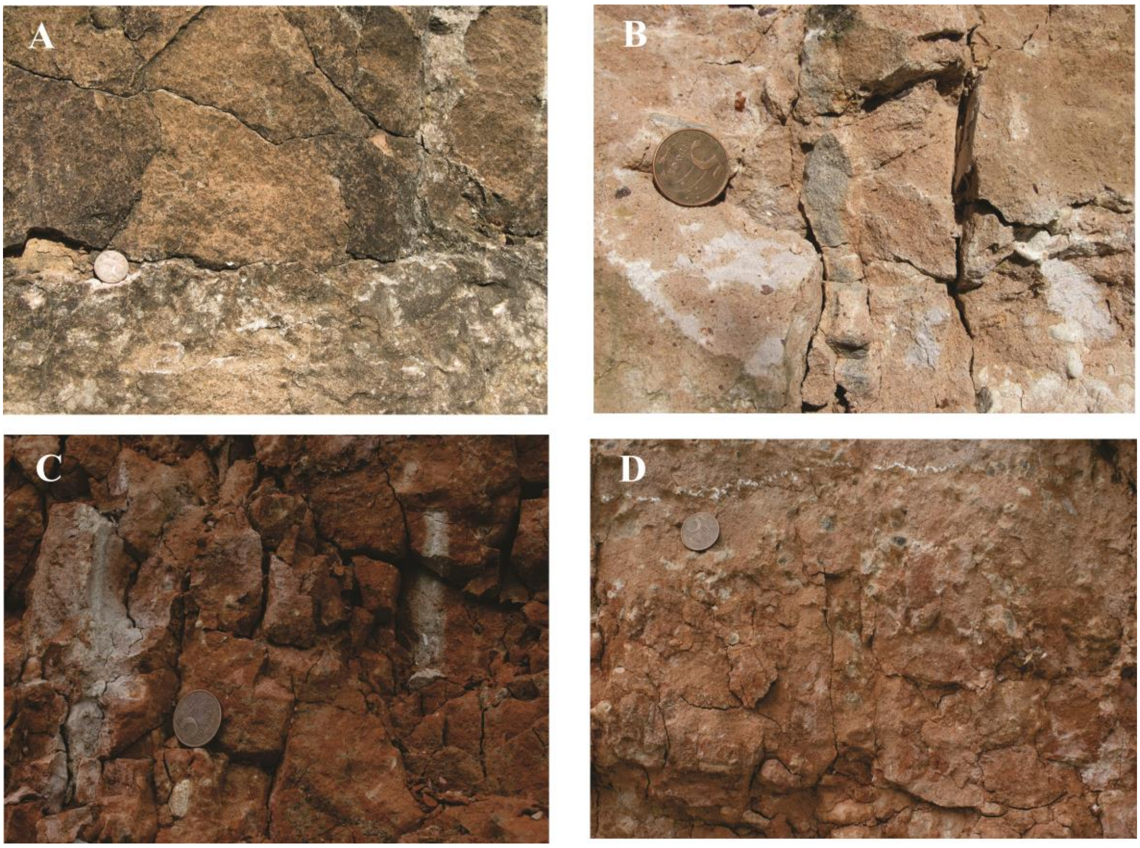


Figure 4: A - Upper limit of Bk horizon with carbonate nodules. B - Root marks and calcans in horizon Bk. C – Horizon Btk, root marks cylindrical and vertical gray with greenish halo, filled by cemented sand and calcium carbonate and blocky structures. D - Horizonte Btk, gradual transition to the higher range of carbonate nodules. Coin with 20 mm in diameter.

C horizons is constituted of poorly defined planar laminations and horizontal alignment of mudstone intraclasts; they testify original sedimentary structures of the parent material. The horizon consists of medium to fine sandstones. The color is orange-red (10R 6/6) and mudstone intraclast are present. These clasts ranging from medium- to coarse-grained and has bright reddish brown color (2.5YR5/8). There is HCl reaction, however, the reaction is mild, with smaller bubbles than 1 mm. Uncommon carbonate nodules occur. The transition to the lower horizon has less than 2 cm (abrupt) (Figure 5).

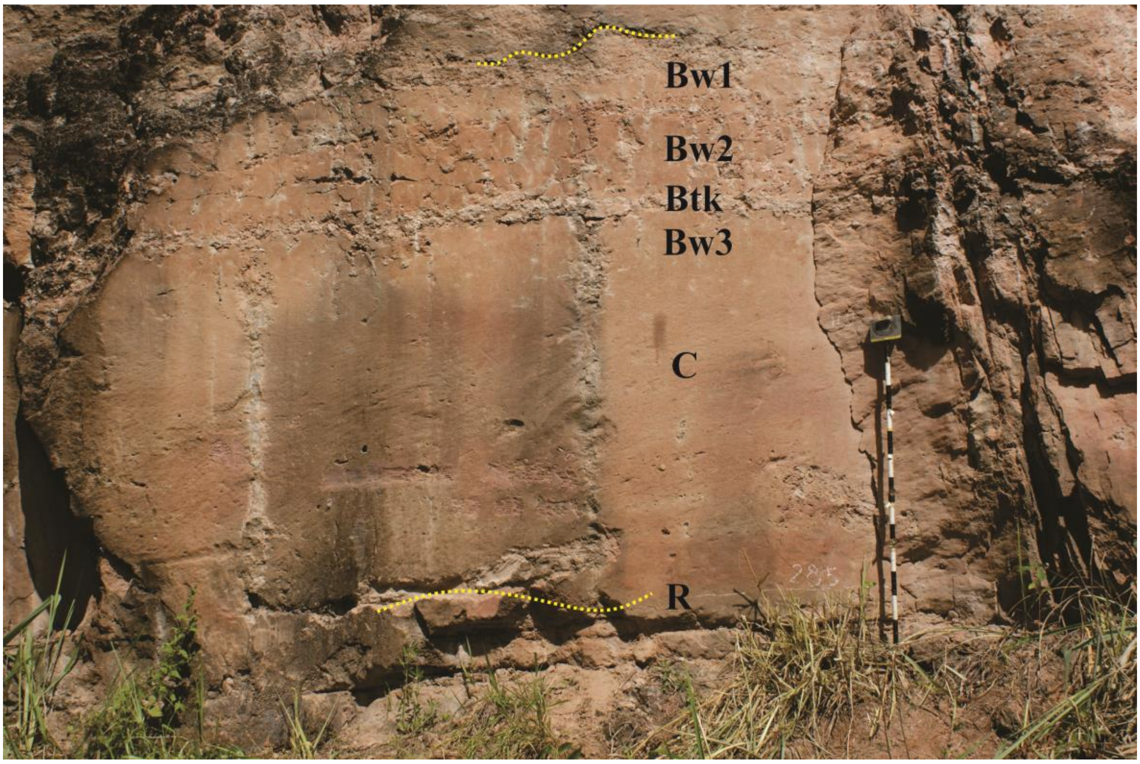


Figure 5: Horizon C, details for mark to tap roots. Scale - Jacob staff: 1.5 m

Geochemistry

As in current soils in paleosols geochemical analyzes are also used, however it is important to highlight some considerations. In paleosols there is some difficulty in performing analysis of cation exchange or base saturation, because the base saturation and capacity of cation exchange soil are not preserved in paleosols and are substantially altered shortly after burial (Retallack 1991, 2001). However, the chemical composition of some of the more resistant mineral paleosols resists to the diagenetic processes and even the metamorphic changes (Barrientos and Selverstone 1987).

When is the burial of paleosols, soon results in compression and the spaces between the pores may be changed or lost. The organisms and the water are compressed by the weight of the overlying layers. The compaction of the loose material of the original soil could create a standard surface slickensides, similar to slickensides produced by expansion and contraction of clay soils of seasonally dry climates (Paton 1974, Gray and Nickelsen 1989).

The use of larger elements geochemical is intended to identify individual indices which quantify all of the weathering processes. Nesbitt and Young (1982) proposed the "chemical index of alteration" (CIA) having a molar ratio of CIA 100 X (Al_2O_3 / (Al_2O_3 + CaO + Na_2O + K_2O)), where each of the elemental concentrations is converted into moles. CIA is a measure of the resistance of feldspar minerals and its hydration to form clay minerals. As the clay content increases Al_2O_3 should also increase as CaO, K_2O and Na_2O contents should decrease, thus leading to higher values of CIA.

Six analyzes of molecular ratios were calculated to evaluate the degree of chemical weathering of paleosols and check which pedogenetic processes were more important. In addition, these indexes have been used to separate the horizons paleosols (Sheldon and Tabor 2009, Retallack 2001, Sheldon et al. 2002).

Bases / alumina ratios ((CaO + MgO + Na_2O + K_2O) / Al_2O_3) can be used to quantify the extent of hydrolysis (Retallack 2001). In Figure 6 the accumulation indicates some major points, it demonstrates greater amount of base as compared with aluminum, this is because the basic elements (CaO, MgO, Na_2O and K_2O) have greater ease to being leached when compared with aluminum and its preservation may indicate the accumulation of bases. Still in Figure 6, in the hydrolysis, while the other points are low it may indicate a decrease of bases compared to aluminum showing that hears a higher hydrolysis rate in the system. Comparing this relationship with the CIA is observed that the proportions between both appear in reverse. The Btk horizontal profile 3 shows the minimum CIA value around 4, leaching with a value close to 1, and the hydrolysis around 39, so you can see the high levels of hydrolysis representing the accumulation of bases, low leaching and CIA highlighting the few chemical changes in this horizon.

Leaching was quantified using the links Ba/Sr and Rb/Sr. Strontium is significantly more soluble than barium and rubidium thus higher values are expected in more leached horizons (Retallack 2001). Leaching occurs in reverse order as compared to the hydrolysis; consequently higher leaching values are expected to decrease the basic loss ratios (CaO + MgO + Na_2O + K_2O / Al_2O_3).

The clay content was quantified using the ratio Al_2O_3 / SiO_2. The clay content can be used in paleosols for confirming Bt horizons. The analyzed profiles, the clay shows a proportion with calcification, which suggests horizons such as Btk.

Calcification ((CaO + MgO) / Al_2O_3) also correlates with the preservation ratio of the bases shown in hydrolysis. Such calcification is characteristic of pedogenic horizons enriched in calcium carbonate occurring in areas where the primary ion source is the wind transport through the dust (Goudie 1983, Machette 1985).

The provenance was calculated by the proportion of TiO_2 / Al_2O_3 and is used as a TiO_2 content indicator can be quite variable among different types of rocks as well as the Al_2O_3 concentration is relatively constant (e.g., granite, basalt vs.; Li, 2000). Both TiO_2 as Al_2O_3 are relatively immobile, the proportion of both must remain constant during pedogenesis. The analyzed values can be observed that there is a wide variation in the results of the proportion TiO_2/Al_2O_3, thus indicating the origin of the same type of parental material, consisting of felsic rocks.

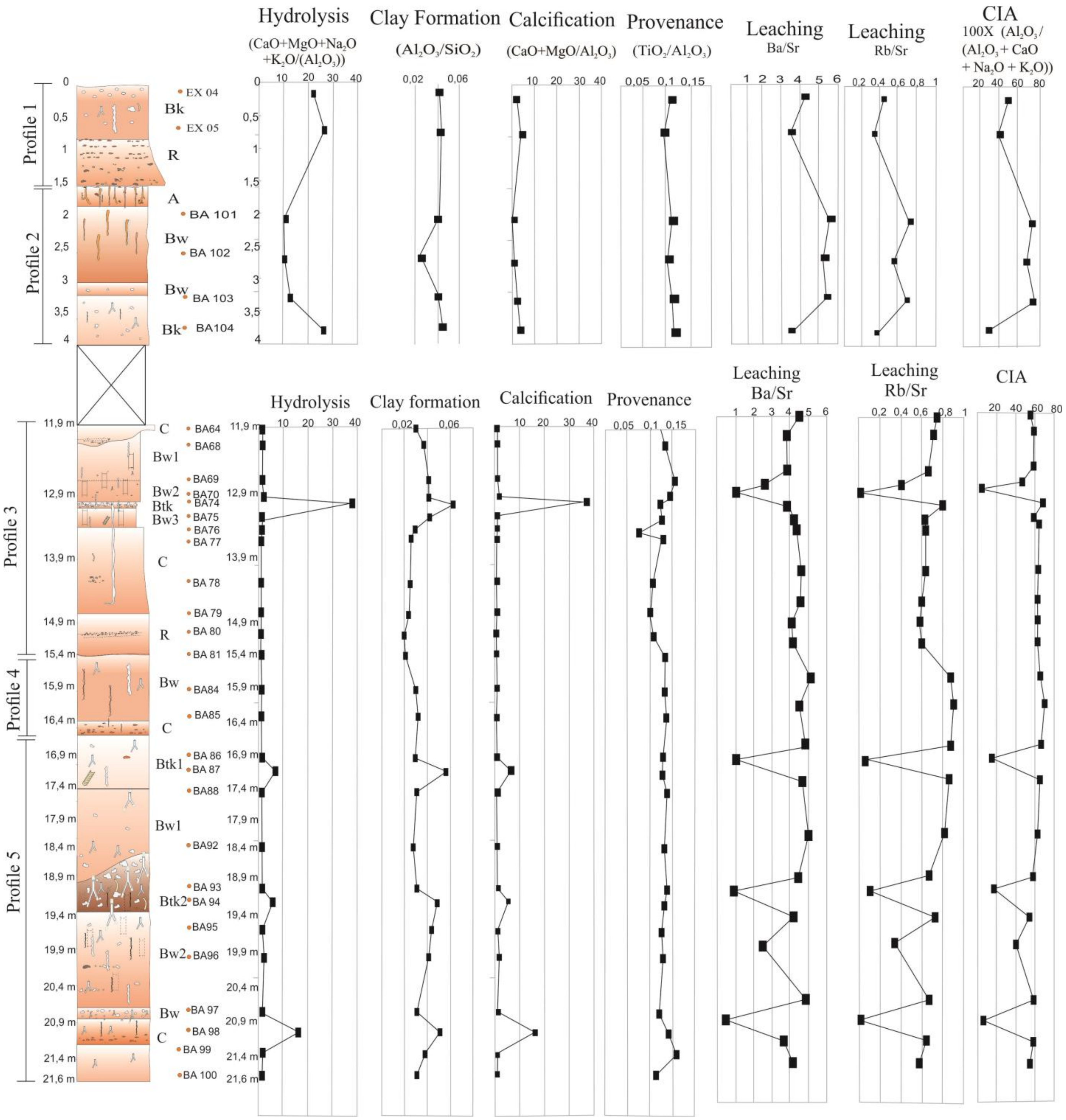


Figure 6: Analyzes with data from chemical elements. Hydrolysis ($CaO+MgO+Na_2O+K_2O/(Al_2O_3)$). Clay Formation ($Al_2O_3/SiO_2$). Calcification ($CaO+MgO/Al_2O_3$). Provenance ($TiO_2/Al_2O_3$). CIA 100X ($Al_2O_3$ /(Al_2O_3 + CaO + Na_2O + K_2O))

Interpretation of horizons

The horizon A can be recognized for abundance of roots traces and bioturbation. The horizon A is not cemented, probably due to leaching of calcium carbonate which precipitated in lower horizon (Bw or Btk). Uncommon preservation of A horizon is due to the easy erosion that it suffered by unchannelized flows, as below described. More dense vegetal cover and low energy of the unconfined subaqueous flows can be at origin of local preservation of A horizon.

In Bw horizon poor defined prismatic structures, separated by thin cuticles carbonate (calcans) can be observed. Bw is a cambic horizon, a horizon where the pedogenetic alteration of the parent material is sufficient to differentiate horizons, but not enough to define other more developed horizons as Bk or Bt.

Bk horizons were identified only in two cases. They are individualized by higher concentration of calcium carbonate relatively to the other horizons. This higher content is indicated by the presence of calcium carbonate nodules and chemical analysis, which show peaks of calcification in correspondence of Bk horizon.

Btk horizon. Three horizons have been described. This horizon is characterized by values mole ratio of Al_2O_3 / SiO_2 (clay content) higher compared with the adjacent horizons indicating accumulation of clay, ash content is too high, the highest rate of clay is what differentiates this horizon compared to Bk horizon.

Horizon C. have been reported three C. Overall, C horizon is identified and classified to have some pedogenetic features, but not enough to define them as horizons A or B. It also show original some features of parental material.

Parental material

Molecular ratios of TiO_2/Al_2O_3 have values of 0.07 to 0.15. Thus they indicate that the source of these sandstones is felsic rocks (Sheldon and Tabor 2009). These values are similar for all paleosol profiles indicating no change of the parent material along the studied section.

<u>Deposits</u>

In paleosol profiles the deposits are described as horizons R. Deposits are constituted of conglomeratic sandstone with contain a significant amount of muddy intraclasts. They are characterized by plane parallel laminations and horizontal alignment of muddy intraclasts.

The deposits are partially preserved in the lower portion of each paleosol profile. They consist of conglomeratic sandstone. The sandstones are medium- to coarse-grained and the conglomerates are constituted of intraformational mudstone clasts, 1 to 60 mm across, angular or sub-rounded, flattened or elliptical in shape (Figure 7). Some calcareous nodules can be present amongst the as intraclasts (pedorelicts). Extraformational clasts are constituted of quartzite and granitic rocks, they are rounded or subrounded and up to 50 mm across. There are more than 60 m in lateral extension; the bottom is sharp and erosive, characterized by small scours, the top is transitional to medium-grained sandstone of C horizon, sandstones with planar parallel laminations and horizontal alignments of pebbles are the only evident sedimentary structure.


Figure 7: Sedimentar deposit with plane-parallel lamination.

Interpretation of the deposits

The dimensions and shapes of conglomeratic clasts suggest deposition from subaqueous flows because usually the subaerial flows cannot carry larger clasts the coarse-grained sands (Pye and Tsoar 2009). Planar-parallel or low-angle laminations are similar to deposits formed in high energy flows of upper flow regime (plane bed) or transition to antidunes (Fielding 2006). The basal erosive surfaces suggest high energy of the subaqueous flows before the deposition. The lateral extent of these deposits indicates unconfined depositional flows.

DISCUSSION

The alternation between sedimentary deposits and topographic stability were the main control factors of the development paleopedogenetics. The genesis of the five paleosol profiles is controlled by unconfined depositional flows by catastrophic flooding phenomena occurring periodically, these flows transporting coarse sandstone, clay intraclasts, pedorelicts and pebles. After the deposition when it happened the stability of the topographic surface, the pedogenesis processes began. However there were no enough time to change the entire deposit, this is demonstrated in C and R horizons.

Calcium carbonate indicate a climatic semiarid because these carbonate it is not water table but pedogenetic, root marks mains in horizon A indicate the sparse vegetation, usually when erosion occurs in A horizons, for being the most superficial horizons are destroyed, probably this vegetation probably this vegetation contributes to its preservation.

In section profiles 1 and 4 has only two horizons, while the other profiles are more developed, this can represent less exposure time in the atmosphere of the profiles 1 and 4 compared to others, or by increased sediment yield or the rate of greater erosion, or a more unstable surface, since the other profiles may represent greater development time and higher environmental stability.

The types of paleosols described in profiles 1 and 4 are classified as compound, these types of paleosols are formed when the sedimentary deposit is relatively rapid and few erosion, occurs the process of pedogenesis but does not change the entire deposit (Marriott and Wright 1993). Can preserve in its sedimentary structures bases as well as demonstrates the most evident form the erosive surfaces (Figures 8 and 9)

In the profiles 2, 3 and 5 the paleosols are classifies with polygenetic paleosols, in this type of paleosols there is enough time and weather conditions that can enable pedogenetic development throughout the deposit and because the new sedimentation and pedogenesis the horizon of a new profile can override the horizon of an older profile, this may also indicate a greater interruption in the sedimentation (Figures 8 and 9).

The geochemical data Ba/Sr, Rb/Sr, hydrolysis and CIA indicate low or very mild conditions of pedogenetic change. Geochemical data indicate felsic source rocks as source of the parental material. This differentiates it markedly in the rocks of the same unit exposed in the northern part of the basin, where, Basilici et.al. (2010) found that the origins of the sandstones are basaltic rocks.

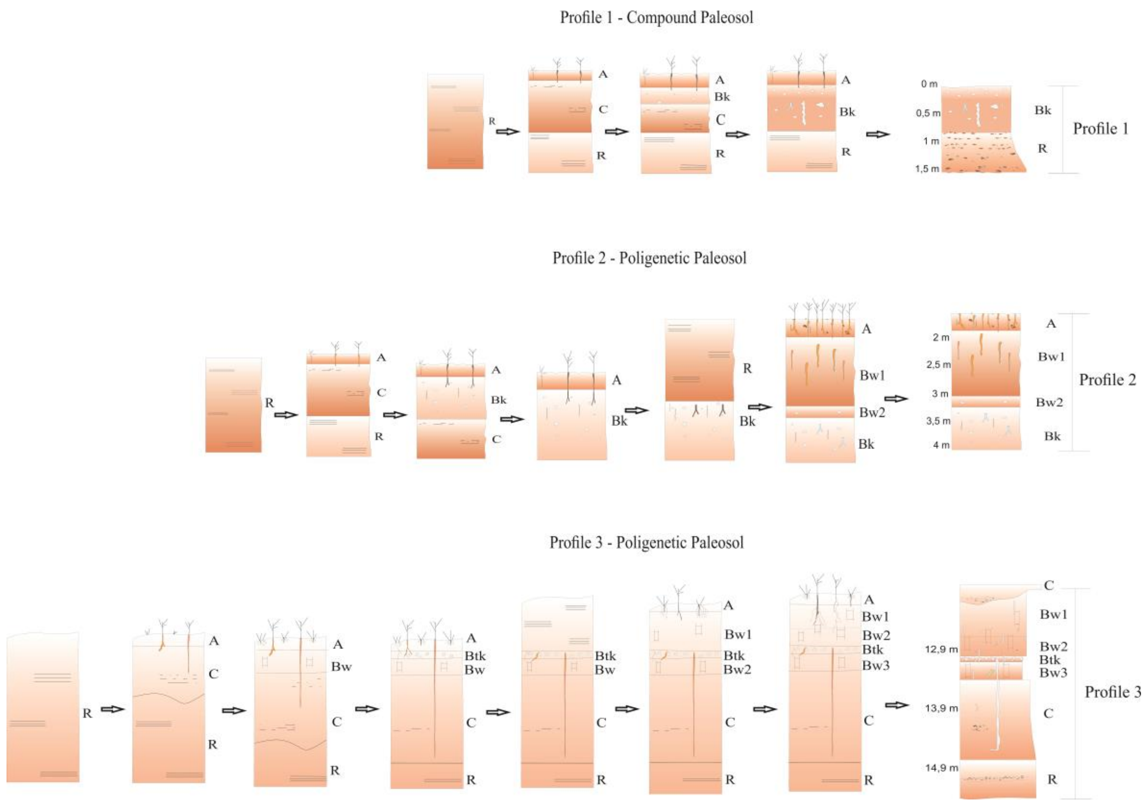


Figure 8: Pedosedimentary reconstruction profiles

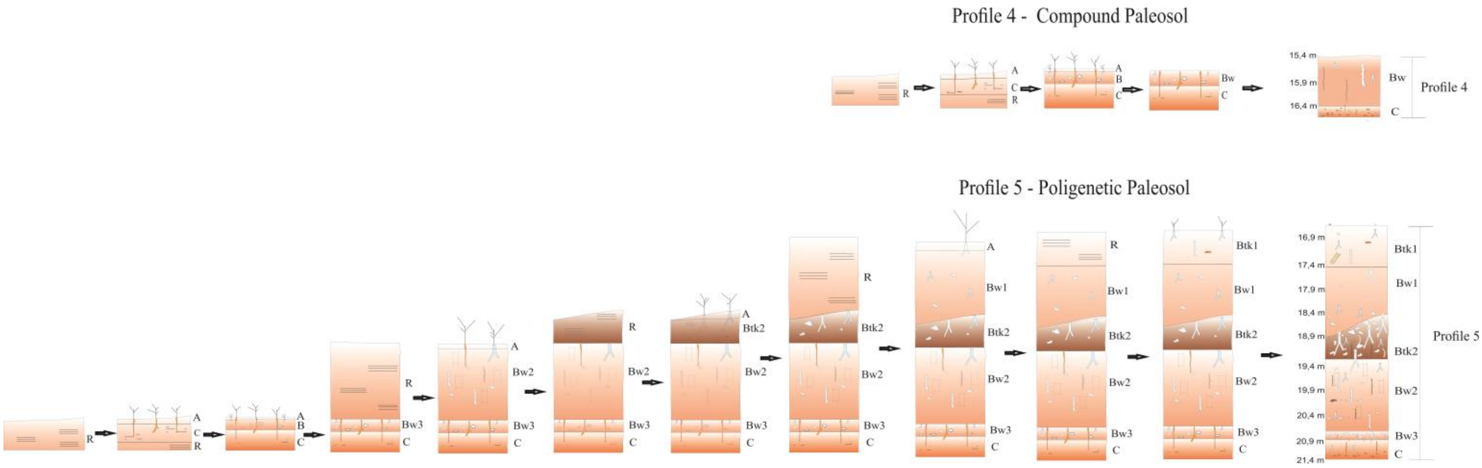


Figure 9: Pedosedimetary reconstruction profiles

CONCLUSIONS

The analysis of the paleosols suggests that the Marília formation formed in a semi-arid paleoenvironment, characterized by sparse vegetation.

The sedimentary section of Marília formation which outcrops on site studies it consists predominantly of paleosols with 95% formed by process paleopedogenetics, only the lithofacies plane parallel laminations it was identified.

The local climatic variations and deposition by water flows are the main drivers of the development of paleopedogenesis probably the wettest periods or for some sporadic event was occurred when the underwater transport.

Acknowledgements

The FAPESP (Project n. 2012/232090) is thanked for financial support for this research.

8. CONCLUSÃO

A gênese dos cinco perfis de paleossolos apresentados no artigo, assim como os perfis descritos no trabalho são controlados por fluxos deposicionais não confinados que ocorriam periodicamente, esses fluxos transportavam areia grossa, clastos, intraclastos de argila e pedorelictos, uma vez depositado e estabilizado iniciava-se o processo de pedogênese, no entanto não houve tempo suficiente para alterar todo o depósito, isso é demonstrado nos horizontes C e R.

As variações climáticas locais e a deposição por fluxos subaquáticos são os principais controladores do desenvolvimento da paleopedogênese, provavelmente nos períodos mais úmidos ou por algum evento esporádico era quando ocorria o transporte subaquático. A atividade eólica também estava ativa nos intervalos dos depósitos subaquáticos retrabalhando os materiais depositados durante os períodos mais áridos.

Com as análises dos paleossolos é possível observar os ciclos de alta frequência caracterizados por deposição de sedimentos e estabilidade da paisagem por determinados períodos.

9. REFERÊNCIAS

Barrientos, X., Selvestone, 1. 1987. Metamorphosed soils as stratigraphic indicators in deformed terranes: an example from the eastern Alps. Geology 1 5 : 841- 44

Basilici, G., Dal Bó, P.F.F., Ladeira, F.S.B., 2009. Climate-induced sediment-palaeosol cycles in a Late Cretaceous dry aeolian sand sheet: Marília Formation (North-West Bauru Basin, Brazil). Sedimentology 56, 1876–1904.

Basilici., Dal' Bó, P.F.F. 2010. Anatomy and controlling factors of a Late Cretaceous Aeolian san sheet: The Marília and Adamantina formations, NW Bauru Basin, Brazil. Sedimentary Geology. p. 71-93.

Batezelli, A. 2015. Continental systems tracts of the Brazilian Cretaceous Bauru Basin and their relationship with the tectonic and climatic evolution of South America. Basin Research. p. 1-25.

Bertini, R.J., Marshall, L.G., Gayet, M., Brito, P. 1993. Vertebrate faunas from the Adamantina and Marilia formations (Upper Bauru Group, Late Cretaceous, Brazil). Neues Jahrbuch fur Geologie und Paleontologie. Abhandlungen 188 (1), p. 71–101.

Bull, W.B. 1991. Geomorphic Responses to Climate Change. Oxford University Press, New York. 506 pp.

Catt, J.A. 1990. Paleopedology manual. Quaternary International, 6. 95 p.

Dal' Bó, P.F.F., Basilici, G., Angelica, R.S., Ladeira, F.S.B. 2009. Paleoclimatic interpretations from pedogenic calcretes in a Maastrichtian semi-arid eolian sand-sheet palaeoenvironment: Marilia Formation (Bauru Basin, southeastern Brazil). Cretaceous Research 30, p. 659–675.

Dal' Bó, P.F.F., Basilici, G., Angelica, R.S. 2010. Factor of paleosol formation in a Late Cretaceous eolian sand sheet paleoenvironment, Marília Formation, Southeastern Brazil. 30, p. 659–675. Palaeogeogr. Palaeoclimatol. Palaeoecol. doi:10.1016/j.palaeo.2010.04.021

Dias-Brito, D., Musacchio, E.A., Castro, J.C. de., Maranhão, M.S., Suarez, J.M., Rodrigues, R. 2001. Grupo Bauru: uma unidade continental do Cretáceo no Brasil – concepções baseadas em dados micropaleontológicos, isotópicos e estratigráficos. Revue de Paléobiologie 20 (1), 245-304.

Fernandes, L. A., Coimbra, A. M. 1996. A Bacia Bauru (Cretáceo Superior, Brasil). Anais da Academia Brasileira de Ciências, Rio de Janeiro. p. 195-205.

Fernandes, L.A., Coimbra, A.M. 2000. Revisão estratigráfica da parte oriental da Bacia Bauru (Neocretáceo). Revista Brasileira de Geociências 30, 717-728.

Fernandes, L.A., Ribeiro, C.M.M. 2015. Evoluntion and palaeoenovironments of the Bauru Basin (Upper Cretaceous, Brazil). Journal of South American Earth Sciences 61. p. 71-90.

Fielding, C. R. 2006. Upper flow regime sheets, lenses and scour fills: Extending the range of architectural elements for fluvial sediment bodies. Sedimentary Geology, 190, 227–240.

Gile, L.H., Peterson, F.F., Grossman, R.B. 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Sci., 101, 347–360.

Gray, M. B., Nickelsen, R. P. 1989. Pedogenic slickensides, indicators of strain and deformation processes in red bed sequences of the Appalachian foreland. Geology 1 7 : 72-75.

Goudie, A.S., 1983. Calcrete. In: Goudie, A.S., Pye, K. (Eds.), Chemical Sediments and Geomorphology: Precipitates and Residual in Near-Surface Environment. Academic Press, London, pp. 93–131.

Kidder, D.L., Worsley, T. R. 2010. Phanerozoic large igneous provinces (LIPs), HEATT (Haline Euxinic Acidic Thermal Transgression) episodes and mass extinctions. Palaeogeography, Palaeoclimatology, Palaeoecology, 295, 162-191, doi: 10.1016/j.palaeo.

Kidder, D.L., Worsley, T. R. 2012. Human-induced hothouse climate. GSA Today, 22, 4-11.

Klappa, C.F. 1980. Rhizoliths in terrestrial carbonates: classification, recognition, genesis, and significance: Sedimentology, v. 26, p. 613–629.

Kraus, M. 1999. Paleosols in clastic sedimentary rocks: their geologic applications. Earth Science Reviews, v. 4.

Li, Y.-H., 2000. A Compendium of Geochemistry. Princeton University Press, Princeton.475 pp.

Machette, N.M. 1985. Calcic soils of the southwestern United States. In: Soils and Quaternary Geology of the Southwestern United States (Ed. D.L. Weide), Geol. Soc. Am. Spec.Pap., 203, 10–21.

Nesbit, H.W., Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature 299, 715–717.

North, C.P., Davidson, S.K. 2012. Unconfined alluvial flow processes: Recognition and interpretation of their deposits, and the significance for palaeogeographic reconstruction. Earth-Science Reviews, 111,199–223.

Paton, T. R. 1974. Origin and terminology for gilgai in Australia. Geoderma l l : 22 1 - 42

Pye, K., Tsoar, H. 2009. Aeolian Sand and Sand Dunes. Springer, Berlin, 476 pp

Retallack, G.J. 1991. Miocene Palesols and Ape Habitats of Pakistan and Kenya. Oxford University Press, NewYork.

Retallack, G.J. 1994. A pedotype approach to latest Cretaceous and earliest Tertiary paleosols in eastern Montana. Bulletin of the Geological Society of America, 106, 1377-1397.

Retallack, G.J. 2001. Soils of the past: an introduction to paleopedology. Allen and Unwin, London, 520 pp.

Riccomini, C. 1997. Arcabouço estrutural e aspectos do tectonismo gerador e deformador da Bacia Bauru no estado de São Paulo. Revista Brasileira de Geociências 27 (2), 153-162.

Ruellan, A. 1971 . The history of soils: some problems of definition and interpretation. In: Yaalon, D.H. (Ed.). Paleopedology: origin, nature and dating of paleosols. International Society of Soil Science and Israel University Press, Jerusalem, pp. 03-13.

Santucci R.M., Bertini R.J. 2001. Distribuição Paleogeográfica e Biocronológica dos Titanossauros (Saurishia, Sauropoda) do Grupo Bauru, Cretáceo Superior do Sudeste Brasileiro. Revista Brasileira Geociências 31, p. 307-315.

Sheldon, N.D., Retallack, G.J., Tanaka,S. 2002. Geochemical climofunctions from North America soils and application to paleosols across the Eocene-Oligocene boundary in Oregan. Journal of Geology 110, 687-696.

Sheldon, N.D. Tabor, N.J. 2009. Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols. Earth-Science Reviews, v. 95, p. 1-52.

Soares, P.C., Landim, P.M.B., Fulfaro, V.J., Neto, A.F.S. 1980. Ensaio de caracterização estratigráfica do Cretáceo no Estado de São Paulo: Grupo Bauru. Rev. Brasil. Geociências, 10, 177–185.

Soil Survey Staff. 1999. Soil taxonomy. Handbook, U.S. Department of Agriculture 436, 869 pp.

10. GLOSSÁRIO

Bioturbação:
Marcas de organismos (raízes, animais) preservados em paleossolos.

Calcans: Manchas esbranquiçadas provocadas pela precipitação de carbonato de cálcio.

Estrutura do solo (agregados, peds):
Organização das partículas dos solos (blocos, prismática, granular), tamanho e grau de desenvolvimento.

Estrutura incipiente:
Estrutura do solo pouco desenvolvida, de difícil identificação.

Horizonte:
Diferentes níveis de um perfil de solo, caracterizados por modificação da cor, textura, estrutura, processo de intemperização.

Horizonte A:
Horizonte superficial, possui cor mais escura pela influência da decomposição da matéria orgânica, e com grande atividade biológica.

Horizonte B:
Horizonte mais desenvolvido, com estruturas, cor, textura e cerosidade mais evidentes, é o horizonte mais adequado para classificar o tipo de solo.

Horizonte C:
Horizonte que preserva algumas estruturas da rocha, porém sofreu o processo de pedogênese.

Horizonte R:
Material de origem. Rocha sem sofrer o processo pedogenético.

Horizonte duripan: horizonte subsuperficial fortemente cimentado por sílica.

Mosqueamento (mottling):
Manchas esbranquiçadas provocadas pela redução do ferro.

Nódulos carbonáticos:
Concentração de carbonato de cálcio em formas de nódulos.

Paleossolos compostos:
Paleossolos em que os processos pedogenéticos não são capazes de alterar todo o material de origem, preservando estruturas da rocha nos horizontes inferiores.

Paleossolos Poligenéticos:
Paleossolos com condições suficientes para permitir o desenvolvimento pedogenético de todo o depósito não preservando estruturas do material de origem.

Superfície de fricção (slickensides):
Estrias no solo provocado pela expansão e contração da argila. Pode indicar alternância entre ambiente úmido e seco.

Paleossolos truncados:
A remoção dos horizontes superiores de um paleossolo pode retirar totalmente o horizonte B, o material restante atua como material de origem para um novo desenvolvimento pedogenético.

11. ANEXO

Artigo 2

STRATIGRAPHIC AND PALAEOENVIRONMENTAL CONTEXT OF A PALAEOSOL DOMINATED SEMIARID FLUVIAL DISTRIBUTARY SYSTEM (BAURU GROUP, UPPER CRETACEOUS, SE BRAZIL)

STRATIGRAPHIC AND PALAEOENVIRONMENTAL CONTEXT OF A PALAEOSOL-DOMINATED SEMIARID FLUVIAL DISTRIBUTARY SYSTEM (BAURU GROUP, UPPER CRETACEOUS, SE BRAZIL)

Giorgio Basilici[1,2] , Patrick Führ Dal' Bo[3] , Emerson Ferreira[1]

[1] Department of Geology and Natural Resources, Institute of Geosciences, State University of Campinas, 13083-870, Campinas (SP), Brazil.

[2] Centro Regional de Investigaciones Científicas y Transferencia Tecnológica/CONICET, Argentina.

[3] Department of Geology, Institute of Geosciences, Federal University of Rio de Janeiro, Rio de Janeiro (RJ), Brazil.

ABSTRACT

The stratigraphic and sedimentological knowledge of the Bauru Group (Upper Cretaceous, SE Brazil) are still broadly insufficient and controversial. This contrasts with a great amount of palaeontological studies. A detailed sedimentological and palaeopedological study allowed to interpret the south-eastern portion of the Bauru Group according to the model of fluvial distributary system. This work has two objectives: (1) to give detailed information on the sedimentological and stratigraphic features of the SE portion of the Bauru Group to support biostratigraphical, taphonomic and palaeoecological studies; (2) to include palaeosols into the model of fluvial distributary system. In south-eastern portion of the Bauru Group three genetic stratigraphic units were described and interpreted, here informally called lower, intermediate and upper units. The lower unit is constituted of muddy sandstone salt flat deposits and sandstone sheet deltas deposits and is interpreted as basinal part of a fluvial distributary system. The intermediate unit is formed of sand-filled ribbon channel and sandy sheet-shaped beds, suggesting distal or medial portion of a fluvial distributary system. The upper unit is almost completely constituted of palaeosols and does not match with the present models of fluvial distributary system. Preserved features of sedimentary structures suggest that the parent material was formed by catastrophic unconfined flows. Moderately developed palaeosols (Inceptisols) testify pauses of sedimentation of the order of 10^4 y, probably linked with a climate aridification that decreased the sedimentary input due to the retreat of the fluvial system. Thus, the upper unit deposited in more distal portion of a fluvial distributary system, where catastrophic unconfined flows, which occurred with recurrence time of 10^4 y, were almost completely pedogenised during the interruption of sedimentation. Including palaeosols into the fluvial distributary system modified the architectural structure of this model.

Key Words: fluvial distributary system, semiarid depositional environment, palaeosols, Late Cretaceous, Bauru Group.

1. INTRODUCTION

In arid or semiarid climate fluvial systems can disappear before to reach a larger river or a standing body of water. This type of fluvial systems, called fluvial distributary system or terminal fan or terminal fluvial fan, was firstly described by Mukerji (1976) and Friend (1978) and subsequently amplified and modified by Tunbridge (1984), Kelly and Olsen (1993), Nichols (2005), Nichols and Fisher (2007), Saéz et al. (2007), North and Warwick (2007) and Cain and Mountney (2009). This depositional system is subdivided in three main portions (Kelly and Olsen, 1993): proximal, medial and distal. The proximal part is characterised by a main feeder channel, whose lateral migrations and avulsions generate a lateral and vertical amalgamated channel body complex with almost absent overbank deposits. The medial portion shows distributary channels, probably without coeval flow (North and Warwick, 2007; Cain and Mountney, 2009), and it forms a geological body with minor channel deposits surrounded by interchannel deposits. The distal portion is characterised by unconfined deposits originated at the termination of the channels and few channel bodies. Depending on the climate and morphological conditions the basinal zone of this system can be characterised by ephemeral lakes or aeolian deposits (Nichols, 2005). In place of terminal fan or terminal fluvial fan, Nichols and Fisher (2007) proposed to use the more general term of "fluvial distributary system", which describes a river system with fan shape, decreasing discharge downwards, and distal area constituted of terminal splays when a lake is absent or deltas when the lake is present. This term is used in this work.

The depositional models of fluvial distributary systems take in account only sediments, whereas palaeosols are rarely cited, often as portion of the interchannel deposits or as fragments (pedorelicts) contained within the channel deposits (Tunbridge, 1984; Nichols and Fisher, 2007; Fisher et al., 2007; Cain and Mountney, 2009). In this paper, we propose to apply the model of fluvial distributary system to explain the stratigraphic organisation and the depositional paleoenvironment of the south-eastern portion of the Bauru Group. However, differently to the usual models of fluvial distributary system, we considered in our model analysis the palaeosols and their relationships with the deposits.

The stratigraphic organisation of the Bauru Group is complex and debated since its first studies (Mezzalira and Arruda, 1965; Soares et al., 1980; Fernandes and Coimbra, 2000; Paula e Silva et al., 2009). Many reasons make complicated the stratigraphic resolution of this sedimentary basin: (1) the lithologic featureless of the succession, which is in general formed of reddish brown sandstone, with relatively uncommon sedimentary structures; (2) the huge dimension of the basin, which exceeds 350,000 km^2; (3) the absence of clear biostratigraphic or geochronological data; (4) the abundance of multiple palaeosol profiles, which, on average, are *c.*60% of the thickness of the sedimentary succession (Basilici et al., 2009); (5) the large scale lateral variations of sedimentological and palaeopedological features; (6) the previous exclusive use of lithostratigraphic criteria to distinguish the different units. These difficulties generated contrasting interpretations of the stratigraphy of this group (Fernandes and Coimbra, 2000; Paula e Silva et al., 2009; Fernandes and Ribeiro, 2015; Batezelli, 2015), which in the field result in a huge difficulty to distinguish the different lithostratigraphic units. Being the Bauru Basin an important sedimentary succession containing a rich and well-preserved Cretaceous fauna association, this difficulty is realised above all by palaeontologists, which complain that the exact definition of the units where the fossils were found is not always an easy task.

In recent years, punctual works on palaeosols and relationships palaeosols/deposits have been realised in northern and south-eastern portions of the Bauru Basin, in an area of approximately 13,000 km^2 (Fig. 1), permitting the collection of many information on the stratigraphy of this basin (Fernandes and Basilici, 2009; Dal' Bó et al., 2009; Basilici et al., 2009; Dal' Bó et al., 2010; Basilici et al., 2010; Basilici et al., 2012). The study area coincides with the sites where the main lithostratigraphic units of the Bauru Basin were originally defined (Soares et al., 1980; Fernandes and Coimbra, 2000).

2. STUDY AREA, GEOLOGIC AND STRATIGRAPHIC SETTING OF THE BAURU GROUP

Small and sporadic outcrops, few previous detailed sedimentological studies and the huge extension of the Bauru Group make deceptive to produce presently a clear framework of the stratigraphic organisation and sedimentary evolution of the entire unit. For these reasons, this work is limited to the analysis of the south-eastern portion of the Bauru Group (Fig. 1).

The sedimentary succession of this basin is developed above one of largest basalt effusion of the earth history, the Serra Geral Formation, due to the separation of South America and Africa. The succession reaches a maximum thickness of around 300 m for a period comprised between Coniacian to Maastrichtian (Fernandes and Ribeiro, 2015) or Aptian to Maastrichtian (Batezelli, 2015). The succession is constituted of fine- to medium grained sandstone with uncommon conglomerate beds (less than 5% of the thickness), which are diffused in northern part of the basin, and sandy mudstone (less than 2% of the thickness). Overall, two groups are distinguished: Caiuá and Bauru groups, which are distributed on the western and eastern part of the basin, respectively (Fig. 2A). The Figures 2B and 2C represent two different stratigraphy interpretations of the Bauru Basin. These interpretations show a consistent quantity of lithostratigraphic units, mostly characterised by interbedded and undefined boundaries, which commonly make unreliable their identification in the field. The cited authors agree with the interpretation of the Caiuá Group deposited in erg system, although they disagree on its chrono- and lithostratigraphic position (Fig. 2B and C). The sedimentological interpretation of the Bauru Group is unclear and partially conflicting. Fernandes and Ribeiro (2015) interpreted the Araçatuba Formation formed in marshland areas, the Vale do Rio do Peixe Formation (or Adamantina Formation, according to Batezelli, 2015) and Echaporã Member of Marília Formation deposited in aeolian sand sheet, and Serra da Galga and Ponte Alta members of Marília Formation formed in distal part of alluvial fan systems. Batezelli (2015) interprets the Araçatuba Formation as lake system, the Adamantina Formation as fluvial systems and the Marília Formation as alluvial fan deposits. Unfortunately, these interpretations did not give an adequate consideration to the palaeosols, which actually constitute on average 60% of the thickness of the Bauru Group.

3. METHODS

In south-eastern portion of the Bauru Group we measured 15 detailed stratigraphic sections for a total thickness of 161 m. Several tens of outcrops were observed to better define the lithofacies and palaeosols of the sedimentary succession. Directly in the area of the Serra de Echaporã (Marília) (Fig.1) we measured a general stratigraphic section of 245 m taking advantage of all possible the outcrops. Methods of analyses and study of deposits and palaeosols has been diversified. In the field, the palaeosols were identified for presence of root traces (rhizoliths), colour, pedogenic structures, parent material, nodules, mottles, calcium carbonate concentration, horizons and absence of sedimentary structures. Forty-five palaeosol profiles were analyzed in detail, for a total 68 m of thickness. In these palaeosol profiles 46 samples were collected from palaeosol horizons. Analyses of the samples were performed for classifying and defining the paleoenvironmental features of the palaeosols, the provenance of parent material and deposits, and the depositional mechanism of the parent material. Field estimation of abundance of calcium carbonate and boundary distinctness of the palaeosol horizons were done using the recommendations of Hodgson (1976). When the horizon thickness was used to calculate time of development the field values were corrected by a compaction factor defined by the compaction equation and relative tables of Sheldon and Retallack (2001). In the laboratory, geochemical, petrographic and microtextural analyses were realized. Geochemical analyses consisted in the determination of major oxides and trace elements of fused beads and pressed pellets, respectively, of 26 samples by X-ray fluorescence spectrometer (Philips, PW2404). Twenty-four thin sections of palaeosols and 6 of deposits were made for textural and provenance analyses and for micromorphologic analyses in the first case. Medium-grained sand quartz grains were selected to observe the surface textural features by scanning electronic microscope (SEM) images. To classify palaeosols the Mack et al. (1993) and USDA (Soil Survey Staff, 1999, 2006) classifications are here used, because both are based on features that may be yet recognized in palaeosols. Deposits are subdivided in lithofacies with a genetic meaning according to lithologic and textural features, thickness and form of the beds, sedimentary structures and bounding surfaces.

4. RESULTS

In this paper, three informal genetic units were recognized: lower, intermediate, and upper units. However, to avoid terminological confusions, proliferation of names and because these units are overall analogous to those defined for Suguio et al. (1977), Soares et al., (1980), Barcelos (1984), Suguio and Barcelos (1987), Fernandes and Coimbra (2000), the names Araçatuba, Adamantina and Marília formations are associated to the lower, intermediate and upper units, respectively. Description and interpretation of the components (deposits and palaeosols) for each of these units follow.

4.1. Lower unit

The lower unit is formed of two lithofacies: deformed interbedding of sandstone and mudstone and planar parallel and cross-laminated sandstone (Tab. 1 and Fig. 3). They constitute *c.*75 and 25% of the thickness of the measured sections, respectively.

4.1.1. Deformed interbedding of sandstone and mudstone

This lithofacies is constituted of irregular, broken, undulated and micro-folded interbedding of patches of well-sorted, fine- to very fine-grained weakly-cemented sandstone (olive grey - 5GY7/1) and mudstone (bright reddish brown - 2.5YR5/8) (Figs. 4A and B), which are organised in intervals 0.3 to 4 m thick and more than 380 m in lateral extension. Sandstone beds are constituted of patches, few millimetres to 50 mm thick and few millimetres to 0.5 m in lateral extension, with jagged lateral edges and cuspate margins (Fig. 4Ai), characterised by protrusion of the mudstone in the sandstone patches (Fig. 4Aii). Sandstone patches sometimes show thin laminae of different grain size and orientation (Fig. 4Ai). Mudstone beds are >1 mm to 30 mm thick, few millimetres to 0.5 m in lateral extension, and show cuspate and jagged margins (Figs. 4Ai and ii; Fig. 4Bi). Locally, mudstone and sandstone laminae have concave-up shape, 0.04 to 0.3 m in width, which in correspondence of lifted margin (crests) form tepee-like structure (Figs. 4Aiii and 4Bii). Small depressions, sandstone filled, 20 to 40 mm wide and 10 to 50 mm deep, with concave bottom and flat top, showing thin internal laminations may be present (Fig. 4Ci). Bioturbation is present and characterised by vertical or subvertical tubes with circular section of 1-

5 mm in diameter and 0.03-0.2 m high (Fig. 4Cii). Small root traces, characterised by drab halos, may be also present (Fig. 4D).

Interpretation. At first glance the "chaotic" aspect of this lithofacies could be interpreted as related to post-depositional physical and/or biological processes that disrupted previous stratifications. In this matter, Tunbridge (1984) interpreted a similar lithofacies of the Devonian Trentishoe Formation. For this author, excess pore water pressure and relative upward water escape generated deformations of the beds consisting in undulation and microfolds. However, a detailed analysis of the type of the deformation and relationships between sandstone and mudstone beds leads to define the structures of this lithofacies as the sedimentary product of thin salt efflorescent crust growing. Smoot and Castens-Seidell (1994) and Goodall et al. (2000) described similar structures produced by efflorescence crusts of evaporite minerals that in saline flat generate deformation of sediments deposited by wind or water on the saline crusts. The crusts form for evaporation of saline groundwater near the surface or for redistribution by wind and further dissolution by rain of solute on the surface. Due to the thin thickness, the saline crusts are easy dissolved by standing water, rainfall or flood on the saline pan and they do not have preservation in geological record. The only record of salt efflorescent crusts is the deformed sediments deposited on the saline crust surface (Smoot and Castens-Seidell, 1994). Irregular sandstone and mudstone patches can be interpreted as trapped sand and mud on the depressions of the moderately thick or thin saline crust surface (Smoot and Olsen, 1988; Smoot 1991; Smoot and Castens-Seidell, 1994). These structure represent aggradational features on the surface of the salt flat due to the progressive deposition of sandy and muddy material for aeolian or water transport, further accumulated for dissolution of the thin salt crust. Structures related to the contemporaneous deformation by efflorescent crust probably are represented by the concave-up laminae of sandstone and mudstone into bowl shapes (Figs. 4Aiii and Bii), which correspond to polygonal forms on the salt flat surface. Small sandstone-filled depressions (Fig. 4Ci) can rather be related to localised solution collapse of the saline crust and progressive sandstone filling. Evaporite deposits are not observed in this study area, but Fernandes et al. (2003) described sandy pseudomorphs after acicular crystals of gypsum in the same unit in nearby areas.

Contemporary bioturbation of digging organisms and roots also contributed to the deformation of the deposits. Light olive gray colour suggests temporary water-logged conditions with iron reduction and consequent grey stainning of the sediment. In summary, this lithofacies formed on a salt flat surface with near surface water table, characterised by a thin saline crust, probably gypsum, on which depression accumulated wind- or water-transported sandy and muddy deposits.

4.1.2. Planar parallel- and cross-laminated sandstone

This lithofacies is formed of tabular beds of well-sorted, fine- and very fine-grained weakly cemented sandstone. The beds are 0.15-0.4 m thick and extended for more than 30 m, although observable in fragmentary exposures. Planar parallel laminations are highlighted by small grain variation and thin accumulation of very fine-grained clasts of magnetite, the laminations are 0.5 to 2 mm thick (Fig. 5A). Cross-laminations show climbing sets 10-20 mm thick with foresets dipping toward NW (Fig. 5B). Locally, the cross laminations are organised in sets with concave-up bottom and with opposite dip of the foresets (Fig. 6). Sometimes, planar parallel-laminations and cross-laminations form small sequences where planar parallel-laminations are located at the base. Thin beds or laminae of mudstone sometimes overlie the cross-laminated sandstone. Uncommonly, the bottom of the sequence is indicated by an erosive surface with scours up to 0.15 m deep where mudstone intraclasts from few millimetres to 0.35 m are accumulated.

Interpretation. Where subaqueous and subaerial aeolian processes interact, as observed in Bauru Group (Basilici et al., 2009), is often difficult to distinguish planar lamination yielded by subaqueous upper flow regime from sand laminations produced by aeolian climbing ripples. We used the following absent or present features to separate the two different structures, as we observed in present day semiarid depositional systems (Basilici and Dal' Bó, 2014): i) aeolian climbing ripple laminations have strong bimodal grain-size signature; ii) laminations of wind ripples commonly show inverse grading and can have thickness larger than 10 mm; iii) small flattened lens of medium-grained sand are often preserved in aeolian wind ripples, representing their coarse crest; iv) commonly laminations of wind ripples have low-angle dip and sets that cut each other; v) planar laminations formed in subaqueous upper flow regime are commonly interbedded with cross-laminated sand indicating small variation of the flow. Thus, planar parallel laminations are interpreted as structures formed in upper flow regime from high velocity subaqueous flows (Best and Bridge, 1992; Bridge and Best, 1997; Fielding, 2006).

Climbing cross lamination are deposited by unidirectional currents in lower flow regime and high bed load transport and correspond to the type A of Jopling and Walker (1968). Cross laminations with concave sets are similar to the unidirectional cross-laminated sandstone (lithotype S1, var. a2) of De Raaf et al. (1977) and where their foresets show opposite dip directions (upper portion of the Fig. 6) they are comparable with the bidirectional cross-laminated sandstone (lithotype S1, var. a2) of the same authors. This similarity suggests that the cross laminations with concave sets were originated by flows characterised by an oscillatory and unidirectional component (combined flows) in a stagnant water body.

The association of this lithofacies to deformed interbedding of sandstone and mudstone, which represent deposits of a salt flat, and the tabular shape of the beds, more than 30 m in extension, suggest that this planar and cross-laminated sandstone may have been originated by unidirectional unconfined flows when the salt flat surface was flooded. Smoot (1991), Smoot and Lowenstein (1991) and Smoot and Castens-Seidell (1994) described tabular-shape, very fine-grained sandstone beds characterised by planar laminations and climbing cross-laminations that they called sheet deltas and interpreted as deposited at the margin of shallow water lakes or flooded salt flats. The interpretation as crevasse splay deposits is excluded given that channelised deposits are absent in this unit. Cross laminations with concave sets are formed by oscillation and combined flows and testify wave action on flooded salt flat surface.

4.2. Intermediate unit

This unit contains four lithofacies: muddy sandstone (45% of the thickness), sandstone sheets (30% of the thickness), channelised sandstone (20% of the thickness) and medium-scale cross-stratified sandstone (5% of the thickness), which can be observed in few artificial outcrops at SW of Marília (Fig. 1).

4.2.1. Muddy sandstone

This facies is formed of tabular muddy very fine-grained sandstone, reddish brown (2.5YR4/8), 0.1-1.5 m thick and more than 40 m in lateral extension (Fig. 7). Boundaries with other lithofacies are sharp. Intense bioturbation obscures possible sedimentary structures (Fig. 8A). Small cylindrical tubes, less than 0.5 mm in diameter and 10-30 mm long, constituted of sparitic calcite and attributable to small rhizocretions (Klappa, 1980), are common.

Interpretation. The fine grained and the large lateral extension of this lithofacies suggest deposition by low-energy and unconfined flows. Bioturbation and rhizocretions indicate rapid colonization after the deposition by biological communities in subaerial conditions. Although these processes disrupted possible sedimentary structures, these were not sufficiently long to generate a complete development of palaeosol profiles.

4.2.2. Sandstone sheets

Sandstone sheets are constituted of bright reddish brown (2.5YR5/8) fine-grained sheet- or flatted lenticular-shaped sandstone beds (Fig. 7). The beds show more than 30 m in lateral extension and are 0.1-0.6 m thick. The bottom is a sharp and flat surface, locally forming small erosive scours; the top is planar and sharp. Overall, the beds are bioturbated (Fig. 8A) and lack sedimentary structures, but planar parallel-laminations are locally observed, associated to granule- or small pebble-grained muddy intraclast alignments. No grain-size grading is observed. Sandstone sheets are interbedded vertically and laterally with muddy sandstone.

Interpretation. Erosive scours testify that this lithofacies was characterised by a depositional flow enough powerful to erode the underlying muddy sandstone. The absence of sedimentary structures and the general homogeneity of the grain-size indicate rapid deceleration of the flow and consequent deposition of sediment from suspension. Similar structureless features are observed in analogous ancient fluvial systems (Tunbridge, 1981, 1984; Kelly and Olsen, 1993; Fisher et al., 2007) and reproduced in experimental conditions (Alexander et al., 2001). Local planar lamination, stressed by mud clasts, may be related to subaqueous upper flow regime. The tabular shape of these beds testify unconfined depositional mechanism, whereas the lenticular shape of some beds may be attributed to the marginal portions of unconfined deposits, which probably had a lobate shape, as observed in modern fluvial splays of Australia (Tooth, 2005).

4.2.3. Channelised sandstone

This lithofacies is formed by bright reddish brown (2.5YR5/8), ribbon shape sandstone bodies up to 2.2 m thick and 25 m laterally extended, with concave-up bottom and flat top (Fig. 7). Internally, various lenticular beds, 0.2-1 m thick and 1-10 m wide, divided by concave-up erosive surfaces, may be recognised. The dominant lithology is moderately-sorted fine-grained sandstone, but at the base of the lenticular beds poorly sorted coarse- to medium-grained sandstone with conglomerate intraclasts is observed (Fig. 8B). Overall, the sandstone is structureless, but local concentration of intraformational clasts permit to identify planar or low-angle laminations and sporadic cross-stratifications, the latter located above the concave-up erosive bottom (Fig. 7). No vertical variation of grain size is observed.

Interpretation. Moderately to poorly sorted sandstone, filling concave-up erosive depressions, which are and characterised by width/thickness ratio <15, constitute the deposits of ribbon-shaped river channels. These represent laterally stable channels subjected to deposition for vertical accretion (Gibling, 2006). The lenticular beds separated by concave-up erosive surfaces suggest various episodes of sedimentation within the same channelised structure, configuring this lithofacies as multistorey channel. The structureless sandstone beds suggest rapid waning flows that did not permit the formation of bedforms such as dunes or ripples, but rapid deposition by suspension (Jones, 1977; Alexander et al., 2001). Cross-stratifications constitute the filling of erosive troughs more than bedforms and the planar or low-angle laminations indicate local deposition for upper flow regime. The absence of vertical variation in grain size and sedimentary structures indicates that the channel was characterised by the same hydraulic processes until its complete filling.

4.2.4. Medium-scale cross-stratified sandstone

Cross-stratifications are constituted by tangential foresets of alternating fine- and very fine-grained sandstone, which dip 15-20º (Fig. 8C). Cross-stratifications set are 1-1.2 m thick, with planar, smooth and sharp, erosional, bottom surface. This lithofacies is interbedded to fine-grained sandstone sheets.

Interpretation. These cross stratifications are interpreted as small aeolian dunes, because they show some typical features of wind and subaerial deposition. (1) The foreset constituted of alternating fine- and very fine-grained sandstone may be interpreted as depositional product of grain flows and grain falls on the lee side of a dune (Hunter, 1977). (2) The planar and smooth bottom is compatible with a flat aeolian deflation surface. (3) This lithofacies is associated with sandstone deposits on an emerged alluvial plain.

4.3. Upper unit

The palaeosols constitute most of the upper unit succession (95% of the thickness); the remaining 5% is formed of sandy conglomerate with mudstone intraclasts. In study area one type of palaeosol and one lithofacies were distinguished: Echaporã pedotype and planar-stratified conglomerate sandstone, respectively.

4.3.1. Echaporã pedotype

The palaeosol profiles of this pedotype are 0.9-2.4 m thick (Fig. 9). Bottom and top of the profiles are highlighted by erosional surfaces, more than 200 m laterally extended (Fig. 10A), which at large scale are horizontal, but locally are characterised by small scours, not more depth of 0.5 m and wide more than 3 m. The pedotype shows the following horizons: A-Bw-(Btk)-C-R, with A, Btk and R in general absent. The parent material of A, B and partially C horizons is formed of moderately to well-sorted fine- to medium-grained sandstone. Medium- and coarse-grained quartz grains are subrounded or rounded and if observed with the SEM in secondary electron mode show surface microtextures interpretable as bubble edges, equidimensional elongated depressions and upturned plates (Mahaney, 2002) (Fig. 10B). Part of C horizon and R horizon, when present, are constituted of medium- and coarse-grained sandstone with small pebbles of intraformational mudstone or felsic igneous rocks and quartzite, which sometimes shows ventifact form (Fig 10C). Petrography of the parent material is constituted of monocrystalline and polycrystalline quartz (73-87%), microcline and plagioclase (5-18%), lithic fragments of sedimentary rocks (2-8%). Four rhizolith types can be observed in this pedotype. (1) Type I is formed of thin branched cylindrical tube, internally empty, *c.*0.5 mm in diameter, 30-40 mm long, constituted by microsparitic calcite (Fig. 11A); this type is attributable to rhizocretions (Klappa, 1980). (2) Type II consists of vertical laterally branched cylinders, 70-200 mm in diameter, 0.05-3 m long, constituted of sand cemented by micritic calcite; sand grains are dispersed and floating within the micritic cement (Fig. 11B). Locally these forms show light greenish grey (7.5GY8/1) halos. In some cases these rhizoliths were observed to cross vertically all the palaeosol profile up to the lower portion C horizon, where they branch horizontally (Fig. 11B). Morphological features and composition of the types II are similar to the rhizotubules described by Kraus and Hasiotis (2006). (3) Type III is formed by sandstone filled cylindrical tubes, 0.5 m long, downward tapering from 20 to 5 mm in diameter, and laterally and downward branching (Fig. 11C). Sandstone filling is coarser than the surrounding parent material, and corresponds to the material of the overlying C or R horizon. These rhizoliths may be classified as root cast (Klappa, 1980). (4) Type IV is constituted of light greenish grey (7.5GY8/1), laterally branching cylindrical tube of calcite cemented sand with diffuse edge, up to 0.4 m long and 0.03 m wide (Fig. 11D), which sometimes present a central tube, less than 1 mm wide, filled in sparitic calcite. This type of root can be classified as drab-haloed root traces (Retallack, 2001). A horizon is uncommonly preserved. Its thickness is less than 0.3 m, orange (2.5YR6/6), and the calcium carbonate content is absent. Type I and III rhizoliths are very common in this horizon. Upper boundary is an erosional, sharp and wavy surface; lower boundary surface is diffuse and smooth. Bw is 0.3-2 m thick, orange (2.5YR7/6), and is characterised by incipient prismatic (150 mm high and 80 mm wide, on average) or angular blocky (50-80 mm wide) structures, which are separated by calcium carbonate thin coatings (*calcans*) (Fig. 11E). Type II and IV rhizoliths are common. A-Bw boundary is diffuse and smooth. When A horizon is absent, upper boundary of Bw is sharp and wavy. Lower boundary of Bw with Btk or C is diffuse and smooth. Btk horizon is 0.1-0.4 m thick, bright reddish brown (2.5YR5/8) or orange (2.5YR7/6). This horizon is characterised by subspherical to irregular nodules, <1 to 40 mm across, 10-20% in abundance (Fig. 11F). The nodules are constituted of micritic calcite with floating fine-grained sand clasts. Type II and IV rhizoliths occur here, but not so common as in Bw horizons. C horizon is 0.2-1.15 m thick, orange (2.5YR7/6) or reddish orange (10R6/6) (Fig. 9), its upper and lower boundaries are diffuse and smooth. Parent material of C horizon shows commonly mud clasts; the calcium carbonate content is less than that the B horizons. R horizon corresponds to the "structureless and planar-stratified conglomerate sandstone" lithofacies, and it is below described. Weathering Molar Ration of Ba/Sr and Rb/Sr show low values, similar to the value in parent material (C and R horizons), and no variations along the profile are evident (Fig. 12 and Tabs. 2 and 3). The peak in correspondence to Btk horizon corresponds to the incorporation of Sr in calcite crystalline lattice (Buggle et al., 2011). Calcification shows high values only where macroscopic concentrations of calcareous nodules occur (Fig. 12 and Tabs. 2 and 3). Clayeyness is in general low, but higher concentrations of clay occur in the same horizons where high concentrations of calcium carbonate occur, helping to define the Btk horizons (Fig. 10 and Tabs. 2 and 3). Hydrolysis (bases/Al_2O_3) and CIA (Chemical Index of Alteration) have values >0.5 and <75, respectively (Fig. 10 and Tabs. 2 and 3). TiO_2/Al_2O_3 has mean values of 0.12.

Interpretation. Br/Sr, Rb/Sr, hydrolysis and CIA are Weathering Molar Ratios related to the weathering development of the palaeosols. The values of these ratios suggest low conditions of palaeopedogenic alterations (Sheldon and Tabor, 2009), mainly if they are compared with the R or C horizons (Fig. 10 and Tab. 3), which are considered to have a geochemical signature similar to the original parent material. This aspect is also confirmed by presence of incipient prismatic structures and poor accumulation of calcium carbonate in Btk horizons, which does not exceed the phase II of Gile et al. (1966), thus indicating a palaeopedogenic evolution of the order of 10^4 y (Machette, 1985). Weathering Molar Ratio of Al_2O_3/SiO_2 gives information on the distribution of clay on the palaeosol profile (clayeyness). Overall, these values are homogeneous, only with very small concentration in Btk horizons, suggesting only poor lessivage of clay particles in few developed palaeosol profiles. To define the time of formation of the palaeosol profiles we can apply an equation of Sheldon (2003)

$$Tf = 17.07\, TBt^2 + 645.8TBt$$

where Tf is time of formation, TBt is the original thickness of the Bt horizons. This equation, using the data of Markevich et al. (1990), relates the original thickness of the Bt horizon with the development time of the palaeosols. Actually, the development of Bt horizon is related to the time, because the illuviation of clay from the upper horizons takes time (Retallack , 2001). The time development obtained by three Btk horizons (Fig. 12) is 8,668, 14,415 and 62,860 y, indicating relatively short periods of formation for these profiles. The other palaeosols profiles without Btk horizon probably record lower times of development. Bw horizon may be interpreted as cambic horizon, that is an horizon that presents some weathered characteristic, but not so developed to be defined as other specific B horizon (Soil Survey Staff, 1999). For all these previous characteristics the Echaporã Pedotype may be classified as Inceptisol (Soil Survey Staff, 1999, 2006) or calcic Protosol (Mack et al., 1993).

A clear idea on the depositional origin of the parent material does not exist because the palaeopedogenesis disrupted all the original sedimentary structures, apart some features preserved in C or R horizons. Some considerations can be based on the textural and grain-size features of parent material. The moderate to well-sorted sandstone and the medium- to coarse-grained sandstone clasts with microtextural features, associated to wind-induced saltation (Mahaney, 2002), testify a subaerial aeolian-dominated environment. Pebble-sized clasts suggest that subaqueous flows could had have importance to generate this parent material, although some of these clasts show ventifact features. Thus, it is not possible clearly define if the parent material was originated by subaqueous flows that reworked wind transported material or vice versa. Geochemical (TiO_2/Al_2O_3) and petrographic data indicate felsic origin of the parent material.

4.3.2. Structureless and planar-stratified conglomeratic sandstone

This lithofacies is constituted of sheet beds of conglomeratic sandstone, 0.1-0.6 m thick, more than 60 m laterally extended. The sandstone is poorly sorted, fine- to coarse-grained; the conglomerate is constituted of mudstone intraclasts, and secondarily of quartzite and granitic clasts. The bed bottom is a horizontal, but irregular, erosional surface on A or B horizon of palaeosol profiles (Fig. 10A) and the top shows a gradual transition to medium-grained sandstone of C horizon. The lithofacies is structureless or organised in alternating beds of sandstone and conglomerate, with pebble-sized showing a bed parallel orientation (Fig. 13). These beds are laterally continuous and seem to represent a single sedimentary episode. The C horizons of the palaeosol profile show similar features to this lithofacies.

Interpretation. Grain size of this lithofacies indicates subaqueous depositional flows, planar parallel beds suggest upper flow regime (Bridge, 2003). Poorly sorted and structureless sandstone and sheet geometry of the beds may be associated to rapid sedimentation of unconfined hyperconcentrated flows (North and Davidson, 2012). It is noteworthy that the undulating basal erosion surface and tabular geometry of this lithofacies are very similar to the erosional sandstone sheet of Fisher et al. (2007) interpreted as unconfined flow deposit on the floodplain of fluvial distributary systems (cf. Fig. 10A with Fig. 3d of Fisher et al., 2007).

5. STRATIGRAPHIC ORGANISATION AND SEDIMENTARY SEQUENCES

5.1. Lower unit

The lower unit is 25 m thick, but its base is not exposed (Fig. 14). This unit matches the Araçatuba Formation according to the sedimentary descriptions of previous authors (Suguio et al. 1977; Fernandes et al., 2003). In particular, the lithofacies named "deformed interbedding of sandstone and mudstone" is extensively diffused in the Araçatuba Formation (Fernandes et al., 2003; their Fig. 4B). The lower unit is characterised by fine- to very fine-grained sand alternated with thin beds of muddy sands. The beds show alternating colours (light olive grey colour (5GY7/1) and bright reddish brown (2.5YR5/8) (Fig. 4A and C), which allow to distinguish it from the overlying units, which are in general characterised by bright reddish brown (2.5YR5/6) or orange (2.5YR7/6) colours. "Deformed interbedding of mudstone and sand" is vertically interbedded with "planar parallel- and cross-laminated sandstone" (Fig. 3). Planar parallel-laminated sandstone and cross-laminated sandstone form depositional sequences 0.2- 0.6 m thick. The absence of well-defined palaeopedogenic features means that this unit was characterised by continuous processes of deposition.

5.2. Intermediate unit

The intermediate unit measures 70 m of thickness (Fig. 14), its transition to the lower unit is apparently gradual developing in less than 10 m in vertical section. This transition is underlined by the disappearance of sandstone with high value colour (light olive grey - 5GY7/1) and the dominance of colours with intermediate value and high chroma (bright reddish brown -2.5YR5/8 or orange - 2.5YR7/6). According to the description of Soares et al. (1980) and Fernandes and Coimbra (2000), the intermediate unit may be attributed to the Adamantina Formation. Most of the intermediate unit is formed of laterally extended tabular muddy sandstone and sandstone beds, which are alternated to channelised sandstone bodies and less common medium-scale cross-stratifications (Fig. 14). The palaeopedogenic features observed in very-fine grained sandstone indicate short time of subaerial exposition and interruption of the depositional processes for a time lower than 1 ky (Allen and Wright, 1989).

5.3. Upper unit

The upper unit is *c.*150 m thick and (Fig. 14) can be attributed to the Marília Formation, because it is located in the same area where Soares et al. (1980) defined the strato-type of Marília Formation and coarser grain-size, general absence of sedimentary structures and presence of carbonate nodules are features already described by Soares et al. (1980) as typical for this unit. The transition from intermediate unit develops in *c.*20 m and it is characterised by the progressive appearance of palaeosol profiles. The upper unit is organised in cyclic alternations of deposits (structureless and planar-stratified conglomeratic sandstone) and palaeosols (Echaporã pedotype) (Fig. 15). These sequences, 0.9 to 2.4 m thick, are separated by erosional surfaces, more than 200 m in extension with scours up to 0.5 m depth and 3 m wide (Fig. 10A). The deposits are located at the base of the sequence (Fig. 15), but sometimes, above the erosional surface only the C horizon with poorly-preserved sedimentary structures is observed. Palaeosol profiles separated by deposits and/or C horizons are denominated compound profiles (Morrison, 1978). The formation of compound profiles entails that the depositional and pedogenic processes were separated in time and that sedimentation was sufficiently rapid and thick for not allow to the pedogenesis to incorporate the material within the soil profile. Daniels (2003) highlighted in present floodplain of semiarid environment that the sedimentation rate above 5 mm/y inhibits the pedogenic processes and allows to the preservation of the sedimentary structures. Echaporã pedotype is an Inceptisol, i.e. a poorly developed palaeosol. Time and not favourable climate conditions influence the formation of Inceptisols (Foss et al., 1993). Time may be defined applying the time-function of Sheldon (2003) to the palaeosol profiles with Btk horizons, where we verified times of formation from 8,668 to 62,860 y. In this study case, climate may be considered a secondary factor, because this same unit in the northern portion of the Bauru Basin shows in similar climate conditions well-developed palaeosols (Basilici et al., 2009). Thus, the time may be considered to be the main factor responsible for the immaturity of these palaeosols.

6. DEPOSITIONAL RECONSTRUCTION OF THE PALAEOENVIRONMENT AND MODEL OF EVOLUTION OF THE BAURU GROUP

This paragraph reconstructs the depositional conditions and the possible evolution of the three units of the Bauru Group exposed in Serra de Echaporã.

6.1. Lower unit: basinal salt flat system

Deformed sandstone and mudstone constitutes three-quarters of the thickness of the deposits of the lower unit (Fig. 3), therefore this lithofacies represents the dominant depositional system. This was produced by the deposition of sand and mud by subaqueous or subaerial flows on a thin saline efflorescent crust, which covered the surface of a salt flat (Smoot and Lowenstein, 1991; Smoot and Castens-Seidell, 1994; Goodall et al., 2000). The clastic material was deposited above an irregular saline crust and successively it was deformed by the contemporaneous growth or dissolution of salts. Evaporite minerals did not preserved due to the undersaturated groundwater and the relatively frequent floods. The salt flat area was rather extended because, although the maximum observed exposure of these deposits is few hundreds of metres, Fernandes et al. (2003) recognised similar lithofacies *c.*100 km northward from the study area. Occasional floods on the salt flat are indicated by planar parallel- and cross-laminated sandstone sequences. This lithofacies testifies rapid subaqueous flows, which spread sand on surfaces some tens of metres wide. The sand initially was deposited in plane bed form, followed with the decreasing of the flow velocity by climbing current ripples; at calm water, a thin bed of muddy sandstone covered the sand. These deposits probably reflect the construction of sheet deltas at the margin of the flooded salt flat (Fig. 16A). Sheet deltas are shoreline subenvironments of dry or saline mudflat settings, which are constituted of sand beds organised in vertical sequences of planar parallel-laminations, climbing-ripple cross-laminations and thin beds of mud, which form wedge-shaped flat bodies (Smoot and Lowenstein, 1991). On the standing waters, established after the flood, wave motion reworked the sand forming wave or combined ripple bedforms. However, the waters did not remain for long time on the depositional surface: uncommon beds with structures produced by wave motion and absence of clayey laminated and bluish grey deposits exclude the presence of deep and permanent waters. On the contrary, efflorescence crust structures, root traces and bright reddish brown colour suggest emergence conditions (Fig. 4). Conclusively, lower unit depositional area may be configured a shallow and ephemeral lake, identifiable as salt flat or playa-lake, where during occasional floods from the neighbouring areas high-velocity and shallow-water unconfined flows transported sediment into the flooded salt flat forming small sheet deltas (Fig. 18A).

6.2. Intermediate unit: distributary system

Most of this unit is constituted of vertical interbedding of sheet sandstone and muddy sandstone beds. The tabular geometry of these lithofacies indicates that these deposits were generated by unconfined shallow-water flows on a floodplain. Sheet sandstone is the product of high-energy flows, probably originated from breakage of the channel margins or from points where the channels extinguished on the floodplain (Fig. 7 and 16B). The sharp upper transition to muddy sandstone suggests that the latter does not represent the waning flow deposits of sheet sandstone but lower-energy overbank deposits (Bridge, 2003). Small rhizocretions and intense bioturbation of the muddy sandstone indicate a pedogenic alteration. However, the pedogenesis was incipient and insufficient to produce a well-developed palaeosol profile, thus indicating short periods of interruption of the depositional processes. Sheet sandstone and muddy sandstone are cut by multistorey channelised bodies filled by lenticular fine-grained sandstone beds that represent various episodes of sedimentation within ribbon-shape fixed channels (Fig. 7 and 16B). The sedimentological features of the channel deposits show that the channels did not laterally migrate and not never were gradually abandoned, but once completely filled they shifted abruptly channel belt. Moderately-sorted sandstone and weak planar or low-angle laminations suggest that channel flows were characterised by high bed-load transport, high velocity and rapid deposition, which did not permit the formation of bars or smaller bedforms. Locally, the alluvial plain was characterised by wind reworking of the sand that formed small aeolian dunes just over one metre high (Fig. 8C and 16B). Thus, the depositional environment of the intermediate unit is represented by an alluvial plain characterised by fixed ribbon channel and by a floodplain subjected to frequent floods and local aeolian reworking (Fig. 16B).

Sheet sandstone beds associated to ribbon-shaped channel deposits are described as typical of the distributary zone of fluvial distributary systems in arid or semiarid areas. In modern examples, Parkash et al. (1983) and Abdullatif (1989) observed that the terminal portion of the course of the Markanda (India) and Gash rivers (Sudan), respectively, is branched in various distributary smaller channels due to the progressive loss of water for evaporation and infiltration. In these areas, the channels are laterally and downstream alternated with unconfined sandy deposits generated at the termination of the channels or by overbank flows. Tooth (2005), describing the inland termination of two ephemeral rivers (Sandover and Sandover-Bundey, Australia), observed that they divide in distributary channels and pass laterally and distally in sandy sheet flood deposits. In ancient depositional systems the examples of terminal fluvial fan are more numerous. Kelly and Olsen (1993), based on three Devonian examples, recognised that medial and distal portion of the fluvial distributary system is constituted of interbedding of channel and sheet sandstone deposits with an increase of the latter in distal part. In Miocene Ebro Basin, Fisher et al. (2007) interpreted sandstone-filled ribbon channel associated with sheet sandstone and pedogenised mudstone as distal part of fluvial distributary system. Cain and Mountney (2009) used similar depositional interpretation for Organ Rock Formation, which is constituted of laterally extensive sandstone sheetflood deposits interbedded with ribbon-shape channel deposits and aeolian dunes or sands sheets. Thus, the architectural structure of the intermediate unit matches well with the medial or distal part of the distributary zone of a fluvial distributary system (Kelly e Olsen, 1993) (Fig. 18B).

6.3. Upper unit: distal distributary system in more arid climate

The upper unit is considerably different from the other two units because is palaeosol dominated and slightly coarser in grain size. Compound profiles of palaeosols indicate interruptions of the depositional processes of the order of 10^4 y, which caused the almost complete alteration of the sediments. Structureless and planar-stratified conglomeratic sandstone and some relicts of sedimentary features preserved in C horizons permit to associate the origin of the parent material to the deposition by unconfined subaqueous flows (Fig. 17A). Wind action is testified by surface textural features observed in sand grains and ventifacts, but no data exist to unravel if the wind formed deposits or the subaqueous flows reworked previous aeolian transported material. Thus, the environmental conditions of the upper unit may be visualised as a flat area subjected to short duration and periodical unconfined floods, which probably reworked previous aeolian transported sands, (Fig. 17A) and successive prolonged periods of pedogenesis (Fig. 17B).

The three units are characterised by gradual stratigraphic transition. Therefore, it is likely that these units constitute portions of the same depositional system. If the lower and intermediate units can be interpreted as basinal and medial or distal zone of a fluvial distributary system, respectively (Kelly and Olsen, 1993; Nichols, 2005; Nichols and Fisher, 2007; Cain and Mountney, 2009) (Fig. 18 A and B), inserting the upper unit in this depositional system results a little complex. This difficulty is mainly related to the fact that the upper unit is constituted almost exclusively by palaeosols, and they are not considered into the model of fluvial distributary system, if not marginally. For example, Fisher et al. (2007) described floodplain mudstone with pedogenic modifications and Cain and Mountney (2009) recognised palaeosol profiles with Bk horizons (calcrete) as part of the overbank deposits. Nevertheless, in both cases the palaeosol types were not identified and the relationship with the depositional processes was not analysed.

In upper unit, the abundance of palaeosols suggests decrease in sedimentation rate. Vertical alternations of compound palaeosols, interpreted as moderately developed palaeosols (Inceptisols), indicate sedimentation processes with recurrence time of the order of 10^4y (Fig. 15). The climate is one of the main factors that governs the depositional processes in endorheic basins (Nichols, 2005). In fact, the hinterland climate of distributary fluvial systems controls the supply of water and the basin climate the loss of water for evaporation (Nichols, 2005; Nichols and Fisher, 2007). Therefore, the lesser availability of material observed in upper unit may be associated to more arid climate that reduced the discharge of the rivers and consequently the input of sediment into the basin. Chumakov et al. (1995) published climate global maps for the Upper Cretaceous, and collocated the study area in Southern Hot Arid belt. Several features testify a semiarid climate for the upper unit formation. (i) Calcium carbonate concentration in palaeosol horizons (Btk horizons) indicates some degree of aridity (Sheldon and Tabor, 2009). (ii) Long tap root traces (type II) are related to deep groundwater level in the soil. (iii) Grain size and general textural features of the parent material of the upper unit testify aeolian transport. (iv) Unconfined flow deposits are common in semiarid environment due to improvise and catastrophic floods (Fielding et al., 2009). More arid conditions provoked the decrease of the sedimentary input of the fluvial distributary system. The sheet-shaped compound palaeosol profiles, whose parent material was interpreted as deposited from unconfined flows, and the absence of channel deposits allow to attribute this unit to the more distal portion of a fluvial distributary system, which was invaded by low-frequency and occasional unconfined flood. Thus, the transition from intermediate to upper unit indicates a general retrogradation of the system (Fig. 18C).

7. CONCLUSIONS

The application of genetic criteria, which consider sedimentary facies of the deposits and palaeosols, to the stratigraphy of the south-eastern portion of the Bauru Group can help to unravel the complicated and apparently featureless stratigraphy of this unit and its sedimentary evolution. In this area, three lithostratigraphic units, informally named as lower, intermediate and upper units, were recognised. They may be identified as Araçatuba, Adamantina and Marília formations, respectively.

The three units constitute a continuous sedimentary succession that may be interpreted as depositional product of a fluvial distributary system. The lower and intermediate units are interpreted as basinal and distal or medial portion of an endorheic fluvial distributary system. The upper unit, which is mostly constituted for palaeosols, does not fit well to the proposed models of fluvial distributary system. In fact, although the palaeosols are known in these depositional systems, they are not considered as important element of this depositional model. Palaeosols of the upper unit represent poor and occasional input of sediment into the depositional system, probably due to a general drying up of the climate, which reduced the river discharge and consequently the generation of sediment into the basin. Preserved sedimentary feature and erosive bottom and sheet shaped of the palaeosol profiles suggest that occasional unconfined flow deposited the parent material of the upper unit. These features and the absence of channelised bodies allow interpreting this unit as more distal portion of a fluvial distributary system where occasional unconfined flow deposited sheet sandstone. During the pauses of sedimentation moderately developed palaeosols (Inceptisols) formed above the deposits for a time of the order of 10^4y.

In conclusion, the coordinate study of palaeosol and sediments permitted to unravel the stratigraphy of the apparently featureless Bauru Group, its sedimentary palaeoenvironment as fluvial distributary system and to insert the palaeosol dominated upper unit into this depositional model.

ACKNOWLEDGES

The authors would like to thank FAPESP (Project 2012/23209-0) and CNPq (Universal 4742272013-8) for having financed this study.

REFERENCES

Abdullatif, O.M. (1989) Channel-fill and sheet-flood facies sequences in the ephemeral terminal River Gash, Kassala, Sudan. Sed. Geol., 63, 171–184.

Alexander, J., Bridge, J.S., Cheel, R.J., Leclair, S.F., 2001. Bedforms and associated sedimentary structures formed under supercritical water flows over aggrading sand beds. Sedimentology 48, 133–152.

Allen, J.R.N., Wright, V.P. (1989) Palaeosols in siliciclastic sequences. Postgraduate Research Institute for Sedimentology, University of Reading, Reading, pp. 97.

Barcelos J.H. 1984. Reconstrução paleogeográfica da sedimentação do Grupo Bauru baseada na sua redefinição estratigráfica parcial.em território paulista e no estudo preliminar fora do Estado de São Paulo. Inst. de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro, Tese de Livre-Docência, 190 p.

Basilici, G., Dal’ Bó, P.F.F., Ladeira, F.S.B. 2009. Climate-induced sediment-palaeosol cycles in a Late Cretaceous dry aeolian sand sheet: Marília Formation (North-West Bauru Basin, Brazil). Sedimentology, 56: 1876-1904

Basilici, G., Dal' Bó, P.F.F. 2010. Anatomy and controlling factors of a Late Cretaceous aeolian san sheet: the Marília and the Adamantina formations, NW Bauru Basin, Brazil. Sedimentary Geology, 226: 71–93.

Basilici, G. and Dal' Bó, F.P. (2014) Influence of subaqueous processes on the construction and accumulation of an aeolian sand sheet. Earth Surface Processes and Landforms, 39, 1014–1029.

Batezelli, 2015. Continental systems tracts of the Brazilian Cretaceous Bauru Basin and their relationship to the tectonic and climatic evolution of South America. Basin Research, Accepted article.

Best, J. and Bridge, J., 1992. The morphology and dynamics of low amplitude bedwaves upon upper stage plane beds and the preservation of planar laminae. Sedimentology 39,737-752

Bridge, J. and Best, J., 1997. Preservation of planar laminae due to migration of low-relief bed waves over aggrading upper-stage plane beds: comparison of experimental data with theory Sedimentology, 44, 253-262

Bridge, J.S. (2003) Rivers and Floodplains. Blackwell, Oxford, UK. pp. 491

Buggle, B., Glaser, B., Hambach, U., Gerasimenko, N. and Marković, S. (2011) An evaluation of geochemical weathering indices in loess-palaeosol studies. Quaternary International, 240, 12-21.

Cain STEPHEN A. and Mountney NIGEL P. (2009) Spatial and temporal evolution of a terminal fluvial fan system:the Permian Organ Rock Formation, South-east Utah, USA Sedimentology 56, 1774–1800

Chumakov, N.M., Zharkov, M.A., Herman, A.B., Doludenko, M.P., Kalandadze, N.N., Lebedev, E.L., Ponomarenko, A.G. and Rautian, A.S. (1995) Climatic belts of the mid-Cretaceous time. Stratigr. Geol. Correlation, 3, 241–260.

Dal' Bó, P.F.F., Basilici, G., Angelica, R.S., Ladeira, F.S.B. 2009. Paleoclimatic interpretations from pedogenic calcretes in a Maastrichtian semiarid eolian sand-sheet palaeoenvironment: Marília Formation (Bauru Basin, southeastern Brazil). Cretaceous Research, 30: 659-675.

Dal' Bó, P.F.F., Basilici, G., Angélica, R.S. 2010. Factors of palaeosol formation in a Late Cretaceous eolian sand sheet paleoenvironment, Marília Formation, Southeastern Brazil Palaeogeography, Palaeoclimatology, Palaeoecology, 292: 349–365.

Daniels J. M. (2003) Floodplain aggradation and pedogenesis in a semiarid environment. Geomorphology 56 (2003) 225–242

De Raaf, J. F. M., Boersma J. R. and Van Gelder A. (1977) Wave-generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland. Sedimentology, 24, 451-483

Fernandes, L.A., Coimbra, A.M. 2000. Revisão estratigráfica da parte oriental da Bacia Bauru (Neocretáceo). Revista Brasileira de Geociências, 30: 717-728.

Fernandes L. A., Giorgio Basilici (2009) - Transition of ephemeral palustrine to aeolian deposits in a continental arid – semiarid environment (Upper Cretaceous Bauru Basin, Brazil). Cretaceous Research 30, 605–614

Fernandes, L.A., Giannini. P.C.F. and Góes, A.M. (2003). Araçatuba Formation: palustrine deposits from the initial sedimentation phase of the Bauru Basin. Anais da Academia Brasileira de Ciências 75(2), 173-187

Fernandes, L.A. and Magalhães Ribeiro, C.M. (2015) Evolution and palaeoenvironment of the Bauru Basin (Upper Cretaceous, Brazil) Journal of South American Earth Sciences 61, 71-90

Fielding, C.R., Allen, J.P., Alexander, J., Gibling. M.R., (2009). Facies model for fluvial systems in the seasonal tropics and subtropics. Geology, 37, 7, 623–626

Fielding, C. R. (2006) Upper flow regime sheets, lenses and scour fills: Extending the range of architectural elements for fluvial sediment bodies Sedimentary Geology 190, pp. 227–240;

Fisher J.A., Nichols G.J., Waltham, D.A., 2007. Unconfined flow deposits in distal sectors of fluvial distributary systems: Examples from the Miocene Luna and Huesca Systems, northern Spain. Sedimentary Geology, 195, 55–73

Foss, J.E, Moormann, F.R. and Rieger, S. (1983) Inceptisols. In: Pedogenesis and Soil Taxonomy. II. The Soil Orders (Eds Wilding, L.P., Smeck N.E. and Hall, G.F.), Development in Soil Science, Elsevier, 11B, 355–381.

Friend, P.F. (1978) Distinctive features of some ancient river systems. In: Fluvial Sedimentology (Ed. A.D. Miall), Mem. Can. Soc. Petrol. Geol., 5, 531–542.

Gibling, M.R. (2006). Width and thickness of fluvial channel bodies and valley fills in the geological record: a literature compilation and classification. Journal of Sedimentary Research, 2006, v. 76, 731–770

Gile, L.H., Peterson, F.F. and Grossman, R.B. (1966) Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science, 101, 347–360.

Goodall, T. M., North C. P. and Glennie K. W. (2000) Surface and subsurface sedimentary structures produced by salt crusts. Sedimentology, 47, 99-118

Hodgson, J.M. (1978). Soil Sampling and Soil Description. Clarendon Press, Oxford, 241 pp.

Hunter RE. 1977. Basic types of stratification in small aeolian dunes. Sedimentology 24: 361–387.

Jopling, A.V. and Walker, R.G. (1968). Morphology and origin of ripples-drift cross-lamination, with examples from the Pleistocene of Massachusetts. Journal Sed. Petr., 38, 971-984

Kelly, S.B. and Olsen, H. (1993) Terminal fans – a review with reference to Devonian examples. Sed. Geol., 85, 339–374.

Klappa, C. F. (1980) Rhizoliths in terrestrial carbonates : classification, recognition, genesis and significance Sedimentology (1980) 27, 613-629

Jones, C. .M. (1977). The effects of varying discharge regimes on bedform sedimentary structures in modern rivers. Geology, 5, 567-570.

Kraus Mary J. and Hasiotis Stephen T. (2006) Significance of different modes of rhizolith preservation to interpreting paleoenvironmental and paleohydrologic settings: examples from Paleogene paleosols, bighorn basin, Wyoming, U.S.A. Journal of Sedimentary Research, v. 76, 633–646

Machette, N.M. (1985) Calcic soils of the southwestern United States. In: Soils and Quaternary Geology of the Southwestern United States (Ed D.L. Weide), Geological Society of America Special Paper, 203, 10–21.

Mack, G.H., James, W.C. and Monger, H.C. (1993) Classification of paleosols. Geological Society of American Bulletin, 105, 129–136.

Mahaney, W.C. (2002) Atlas of Sand Grain Surface Textures and Applications. Oxford University Press, Oxford, 237 pp.

Markewich, H.W., Pavich, M.J., Buell, G.R., 1990. Contrasting soils and landscapes of the Piedmont and Coastal Plain, eastern United States. Geomorphology 3, 417–447.

McKee, E.D., Crosbye, J. & Berryhillh, .C. (1967) Flood deposits. Bijou Creek, Colorado, June 1965. J. Sedim. Petrol. 37, 829-85 1.

Mezzalira, S., e Arruda, M.R., 1965. Observações geológicas na região do Pontal do Paranapanema, Estado de São Paulo. Anais Academia Brasileira de Ciências, 37: 69·77.

Morrison, R.B. (1978) Quaternary soil stratigraphy—concepts, methods, and problems. In: Quaternary Soils (Ed Mahaney, W.C.), Geo Abstracts, Norwich, 77–108.

Mukerji, A.B. (1976) Terminal fans of inland streams in Sutlej–Yamuna Plain, India. Zeits. Geomorphol. Neue Folge, Bd. 20, 190–204.

Nichols, G. J. 2005. Sedimentary evolution of the Lower Clair Group, Devonian, West of Shetland: climate and sediment supply controls on fluvial, aeolian and lacustrine deposition. In: Doré, A. G. & Vining, B. A. (eds) Petroleum Geology: North-West Europe and Global Perspectives—Proceedings of the 6th Petroleum Geology Conference, 957–967.

Nichols, G.J. and Fisher, J.A. (2007) Processes, facies and architecture of fluvial distributary system deposits. Sed. Geol., 195, 75–90.

North, C.P. and Warwick, G.L. (2007) Fluvial fans: myths, misconceptions, and the end of the terminal-fan model. J. Sed. Res., 77, 693–701.

North C.P., Davidson S.K. (2012). Unconfined alluvial flow processes: Recognition and interpretation of their deposits, and the significance for palaeogeographic reconstruction Earth-Science Reviews 111, 199–223.

Paula e Silva de, F., Chang, H.K., Caetano-Chang, M.R. 2009. Sedimentation of the Cretaceous Bauru Group in São Paulo, Paraná Basin, Brazil. Journal of South American Earth Sciences, 28: 25–39.

Parkash, B., Awasthi, A.K. and Gohain, K. (1983) Lithofacies of the Markanda terminal fan, Kurukshetra district, Haryana, India. In: Modern and Ancient Fluvial Systems (Eds J.D. Collinson and J. Lewin), Spec. Publ. Int. Assoc. Sedimentol., 6, 337–344.

Retallack, G.J. (2001) Soils of the Past: an Introduction to Paleopedology. 2nd ed. Blackwell, Oxford, 404 pp.

Retallack, G.J. (2005) Pedogenic carbonate proxies for amount and seasonality of precipitation in paleosols. Geology, 33, 333–336.

Saéz, A., Anadón, P., Herrero, M.J. and Moscariello, A. (2007) Variable style of transition between Palaeogene fluvial fan and lacustrine systems, southern Pyrenean foreland, NE Spain. Sedimentology, 54, 367–390.

Sheldon, N.D., 2003. Pedogenesis and geochemical alteration of the picture gorge subgroup, Columbia River Basalt, Oregon. Geological Society of America Bulletin 115, 1377–1387.

Sheldon, N.D., Retallack, G.J., 2001. Equation for compaction of palaeosols due to burial. Geology 29, 247–250.

Sheldon, N.D. and Tabor, N.J. (2009) Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols. Earth Science Reviews, 95, 1–52.

Sheldon, N.D., Retallack, G.J., Tanaka, S., 2002. Geochemical climofunctions from North America soils and application to paleosols across the Eocene–Oligocene boundary in Oregon. Journal of Geology 110, 687–696.

Smoot, J. P. and Olsen, P. E. (1988) Massive mudstones in basin analysis and paleoclimatic interpretation of the Newark Supergroup (In Manspeizer W. ed.) Triassic Jurassic Rifting North America and North Africa. Amsterdam, Elsevier p. 249 274

Smoot, J. P. and Lowenstein, T. K., 1991. Depositional environments of non marine evaporites. In Melvin, J. L. ed. Evaporites Petroleum and Mineral Resources. Amsterdam Elsevier p. 189-347

Smoot, J. P., 1991. Sedimentary facies and depositional environments of early Mesozoic Newark Supergroup basins, eastern North America. Palaeogeography, Palaeoclimatology, Palaeoecology, 84, 369-423

Smoot, J.P. and Castens-Seidell, B. (1994) Sedimentary features produced by efflorescent crusts, Saline Valley and Death Valley, California. In: Sedimentology and Geochemistry of Modern Ancient Saline Lakes (Eds R.W. Renaut and W.M. Last), Spec. Publ. Soc. Econ. Paleont. Miner., Tulsa, 50, 73±90.

Soares, P.C., Landim, P.M.B., Fulfaro, V.J., Neto, A.F.S. 1980. Ensaio de caracterizacão estratigráfica do Cretáceo no Estado de São Paulo: Grupo Bauru. Revista Brasileira de Geociências, 10: 177–185.

Soil Survey Staff (1999) Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. US Department of Agriculture, Natural Resource Conservation Service, Washington, D.C., Vol. 436, 871 pp.

Soil Survey Staff (2006) Keys to Soil Taxonomy, 10th edn. US Department of Agriculture, Natural Resource Conservation Service, Washington, D.C., 332 pp.

Spice, B. and Skelton, P.W. (2003) In: Skelton P.W. The Cretaceous world. The Open University, Cambridge University Press, Cambridge, 249-271

Suguio K., Fúlfaro V.J., Amaral G., Guidorzi L.A. 1977. Comportamentos estratigráficos e estrutural da Formação Bauru nas regiões administrativas 7 (Bauru), 8 (São José do Rio Preto) e 9 (Araçatuba) no Estado de São Paulo. In: SBG/Núcleo SP, Simpósio de Geologia Regional, I, São Paulo, Atas, p. 231 -247.

Suguio K. 1981. Fatores paleoambientes e paleoclimáticos e subdivisão estratigráfica do Grupo Bauru. In:, SBG/Núcleo SP, Mesa Redonda: A Formação Bauru no Estado de São Paulo e Regiões Adjacentes, São Paulo, Coletânea de trabalhos e debates, p. 15-26.

Tooth, S. 2005 Splay formation along the lower reaches of ephemeral rivers on the northern plains of arid central Australia Journal of Sedimentary Research, v. 75, 636–649

Tunbridge, I.,P . (1981) Sandy high energy flood sedimentation--some criteria for recognition, with an example from the Devonian of SW England. Sediment. Geol. 28, 79 95.

Tunbridge, I.P., 1984. Facies model for a sandy ephemeral stream and clay playa complex; the Middle Devonian Trentishoe Formation of North Devon, U.K. Sedimentology, 31: 697-715.

CAPTIONS

Figure 1. Location map of the study areas. Previous study areas were considered in Basilici et al. (2009), Dal' Bó et al. (2009) and Basilici and Dal' Bó (2010).

Figure 2. (A) Schematic geological map of the Bauru Basin. (B) Stratigraphic interpretation according to Batezelli (2015). (C) Stratigraphic interpretation according to Fernandes and Ribeiro (2015).

Figure 3. Detailed stratigraphic sketch of the lower unit (attributed to Araçatuba Formation). Deformed interbedding of sandstone and mudstone (lithofacies dsm in the picture) constitute most of the succession. Lithofacies: dsm = deformed interbedding of sandstone and mudstone; pcs = planar parallel and cross-laminated sandstone.

Figure 4. Lower unit. The lithofacies deformed interbedding of sandstone and mudstone is interpreted as deformed sediments by superficial growing of thin salt efflorescence crusts. (A) Thin beds or laminae of sandstone (olive grey - 5GY7/1) and mudstone (bright reddish brown - 2.5YR5/8) show jagged lateral edge and cuspate margins. Some sandstone are characterised of thin internal laminations (i). Protrusions of mudstone in sandstone patches (ii) can represent the

"popcorn" surface of salt crust. Mudstone and sandstone concave-up laminae (iii) are interpreted as surface deformation features that correspond to polygonal forms on the salt flat surface. Coin: 20 mm. (B) Irregular patches of mudstone and sandstone (i) representing aggradational features of salt efflorescence crusts. Bowl-shaped laminae of mudstone and sandstone (ii) reflect surface deformation structures like polygons or mound shapes. Object for scale is 26 mm in diameter. (C) (i) Small sandstone-filled depression can represent solution collapse structures associated with efflorescent crust fabric. (ii) Bioturbation is present, but not common, this consists in small sandstone-filled vertical tube, with circular section of 1-5 mm in diameter and 0.03-0.2 m high. Object for scale is 26 mm in diameter. (D) Root trace with drab halo (arrowed) testifies iron reduction and depletion under reducing conditions around the root walls. Coin: 20 mm.

Figure 5. Lower unit. Lithofacies planar parallel- and cross-laminated sandstone. (A) Planar parallel-laminated sandstone was formed in upper flow subaqueous regime. Coin: 22 mm. (B) Cross-laminated sandstone represents subaqueous climbing current ripples. Coin: 20 mm.

Figure 6. Lower unit. Lithofacies planar parallel- and cross-laminated sandstone. Trough **c**ross-laminations with bipolar and opposite dip of the foreset are interpreted as wave-reworked sand. The section is close to the direction of the foreset dip. Coin: 20 mm.

Figure 7. Intermediate unit. Muddy sandstone (ms) and sandstone sheets (ss) constitute most of the lithofacies of the intermediate unit. They are interpreted as unconfined flows. Channelised sandstone (chs) represents the filling of ribbon-shaped channel. The lenticular beds separated by concave-up erosive surfaces suggest various episodes of sedimentation.

Figure 8. Intermediate unit. (A) Sheet shape beds of muddy sandstone and sandstone sheets are commonly intensively bioturbated. Coin: 20 mm. (B) Conglomerate intraclasts accumulated at the base of the channelised sandstone lenticular beds. The small holes (arrowed) represent muddy intraclast positions. Pencil: 145 mm. (C) Medium-scale cross-stratifications (css) are interpreted as small aeolian dune deposits. They are interbedded with fine-grained sandstone sheets (ss)

and perhaps. Poor exposure does not permit to interpret the facies indicated with interrogative point. Probably may represent subaqueous bedforms due to the presence of muddy intraclasts.

Figure 9. Palaeosol profiles representing the Echaporã pedotype. Bottom and top are divided by erosive surfaces; A-Bw1-Btk-Bw2-C-R horizons may be present, but commonly A, Btk and R horizon are lacking. This pedotype is interpreted as Inceptisol or calcic Protosol and it is constituted by compound profiles.

Figure 10. Upper unit. (A) The dotted lines indicate the erosive bottom of the compound palaeosol profiles, described as Echaporã pedotype. Above this erosive surface structureless or planar-stratified conglomerate sandstone occurs, testifying deposition of unconfined subaqueous flows. The red cone is *c.*0.5 m high. (B) Subrounded clast of coarse-grained sand with bulbous edges, which indicate wind transport. (C) Some pebble-sized clasts show ventifact appearance.

Figure 11. Echaporã pedotype. (A) Type I of root trace. Thin rhizocretions formed of sparitic thin cylindrical tubes (arrowed). Coin: 22 mm. (B) Type II of root trace. Long rhizotubules attributable to tap roots. The arrow shows the root system turning horizontal, probably where the root reached the ground water level or sufficient humidity. (C) Type III of root trace. Sand-filled root cast. Note the lateral branching and the downward tapering. Coin: 22 mm. (D). Type IV of root trace. Drab-haloed root traces. Coin: 22 mm. (E) Incipient prismatic structures separated by *calcans* (white patches in photo) constitute a feature of the Bw horizon. Pencil: 145 mm. (F) Non-coalescent carbonate nodules in Btk horizon. Pencil: 145 mm.

Figure 12. Molecular Weathering Ratios (MWR) of profiles of Echaporã pedotype.

Figure 13. Structureless and planar-stratified conglomerate sandstone is described as R horizon in palaeosol profiles. Muddy clast alignment on horizontal surfaces alternated with poorly sorted fine- to coarse-grained sandstone is the main sedimentary structure. Coin: 22 mm.

Figure 14. Stratigraphic synthesis of the study area. The beds are not in scale and the transition between the units is gradual, as indicated in the text.

Figure 15. Inceptisol palaeosol profiles of upper unit of south-eastern portion of the Bauru Basin are organised in cyclic sequences of compound palaeosols. Legend in Figs. 3, 7 and 12.

Figure 16. (A) The lower unit was deposited in a salt flat or playa-lake. The interbedding of sandstone and mudstone, deformed by efflorescent salt crust growth, constitute most of the depositional unit. During the floods, at the margin of the salt flat, unconfined flows formed sheet delta. (B) The intermediate unit deposited in medial or distal zone of a fluvial distributary system. Small and fixed ribbon-channel deposits cut prevalent interbedding of sandstone sheet and muddy sandstone beds, formed by unconfined flows. Rarely, aeolian cross-stratifications can be observed .

Figure 17. (A) The upper unit deposited by unconfined subaqueous deposits, which probably partially reworked wind-transported material. (B) A relatively long period of stasis of sedimentation of the order of 10^4 y favoured pedogenesis of the previous deposits and the formation of Inceptisols.

Figure 18. Cartoon showing the depositional and stratigraphic evolution of the south-eastern portion of the Bauru Basin. (A) Lower unit, (B) intermediate unit and (C) upper unit. See text for details.

Table 1. Summary of lithofacies and pedotype observed in south-eastern portion of the Bauru Group.

Table 2. Major and trace element data.

Table 3. Molecular Weathering Ratios used as palaeoenvironmental proxies in Echaporã pedotype.

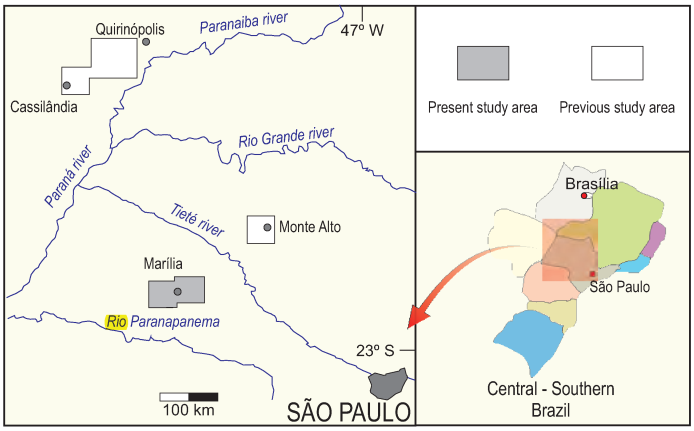
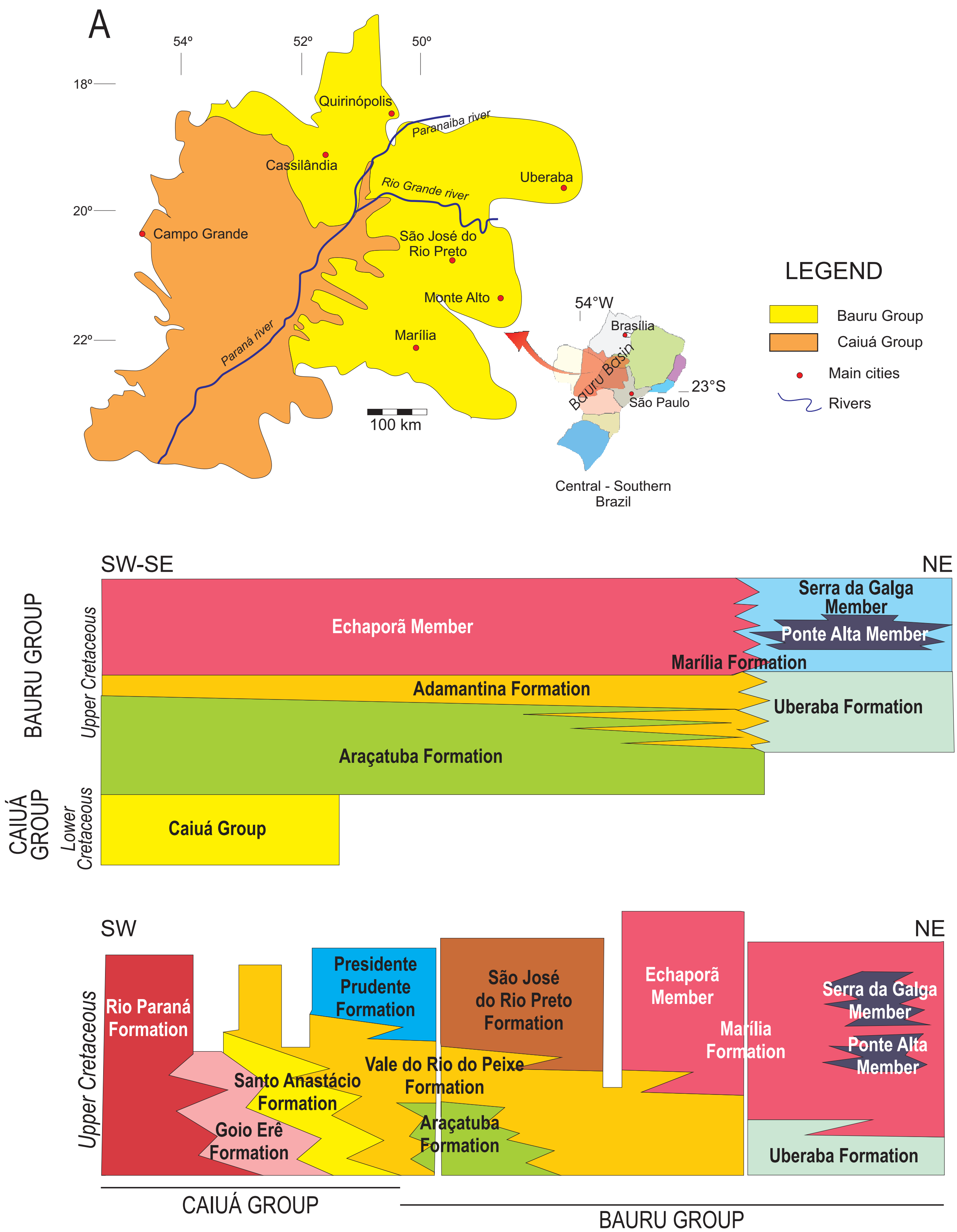

Quirinópolis
Paranaiba river
47° W
Cassilândia
Present study area
Previous study area
Rio Grande river
Paraná river
Tietê river
Monte Alto
Brasília
Marília
São Paulo
Rio Paranapanema
23° S
100 km
SÃO PAULO
Central - Southern
Brazil

FIGURE 1



A
54º
52º
50º
18º
20º
22º
Quirinópolis
Paranaiba river
Cassilândia
Uberaba
Rio Grande river
Campo Grande
São José do
Rio Preto
Monte Alto
Marília
Paraná river
100 km
54°W
Brasília
Bauru Basin
23°S
São Paulo
Central - Southern
Brazil
LEGEND
Bauru Group
Caiuá Group
Main cities
Rivers
SW-SE
NE
BAURU GROUP
Upper Cretaceous
CAIUÁ GROUP
Lower Cretaceous
Echaporã Member
Serra da Galga Member
Ponte Alta Member
Marília Formation
Adamantina Formation
Uberaba Formation
Araçatuba Formation
Caiuá Group
SW
NE
Upper Cretaceous
Rio Paraná Formation
Presidente Prudente Formation
São José do Rio Preto Formation
Echaporã Member
Marília Formation
Serra da Galga Member
Ponte Alta Member
Santo Anastácio Formation
Vale do Rio do Peixe Formation
Goio Erê Formation
Araçatuba Formation
Uberaba Formation
CAIUÁ GROUP
BAURU GROUP

FIGURE 2

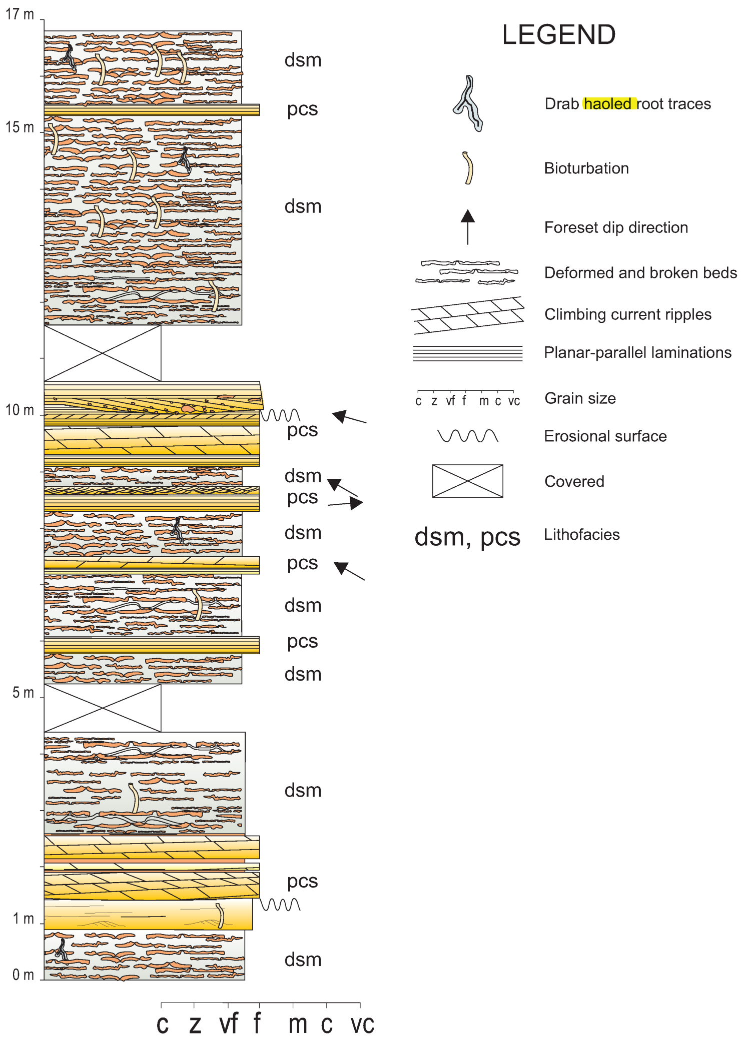

17 m
15 m
10 m
5 m
1 m
0 m
dsm
pcs
dsm
pcs
dsm
pcs
dsm
pcs
dsm
pcs
dsm
dsm
pcs
dsm
c z vf f m c vc
LEGEND
Drab haoled root traces
Bioturbation
Foreset dip direction
Deformed and broken beds
Climbing current ripples
Planar-parallel laminations
c z vf f m c vc
Grain size
Erosional surface
Covered
dsm, pcs
Lithofacies

FIGURE 3

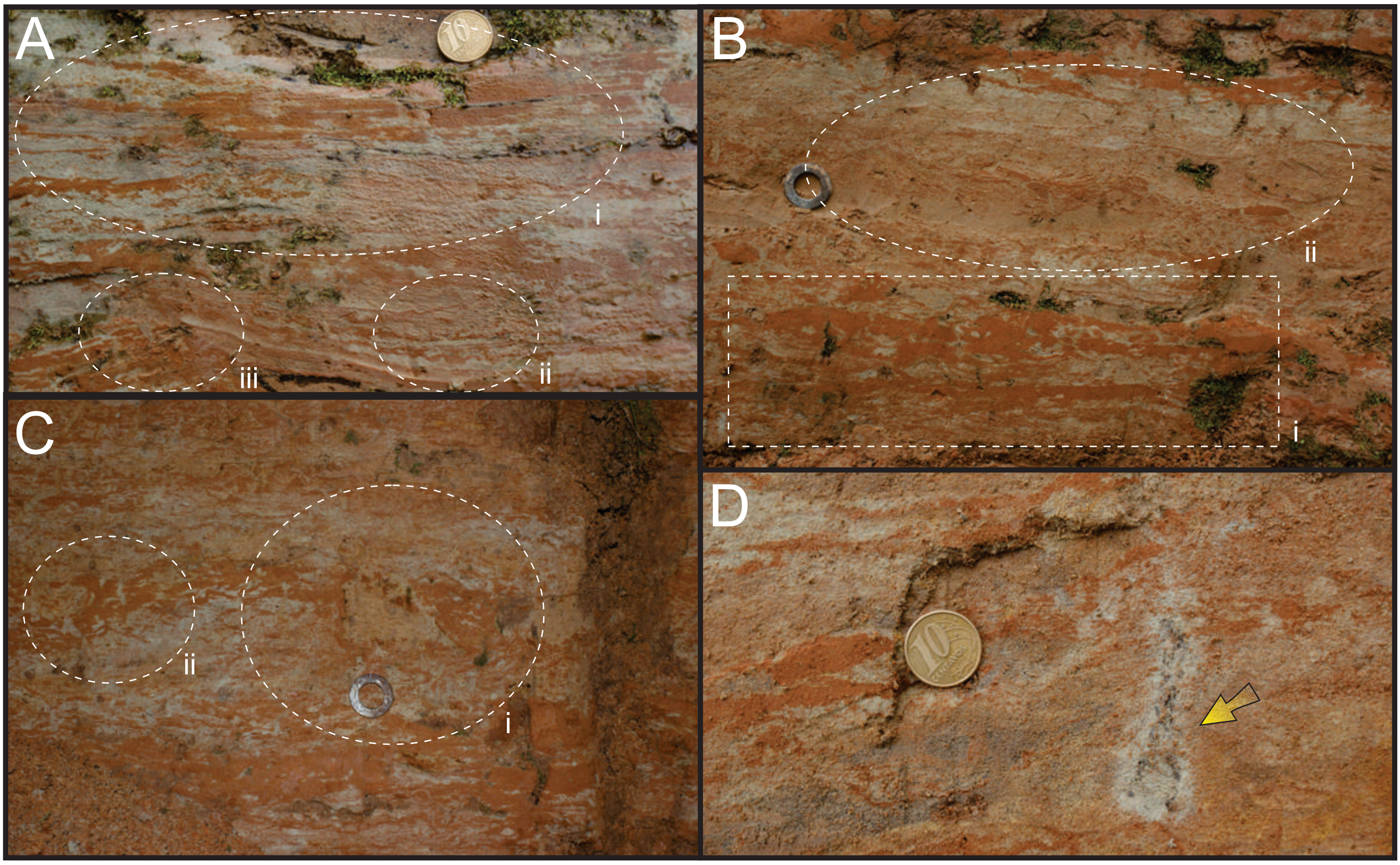


FIGURE 4

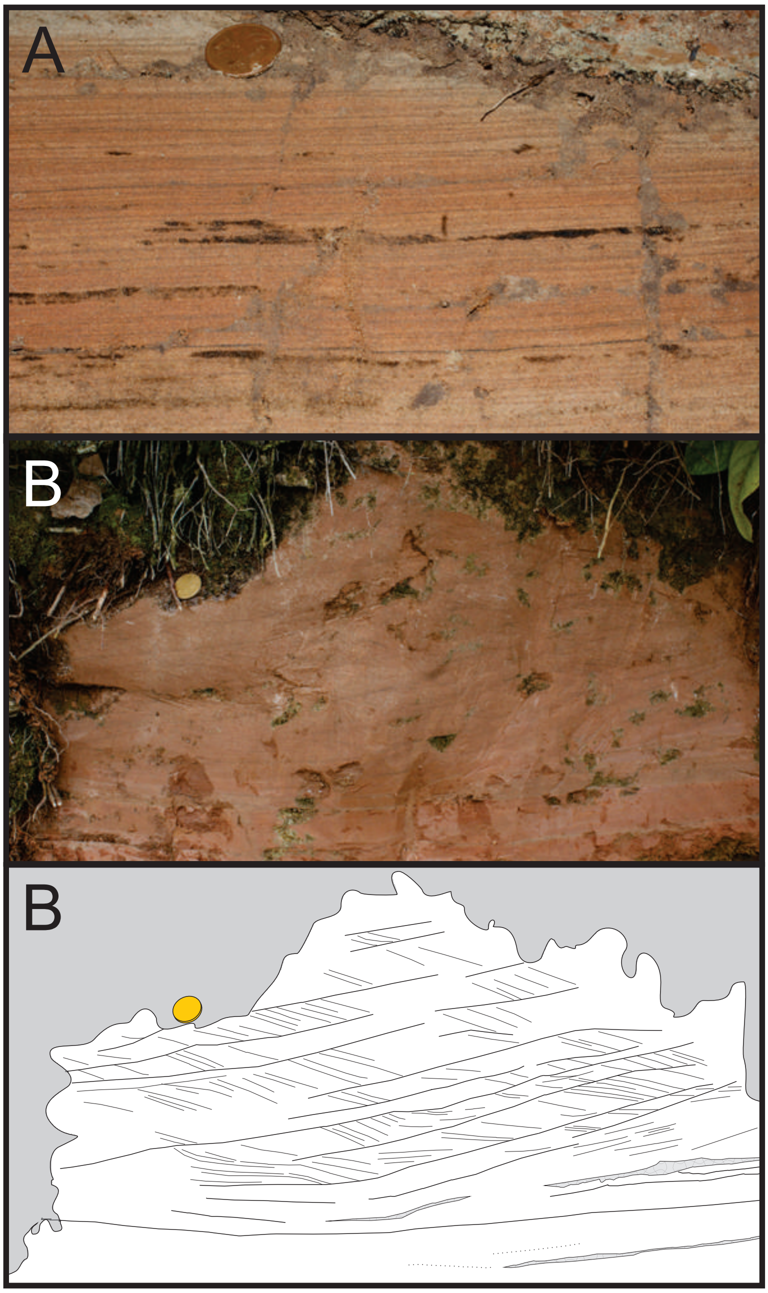


FIGURE 5

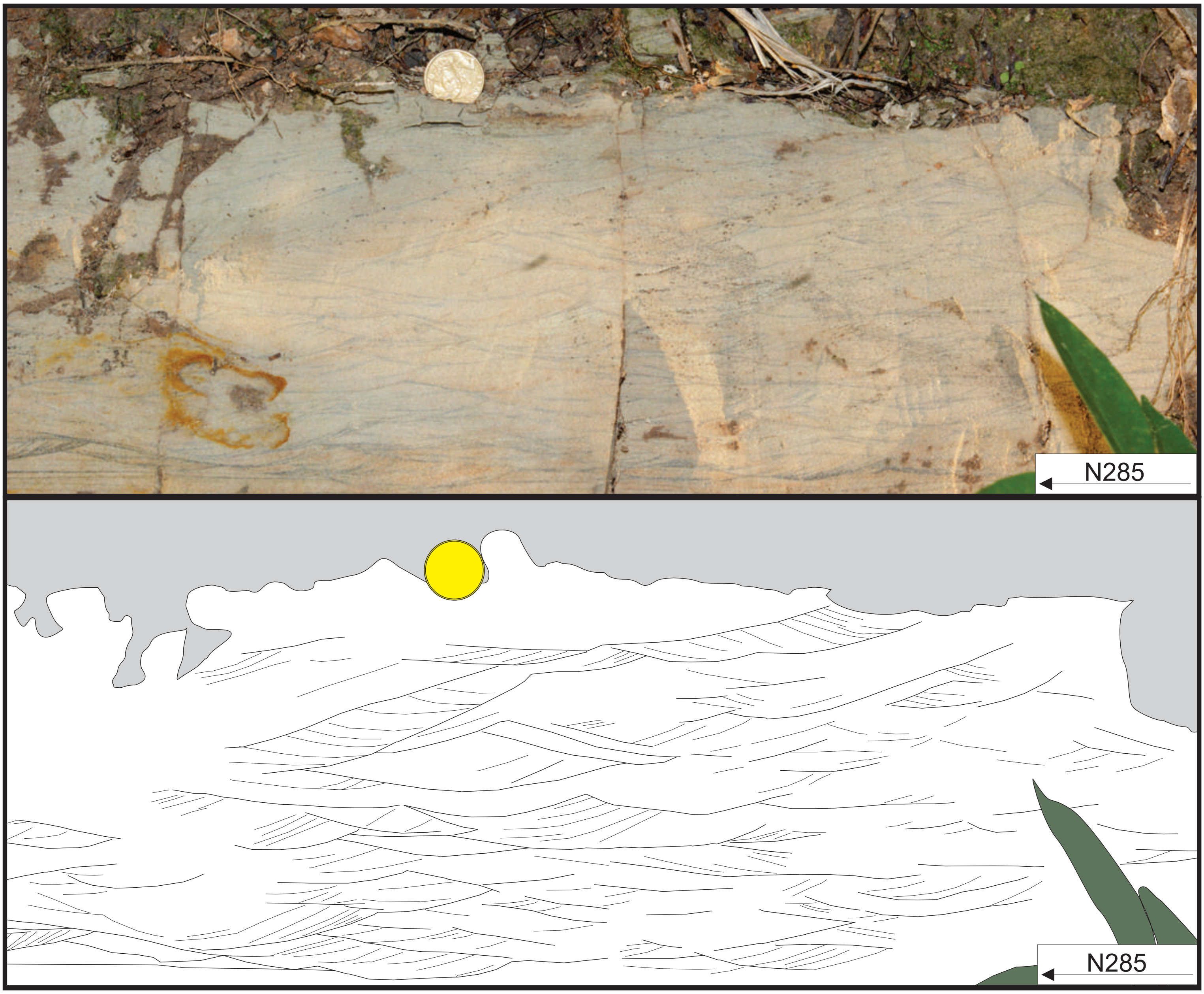


FIGURE 6

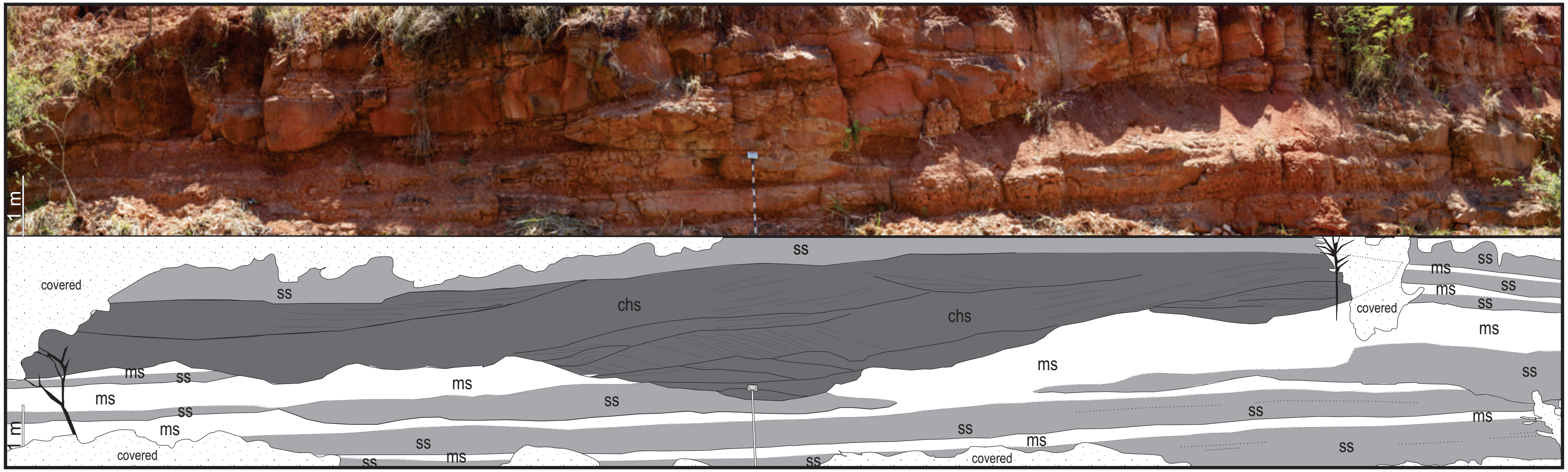

1 m
covered
ss
ss
chs
chs
ms
ss
ms
ss
ms
ss
covered
ms
ss
ms
ss
ms
ss
ms
ss
ss
ms
ss
ms
ss
ss
ss
ms
ss
ms
covered
ss
ms
covered
ss

FIGURE 7

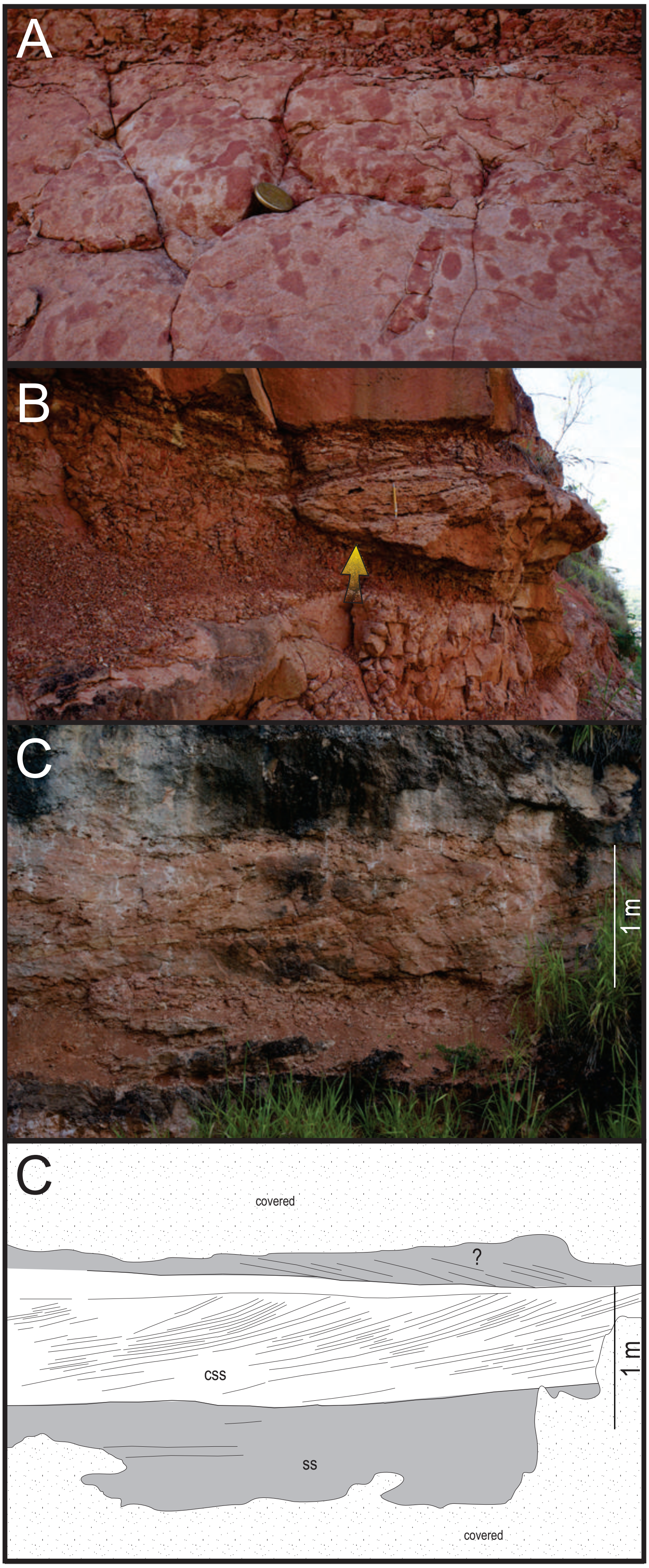


FIGURE 8

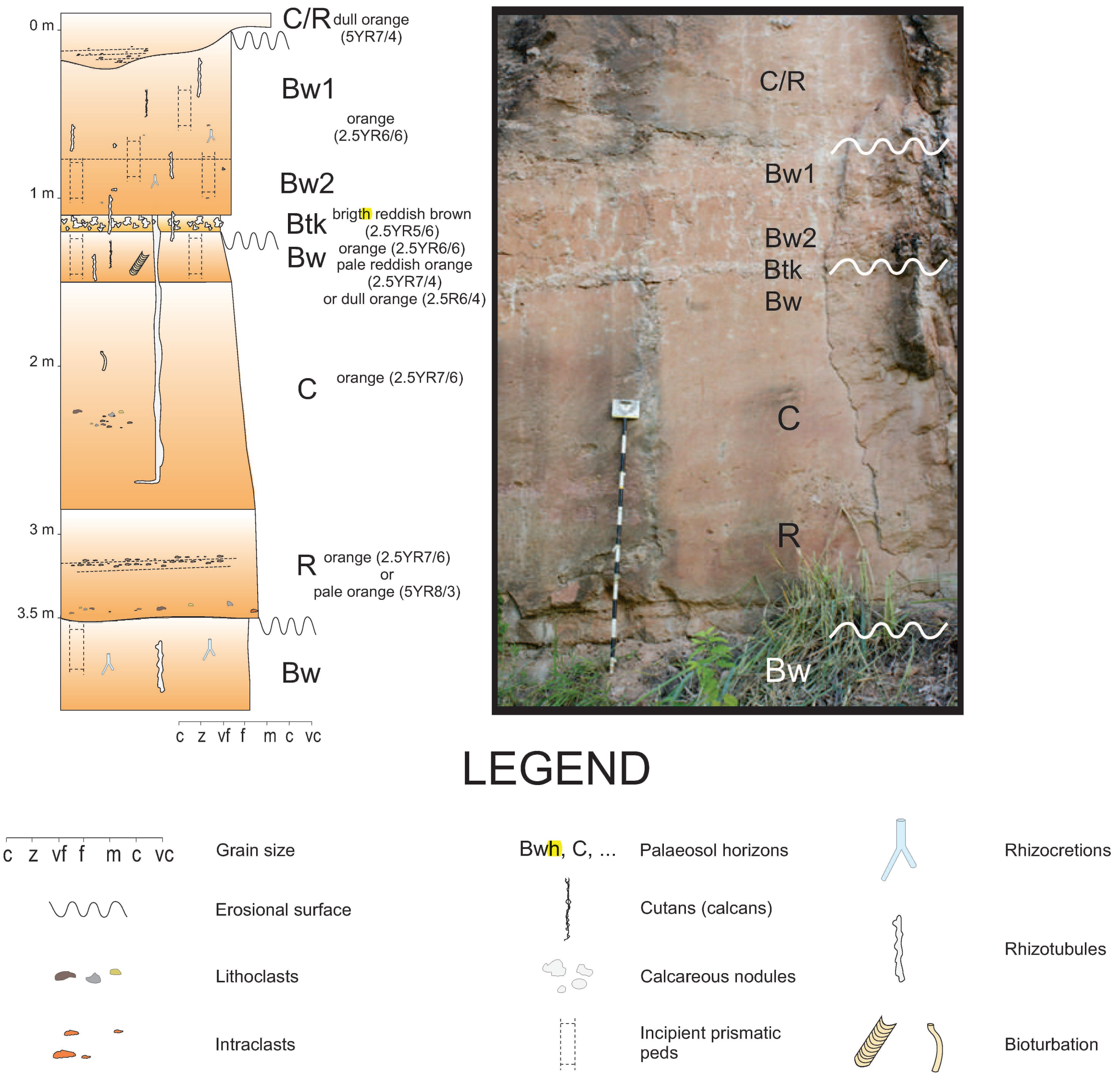

0 m
1 m
2 m
3 m
3.5 m
C/R dull orange (5YR7/4)
Bw1 orange (2.5YR6/6)
Bw2
Btk brigth reddish brown (2.5YR5/6)
Bw orange (2.5YR6/6) pale reddish orange (2.5YR7/4) or dull orange (2.5R6/4)
C orange (2.5YR7/6)
R orange (2.5YR7/6) or pale orange (5YR8/3)
Bw
c z vf f m c vc
C/R
Bw1
Bw2
Btk
Bw
C
R
Bw
LEGEND
c z vf f m c vc
Grain size
Erosional surface
Lithoclasts
Intraclasts
Bwh, C, ...
Palaeosol horizons
Cutans (calcans)
Calcareous nodules
Incipient prismatic peds
Rhizocretions
Rhizotubules
Bioturbation

FIGURE 9

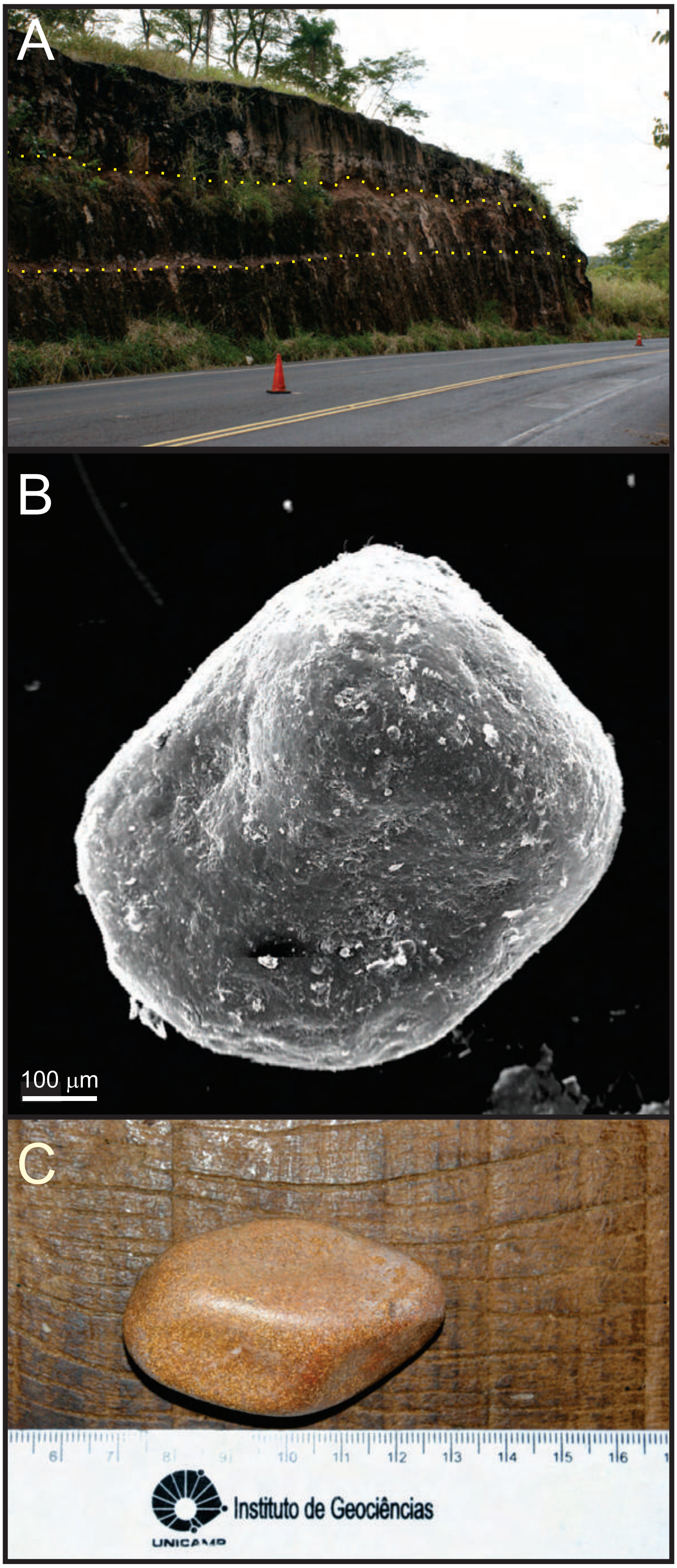

A
B
100 µm
C
6 7 8 9 10 11 12 13 14 15 16
Instituto de Geociências
UNICAMP

FIGURE 10

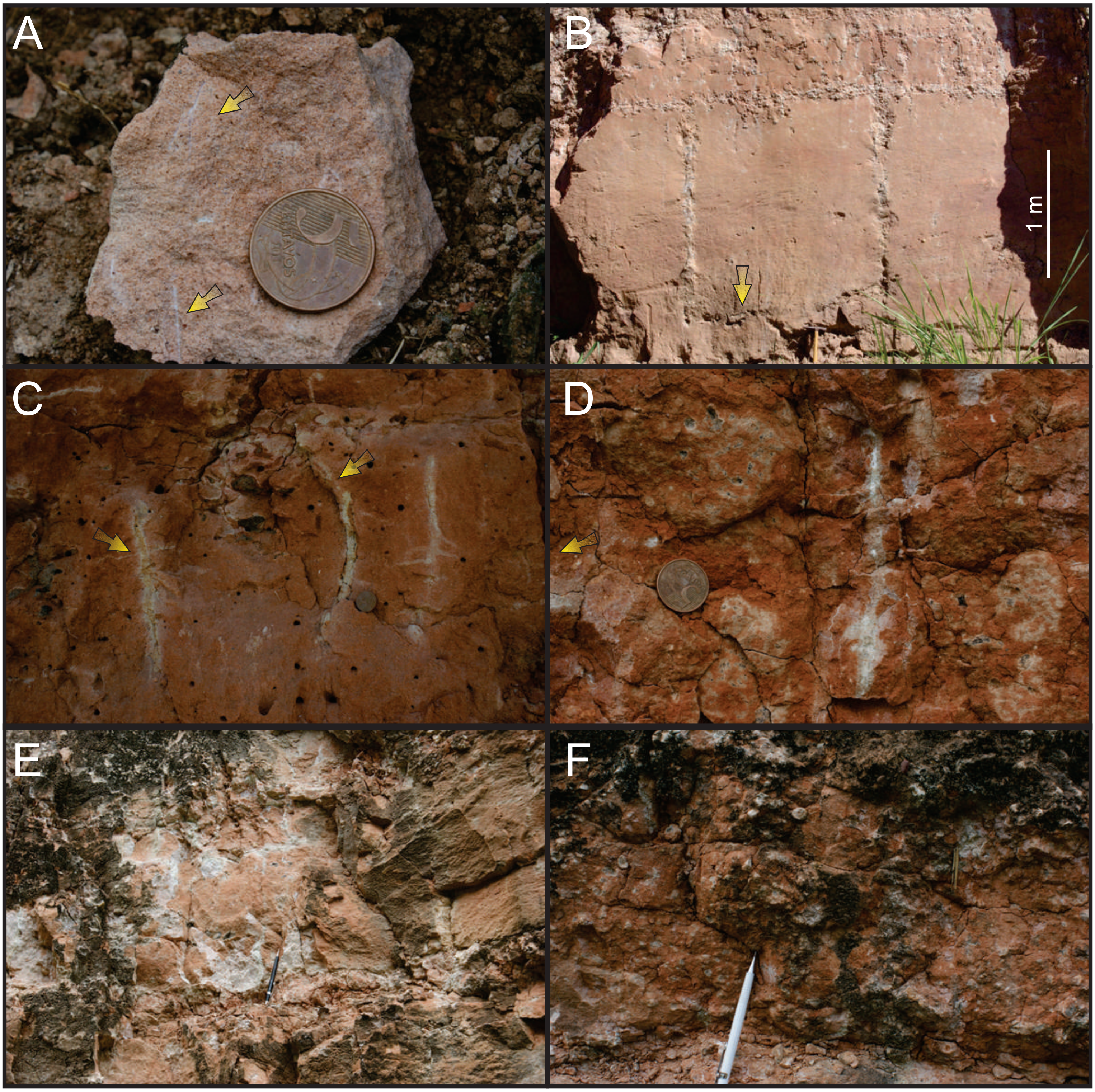
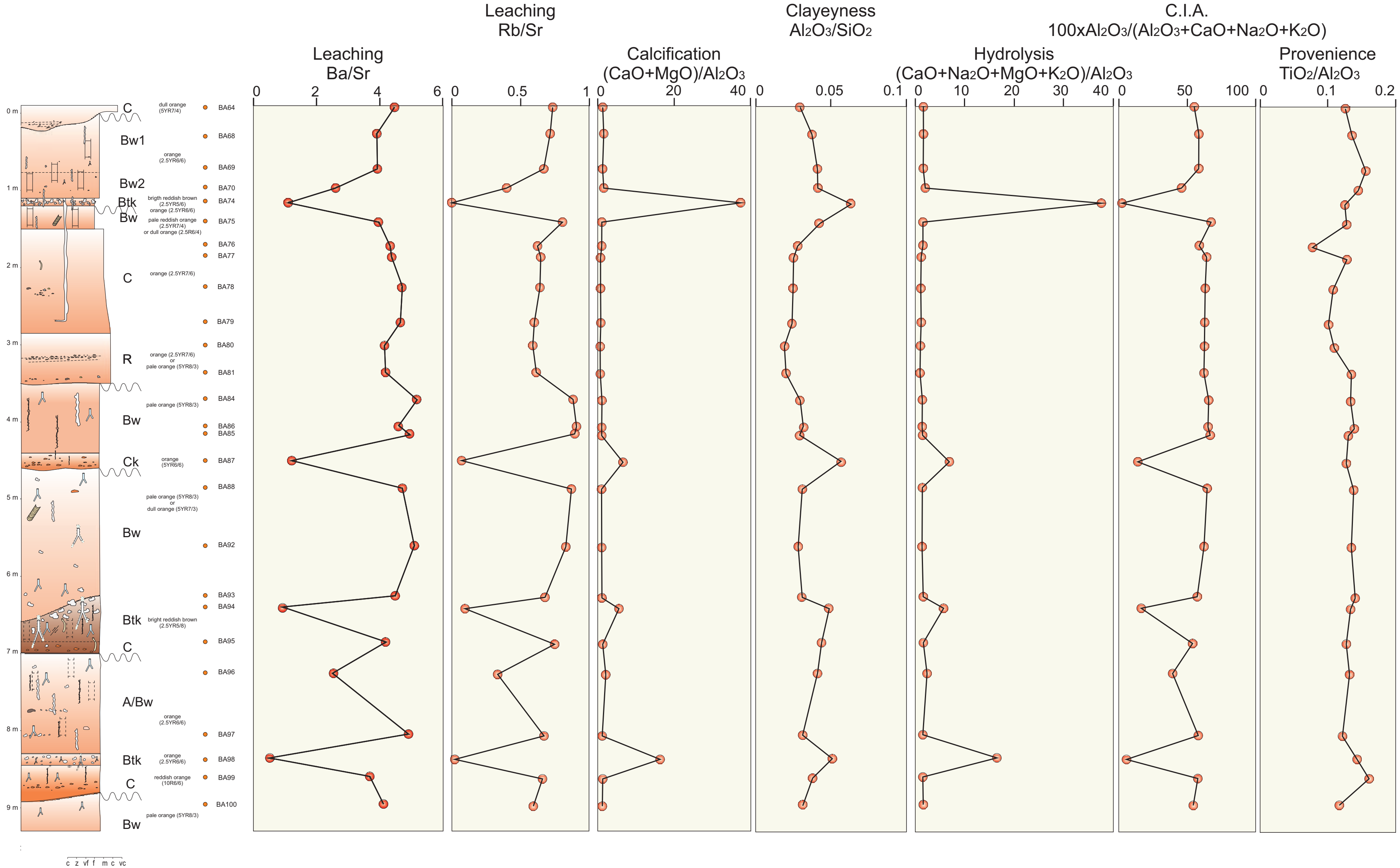


FIGURE 11



Leaching
Ba/Sr
Leaching
Rb/Sr
Calcification
(CaO+MgO)/Al2O3
Clayeyness
Al2O3/SiO2
Hydrolysis
(CaO+Na2O+MgO+K2O)/Al2O3
C.I.A.
100xAl2O3/(Al2O3+CaO+Na2O+K2O)
Provenience
TiO2/Al2O3
C
Bw1
Bw2
Btk
Bw
C
R
Bw
Ck
Bw
Btk
C
A/Bw
Btk
C
Bw
BA64
BA68
BA69
BA70
BA74
BA75
BA76
BA77
BA78
BA79
BA80
BA81
BA84
BA86
BA85
BA87
BA88
BA92
BA93
BA94
BA95
BA96
BA97
BA98
BA99
BA100
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
8 m
9 m
c z vf f m c vc

FIGURE 12

FIGURE 13

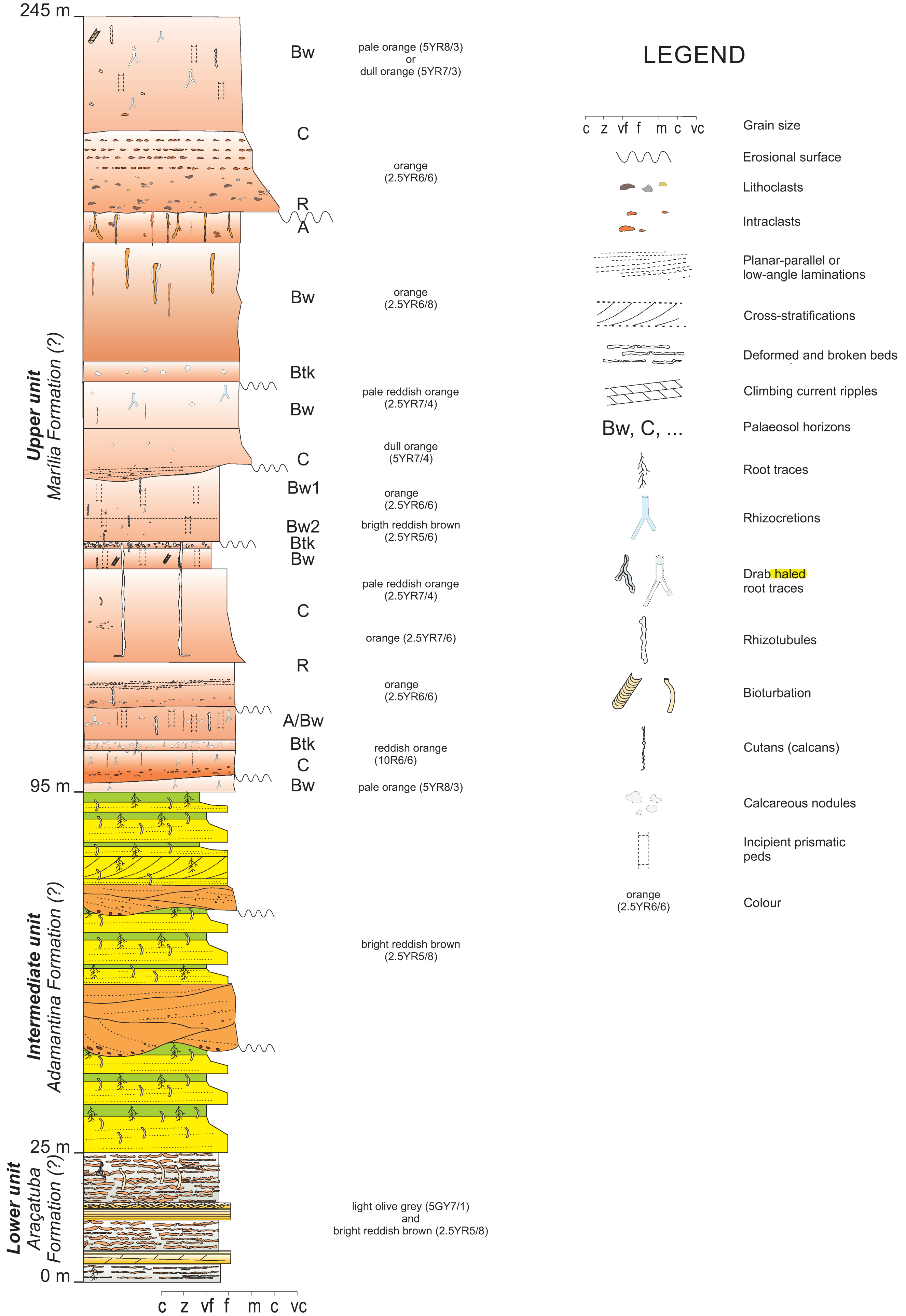

245 m
Bw
pale orange (5YR8/3)
or
dull orange (5YR7/3)
C
orange
(2.5YR6/6)
R
A
Bw
orange
(2.5YR6/8)
Btk
Bw
pale reddish orange
(2.5YR7/4)
C
dull orange
(5YR7/4)
Bw1
orange
(2.5YR6/6)
Bw2
Btk
Bw
brigth reddish brown
(2.5YR5/6)
pale reddish orange
(2.5YR7/4)
C
orange (2.5YR7/6)
R
orange
(2.5YR6/6)
A/Bw
Btk
reddish orange
(10R6/6)
C
Bw
pale orange (5YR8/3)
95 m
Upper unit
Marília Formation (?)
Intermediate unit
Adamantina Formation (?)
bright reddish brown
(2.5YR5/8)
25 m
Lower unit
Araçatuba
Formation (?)
light olive grey (5GY7/1)
and
bright reddish brown (2.5YR5/8)
0 m
c z vf f m c vc
LEGEND
c z vf f m c vc
Grain size
Erosional surface
Lithoclasts
Intraclasts
Planar-parallel or
low-angle laminations
Cross-stratifications
Deformed and broken beds
Climbing current ripples
Bw, C, ...
Palaeosol horizons
Root traces
Rhizocretions
Drab haled
root traces
Rhizotubules
Bioturbation
Cutans (calcans)
Calcareous nodules
Incipient prismatic
peds
orange
(2.5YR6/6)
Colour

FIGURE 14

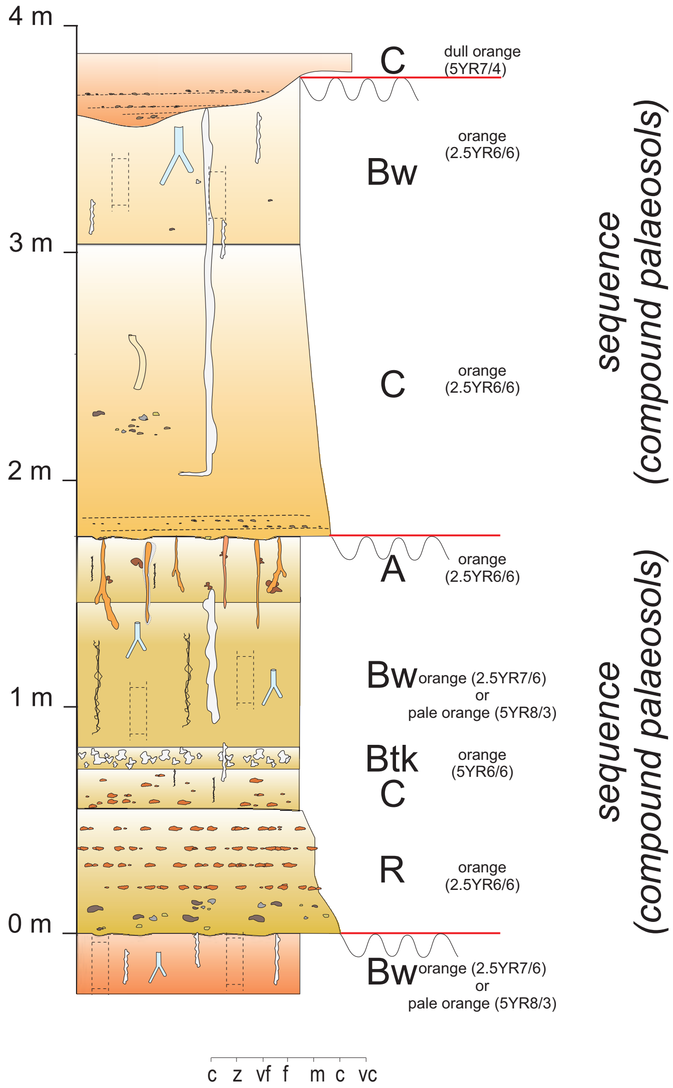

4 m
3 m
2 m
1 m
0 m
C
dull orange (5YR7/4)
orange (2.5YR6/6)
Bw
C
orange (2.5YR6/6)
A
orange (2.5YR6/6)
Bw orange (2.5YR7/6) or pale orange (5YR8/3)
Btk
orange (5YR6/6)
C
R
orange (2.5YR6/6)
Bw orange (2.5YR7/6) or pale orange (5YR8/3)
sequence (compound palaeosols)
sequence (compound palaeosols)
c z vf f m c vc

FIGURE 15

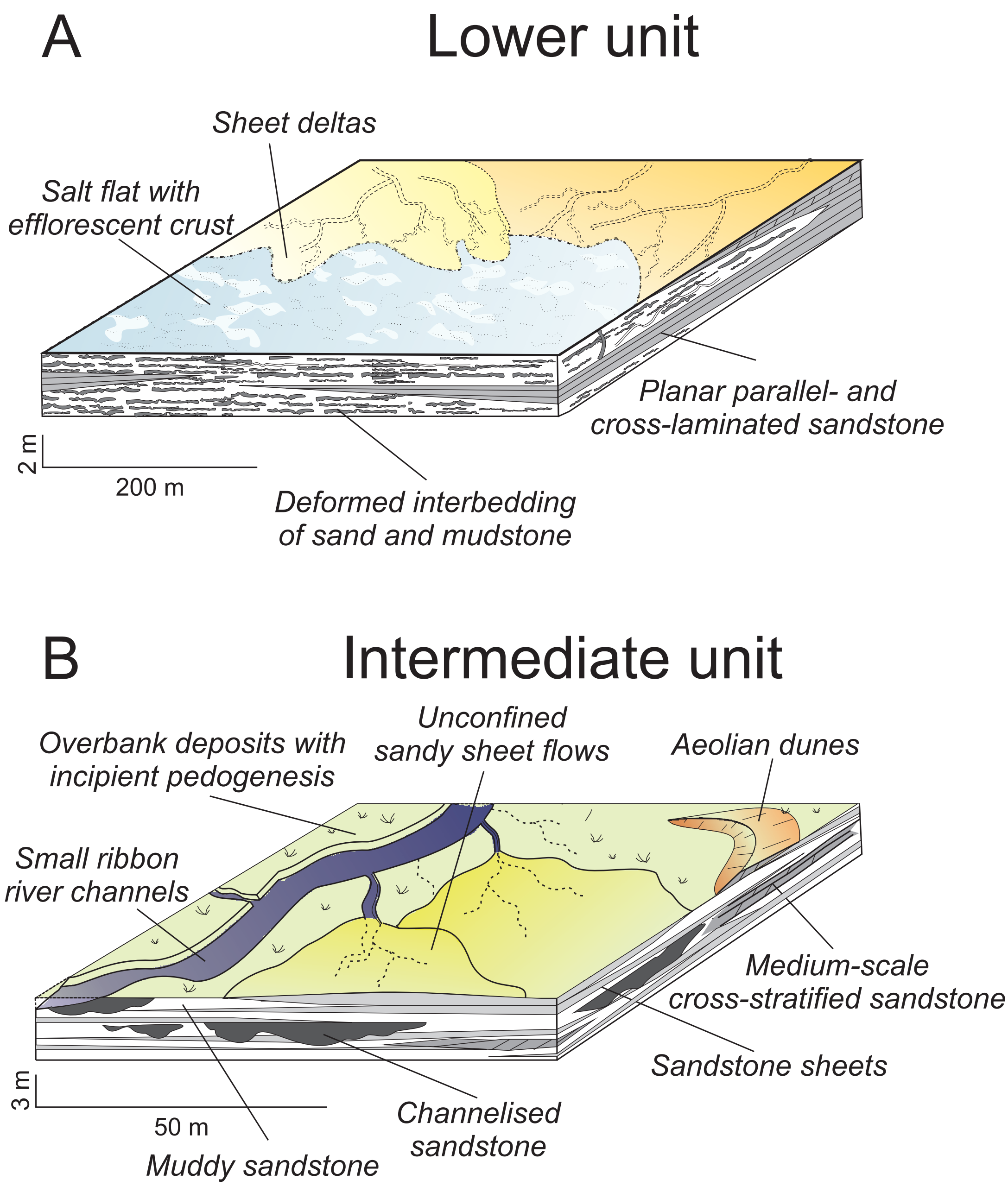

A
Lower unit
Sheet deltas
Salt flat with
efflorescent crust
Planar parallel- and
cross-laminated sandstone
2 m
200 m
Deformed interbedding
of sand and mudstone
B
Intermediate unit
Unconfined
sandy sheet flows
Overbank deposits with
incipient pedogenesis
Aeolian dunes
Small ribbon
river channels
Medium-scale
cross-stratified sandstone
Sandstone sheets
3 m
50 m
Channelised
sandstone
Muddy sandstone

FIGURE 16

Upper unit

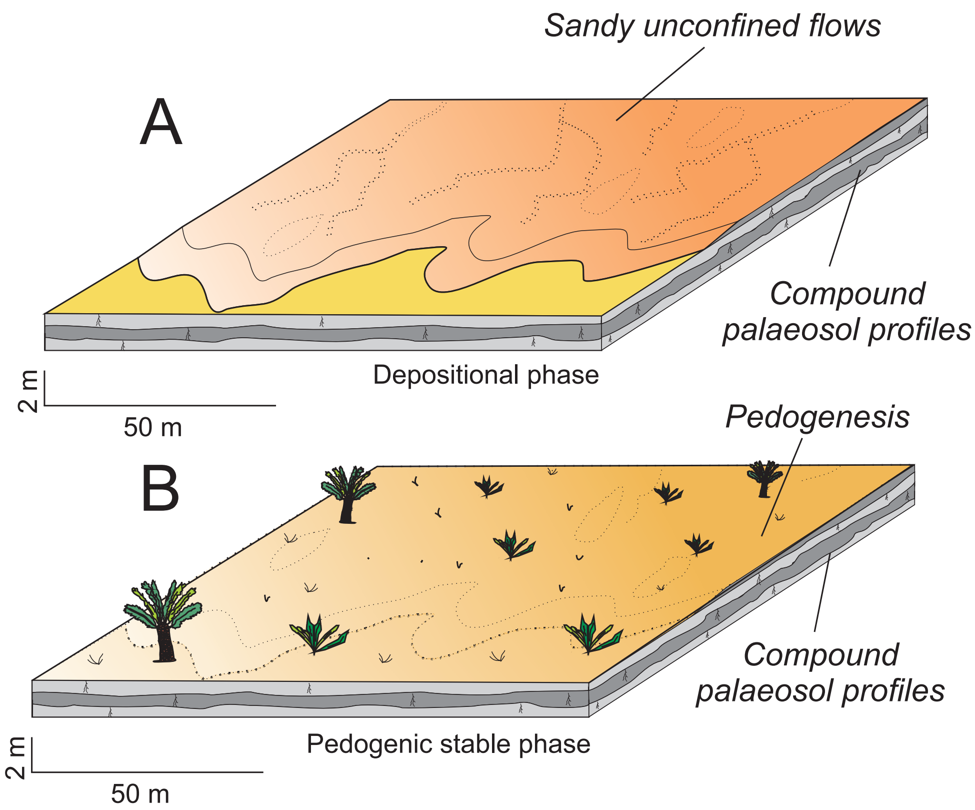


FIGURE 17

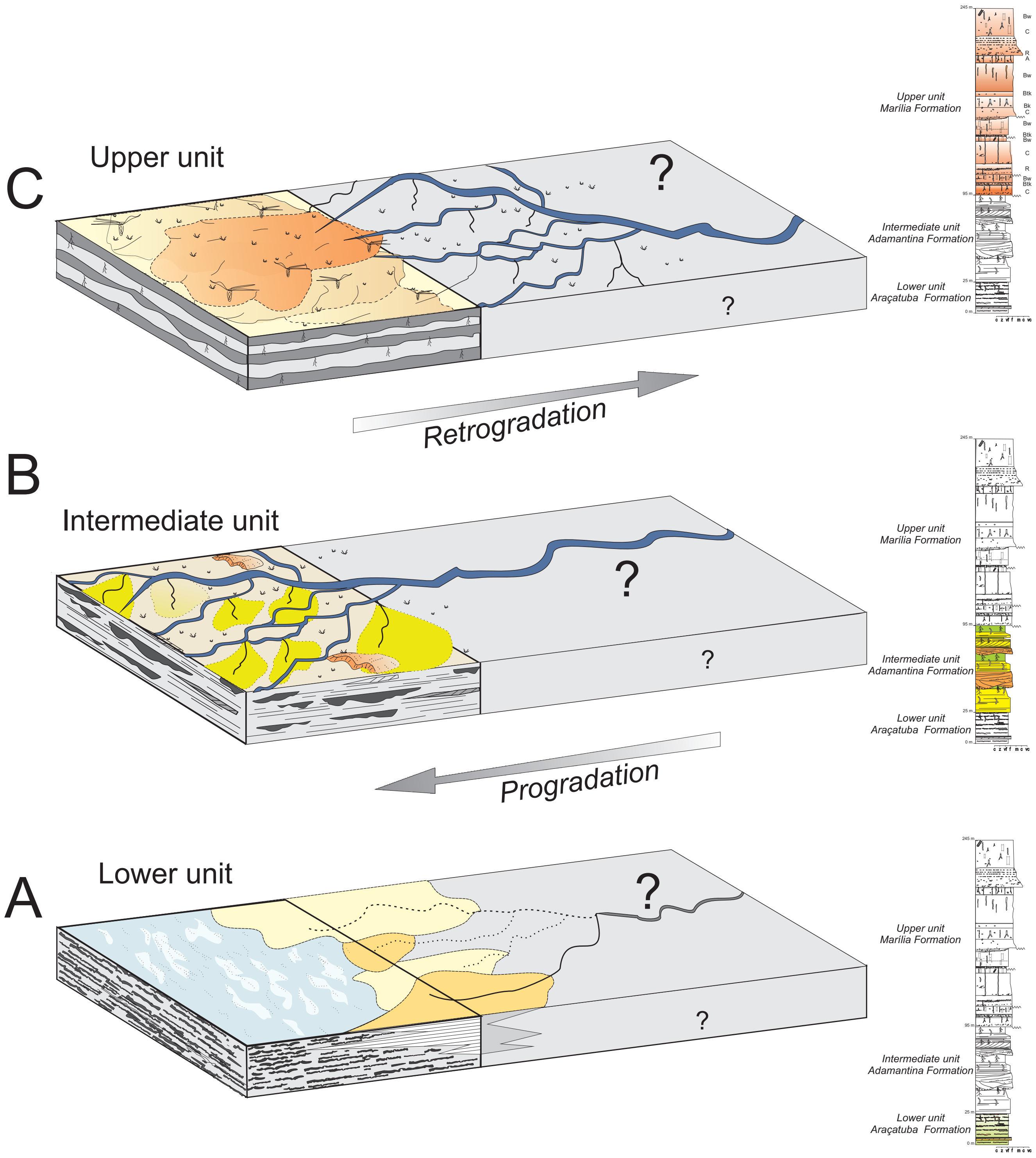

C
Upper unit
?
?
Upper unit
Marília Formation
Intermediate unit
Adamantina Formation
Lower unit
Araçatuba Formation
Retrogradation
B
Intermediate unit
?
?
Upper unit
Marília Formation
Intermediate unit
Adamantina Formation
Lower unit
Araçatuba Formation
Progradation
A
Lower unit
?
?
Upper unit
Marília Formation
Intermediate unit
Adamantina Formation
Lower unit
Araçatuba Formation

FIGURE 18

Facies and palaeosols name	Stratigraphic occurrence	Description	Interpretation	Figures
Deformed interbedding of sandstone and mudstone	Lower unit	Irregular, broken, undulated and micro-folded interbedding of laminae or patches of well-sorted, fine- to very fine-grained weakly-cemented sandstone (olive grey - 5GY7/1) and mudstone (bright reddish brown - 2.5YR5/8) Drab-haloed root traces and bioturbation are present.	Sedimentary structures formed by growing of thin salt efflorescent crusts on a salt flat or playa-lake. Root traces and reddish colour indicate subaerial conditions.	Fig. 4
Planar parallel and cross-laminated sandstone	Lower unit	Tabular beds of well-sorted, fine- and very fine-grained weakly cemented sandstone. Planar parallel laminations, climbing cross-laminations and this mudstone beds constituted small sequences in this order. Trough cross-laminations with opposite dip of the foresets are present.	Deposition by unidirectional subaqueous waning flows passing from upper to lower flow regime. These deposits formed sheet deltas at the margin of the flooded salt flat. Trough cross-laminations with opposite dip of the foresets indicate wave reworking.	Figs. 5 and 6
Muddy sandstone	Intermediate unit	Tabular muddy very fine-grained sandstone. Bioturbation and small rhizocretions are present.	Deposition by low-energy and unconfined flows in floodplain area. Root traces indicate incipient pedogenesis.	Figs. 7 and 8A
Sheet sandstone	Intermediate unit	Sheet shape beds of fine-grained sandstone, structureless or with local planar laminations.	Deposition by unconfined depositional subaqueous flows characterised by rapid deceleration of the flow and consequent deposition of sediment from suspension. Planar laminations may be related to subaqueous upper flow regime.	Figs. 7
Channelised sandstone	Intermediate unit	Ribbon shape sandstone bodies with concave-up bottom and flat top. Internally, constituted by various lenticular beds divided by concave-up erosive surfaces.	Deposition in multistorey ribbon-shape fixed channel.	Figs. 7 and 8B
Medium-scale cross-stratified sandstone	Intermediate unit	Tangential cross-stratifications of fine- and very fine-grained sandstone.	Small aeolian dunes.	Fig. 8C
Echaporã pedotype	Upper unit	A-Bw-(Btk)-C-R, horizons in most complete profiles. A, Btk and R horizon are in general absent. Parent material is fine- to medium-grained, moderately to well-sorted sandstone. Incipient prismatic structures and poorly developed calcium carbonate concentration are present.	Poorly developed palaeosols. Inceptisol or calcic Protosol.	Figs. 9, 10, 11 and 12
Structureless and planar-stratified conglomeratic sandstone	Upper unit	Sheet beds of conglomeratic sandstone. Structureless or organised in alternating beds of sandstone and conglomerate, with pebble-sized showing a bed parallel orientation.	Unconfined subaqueous flows.	Fig.13

TABLE 1

Sample	Depth m	Leaching Ba/Sr	Leaching Rb/Sr	Calcification	Clay formation	Hydrolysis	C.I.A.	Provenience TiO2/Al2O3
BA64	0	4.42	0.74	1.31	0.03	1.68	55.6	0.13
BA68	35	3.87	0.71	1.23	0.04	1.61	58.9	0.14
BA69	80	3.87	0.67	1.26	0.04	1.61	58.6	0.15
BA70	105	2.57	0.4	1.66	0.04	2.02	46.5	0.14
BA74	125	1.07	0.01	37.3	0.06	37.5	2.71	0.12
BA75	150	3.92	0.8	1.16	0.04	1.5	67.8	0.13
BA76	180	4.28	0.63	1.12	0.03	1.51	59.1	0.08
BA77	195	4.33	0.64	0.77	0.03	1.18	64.3	0.13
BA78	235	4.64	0.64	0.71	0.03	1.12	63.7	0.11
BA79	280	4.6	0.6	0.8	0.02	1.19	62.8	0.1
BA80	310	4.11	0.59	0.6	0.02	1.02	62.9	0.11
BA81	345	4.14	0.61	0.6	0.02	1.03	62.8	0.13
BA84	380	5.12	0.89	0.99	0.03	1.41	65.9	0.13
BA86	415	4.55	0.91	0.96	0.03	1.37	65.6	0.14
BA85	425	4.89	0.89	1.01	0.03	1.42	66.7	0.13
BA87	460	1.18	0.08	6.64	0.06	6.92	14.3	0.13
BA88	495	4.67	0.87	1.02	0.03	1.42	64.8	0.14
BA92	570	5.04	0.83	1	0.03	1.42	62.7	0.13
BA93	635	4.43	0.68	1.16	0.03	1.58	57.4	0.14
BA94	650	0.9	0.1	5.5	0.05	5.82	16.8	0.13
BA95	695	4.15	0.75	1.29	0.04	1.65	54.2	0.13
BA96	735	2.5	0.35	2	0.04	2.35	39.6	0.13
BA97	815	4.87	0.67	1.16	0.03	1.55	58.3	0.12
BA98	845	0.49	0.03	16.2	0.05	16.5	6.06	0.14
BA99	870	3.65	0.66	1.23	0.04	1.55	58	0.16
BA100	905	4.07	0.59	1.19	0.03	1.56	54.7	0.12

TABLE 3

Major oxides (weight percentage)

Sample	Depth m	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	*Total*
BA64	0	86.65	0.427	4.35	1.63	0.016	1.51	1.03	0.19	1.19	0.042	2.9	99.9
BA68	35	83.8	0.562	5.31	1.8	0.022	1.91	0.93	0.29	1.42	0.05	3.25	99.3
BA69	80	82.45	0.697	5.75	2.28	0.02	2.06	1.12	0.28	1.45	0.058	3.49	99.6
BA70	105	80.46	0.639	5.66	2.21	0.025	1.94	2.46	0.28	1.45	0.062	4.29	99.5
BA74	125	19.55	0.205	2.1	1.1	0.14	1.32	41.25	0	0.35	0.004	33.8	99.8
BA75	150	82.97	0.596	5.97	2.28	0.021	2.43	0.44	0.3	1.42	0.055	3.44	99.9
BA76	180	87.79	0.248	4.13	1.32	0.014	1.33	0.69	0.2	1.18	0.048	2.49	99.4
BA77	195	89.44	0.387	3.87	1.57	0.021	0.96	0.31	0.18	1.19	0.041	1.74	99.7
BA78	235	90.38	0.323	3.84	1.41	0.018	0.84	0.33	0.18	1.19	0.042	1.55	100.1
BA79	280	89.87	0.29	3.68	1.29	0.02	0.87	0.41	0.16	1.08	0.036	1.71	99.4
BA80	310	91.96	0.262	3.06	1.13	0.015	0.52	0.28	0.13	1	0.033	1.27	99.6
BA81	345	91.67	0.336	3.2	1.23	0.018	0.55	0.29	0.14	1.05	0.037	1.16	99.7
BA84	380	86.93	0.457	4.38	1.51	0.015	1.54	0.24	0.2	1.39	0.037	3.14	99.8
BA86	415	86.13	0.508	4.67	1.63	0.013	1.57	0.28	0.2	1.49	0.04	3.27	99.8
BA85	425	87.15	0.443	4.36	1.52	0.015	1.59	0.22	0.15	1.41	0.04	3.14	100
BA87	460	54.86	0.521	5.26	2.34	0.125	1.93	16.54	0.11	1.19	0.044	16.8	99.7
BA88	495	86.57	0.494	4.59	1.7	0.014	1.6	0.34	0.18	1.46	0.041	3.33	100.3
BA92	570	87.37	0.442	4.21	1.4	0.017	1.38	0.39	0.17	1.4	0.039	2.93	99.7
BA93	635	86.03	0.495	4.53	1.65	0.021	1.5	0.8	0.21	1.44	0.042	3.47	100.2
BA94	650	62.18	0.534	5.12	2.13	0.044	1.73	13.07	0.17	1.29	0.055	13.6	99.9
BA95	695	80.92	0.598	6.04	2.38	0.019	1.92	1.6	0.29	1.58	0.058	5	100.4
BA96	735	80.91	0.585	5.67	2.32	0.038	1.84	3.67	0.24	1.47	0.052	2.8	99.6
BA97	815	86.18	0.435	4.58	1.61	0.015	1.51	0.82	0.22	1.31	0.045	3.52	100.3
BA98	845	38.79	0.376	3.37	1.51	0.068	1.34	28.18	0.14	0.69	0.06	24.9	99.4
BA99	870	82.01	0.663	5.3	2.51	0.023	1.73	1.17	0.22	1.25	0.06	4.34	99.3
BA100	905	85.53	0.412	4.54	1.76	0.014	1.31	1.16	0.17	1.27	0.049	3.75	100

Trace elements (ppm)

Sample	Depth m	*Ba*	*Ce*	*Cr*	*Cu*	*Ga*	*La*	*Nb*	*Nd*	*Ni*	*Pb*	*Rb*	*Sc*	*Sr*	*Th*	*V*	*Y*	*Zn*	*Zr*
BA64	0	319	24	42	3.4	3.7	14	10	10	8.1	8	33	5	46	2.6	51	6.6	14.4	172
BA68	35	340	27	61	4.5	5.9	15	15	16	12.7	10.9	39	6	56	5.1	56	7.5	19.7	188
BA69	80	370	36	87	5.4	5	<13	18.4	15	13.5	9.4	40	9	61	5	61	8.6	22.2	222
BA70	105	390	35	206	4.2	4.4	18	17.5	22	12.4	11.2	38	7	97	4.3	65	9.2	22.4	208
BA74	125	704	17	12.9	<1.5	4.4	31	6.6	<8	9.9	17.5	4.2	16	418	<2	33	19.9	10.8	54
BA75	150	307	36	46	4.9	6	18	13.3	21	12.9	9.1	39	10	50	5.8	71	8.7	20.5	205
BA76	180	349	16	19.7	4.1	4.9	13	8	<8	8.3	7.3	32	5	52	4.3	41	5.9	14.2	100
BA77	195	346	20	39	3.6	2.7	14	8.8	16	8.2	9.1	32	4	51	5.9	49	5.7	13.8	125
BA78	235	371	24	90	2.3	3	16	7.8	<8	7.8	8.9	32	4	51	3.6	53	5	15.9	104
BA79	280	368	20	155	2	2.6	19	7.9	10	8.5	9.4	30	5	51	2.9	64	5.6	14.4	99
BA80	310	309	11	62	3.1	<2	<13	7	<8	5	7.4	27.7	<3	48	<2	36	6.3	10	107
BA81	345	318	14	51	3	3.3	<13	8.1	8	6.3	8.8	29.4	<3	49	2.3	48	6.2	11.8	110
BA84	380	353	16	57	3.4	6.2	15	14.5	17	9.7	10.4	38	4.5	44	3.5	43	7.4	15.2	190
BA86	415	328	24	45	4.8	6.3	16	15.7	21	10.1	10	41	3.3	46	5.4	46	8.5	14.6	210
BA85	425	345	23	32	4.7	6.1	17	13.6	13	9.9	10.3	39	4.7	45	6	43	8.4	14	183
BA87	460	798	50	41	4.5	7	38	19.8	31	17	24.7	33	9	430	5.6	56	18.5	23.8	153
BA88	495	344	30	39	5.3	6.4	16	14.9	12	9.8	10.8	40	3.3	47	4.2	50	7.7	14.8	201
BA92	570	371	18	34	3.5	4.6	21	14	14	8.1	10.6	38	5.3	47	4.9	48	6.1	14.4	194
BA93	635	410	22	35	4.5	5.9	16	15.5	15	9.1	12.4	39	4.3	59	4.6	52	7.7	15.1	195
BA94	650	487	41	41	4.6	6.3	39	21.6	23	14.8	15.4	35	9.9	345	5.2	61	13.5	24.5	182
BA95	695	410	25	42	8.2	8.8	19	18.7	26	14.6	10.1	46	5.7	63	4.5	73	10.9	24	224
BA96	735	475	36	44	7.7	7.5	26	18.4	33	13.4	13	41	5.1	121	5.9	73	12	23.1	203
BA97	815	420	18	36	4.6	5.9	16	13.1	<11	9.3	10.1	36	3.3	55	4.4	55	7.2	16	171
BA98	845	472	38	21	<1	5.2	32	12.7	21	10.3	13.8	15.8	10.9	611	3.4	30	13.5	17	143
BA99	870	320	31	60	5.7	7	19	14.6	26	13.6	11.3	36	5.1	56	5	79	10.4	21	285
BA100	905	364	17	36	3.9	6.1	10	10.9	11	10.5	9.1	33	4.6	57	2.7	57	6.9	16.7	159

TABLE 2