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DAVI PAULO SILVA

ANÁLISE DE FÁCIES E ESTRATIGRAFIA DE SEQUÊNCIAS NO MEMBRO FUNIL, PALEOPROTEROZOICO DO ESCUDO DAS GUIANAS

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ANÁLISE DE FÁCIES E ESTRATIGRAFIA DE SEQUÊNCIAS NO MEMBRO FUNIL, PALEOPROTEROZOICO DO ESCUDO DAS GUIANAS

Dissertação de mestrado apresentado ao Programa de Pós-Graduação em Geociências da Universidade Federal do Amazonas.

ORIENTADOR: PROF. DR. ROBERTO CESAR DE MENDONÇA BARBOSA

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Dissertação apresentada ao Programa de Pós-Graduação em Geociências da Universidade Federal do Amazonas, como requisito parcial para obtenção do Título de Mestre em Geociências, área de concentração em Geociências.

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(**ROMANOS 11:36**)

[...] Ele não é mais um bebê na manjedoura
Ele não está pendurado numa cruz
Ele ressuscitou, Ele está vivo
E com poder e glória voltará [...]
(CPN)

RESUMO

A avaliação sedimentar e aplicação de conceitos de estratigrafia de sequências em rochas pré-cambrianas são menos frequentes quando comparadas com as de idade fanerozoica, principalmente ligado à alta taxa de reciclagem da crosta pré-cambriana e a processos de recristalização que dificultam o estabelecimento de padrões de empilhamento e superfícies estratigráficas chave. Contudo, sucessões sedimentares pré-cambrianas com exposições amplas e estruturas sedimentares bem preservadas do Membro Funil, distribuídas na Serra do Tepequém (RR) representam uma ótima oportunidade de entender como a sedimentação responde a variações de alta frequência da linha de costa e assim, proporcionar uma melhor correlação estratigráfica dessas exposições com o Supergrupo Roraima. Diante destas condições, essa pesquisa apresenta a avaliação faciológica e de estratigráfica de sequência no Membro Funil com o objetivo de fornecer critérios de distinção entre as unidades da serra, entender a deposição da unidade no contexto de variações eustáticas e tecer considerações a respeito da paleogeografia no Escudo das Guianas. A avalição faciológica identificou 13 fácies que integram uma planície de maré com paleocosta orientada à NE-SW, no contexto paleoproterozoico, que abrangem depósitos de canais fluviais *braided*, canais de maré, planícies lamosas e mista. O Membro Funil representa a porção distal correlata aos depósitos continentais da Formação Arai do Supergrupo Roraima, no extremo nordeste do estado de Roraima. A unidade está organizada em sequências *deepening* e *thickening upward* de 4ª ordem limitadas por superfícies de inundação marinha, representada pela sobreposição dos depósitos de planície lamosa por planície mista e pelo espessamento dos depósitos de canais de maré, que configuram um empilhamento retrogradacional englobado no trato de sistema transgressivo da sequência inferior do Supergrupo Roraima. As sequências de 4ª ordem internamente são marcadas por camadas com padrão *thinning upward* separadas em domínio fluvial e transicional. Essa organização estratal indica a criação progressiva do espaço de acomodação ligada a migração da linha de costa em direção ao continente. As informações geradas aqui permitiram, de forma inédita, o estabelecimento de sequências no Membro Funil, além de uma releitura da estratigrafia da porção basal do Supergrupo Roraima à luz de conceitos da estratigrafia de sequências.

Palavras-chave: Cráton Amazonas; Pré-Cambriano; Formação Arai; Planície de maré.

ABSTRACT

The sedimentary evaluation and application of sequence stratigraphy concepts in Precambrian rocks are less frequent concerning Phanerozoic age, mainly linked to the high recycling rate of the Precambrian crust and to recrystallization processes that hinder the establishment of stacking patterns and stratigraphic surfaces. However, Precambrian sedimentary successions with broad exposures and well-preserved sedimentary structures of the Funil Member distributed in Serra do Tepequém (RR) represents an excellent opportunity to understand how sedimentation responds to high-frequency variations of the coastline and thus provide a better stratigraphic correlation of these exposures with the Roraima Supergroup. Because of these conditions, this research presents the facies analysis and stratigraphic sequence in the Funil Member with the objective of providing criteria of distinction between the units of the mountain, understanding the deposition of the unit in the context of eustatic variations and making considerations on Guiana Shield paleogeography. The facies analysis identified 13 facies that comprise tidal flat with paleoshoreline oriented to NE-SW, in the Paleoproterozoic context, that include deposits of braided river channels, tidal channels, mud and mixed flats. The Funil Member represents the distal portion related to the continental lake deposits of the Arai Formation of the Roraima Supergroup, in the extreme northeast of Roraima State. The unit is organized in 4^{th} order deepening and thickening upward sequences limited by marine flooding surfaces, represented by the overlapping of mud flat deposits, mixed flat and thickening of tidal channel deposits, which configure a retrogradational stacking included in the transgressive systems tract of the lower sequence of the Roraima Supergroup. The 4^{th} order sequences are internally marked by layers with an upward thinning pattern separated in fluvial and transitional domains. This stratum organization indicates the progressive creation of accommodation space linked to migration of the coastline to continent. The information generated here allowed, in an unprecedented way, the establishment of sequences in the Funil Member, in addition to a re-reading of the stratigraphy of the basal portion of the Roraima Supergroup in the light of concepts of the sequence stratigraphy.

Keywords: Amazon Craton; Precambrian; Arai Formation; Tidal plain.

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CAPÍTULO 1 INTRODUÇÃO

1.1 Apresentação

O Pré-Cambriano é marcado por mudanças ambientais planetárias extremas como, por exemplo, o rápido crescimento e reciclagem crustal, aumento da concentração de oxigênio na atmosfera, surgimento das primeiras formas de vida nos amplos oceanos e glaciações globais (BETTS et al, 2018; HOLLAND, 2006; ROSAS & KORENAGA, 2018; YOUNG, 2013, 2018). Sendo assim, tem sido crescente o número de pesquisas em sucessões pré-cambrianas, que auxiliam na interpretação e entendimento das condições paleoambientais que imperavam nos primórdios do planeta (FRALICK & RIDING, 2015; IELPI & RAINBIRD, 2016; KALE, 2016; SIAHI et al, 2016; SOUZA et al, 2019).

Apesar deste éon constituir mais de 80% da história da Terra, avaliações sedimentares são menos frequentes, resultado principalmente de menores exposições ligadas à ampla reciclagem da crosta além do maior interesse econômico em rochas sedimentares fanerozoicas reservatório de hidrocarbonetos (ALTERMANN & CORCORAN, 2002; LONGDE et al, 2015).

Rochas sedimentares proterozoicas do Escudo das Guianas são encontradas no Bloco Sedimentar Pacaraima (BSP), com afloramentos concentrados principalmente na Venezuela, Guianas, Suriname e nos extremo nordeste e noroeste do estado de Roraima, Brasil (REIS et al, 2017; REIS & YÁNEZ, 2001). Rochas do BSP são litoestratigraficamente reunidas no Supergrupo Roraima, que foram depositadas discordantemente sobre as rochas vulcânicas do Grupo Surumu durante o Orosiriano (PINHEIRO et al, 1990; REIS & YÁNEZ, 2001; SANTOS et al, 2003; UHLEIN et al, 2015).

O Supergrupo Roraima é caracterizado por depósitos que registram a implantação de ambientes amplamente continentais na base, passando progressivamente para condições transicionais no topo, além de intercalações vulcânicas piroclásticas, diques e soleiras de diabásio (LONG, 2002; PINHEIRO et al, 1990; REIS et al, 2017; REIS & YÁNEZ, 2001; WANKLER et al, 2001, 2003). Grande parcela do seu conhecimento estratigráfico e geocronológico foi desencadeado pela ocorrência de ouro e diamante detríticos concentrados nas drenagens que secciona uma unidade conglomerática oligomítica, fornecendo assim informações preliminares sobre a paleogeografia proterozoica do Escudo das Guianas (PINHEIRO et al, 1990; REIS et al, 2017; WANKLER et al, 2003).

Na porção norte do Estado de Roraima, exposições de rochas sedimentares com estruturas primárias preservadas e correlatas ao Supergrupo Roraima estão concentradas na Serra do Tepequém, um morro testemunho isolado na forma de platô (FERNANDES FILHO et al, 2012; REIS et al, 2017). Entretanto, o contexto estratigráfico destas rochas ainda não é um consenso entre os geólogos. Parte deste conflito é atribuída aos estratos tectonicamente deformados que dificulta o controle estratigráfico, à não utilização de superfícies estratigráficas regionais e princípios da estratigrafia de sequências, além de os trabalhos prévios de mapeamentos serem de caráter regional e com enfoque apenas na caracterização petrográfica superficial (FRAGA et al, 2010; LUZARDO, 2006), enquanto estudos de fácies sedimentares e estratigráficos, que poderiam fornecer critérios de distinção entre estas unidades são escassos (FERNANDES FILHO, 2010).

Esse quadro impediu a precisa correlação estratigráfica com unidades correlatas do BSP, bem como tecer considerações sobre a dispersão sedimentar e a reconstituição paleogeográfica do Proterozoico do sul do Escudo das Guianas. Adicionalmente, as exposições vulcânicas intercaladas nas unidades da Serra do Tepequém nunca foram caracterizadas faciologicamente, tampouco datadas, o que poderiam ajudar na correlação estratigráfica com a porção nordeste do Escudo das Guianas.

Neste sentido, esta pesquisa de mestrado propõe uma reinterpretação do quadro litoestratigráfico para as rochas da Serra do Tepequém no contexto do BSP com base na caracterização faciológica, paleoambiental, juntamente com os conceitos de estratigrafia de sequência aplicados nas rochas do Membro Funil, unidade intermediária desta serra. A escolha desta unidade, em especial, é devido ao Membro Funil apresentar em seu topo um dos poucos controles estratigráficos do Supergrupo Roraima, caracterizado por uma superfície erosiva de caráter regional (FERNANDES FILHO, 2010). Assim, estes objetivos têm o intuito de fornecer critérios de distinção entre as unidades da Serra do Tepequém e contribuir no entendimento das condições paleogeográficas do proterozoico do Escudo das Guianas.

1.2 Justificativa

Estudo geológicos em sucessões sedimentares pré-cambrianas na Amazônia demandam um grande esforço logístico devido à ampla cobertura vegetal e espesso manto intempérico que resultam em uma baixa densidade de exposições. De fato, essa particularidade concentra as escassas janelas de informações geológicas em locais onde agentes erosivos naturais atuam com maior intensidade, como por exemplo nas margens dos grandes rios da região que sazonalmente são encobertos durante as cheias, restringindo temporalmente seu acesso. Aliado a esses fatos, o intemperismo que oblitera as estruturas sedimentares e o distanciamento geográfico entre as exposições dificulta sobremaneira as correlações estratigráficas a nível regional e um entendimento mais refinado das condições paleogeográficas.

Avaliações em rochas sedimentares pré-cambrianas sugerem condições e eventos únicos que indicam diferenças nas taxas de intensidades dos processos intempéricos, erosivos, períodos de glaciações globais, oxigenação da atmosfera, ascensão dos eucariontes, quando comparado aos atuais (PARTIN et al, 2013; VAN KRANENDONK et al, 2012; YOUNG, 2017). Contudo, por não existirem modelos faciológicos proterozoicos a reconstituição das condições paleambientais somente pode ser realizado por meio de abordagens atualistas, que permitem entender como os eventos pretéritos moldaram nosso planeta até os dias atuais (DONALDSON et al, 2002; GEORGE, 2017; YUE et al, 2018).

No entanto, amplas exposições de rochas sedimentares pré-cambrianas da Serra do Tepequém com estruturas sedimentares preservadas representam excelentes meios para o entendimento das condições deposicionais deste éon. Levantamentos geológicos englobando a área de estudo realizados pela Reis (1999) e Fraga et al. (2010) foram apenas de âmbito regional e dificultaram assim, a individualização das unidades da serra, a correlação e reconstituições paleoambientais mais precisas, especialmente no contexto do BSP com as principais exposições fora do território brasileiro.

Diante do exposto, o levantamento de dados faciológicos e conotações estratigráficas do Membro Funil, realizadas nessa pesquisa, visam contribuir com critérios de distinção entre unidades da sucessão sedimentar da Serra do Tepequém, bem como refinar informações paleoambientais importantes para a correlação paleogeográfica com as rochas do Supergrupo Roraima.

1.3 Objetivos

Essa dissertação de mestrado teve como principais objetivos:

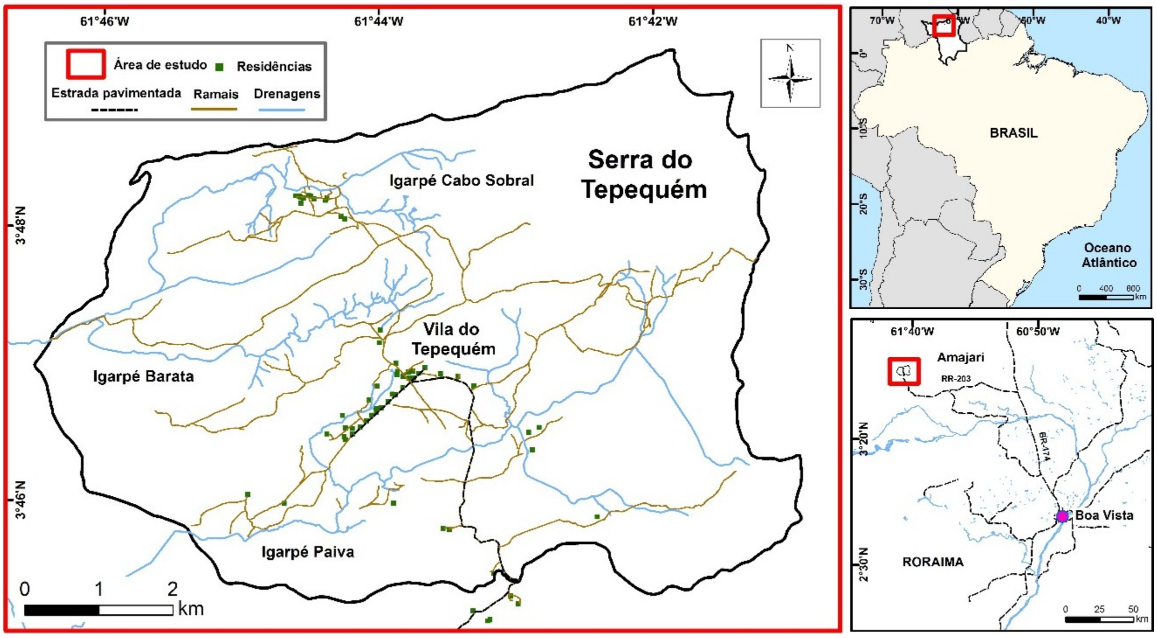
1. Caracterização faciológica e estratigráfica das rochas do Membro Funil;
2. Determinação do padrão de dispersão sedimentar do Membro Funil;
3. Reconstituição das condições paleohidrodinâmicas e paleodeposicionais do Membro Funil;

4. Posicionar estratigraficamente os corpos vulcânicos intercalados no Membro Funil;
5. Aplicação dos conceitos de estratigrafia de sequências no Membro Funil;
6. Correlacionar o Membro Funil com as unidades do Supergrupo Roraima e auxiliar em considerações paleogeográficas do proterozoico do Escudo das Guianas e;
7. Sugerir uma nova proposta litoestratigráfica para a Serra do Tepequém.

1.4 Localização, acesso e caracterização da área de estudo

A área de estudo está localizada na porção centro-norte do Estado de Roraima, no município de Amajari, a cerca de 210 km de distância da capital Boa Vista. A região de interesse tem como principal via de acesso a rodovia estadual RR-203, que liga à rodovia federal BR-174 (FIGURA 1).

Figura 1 – Mapa de localização da área de estudo. A Serra do Tepequém está localizada no Município de Amajari, situada aproximadamente 210 km da capital de Roraima, Boa Vista. O principal acesso terrestre a área é realizada pela rodovia estadual RR-203, via rodovia federal BR-174



Fonte: O autor (2019).

A serra apresenta a forma de um platô (conhecida como *Tepui*), com variações altimétricas que podem alcançar mais de 1.100 m, como por exemplo, na borda sudeste (BESERRA NETA et al, 2009). O clima na região é predominantemente quente e úmido, do tipo climático "Am" segundo a classificação de Köppen (KÖPPEN & GEIGER, 1928), com temperaturas médias anuais entre 22 a 24ºC e precipitação média variando de 1.700 a 2.000 mm/ano (BARBOSA, 1997; BESERRA NETA, 2007; CORREA et al, 1975).

A estação de chuvas inicia por volta do mês Abril até Setembro com ápice de precipitação em Junho, cuja média alcança 433.4 mm. A estação mais seca inicia em Outubro e vai até Março, com média de 38.2 mm em Dezembro (BESERRA NETA et al, 2009). Na Serra do Tepequém a vegetação consiste de savanas nas regiões de planície principalmente ligado a exploração de ouro e diamante e floresta de grande porte ao longo das encostas. As principais drenagens encontradas na serra são os igarapés Cabo Sobral (norte), Barata (central) e Paiva (sul), que são caracterizados pelo padrão paralelo alinhados à direção preferencial NE-SW (ALMEIDA et al, 2010; BESERRA NETA, 2007; NASCIMENTO et al, 2015).

1.5 Organização da dissertação

Essa dissertação de mestrado está organizada em seis capítulos, no capítulo 1 são realizadas a apresentação do tema da pesquisa, as hipóteses de trabalho, os objetivos e a localização geográfica da área de estudo. No capítulo 2 são apresentadas as técnicas e as propostas metodológicas que foram utilizadas nesta pesquisa, enquanto o capítulo 3 sintetisa o estado da arte do conhecimento geológico regional, com destaque para e evolução da nomenclatura estratigráfica da unidade alvo.

No capítuo 4 são apresentados os principais resultados e discussões, na forma de um artigo científico submetido a um periódico internacional, com as principais contribuições dessa pesquisa, como o estabelecimento de sequências do Membro Funil e uma reinterpretação estratigráfica da sequência basal do Supergrupo Roraima na Serra do Tepequém. O capítulo 5 reune as principais considerações finais alcançadas, enquanto que o capítulo 6 apresenta todo o material bibliográfico (artigo, trabalhos acadêmicos, livros e etc.) que fundamentaram esta dissertação.

CAPÍTULO 2 MATERIAIS E MÉTODOS

Para atingir os objetivos propostos nesta pesquisa de mestrado, os seguintes métodos foram utilizados:

- **Consulta bibliográfica**: consulta de acervo bibliográfico, como livros didáticos, trabalhos acadêmicos (monografia, dissertação e tese), além de artigos internacionais e nacionais. Esse método teve como intuito obter o máximo de conhecimento necessário para o entendimento acerca do contexto geológico da unidade alvo e dos métodos aplicados.
- **Elaboração de produtos cartográficos**: imagens de satélite obtidas no *site Earth Explorer – Home* do Serviço Geológico dos Estados Unidos (USGS) da área de estudo foram previamente selecionadas e passaram por procedimentos pré-processuais, como por exemplo, o georreferenciamento e técnicas de realce com o uso do *software* ArcGIS. Este último ampliou os contrastes de cores e permitiu uma melhor observação para a delineação manual dos dados vetoriais (MENESES & ALMEIDA, 2012).

Dados do sensor *Shuttle Radar Topography Mission* (SRTM), disponibilizados no *site* Brasil em Relevo – Monitoramento por Satélite da EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), foram usados para identificar os lineamentos morfoestruturais, que auxiliaram no reconhecimento de falhas na área de estudo (ANDRADES FILHO & FONSECA, 2009) e na elaboração das curvas de níveis (LEITE et al, 2015). Estes, aliados ainda ao banco de dados do *software Google Earth*, permitiram a localização das melhores exposições rochosas para empilhamento estratigráfico, tentando ao máximo evitar as regiões mais afetadas tectonicamente.

Posteriormente, o produto cartográfico elaborado foi comparado com a base de dados (curva de nível, litologia, lineamento, drenagem, acessos e residências) adquiridos nos *sites* da CPRM (Serviço Geológico do Brasil), IBGE (Instituto Brasileiro de Geografia e Estatística) e *OpenStreetMap* e, após observações realizadas *in loco,* foram procedidas as devidas correções. O produto final confeccionado é representado por um mapa de localização e geológico com a distribuição espacial das exposições analisadas.

- **Análise faciológica**: a análise faciológica consistiu na descrição e individualização das fácies, bem como a interpretação das condições hidrodinâmicas de formação. Assim, cada fácies foi caracterizada a partir de seus atributos externos (relação estratigráfica, geometria e continuidade lateral) e internos (por exemplo, textura, estruturas sedimentares e medidas de paleocorrentes), que permitiram a sua diferenciação das outras fácies adjacentes (CHAKRABORTY et al, 2009).

Após a caracterização, cada fácies foi identificada por uma sigla segundo o código estabelecido por Miall (2006), porventura contendo modificações necessárias em casos de fácies não cadastradas pelo autor. O empilhamento vertical destas fácies foi representado em perfis colunares com suas respectivas coordenadas geográficas obtidas por meio de um receptor GPS (*Global Positioning System*) Garmin e posteriormente plotados no mapa geológico. As medidas da espessura real das camadas foram obtidas a partir das correções a respeito dos mergulhos dessas camadas e o declive da superfície que estão expostas, segundo os procedimentos de Lisle et al. (2014) e Ragan (2009). Após a descrição e confecção dos perfis, foram realizados registros fotográficos das feições de detalhe e aquisição das imagens representativas dos afloramentos para a elaboração de fotomosaicos (ARNOT, 1997), que auxiliaram na delimitação das fácies através de suas relações laterais e verticais.

As fácies identificadas foram associadas, com base nos perfis colunares e nos fotomosaicos, que permitiram uma melhor individualização e identificação dos processos sedimentares que definem subambientes deposicionais. Essas interpretações foram apresentadas no bloco diagrama representativo da distribuição espacial dos paleoambientes deposicionais do Membro Funil.

Para a obtenção dos dados acerca do paleofluxo foram obtidas as orientações dos *foresets* de estratos cruzados, segundo os procedimentos de DeCelles et al. (1983) e Dasgupta (2002). Assim, foram obtidas no mínimo 10 medidas em cada fácies para aumentar a confiabilidade dos *trends* de dispersão dos sedimentos. Para corrigir a interferência tectônica nos estratos, as medidas de paleocorrentes passaram por processos de rotação baseados nas medidas de S_0 de camadas de argilito e plotadas em diagramas de roseta (TUCKER, 2014).

Estratigrafia de sequências: a estratigrafia de sequências representa a mais recente evolução técnica de investigação do registro sedimentar que busca o reconhecimento de padrões estratrais e de superfícies estratigráficas chaves em bacias sedimentares para explicar tendências deposicionais associadas à migração da linha de costa (CATUNEANU, 2017, 2019; ZECCHIN et al, 2017). As tendências deposicionais são controladas por fatores como oscilações do nível de base regional (nível do mar) e o espaço sucetível para a acumulação de sedimentos, estes influenciados por outros fatores alóctones, como por exemplo, tectônica, eustasia e clima (CATUNEANU & ERIKSSON, 2007; CATUNEANU, 2017).

Nesse sentido, após a confecção dos perfis das exposições estudadas, o registro estratigráfico do Membro Funil foi analisado em busca de parâmetros faciológicos que evidenciavam tendências deposicionais de espessamento ou raseamento da lâmina d'água, bem como o mapeamento de superfícies estratigráficas chave, fundamentais para o posicionamento de sequências deposicionais em tratos de sistemas (CATUNEANU, 2017, 2019).

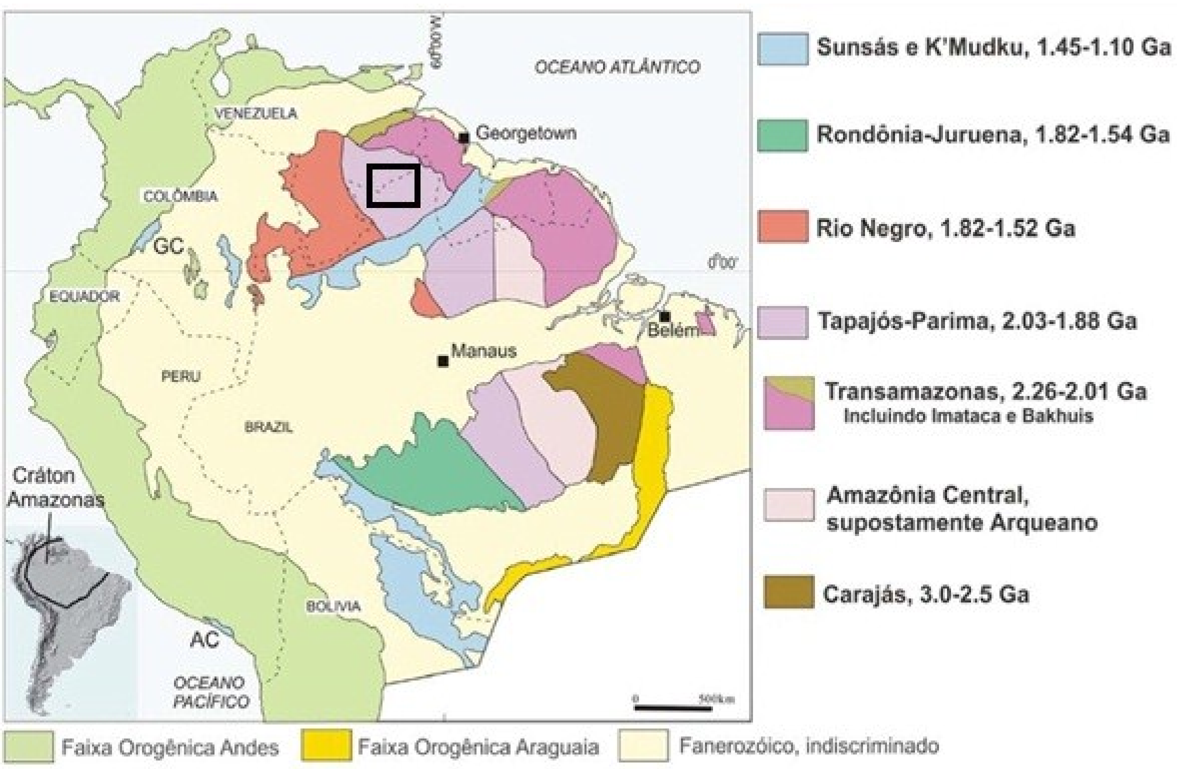
Tendências deposicionais, parâmetros e critérios sedimentológicos de ciclicidade no Membro Funil foram estabelecidos de acordo Zecchin et al. (2017), que leva em consideração espessura, mudança no empilhamento de fácies, espessura relativa da lâmina d'água, tendências de espessamento de associações de fácies e extenção lateral, com destaque para a escala e hierarquização estratigráfica (CATUNEANU, 2019), guardadas as particularidades da aplicação de técnicas de estratigrafia de sequências em sucessões pré-cambrianas (CATUNEANU et al, 2005; CATUNEANU et al, 2012; ERIKSSON et al, 2005).

CAPÍTULO 3 GEOLOGIA REGIONAL

3.1 Contexto geológico da Serra do Tepequém

A área estudada está situada na porção central do Escudo das Guianas, compartimento tectônico mais a norte do Cráton Amazonas. Santos et al. (2000), com base em dados aerogeofísicos e isotópicos, estabeleceram um modelo de evolução geocronológica para o cráton subdividindo-o em oito províncias geotectônicas (FIGURA 2). A província de maior relevância para este estudo, por englobar a região de interesse, é representada pela Província Tapajós-Parima, que mantém correspondência com a Província Ventuari-Tapajós, na proposta de compartimentação de Tassinari & Macambira (1999, 2004).

Figura 2 – Mapa geológico com detalhe da porção norte do continente sul-americano com a compartimentação geocronológicas do Cráton Amazonas. A área de estudo está inserida no segmento mais ao norte da Província Tapajós-Parima (retângulo preto)

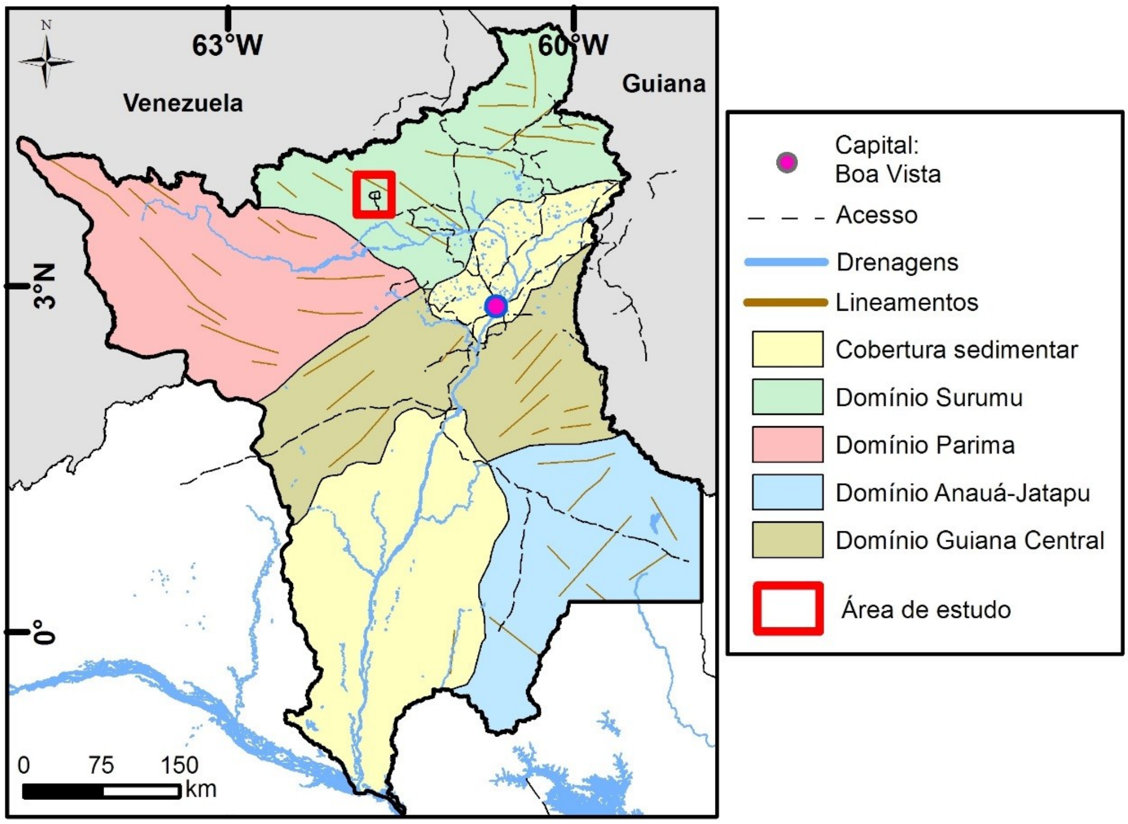


Fonte: Santos et al. (2006).

A Província Tapajós-Parima reúne um conjunto de rochas granitoides, gnaisses cálcio-alcalinos, sequências meta-vulcanossedimentares, além de gabros e anfibolitos, com idade entre 2.03-1.88 Ga (U-Pb em zircão), que representam um extenso cinturão com *trend* N20-30W formado a partir de processos acrescionários e com desenvolvimento de arcos magmáticos (SANTOS et al, 2000).

Dentro deste contexto geocronológico, Reis & Fraga (1998, 2000) compartimentaram o estado de Roraima em quatro principais domínios litoestruturais, caracterizados por suas associações geológicas, idades e feições estruturais. A área de estudo, Serra do Tepequém, está inserida no Domínio Surumu, disposto a norte-nordeste do estado de Roraima e é caracterizado estruturalmente por lineamentos orientados preferencialmente para E-W a WNW-ESSE e de forma secundária para NW-SE (REIS et al, 2003, 2004) (FIGURA 3).

Figura 3 – Compartimentação litoestrutural do Estado de Roraima em quatro domínios. A área de estudo está situada no Domínio Surumu situado na porção norte-nordeste de Roraima

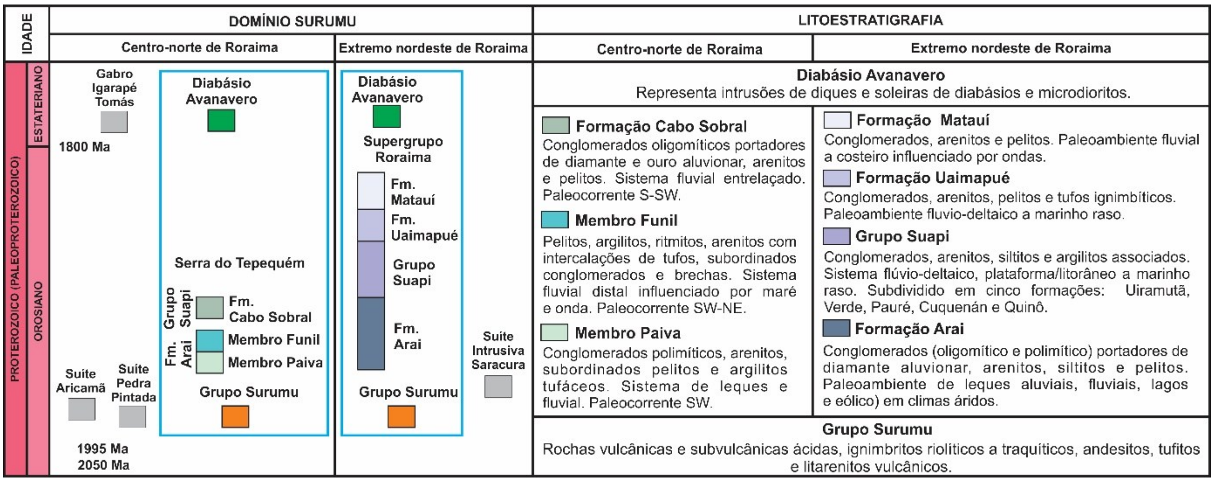


Fonte: O autor (2019)
Modificado de Reis et al. (2003).

Os litotipos presentes no Domínio Surumu e que embasam as rochas da Serra do Tepequém são compostos por derrames vulcânicos ácidos piroclásticos com idades entre 1.966 ± 9 Ga (U-Pb em cristais de zircão) e 1.990 ± 3 Ga (Pb-Pb em cristais de zircão) (FRAGA et al, 2010; SCHOBBENHAUS et al, 1994). Estas rochas vulcânicas estão agrupadas no Grupo Surumu, representativa do “Episódio Orocaima” (REIS et al, 2000, 2003).

Na porção leste do Domínio Surumu, também sotopostos discordantemente sobre as unidades vulcânicas e piroclásticas Surumu, ocorrem rochas sedimentares siliciclásticas com intercalações vulcânicas do Supergrupo Roraima de idade paleoproteorozoica (PINHEIRO et al, 1990; REIS et al, 2017). Morros testemunhos isolados e distribuídos ao longo do Domínio Surumu têm sido correlatos às unidades deposicionais deste supergrupo, entre eles os depósitos encontrados da Serra do Tepequém (BORGES & D'ANTONA, 1988; FERNANDES FILHO, 2010) (FIGURA 4).

Figura 4 – Coluna litoestratigráfica no Domínio Surumu no centro-norte e extremo nordeste de Roraima. Destaque em azul representa as unidades litoestratigráficas descritas ao lado. (Dados de: Borges & D'Antona, 1988; Fraga et al, 2010; Pinheiro et al, 1990; Reis & Yánez, 2001; Reis et al, 2017)



Fonte: O autor (2019).

Durante o mesoproterozoico a tectônica distensiva imposta ao Domínio Surumu culminou com a intrusão de enxames de diques e soleiras básicas a intermediarias, atribuídos ao Diabásio Avanavero, de idade 1.78 Ga (U-Pb em cristais de baddeleyita e zircão) (PINHEIRO et al, 1990; SANTOS et al, 2003). Essa manifestação magmática secciona as unidades Trairão, Aricamã, Pedra Pintada e Surumu, além de ocorrerem intercaladas com as rochas siliciclásticas do Supergrupo Roraima (FRAGA et al, 2010; LEAL et al, 2006; PINHEIRO et al, 1990). No entanto, de acordo com Fraga et al. (2010) estas intrusões não ocorrem nas rochas da Serra do Tepequém.

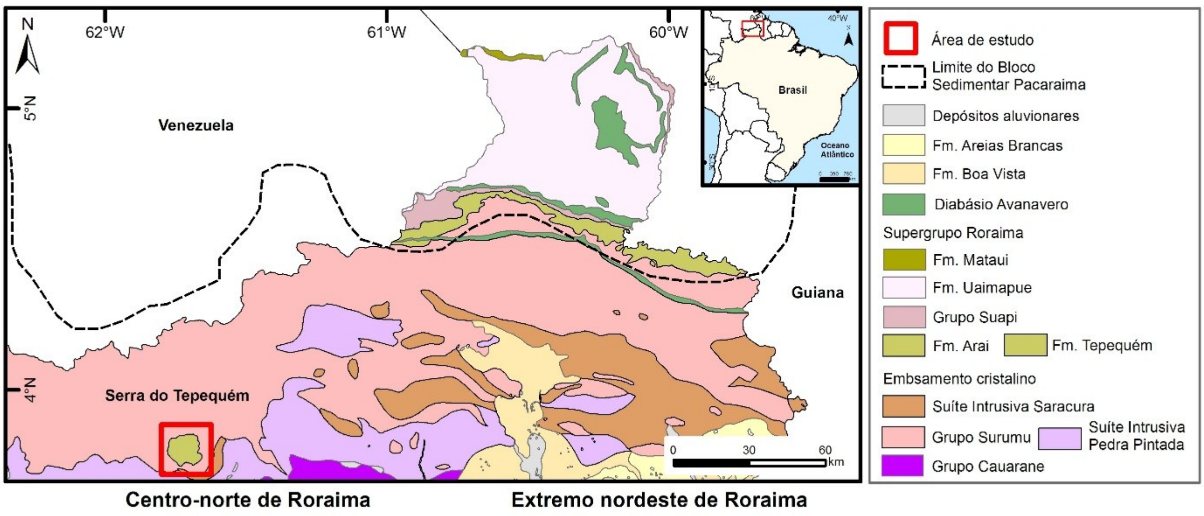
Parte das rochas que compõem este domínio, especialmente na porção setentrional, foram posteriormente submetidas ao Episódio *K'Mudku* (1.49-1.14 Ga), um evento tectônico deformacional concentrado em uma faixa com orientação NE-SW (CORDANI et al, 2010; SANTOS et al, 2006). Fraga (2002) aponta que este evento compressivo ocorreu sob condições de baixo grau metamórfico e resultou na geração de zonas de cisalhamento rúptil-dúctil, além de falhas transpressivas e rochas de falhas (REIS et al, 2003; SOUZA et al, 2015). Por outro lado, Santos et al. (2006) sugerem condições de médio a alto grau metamórfico devido à tectônica colisional que gerou zonas de cisalhamento caracterizadas por cavalgamentos oblíquos de cinemática sinistral, além de magmatismo associado.

Completando o quadro estratigráfico, ocorrem perfis intempéricos imaturos paleógenos em áreas isoladas, que recobrem parcialmente as rochas vulcânicas do Grupo Surumu e siliciclásticas da Serra do Tepequém (FRAGA et al, 2010). Por fim, há a ocorrência dos depósitos aluvionares, constituídos por argilas, areias e cascalhos inconsolidados, que muitas vezes derivam dos rejeitos de antigos garimpos e da erosão de rochas sedimentares (BORGES & D'ANTONA, 1988; BESERRA NETA et al, 2009).

3.2 O Supergrupo Roraima

O Bloco Sedimentar Pacaraima representa a sedimentação proterozoica na porção meridional do Cráton Amazonas e apresenta ampla distribuição, com exposições na Venezuela, Brasil, Guiana e Suriname (GIBBS & BARRON, 1983; PINHEIRO et al, 1990; REIS & YÁNEZ, 2001; REIS et al, 2017). A maior porção continua deste bloco recobre cerca de 73.000 km² da Guiana, Venezuela e do extremo nordeste do Brasil, representado pelo Supergrupo Roraima (REIS et al, 2017) (FIGURA 5).

Figura 5 – Mapa geológico da porção meridional do Cráton Amazonas com destaque para a faixa de rochas de idade proterozoica reunidas no Bloco Sedimentar Pacaraima. Na porção centro-norte de Roraima está localizada a Serra do Tepequém, cujas rochas são correlatas ao Supergrupo Roraima



Fonte: O autor (2019)
Unidades geológicas pertencentes ao banco de dados da CPRM.

A sucessão estratigráfica deste Supergrupo na porção setentrional do Estado de Roraima, sobreposta discordantemente sobre as rochas do Grupo Surumu, possui aproximadamente 2.770 m de espessura (REIS & YÁNEZ, 2001). Este Supergrupo abrange rochas vulcanossedimentares representativas de paleoambientes continentais a marinhos, depositados em uma bacia do tipo *foreland* (PINHEIRO et al, 1990; REIS & YÁNEZ, 2001; SANTOS et al, 2003).

A idade de deposição máxima dessas rochas tem como base os dados de datação das rochas vulcânicas do Grupo Surumu, que correspondem ao embasamento para a sedimentação (SANTOS et al, 2003). Os valores de idade mínima de sedimentação são inferidos pela datação dos corpos Avanavero intrusivos nesta unidade (REIS & YÁNEZ, 2001; REIS et al, 2017; SANTOS et al, 2003). Além dessas idades, valores de datações em zircões, pelo método U‑Pb SHRIMP, encontradas nos tufos intercalados na Formação Uaimapué, indicam idade das sucessões mais superiores em torno de 1.87 Ga (REIS & YÁNEZ, 2001; REIS et al, 2017; SANTOS et al, 2003).

Existem diversas propostas estratigráficas para o Supergrupo Roraima na porção aflorante no Brasil (BOUMAN, 1959; REIS et al, 1985, 1988, 1990; SANTOS, 1985), contudo a utilizada neste projeto foi a de Reis & Yánez (2001), por terem sido os primeiros a integrarem a correlação estratigráfica deste supergrupo no Brasil com os países da Venezuela e Guiana. Nesse sentido, segundo essa proposta, o empilhamento vulcanossedimentar é representado por (ver FIGURAS 4):

Formação Arai, constituído por conglomerado (oligomítico e polimítico) portadores de diamante e ouro aluvionar, arenitos, siltitos e pelitos depositados erosivamente sobre o Grupo Surumu. É caracterizada na base por um sistema de leques aluviais em climas áridos, que gradativamente para o topo registram depósitos lacustres, dunas eólicas e *wadis*, e por fim um sistema fluvial entrelaçado (PINHEIRO et al, 1990; REIS & YÁNEZ, 2001). Intrusões associadas ao Diabásio Avanavero, representada pela soleira Cotingo e diques, ocorrem nas porções basais dessa formação (REIS & YÁNEZ, 2001);

Grupo Suapi, sobreposto discordantemente à Formação Arai, representa sucessivos eventos progradracionais e retrogradacionais (REIS & YÁNEZ, 2001), reunidos em cinco formações:

Formação Uiramutã, representada por espessos pacotes de arenitos e subordinados argilitos e siltitos são atribuídos a um sistema deltaico com domínio misto de marés e ondas, cujo padrão de paleocorrentes bidirecionais indicam os quadrantes NE e SW (REIS & YÁNEZ, 2001; REIS et al, 2017);

Formação Verde, abrange ritmitos finos, argilitos e siltitos depositados discordantemente sobre a Formação Uiramutã, que registram a uma transgressão marinha e implantação de um mar epicontinental influenciado por ondas de tempestades ("Mar Verde") (CASTRO & BARROCAS, 1986; REIS & YÁNEZ, 2001);

Formação Pauré, constituída por arenitos médio a grossos ou conglomeráticos representam a implantação de um sistema flúvio-deltaico que progradava para SW em resposta a um período regressivo (PINHEIRO et al, 1990; REIS & YÁNEZ, 2001);

Formação Cuquenán, assinala um novo episódio de transgressão da linha de costa marcada por sedimentação pelítica intercalada com finas camadas de arenitos finos a siltitos atribuídos a depósitos de frente deltaica turbidítica (PINHEIRO et al, 1990; REIS et al, 2017). Essa formação é afetada pelo magmatismo Avanavero, como indicado pela presença da soleira Pedra Preta (REIS et al, 2017);

Formação Quinô, representa uma sedimentação basal fluvial com migração para SW constituída por arenitos e conglomerados, que passam para as porções superiores a uma sedimentação flúvio-estuarina representada por arenitos finos e folhelhos intercalados (REIS & YÁNEZ, 2001; REIS et al, 2017).

A sucessão paleoproterozoica é finalizada pelas formações **Uaimapué** e **Matauí**. A primeira é constituída por conglomerados, arenitos, pelitos e tufos ignimbíticos, que registram um paleoambiente fluvial-deltaico a marinho raso com forte influência de vulcanismo ácido durante a sedimentação, enquanto a segunda apresenta conglomerados, arenitos e pelitos associados à sedimentação fluvial a costeiro influenciado por ondas (PINHEIRO et al, 1990; REIS & YÁNEZ, 2001; REIS et al, 2017).

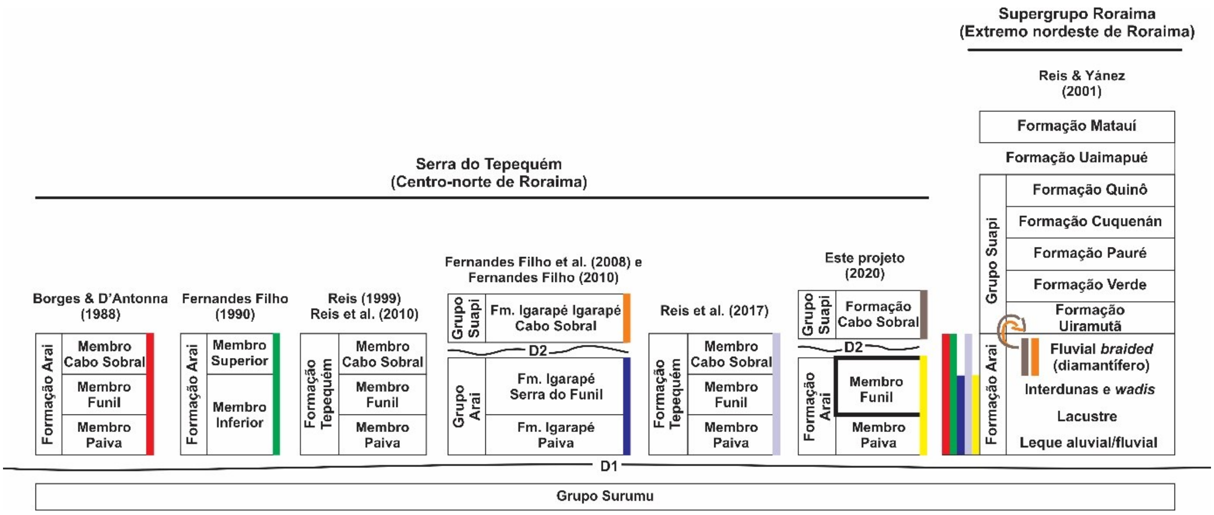
3.3 A Serra do Tepequém

3.3.1 Aspectos litoestratigráficos

Para a caracterização litoestratigráfica da sucessão sedimentar da Serra do Tepequém foram levantadas diversas proposições (FIGURA 6), algumas delas com proposição/formalização de unidades desrespeitando integralmente o Código de Nomenclatura Estratigráfica (HEDBERG, 1976; PETRI et al, 1986; MURPHY & SALVADOR, 1998), o que resultou em disparidades e problemas de correlação. Assim, ainda não existe um consenso acerca da nomenclatura e hierarquização litoestratigráfica.

Borges & D´Antona (1988) subdividiram o empilhamento sedimentar da Serra do Tepequém em três membros: Paiva, Funil e Cabo Sobral, englobando-os na Formação Arai. Foram os primeiros a correlacionar litoestratigraficamente estas rochas com as da unidade basal do Supergrupo Roraima, também denominada por Formação Arai (REIS & CARVALHO, 1996; REIS & YÁNEZ, 2001; REIS et al, 2017).

Figura 6 – Principais proposições litoestratigráficas referentes às unidades da Serra do Tepequém. As barras verticais coloridas representam correlações com as unidades do Supergrupo Roraima. D1 e D2 são discordâncias regionais. Destaque neste projeto para o Membro Funil (retângulo com linhas mais espessas)



Fonte: O autor (2019).

Fernandes Filho (1990), baseado no posicionamento estratigráfico, topografia, litologia, estruturas sedimentares e continuidade lateral manteve a mesma correlação direta com a unidade basal do supergrupo. Entretanto, diferentemente de Borges & D´Antona (1988), subdividiu os depósitos da Serra do Tepequém em dois membros: Inferior e Superior, mas também os agrupando na Formação Arai.

Posteriormente, Reis (1999) e Reis et al. (2010) apesar da concordância com a subdivisão das rochas da Serra do Tepequém nos membros já estabelecidos por Borges & D'Antona (1988), agruparam estas unidades na Formação Tepequém, pois esta subdivisão foi estabelecida na serra e não em regiões de ocorrência da Formação Arai (FERNANDES FILHO, 2010; REIS et al, 2010).

Fernandes Filho et al. (2008, 2012) e Fernandes Filho (2010), com base em litoestratigrafia realizada na Serra do Tepequém e na região de Uiramutã, reescreveram e redefiniram a Formação Arai elevando à categoria de grupo. Consequentemente, as unidades sedimentares presente na Serra do Tepequém, antes estabelecidas como membros, foram elevadas à categoria de formação, denominadas da base para o topo em: Igarapé Paiva, Serra do Funil e Igarapé Cabo Sobral. As duas primeiras formações integram o Grupo Arai, enquanto a última, delimitada na base por superfície erosional (D2), representa a parte basal do Grupo Suapi, ambos correlatos ao Supergrupo Roraima (FERNANDES FILHO et al, 2008; FERNANDES FILHO, 2010).

Recentemente Reis et al. (2017), usando a proposição Formação Tepequém admitiram uma correlação com as rochas do Supergrupo Roraima, apesar de sugerir um modelo de caldeira vulcânica como origem a estes depósitos.

A partir deste contexto esta pesquisa de mestrado, no intuito de dirimir essa falta de consenso e integrar uma correlação litoestratigráfica das rochas da Serra do Tepequém com as rochas do Supergrupo Roraima, sugere a seguinte proposta para a sucessão sedimentar na área estudada, com base no Cógido de Nomenclatura Estratigráfica (HEDBERG, 1976; PETRI et al, 1986; MURPHY & SALVADOR, 1998):

(1) Conservação dos nomes consagrados inicialmente estabelecidos por Borges & D'Antona (1988) por motivo de prioridade, ou seja, Paiva, Funil e Cabo Sobral;

(2) Uso de discordâncias regionais e camadas-chaves para delimitação de unidades.

Fundamentado nisso, as duas unidades acima da discordância que as separa das vulcânicas do Grupo Surumu (superfície D1) e abaixo da discordância erosiva (superfície D2) estabelecidas por Fernandes Filho (2010) são englobadas na Formação Arai, respectivamente denominadas da base para o topo em: Membro Paiva e Membro Funil. Aqui é atribuída a categoria de membro, pois Fernandes Filho (2010) aponta um contato gradacional como superfície limitante entre estas duas unidades.

Acima da superfície D2, ocorrem camadas-chaves constituídas por conglomerados oligomíticos, fontes secundárias de diamante e ouro aluvionar, representativos da Formação Igarapé Cabo Sobral de Fernandes Filho (2010). Essa unidade é correlata aos depósitos de topo da Formação Arai de Reis e Yánez (2001), no extremo nordeste de Roraima, o que explica o motivo de Fernandes Filhos deslocar esta unidade para o sobreposto Grupo Suapi, justamente por ser embasada por superfície erosiva de caráter regional (superfície D2).

Neste sentido, esta unidade na Serra do Tepequém é aqui categorizada como Formação Cabo Sobral e inserida na base do Grupo Suapi. Nesta proposta não se opta pela categoria de membro, pois esta unidade apresenta uma extensão regional significativa, além de que a categoria membro deve estar ligada a alguma formação, o que não ocorre por estar inserida em unidade litoestratigráfica de maior hierarquia (PETRI et al, 1986).

Sendo assim, a sucessão sedimentar da Serra do Tepequém fica aqui subdividida em 3 unidades, da base para o topo: Paiva, Funil e Cabo Sobral. As duas primeiras são englobadas na Formação Arai, na categoria de membro, enquanto a última é categorizada na Formação Cabo Sobral, pertencente à base do Grupo Suapi.

Estas subdivisões são correlatas litoestratigraficamente às mesmas estabelecidas por Reis e Yánez (2001), para o Supergrupo Roraima no extremo nordeste de Roraima, contudo trabalhos posteriores nesta porção serão necessários para retirada da porção superior da Formação Arai e consequentemente sua inclusão na base do Grupo Suapi, abaixo da Formação Uiramutã. Esta reorganização manterá uma padronização e integração da litoestratigrafia sedimentar proterozoica do Escudo das Guianas, eliminando com isso a atual falta de consenso.

3.3.2 Unidades Sedimentares da Serra do Tepequém

3.3.2.1 Membro Paiva, unidade basal da Formação Arai

Esta unidade ocorre discordantemente sobre rochas vulcânicas do Grupo Surumu (superfícies D1), cujo contato em grande parte se encontra encoberto por depósitos coluvionares. Representa o início da sedimentação siliciclástica basal da serra, com espessura aproximada de 250 m, constituída por conglomerados poligomíticos, arenitos e pelitos subordinados, localmente silicificados, arranjados em ciclos com padrão granodecrescente ascendente de até 5 m de espessura (FERNANDES FILHO, 2010; REIS et al, 2010).

A base dos ciclos é normalmente composta por conglomerados poligomíticos que variam em granulometria de seixo a matacão, constituídos por grãos de quartzo leitoso, *chert*, arenitos, pelitos, rochas vulcânicas e metamórficas, imersos em matriz arenosa média a grossa com grãos de hematitas. Internamente podem apresentar estruturação maciça à estratificação plano-paralela incipiente (FERNANDES FILHO, 2010; FERNANDES FILHO et al, 2012).

Os arenitos variam em granulometria de fina a grossa, podendo ser conglomeráticos, com estruturas como marca de onda assimétrica, laminação plano-paralela, cruzada de baixo ângulo, convoluta, lineação de partição, estratificação cruzada sigmoidal e acanalada com *foresets* marcados por grãos de hematita (FERNANDES FILHO, 2010; REIS et al, 2010).

Marcando o topo dos ciclos sedimentares completos ocorrem pelitos com laminação plano-paralela à levemente ondulada, podendo ocorrer de forma maciça e/ou associados a gretas de contração, convoluções e estruturas de sobrecarga (FERNANDES FILHO, 2010).

Segundo Reis et al. (2010), a deposição siliciclástica foi contemporânea a manifestações vulcânicas, como observado nas porções basais da serra, onde há conglomerados poligomíticos sobrepostos discordantemente a níveis argilosos esbranquiçados, interpretados como rocha vulcânica ácida alterada do Grupo Surumu. Além disso, também são relatados argilitos tufáceos ou tufos de queda intercalados com arenitos nos níveis estratigráficos superiores.

O paleoambiente interpretado para essa unidade é caracterizado por um sistema fluvial entrelaçado proximal, cujas paleocorrentes obtidas em estratos cruzados indicam migração de sedimentos para SW, associados ainda à planície de inundação e depósitos de *crevasse splay*, este último com geometria sigmoidal e padrão de paleocorrente para NW (FERNANDES FILHO, 2010; REIS et al, 2010).

Petrograficamente os arenitos foram classificados como litarenitos e quartzo arenitos, constituídos principalmente por fragmento de rochas vulcânicas e grãos de quartzo policristalino, além de matriz rica em hidróxido de ferro. Os constituintes diagenéticos são representados por sílica e argilominerais recristalizados, que por vezes apresentam orientação (REIS et al, 2010).

As rochas piroclásticas presentes são representadas por argilitos tufáceos ou tufos de queda e ignimbritos. Os tufos de queda são formados inteiramente por uma massa de sericita, além de partículas interpretadas como *lapilli* acrescionário. Os ignimbritos são avermelhados com forte sericitização e hematitização, mas ainda com fenocristais, lascas vítreas e fragmentos de púmice preservados (REIS et al, 2010).

3.3.2.2 Membro Funil, unidade superior da Formação Arai

O Membro Funil ocorre sobreposto gradacionalmente (FERNANDES FILHO, 2010), ou em contato aparentemente brusco e discordante com o Membro Paiva (REIS et al, 2010). Esta unidade apresenta uma espessura em torno de 150 m, organizada em sucessões granodecrescentes ascendentes em ciclos de até 4 m de espessura (FERNANDES FILHO, 2010). As principais litologias estão associadas a arenitos, ritmitos arenito/pelito, pelitos e subordinadamente conglomerados e brechas, normalmente friáveis, mas com estruturas sedimentares preservadas (FERNANDES FILHO, 2010; REIS et al, 2010).

Os arenitos variam de fino a médio, com subordinados grossos a conglomeráticos, com estratificação cruzada acanalada ou tangencial (bandamento de maré), cruzada do tipo espinha de peixe, cruzada planar, laminação plano-paralela, cavalgante supercrítica e de baixo ângulo, além de deformações convolutas (FERNANDES FILHO, 2010; FERNANDES FILHO et al, 2012; REIS et al, 2010). Em especial, estratos cruzados podem preservar recobrimento dos *sets* e *foresets* por lâminas de pelitos maciço ou laminado formando *mud couplets*, além de clastos tabulares de pelito na base de ambos. No entanto, os *foresets* também podem ser marcados pela concentração de grãos de hematitas. Adicionalmente, nesta unidade são encontrados com frequência fácies com acamamento heterolíticos (FERNANDES FILHO, 2010).

Em fácies argilosas é comum a preservação de gretas de contração associadas ao topo dos ciclos sedimentares completos. Em contrapartida, a base dos ciclos granodescrescentes ascendentes é destacada por brechas e conglomerados com clastos de argila, tamanho grânulo a seixos, imersos em matriz arenosa fina a média (FERNANDES FILHO, 2010; REIS et al, 2010).

Segundo Reis et al. (2010), a abundância de rochas pelíticas avermelhadas mostra semelhança com alguns níveis argilosos tufáceos da unidade sotoposta, apontando assim também para a ocorrência de erupções produtoras de grandes volumes de cinza vulcânica durante a deposição.

Estes depósitos representam em parte, o afogamento do sistema fluvial sotoposto, sendo compatível com paleoambiente fluvial influenciado por maré e onda, associado a planícies e canais de maré (FERNANDES FILHO et al, 2008, 2012; FERNANDES FILHO, 2010; REIS et al, 2010). Os dados de paleocorrentes obtidos nos estratos cruzados mostram dispersão alta à moderada com padrão bimodal SW-NE, com orientação principal das paleocorrentes para SW (fortes correntes fluviais e de maré de vazante) e linha de costa orientada segundo NW-SE (FERNANDES FILHO, 2010).

Com base na petrografia, os arenitos foram classificados como litarenitos e são constituídos por grãos de quartzo subarredondados a angulosos, fragmentos de tufos ácidos, clastos de pelitos, minerais opacos e raros zircão e muscovita (REIS et al, 2010). Litoarenitos restritos na Cachoeira do Funil, região norte da serra, por vezes apresentam leve foliação marcada por minerais de sericitas (REIS et al, 2010). As rochas pelíticas, segundo Luzardo (2006) são classificadas como ardósias, composicionalmente constituídas por sericita, pirofilita, muscovita e raramente ilitas, além de opacos atribuídos a hematitas.

3.3.2.3 Formação Cabo Sobral, unidade basal do Grupo Suapi

Esta unidade ocorre sobreposta discordantemente às anteriores, sendo delimitada na base por superfície de caráter erosiva D2 (FERNANDES FILHO, 2010). Todo o pacote sedimentar pode alcançar até 30 m de espessura, com exposições concentradas principalmente no topo dos morrotes, marcando assim a última sucessão sedimentar paleoproterozoica da Serra do Tepequém (FERNANDES FILHO et al, 2012; REIS et al, 2010).

Esta unidade é constituída predominantemente por ortoconglomerados oligomíticos, arenitos finos a grossos, podendo ser conglomeráticos, com subordinados pelitos (FERNANDES FILHO, 2010; REIS et al, 2010). Esses conglomerados são considerados como fonte secundária de diamantes e ouro aluvionar que eram explorados na região (BORGES & D'ANTONA, 1988), o que dificulta a preservação de exposições da unidade devido à ação antrópica.

Os conglomerados são sustentados por clastos do tamanho seixo e subordinadamente calhau, constituídos predominantemente por quartzo leitoso, seguido de poucos grãos de arenitos, pelitos e rochas vulcânicas, ambos imersos em matriz arenosa de granulometria média a grossa com grânulos. Internamente apresentam aspecto maciço, mas podem apresentar estratos cruzados planar, além de gradação normal e raramente inversa (FERNANDES FILHO, 2010; FERNANDES FILHO et al, 2012; REIS et al, 2010).

Os arenitos presentes apresentam granulometria variando de fina a grossa, podendo ser também conglomeráticos. As principais estruturas sedimentares constatadas são a estratificação cruzada acanalada, seguida de cruzada tabular, além de subordinada presença de estratificação plano-paralela com estruturas de lineação de partição, acamamento ondulado e estratificação convoluta a recumbente (FERNANDES FILHO, 2010; REIS et al, 2010). De acordo com Reis et al. (2010), a sedimentação dessa unidade praticamente não foi afetada por vulcanismo.

O paleoambiente interpretado para esta unidade é caracterizado por um sistema fluvial entrelaçado de elevada energia, cujas paleocorrentes apontam para um padrão unimodal estreito, com *trends* preferencial para S-SW e subordinadamente para S-SE e W-NW (FERNANDES FILHO, 2010; FERNANDES FILHO et al, 2012; REIS et al, 2010).

Petrograficamente, os conglomerados são constituídos predominantemente por grãos de quartzo, geralmente policristalino ocasionalmente achados e cimentados por quartzo autigênico (LUZARDO, 2006; REIS et al, 2010). Além disso, subordinados fragmentos de rocha de argilito ferruginoso, tufo ácido sericitizado e arenito estão presentes (REIS et al, 2010). Os arenitos são bem silicificados e constituídos por grãos de quartzo, microclínio e raros plagioclásios, fragmentos de *chert* e tufos, além de zircão, minerais opacos e rutilo (REIS et al, 2010).

3.3.3 Aspectos estruturais e metamórficos

O contexto acerca da estruturação das rochas da Serra do Tepequém, assim como os aspectos relacionados aos eventos metamórficos superimpostos a essa unidade, ainda são alvos de discussões. Segundo Borges & D'Antona (1988), o aspecto estrutural descrito para as unidades desta serra apresenta uma geometria de sinclinório assimétrico com *trend* NE-SW e caimento para o quadrante SW, além de padrão de fraturamento predominantemente nos *trend* NW-SE e NE-SW, ocasionado por intrusões ígneas (BORGES & D'ANTONA, 1988; FERNANDES FILHO et al, 2012).

Estruturalmente, Fernandes Filho (1990) descreveu para as rochas da serra a geometria de um sinclinório composto por dobras menores sinclinais e anticlinais assimétricas e abertas com *trend* para o quadrante NE, relacionado à compactação diferencial (não-tectônico). Além disso, identificou zonas de falha com o mesmo *trend*, predominantemente subverticais, marcadas por foliação cataclástica interpretadas como resultado de tectonismo regional (FERNANDES FILHO et al, 2012).

Fraga et al. (1994a, b) também identificaram a presença de dobras suaves abertas (sinformais e antiformais), com eixos com tendências para os quadrantes E-W e ENE-WSW. Estas dobras estão associadas a um arranjo de falhas, além de clivagem nas rochas sedimentares, especificamente na borda norte da serra. Essa estruturação foi relacionada à fraca inversão da porção sul da Bacia de Roraima, relacionado ao episódio *K´Mudku* (COSTA et al, 1991), além de feixes de cavalgamentos na direção E-W e com transporte tectônico para sul (Fraga et al, 1994b).

Já para Luzardo (2006), a Serra do Tepequém, uma sucessão meta-vulcanossedimentar, constitui uma megassinclinal aberta e suspensa, com eixo subhorizontal de *trend* NE, além de plano axial subvertical com a presença de rochas com clivagem ardosiana paralela ao mesmo, definida pela orientação de micas brancas (muscovita/ilita). Descreveu ainda, a ocorrência de lineações marcadas por seixos estirados e manchas elípticas paralelos ao eixo das dobras.

Este mesmo autor, por meio de técnicas de Difração de Raios-X em amostra total nas rochas pelíticas identificou a presença de pirofilita e muscovita/illita, além da presença de actinolita e pumpellyíta presentes nos metabasaltos intercalados na sequência sedimentar. Com base nisso, sugeriu um evento metamórfico regional dínamo-termal incipiente ou orogênico de muito baixo grau, na fácies Prehnita-Pumpellyíta para as rochas Serra do Tepequém (LUZARDO, 2006). No entanto, segundo Fraga et al. (2010) as deformações nos argilitos e em alguns arenitos são de ocorrências restritas e a presença de minerais metamórficos, como a pirofilita, pode ser atribuída a processos hidrotermais ou alteração argílica avançada.

Fernandes Filho et al. (2012), a partir de análise estrutural realizada na Serra do Tepequém, atribuíram uma estruturação formada por dobras forçadas quilométricas do tipo *kink bands* e *chevrons*. Os acamamentos dos flancos dessas dobras apresentam mergulhos para os quadrantes SE e NW, delimitados por zonas de falhas oblíquas sinistrais com rejeitos normais e inversos de *trend* NE-SW.

Ainda segundo esses autores, esse arcabouço geométrico é devido a reativações dos planos de fraqueza preexistentes, representado pelas tramas dúcteis no embasamento da serra, caracterizando assim, um ambiente de deformação de nível crustal raso a médio, diferente dos modelos propostos anteriormente como resultado de deformação dúctil sob regime compressivo.

CAPÍTULO 4 RESULTADOS E DISCUSSÕES (ARTIGO CIENTÍFICO)

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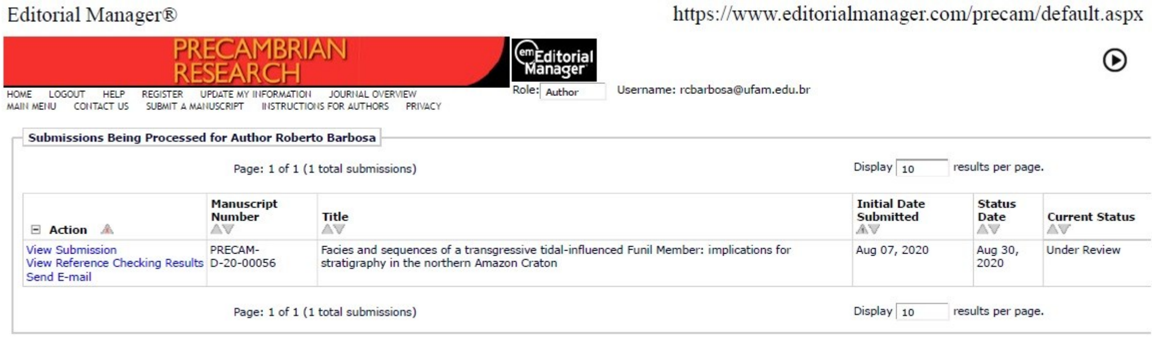
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Artigo submetido na revista Precambrian Research no dia 07/08/2020 e aceito para revisão editorial no dia 30/08/2020.

Facies and sequences of a transgressive tidal-influenced Funil Member: implications for stratigraphy in the northern Amazon Craton

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ABSTRACT

Despite the challenges of applying techniques of sequence stratigraphy to Precambrian siliciclastic successions due to the particularities of this eon, during recent years the number of studies published on this topic has increased. This has contributed to understanding of how these basins were filled, and especially the establishment of a hierarchy and sequences as a product of a complete cycle of advance and retreat of sea level, independent of the scale of the evaluation. Facies and stratigraphic analysis of the Paleoproterozoic transgressive deposits of the Funil Member of the Guyana Shield, reveals a tidal coastal system with a paleocoast oriented to the NE-SW in a foreland basin, with a retrogradational stacking pattern. The unit is organized in 4th order deepening-upward sequences marked by superposition of deposits of a mud flat through the thickening of tidal channels and mixed flats separated by marine flooding surfaces. Internally, the sequences are formed by layers with a fining-upward stacking pattern separated into fluvial and transitional domains. The strata organization of the Funil Member reflects a progressive increase in accommodation space and implantation of marine conditions associated with migration of the coastline in direction of the continent as part of the transgressive system tract. This systems tract is erosively sectioned at the top by a sequence limit which separates the upper sequence and marks a new progradational-retrogradational depositional cycle in the Roraima Supergroup. This analysis allowed for better comprehension of how Proterozoic fluvial systems respond to a coastline transgression, improved the recognition of sequences, and provided a stratigraphic reanalysis of the basal portion of the Roraima Supergroup in the context of sequence stratigraphy.

Keywords: Paleoproterozoic; Sequence Stratigraphy; Transgressive Systems; Tidal coastal flat.

1. INTRODUCTION

The application of concepts of sequence stratigraphy to Proterozoic successions is challenging, because the principal mechanisms that control sedimentation and the nature of basin formation were different compared to their Phanerozoic analogs, for which the criteria were established for stacking patterns of parasequences (POSAMENTIER & ALLEN, 1999), sequences, and stratigraphic surfaces that are key to identification of systems tracts (CATUNEANU, 2019; CATUNEANU & ERIKSSON, 2002; MUTO & STEEL, 1997).

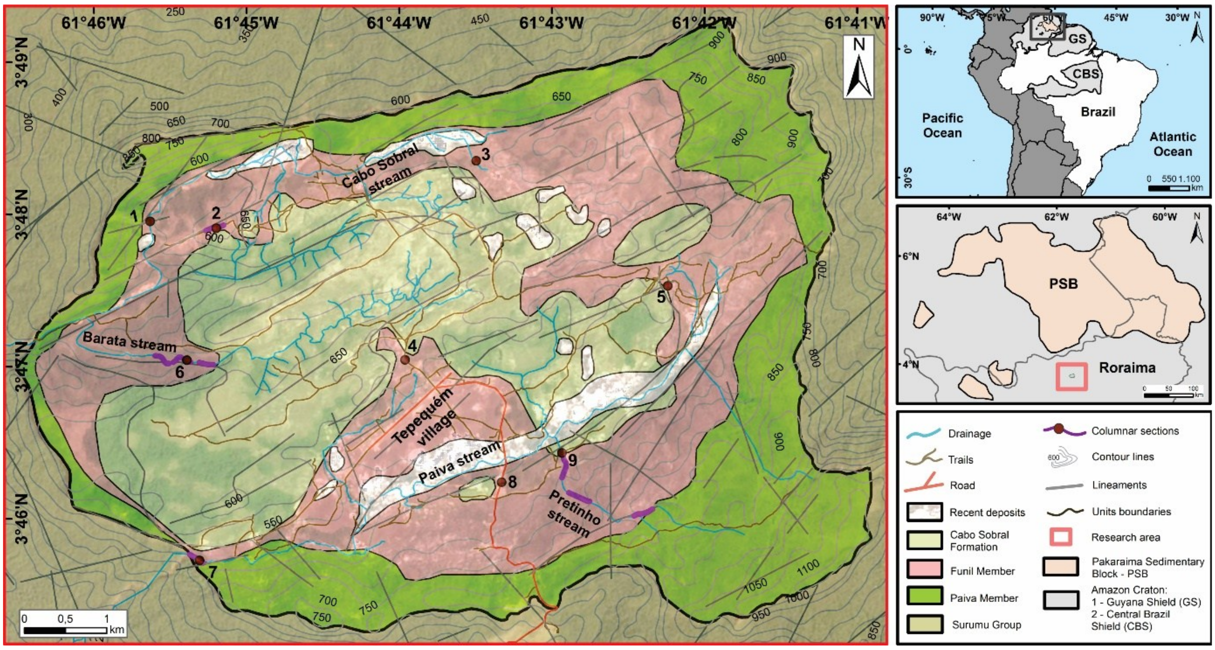
In fact, the low potential for crust preservation due to the high rate of crust growth, movement of tectonic plates, and mantle plumes (BOSE et al, 2012; KAMBER, 2015; STRAND, 2012), difficulties in biostratigraphic control as a result of a lack of inequivocal biogenic criteria (ALTERMANN, 2002; CATUNEANU, et al, 2005; ERIKSSON et al, 1998; MAZUMDER et al, 2015), and recrystallization and metamorphic processes in these rocks hinders the recognition of stacking patterns. However, many studies have contributed to the understanding of how the interaction between allochthonous and autochthonous factors controls the stacking of Proterozoic siliciclastic successions (BANERJEE, 2000; CHAKRABORTY & PAUL, 2008; CHAKRABORTY et al, 2012; LAMOTHE et al, 2019; Martins-Neto, 2009; SIMPSON & ERIKSSON, 1991; SOUZA et al, 2019), especially associated with high frequency fluctuations of the coastline (BÁLLICO et al, 2017; ERIKSSON & SIMPSON, 1990; KUNZMAN et al, 2020; MAGALHÃES et al, 2016; SAMANTA et al, 2019; STRAND, 2012) in virtue of the restricted accommodation space for sediments, which generates sequences in relatively smaller scales when compared to Phanerozoic ones (CATUNEANU, 2019; CATUNEANU & ERICKSSON, 2007).

In this context, with the objective of increasing understanding of depositional architecture and the establishment of sequences in Paleoproterozoic siliciclastic successions, this research presents a faciological evaluation of transgressive intertidal deposits from the Funil Member (Roraima Supergroup) exposed on the Tepequém mountain, state of Roraima, Brazil (FIGURE 1) using concepts of sequence stratigraphy. The principal objectives are: (1) paleoenvironmental reconstruction of the Funil Member, (2) identification of stacking patterns, stratigraphic surfaces, and establishment of sequences, (3) stratigraphic and paleographic correlation of the Paleoproterozoic of the Guyana Shield, and (4) to propose a reanalysis of stratigraphic stacking of the lower succession of the Roraima Supergroup.

2. METHODS

Facies analysis consists of individualization of facies (CHAKRABORTY et al, 2009), identified by abbreviations (MIALL, 2006) with adaptations for cases of facies that had not previously been registered. Vertical stacking is represented in nine columnar profiles indicated in Figure 1 with real thickness of the facies measured perpendicular to bedding.

Figure 1 – Geological context of the Proterozoic volcano-sedimentary units of the northern Amazon Craton. Rocks of the Tepequém mountain are situated in the central portion of the Guyana Shield (GS) and are correlated to the rocks of the Roraima Supergroup, a unit of the Pacaraima Sedimentary Block (PSB). The spatial distribution data of the units of the mountain are credited to the geologic mapping teams from the Federal University of Amazonas (UFAM), 2018 and 2019



Photographic details and photomosaics of the facies (ARNOT, 1997) aid in the individualization and recognition of sub-environments from their associations. The paleoflow measurements were obtained in crossed foresets with a minimum of 10 measurements per facies to increase the reliability of the sediment dispersion trends (DASGUPTA, 2002; DECELLES et al, 1983). The acquired paleocurrents were corrected based on measurements of S_0 from undeformed mudstone layers and represented in rosette diagrams.

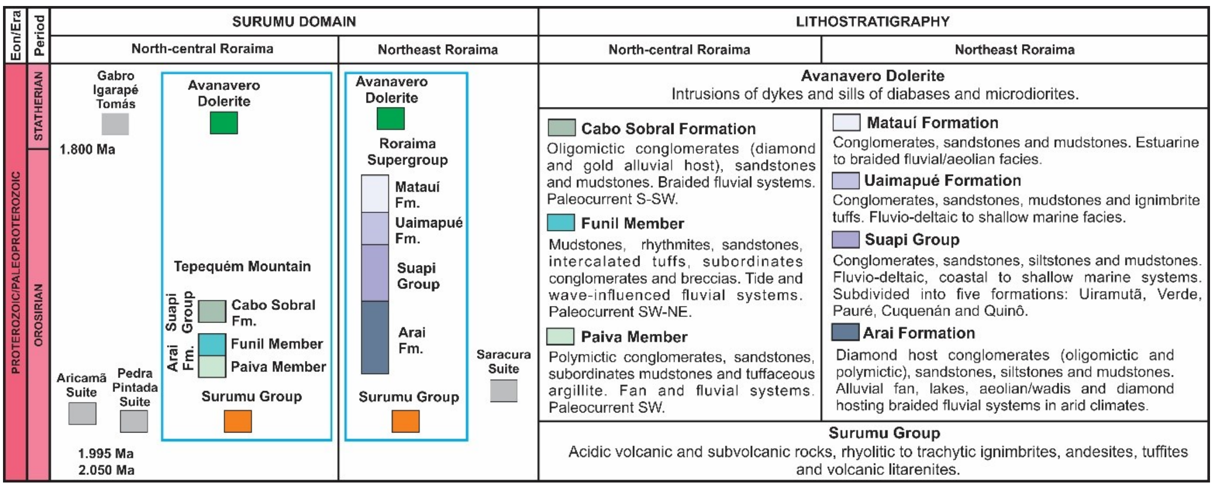
The stratigraphic sequence analysis followed the method proposed by Catuneanu (2017, 2019) based on surfaces that are crucial for delimiting depositional sequences and their respective patterns of sedimentary stacking characteristic of depositional systems tracts. Additionally, sedimentological parameters and criteria for stacking patterns were established according to Zecchin et al. (2017) whose criteria included thickness, change in facies stacking, relative thickness of the water depth, tendencies of thickness of facies associations, and lateral extension.

3. GEOLOGICAL SCENARIO

Records of Precambrian sedimentation in the Amazon Craton are present in the central portion of the Guyana Shield, Ventuari-Tapajós Province described by Tassinari & Macambira (1999), and correlated with the Tapajós-Parima Province, according to the tectonic provinces model of Santos et al. (2000). This sedimentary succession represented by the Pacaraima Sedimentary Block (PSB) possesses a wide spatial distribution, but is discontinuous in Venezuela, Brazil, Guyana and Suriname (GIBBS & BARRON, 1983; PINHEIRO et al, 1990; REIS & YÁNEZ, 2001; REIS et al, 2017).

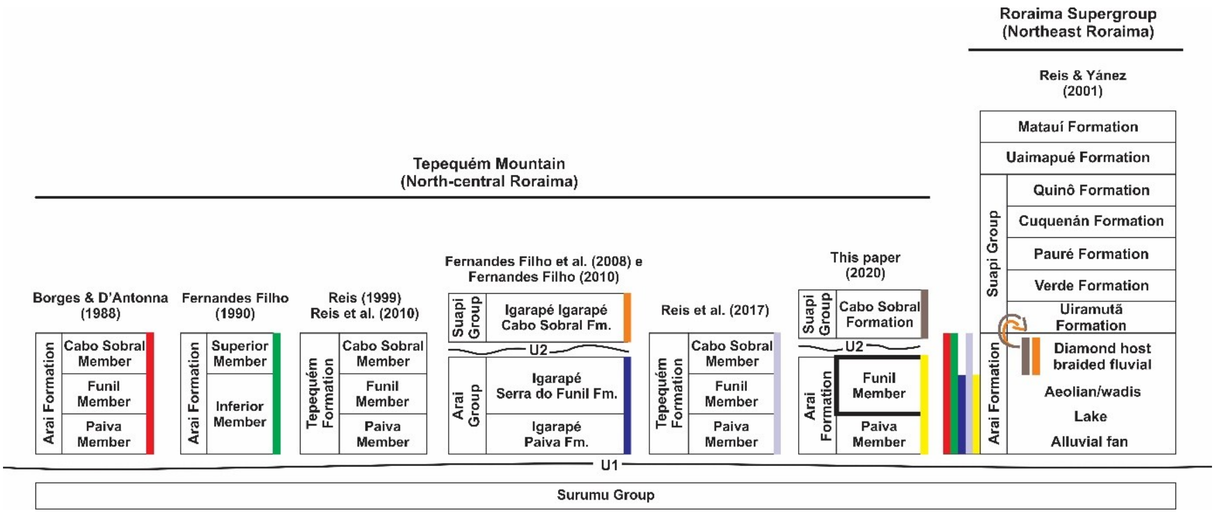
In the Brazilian portion this rock outcrops in the extreme northeast of Roraima state and is lithostratigraphically reunited in the Roraima Supergroup, discordantly superimposed to volcanic rocks of the Surumu Supergroup (PINHEIRO et al, 1990; REIS et al, 2017). The Roraima Supergroup possesses is 2.770 m thick and is composed of volcano-sedimentary rocks representative of continental to marine paleoenvironments deposited in a foreland basin (FIGURE 2) (PINHEIRO et al, 1990; REIS et al, 2017; SANTOS et al, 2003). The maximum age of deposition is 1.98 Ga (U-Pb in zircon crystals) dated in the volcanic basement of the Surumu Group (SANTOS et al, 2003), while the minimum age of the sedimentation is inferred by the dating of the intrusive Avanavero Diabase, with an age of 1.78 Ga (U-Pb in baddeleyite and zircon crystals) (REIS et al, 2017; SANTOS et al, 2003).

Figure 2 – Lithostratigraphic column from the Surumu Domain in the central-north and extreme northeast regions of Roraima state. (Data from: Fraga et al, 2010; Pinheiro et al, 1990; Reis & Yánez, 2001; Reis et al, 2010, 2017)



There is a large diversity of stratigraphic proposals for the Roraima Supergroup in the Brazilian portion (REIS et al, 2017), however Reis & Yánez (2001) were the first to integrate a stratigraphic correlation with Venezuela and Guiana exposures (REIS et al, 2017). According to these authors, the Roraima Supergroup is subdivided into 4 lithostratigraphic units, from the base to the top: Arai Formation, Suapi Group, Uaimapué Formation, and the Matauí Formation. The Suapi Group internally encompasses five formations, from the base to the top: Uiramutã, Verde, Pauré, Cuquenán and Quinô (FIGURE 3).

Figure 3 – Principal lithostratigraphic propositions of the units of the Tepequém Mountain. The colored lines represent correlations with the units of the Roraima Supergroup. U1 and U2 are regional discordances. Emphasis on the Funil Member in this study (rectangle with thick black line)



3.1. Tepequém Mountain

Tepequém mountain is located in the north of the state of Roraima and is inserted in the regional tectonostratigraphic context of the Surumu Domain, as are the rocks from the Roraima Supergroup, in the extreme northeast of the state (REIS et al, 2003, 2004). There is still no consensus about the stratigraphy of Tepequém mountain, in the context of the Roraima Supergroup, although there are several proposals (FIGURE 3). Several of these proposals, however, entirely disrespect the Stratigraphic Nomenclature Code (HEDBERG, 1976; PETRI et al, 1986), thus resulting in disparities and problems with correlation.

Borges & D´Antona (1988) subdivided this succession into three members: Paiva, Funil and Cabo Sobral, placing them in the Arai Formation, and were the first to lithostratigraphically correlate these rocks with those from the basal unit of the Roraima Supergroup, also denominated the Arai Formation. Fernandes Filho (1990), using stratigraphic and sedimentary data, maintained this direct correlation with the basal unit of the supergroup. However, this author subdivided these deposits into two members: Lower and Upper, despite also having inserted them into the Arai Formation.

Subsequently, Reis (1999) and Reis et al. (2010), in spite of being in agreement with the subdivisions into two members as proposed by Borges & D'Antona (1988), grouped these units into the Tepequém Formation, under the justification that this subdivision was established at the mountain and not in regions where the Arai Formation occurs. Fernandes Filho et al. (2008) and Fernandes Filho (2010), based on lithostratigraphic studies of the mountain and in the region of Uiramutã elevated the Arai Formation to the category group. In this way, the members of the Tepequém mountain were redefined into the following formations, from the base to the top: Igarapé Paiva, Serra do Funil and Igarapé Cabo Sobral. The first two were inserted into the Arai Group, while the last one, delimited at the base by surface erosion, was moved to the base of the Suapi Group, both being correlated to the Roraima Supergroup.

Recently, Reis et al. (2017), using the denomination Tepequém Formation, discussed a correlation with rocks from the Roraima Supergroup, despite having suggested a volcanic caldera model as the origin of these deposits. In this context, the current study intends to settle the lack of consensus and integrate a lithostratigraphic correlation of the rocks of the Tepequém mountain with those of the Roraima Supergroup, and proposes a sedimentary succession for this mountain (FIGURE 3), based on the Stratigraphic Nomenclature Code (HEDBERG, 1976; PETRI et, 1986) as follows:

(1) Conservation of the names Paiva, Funil and Cabo Sobral, initially established by Borges & D'Antona (1988) as an important priority.

(2) Use of regional unconformity and key beds for delimitation of units.

In this context, the two units above the unconformity (U1) that separate them from the Surumu Group and that are below the regional erosive unconformity (U2) established by Fernandes Filho (2010), are therefore included in the Arai Formation. These are denominated, from the base to the top as: Paiva Member and Funil Member. The category of Member is adequate, since Fernandes Filho (2010) indicates a gradational passage between these two units (HEDBERG, 1976; PETRI et al, 1986).

The unit above the unconformity U2 is composed of oligomitic conglomerates that are secondary sources of alluvial diamonds, which serve as key beds. These are correlated to the upper deposits of the Arai Formation described by Reis & Yánez (2001). Since it is delimited at the base by a regional erosive surface, Fernandes Filho (2010) moved this formation to the base of the superimposed unit, the Suapi Group. This interpretation is also shared in the current study but using the nomenclature Cabo Sobral Formation, because the category of formation has extensive regional significance and is linked to a lithostratigraphic unit of greater hierarchical relevance (HEDBERG, 1976; PETRI et al, 1986).

In this context, the sedimentary succession of Tepequém mountain is subdivided into 3 units, from the base to the top: Paiva and Funil Members (Arai Formation) and the Cabo Sobral Formation (base of the Suapi Group) (FIGURE 3). These subdivisions are lithostratigraphically correlated with the same ones established by Reis & Yánez (2001) for the Roraima Supergroup. However, subsequent studies in the extreme northeast of Roraima will be necessary to modify the upper portion of the Arai Formation and consequently include it in the base of the Suapi Group, below the Uiramutã Formation. This reorganization will maintain the standardization and integration of Proterozoic sedimentary lithostratigraphy of the Guyana Shield.

3.2. Arai and Cabo Sobral Formations

The Arai Formation is subdivided into the Paiva and Funil Members. The Paiva Member discordantly overlies the Surumu Group and represents the beginning of the basal siliciclastic sedimentation of the Tepequém mountain. It is approximately 250 m thick and consists of polygomitic conglomerates, sandstones and subordinate pelites (FERNANDES FILHO, 2010; REIS et al, 2010). This Formation represents a proximal braided fluvial system that migrated from the SW, associated with a floodplain and crevasse splay deposits (FERNANDES FILHO, 2010; REIS et al, 2010). According to Reis et al. (2010), this siliciclastic deposition is intercalated with tuffaceous mudstone, or pyroclastic tuff from the Surumu Group.

The Funil Member occurs gradationally superimposed or in apparent abrupt and discordant contact with the Paiva Member (FERNANDES FILHO, 2010; REIS et al, 2010). It is about 150 m thick and is characterized by sandstones, rhythmites of sandstone/pelite, pelites, and subordinately, conglomerates and breccia (FERNANDES FILHO, 2010; REIS et al, 2010). These deposits partially suggest the flooding of the underlying fluvial system associated with coastal plains and tidal channels (FERNANDES FILHO et al., 2008; REIS et al, 2010). It possesses a bimodal pattern, with principal paleocurrents to the SW and subordinated to the NE, perpendicular to the NW-SE paleocoastline (FERNANDES FILHO, 2010). According to Reis et al. (2010), the deposition of large volumes of volcanic ash occurred concomitant to sedimentation.

The Cabo Sobral Formation is discordantly superimposed to the Funil Member, delimited at the base by an erosional surface, and represents the last Paleoproterozoic sedimentary succession of Tepequém mountain (FERNANDES FILHO, 2010; REIS et al, 2010). The entire sedimentary stacking reaches up to 30 m in thickness and is composed by oligomitic orthoconglomerates, fine to conglomeratic sandstones, with subordinate pelites (FERNANDES FILHO, 2010; REIS et al, 2010). The conglomerates are considered to be a secondary source of alluvial diamonds and gold (BORGES & D'ANTONA, 1988). The paleoenvironment is interpreted as a high-energy braided fluvial system that preferentially migrated to the S-SW and subordinately to the S-SE and W-NW (FERNANDES FILHO, 2010; REIS et al, 2010).

4. FACIES AND FACIES ASSOCIATIONS

The faciological evaluation of the Funil Member was conducted along drainage channels, waterfalls, gullies, and in artificial cuts along roads (FIGURE 1). Normally, rocky outcrops along streams and waterfalls present silicified strata, while those exposed along the edges of roads and in gullies are much more friable. These outcrops can be more than 30 m in thickness and extend for more than 100 m, and are predominantly constituted by sandstones, pelites and conglomerates, besides subordinately intercalated metamorphic and pyroclastic volcanic rocks. The color tones are red, orange, and blue-gray to white. The majority of the sedimentary structures are well-preserved and allow for recognition of the paleo-hydrodynamics of sedimentation conditions, and some outcrops present inclined bedding averaging 20°, which can complicate analysis of stratigraphic stacking. In total, 13 facies stacked in columnar profiles were described and interpreted (FIGURE 4) and summarized in Table 1, Figures 5 and 6.

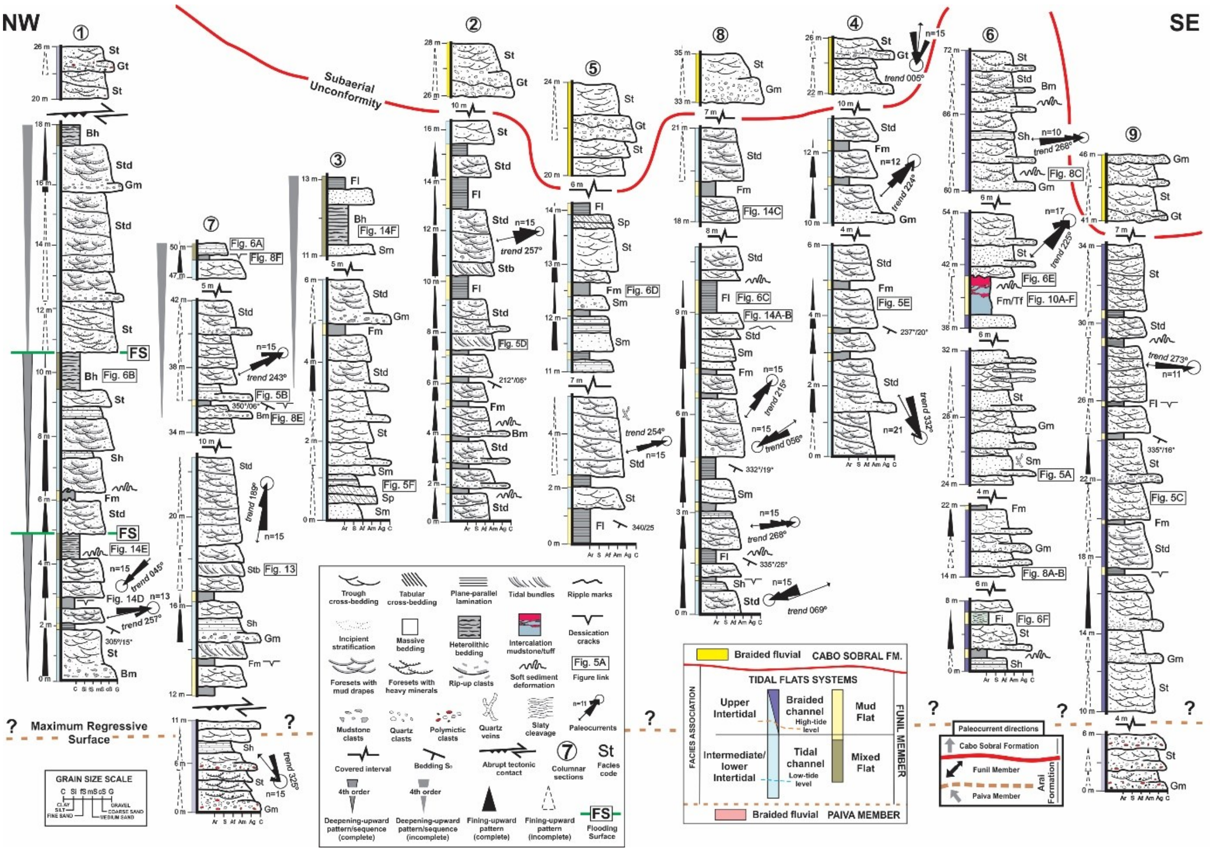
4.1. Intertidal Deposits – FA1

The identified facies were grouped in facies associations that represents intertidal deposits (FA1). These deposits were geomorphologically subdivided into upper and intermediate/lower areas, which describes part of a coastal system influenced by tides implanted in the central portion of the Guyana Shield (TABLE 2).

4.1.1. Intertidal, Upper Area – Iua

The upper area constitutes a set of strata that can be thicker than 70 m and exhibits tabular to lenticular geometry. These facies occur in the profiles 6 to 9, respectively in the Barata and Pretinho streams, exposed to the NW and SE of Tepequém mountain. This depositional area is characterized by braided fluvial channels, which occasionally present a minimal influence of tides which cut out mud flats.

Figure 4 – Columnar profiles of the Funil Member at Tepequém mountain delimited at the top by the subaerial unconformity and at the base by the maximum regressive surface, separating, respectively, the Cabo Sobral Formation and the Paiva Member. The depositional architecture of this unit is organized in 4th order retrogradational sequences with a deepening and finning-upward stacking pattern delimited by marine flooding surfaces. Observe that internally the deepening-upward pattern is composed by layers with a fining-upward pattern. Intermediate/lower intertidal deposits increase in thickness towards the top and overlay the upper intertidal deposits. Location of the profiles in Figure. 1



Braided Fluvial Channels – BC

Description: a set of lenticular and tabular layers, occasionally amalgamated, with an incomplete fining-upward stacking pattern of up to 3 m in thickness and laterally continuous for more than 20 m (FIGURE 7). The base of the layers with a fining-upward stacking pattern is erosive highlighted by gravelly lenses with an open framework of the Gm (FIGURES 5A and 8A) and Bm facies (FIGURE 5B).

Towards the top, gravelly facies are gradually superimposed by the sandy St (FIGURE 8B), Sp, Sh, Sm (FIGURE 5F) and rarely by the Std facies, with gradational and/or erosive contacts. The foresets of the top, in particular, present discontinuous mud drapes in medium- to coarse-grained sand tabular clast, which are thicker towards the bottom set. Eventually, foresets present disharmonic convolutions (FIGURE 8C), while measurements of paleocurrents obtained from the undeformed St facies indicate migration of the bedforms to the W/SW quadrant (FIGURES 5C and 8D).

Table 1 – Table with code, description, and interpretation of the 13 identified facies of the Funil Member at Tepequém mountain

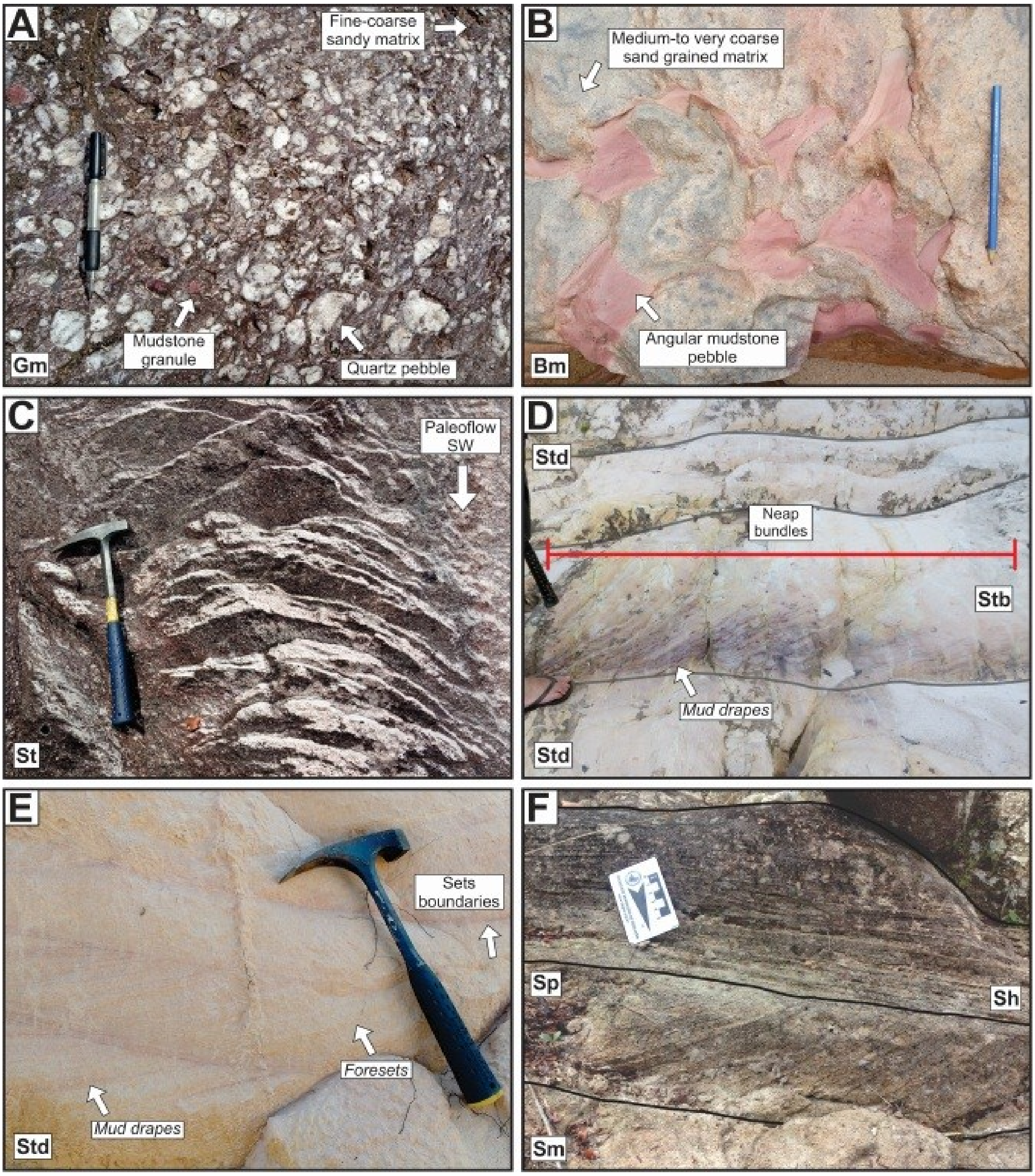
Facies: Code	Description	Interpretation
Massive Conglomerate: Gm	Massive oligomitic conglomerate composed of gravel to pebbles of mudstone and quartz, sub-rounded to round, randomly immersed in a fine- to coarse-grained sandy matrix.	Deposition of poorly-selected sediments with a high concentration and internal cohesion by flow of plastic detritus.
Massive Breccia: Bm	Massive oligomitic breccia with gravel to subangular mudstone pebbles dispersed without preferential orientation in a medium- to coarse-grained sand matrix.	Transport of poorly-selected sediments based on detritus flow associated with erosion of the clay substrate.
Sandstone with trough cross-stratification: St	Sandstone with trough cross-stratification organized in sets of up to 50 cm. Moderately selected and composed of medium- to coarse-grained sand, subangular to rounded, with occasional quartz or mudstone gravel. The foresets indicate paleoflux to the SW and are sometimes marked by heavy minerals grains, and in which stand out convolutions.	Migration of sand dunes with sinuous to linguoid crests, under unidirectional and a lower regime flow.
Sandstone with cross-stratification with mud drapes: Std	Sandstone with cross-stratification organized in sets of up to 50 cm. Moderately selected and composed of fine- to coarse-grained sand, subangular to rounded with rare mudstone gravel that is rounded to angled. The foresets suggest a paleoflux to the SW and subordinately to the NE. Sets and foresets characterized by mud drapes with the rare occurrence of concentration of heavy minerals grains, which demonstrate convolutions. Eventually, at the top of the sets, asymmetric, ripple marks are preserved, with up to 5 cm in amplitude and 10 cm in length, indicating paleoflow to the NE.	Migration of 3D sand dunes, under unidirectional and a lower regime flow, alternating with periods of stagnant water and settling of fine sediments in suspension. Migration of parasitic ripple marks in the direction of the subordinate current.
Sandstone with tidal bundles: Stb	Sandstone with tidal bundles, moderately selected and composed of fine- to coarse-grained sand, sub-rounded to rounded with rare mudstone gravel immersed in the matrix, principally in the basal portions. Foresets regularly alternate between thicker and texturally coarser, with rare mud drapes and thinner foresets that are texturally finer and highlighted by continuous mud drapes of up to 1 cm concentrated in the toe set. Eventually, the foresets are sectioned by reactivation surfaces.	Migration of 3D sandy bedforms, under unidirectional and a lower regime flow, alternating with periods of absence of tractive currents and settling of clay sediments in suspension.
Sandstone with tabular cross-stratification: Sp	Sandstone with tabular cross-stratification organized in sets of up to 20 cm. Well-selected grains represented by fine- to medium-grained sand, sub-rounded to rounded.	Migration of 2D sandy dunes, under unidirectional and a lower regime flow.
Sandstone with planar lamination: Sh	Sandstone with planar lamination organized in sets of up to 20 cm. Grains moderately- to well-selected represented by fine- to medium-grained sand, rounded to sub-rounded.	Migration of subaqueous sandy sheets under unidirectional and a upper flow regime.

Massive sandstone: Sm	Massive sandstone, moderately selected and composed of fine- to coarse-grained sand, sub-rounded to rounded with occasional mudstone gravel dispersed in the matrix.	Deposition under high-energy fast flow, lacking structure due to total liquification or diagenetic recrystallization.
Heterolithic bedding: Hb	Flaser, wavy and linsen bedding of fine to medium grained massive sandstone lenses or asymmetric ripple marks alternating with laminae of mudstone, delimited by gradational, abrupt well-defined or sinuous bulging contacts. The mudstone is massive and occurs covering the sandy laminae in a continuous or discontinuous manner. Sandy injection dykes.	Migration of subaqueous sandy ripple marks under unidirectional and a lower regime flow, alternating with settling of clay sediments. Dykes resulting from fluidification processes.
Laminated mudstone: Fl	Mudstone with planar lamination organized in sets of up to 40 cm. Eventually, there occur contraction cracks at the top surface.	Deposition of clay sediments by settling in water in the absence of currents. Subaerial exposition.
Massive mudstone: Fm	Massive mudstone with contraction cracks at the top of the layer. Eventually present centimeter-sized flames composed of round to sub-rounded fine sand grains.	Deposition of clay sediments by settling in water in the absence of currents. Subaerial exposition.
Phyllonite: Fi	Very fine and homogenous phyllonite, internally structured by millimetric penetrative planes, undulating and slightly arched, with a lustrous shine associated with slaty cleavage, similar to the textural aspect of a phyllite.	Recrystallization of clay bodies through low-grade metamorphism in zones of deformation.
Intercalation of mudstone/tuff: Fm/Tf	Mudstone/tuff laterally interlaminated and continuous for more than 10 m with up to 2 m in thickness. Composed of intercalations of massive red mudstone with grey to blue-green tuff.	Deposition of clay sediments simultaneously with felsic pyroclastics (ash-fall tuffs), through settling with little and/or the absence of tractive forces.

Interpretation: the predominance of lenticular to tabular amalgamated bodies with basal erosive limits highlighted by the Gm and Bm facies interpreted as detritus flow (BROUGHTON, 2018; HAYMAN et al, 2020), superimposed by the St and Sp facies related to the migration of dunes with straight to sinuous crests (ASHLEY, 1990; SARKAR et al, 2012), besides the presence of the Sh facies resulting from the migration of sandy sheets (MAGALHÃES et al, 2014) suggest channels with an elevated bedload contribution (MIALL, 2006; OJO & AKANDE, 2012).

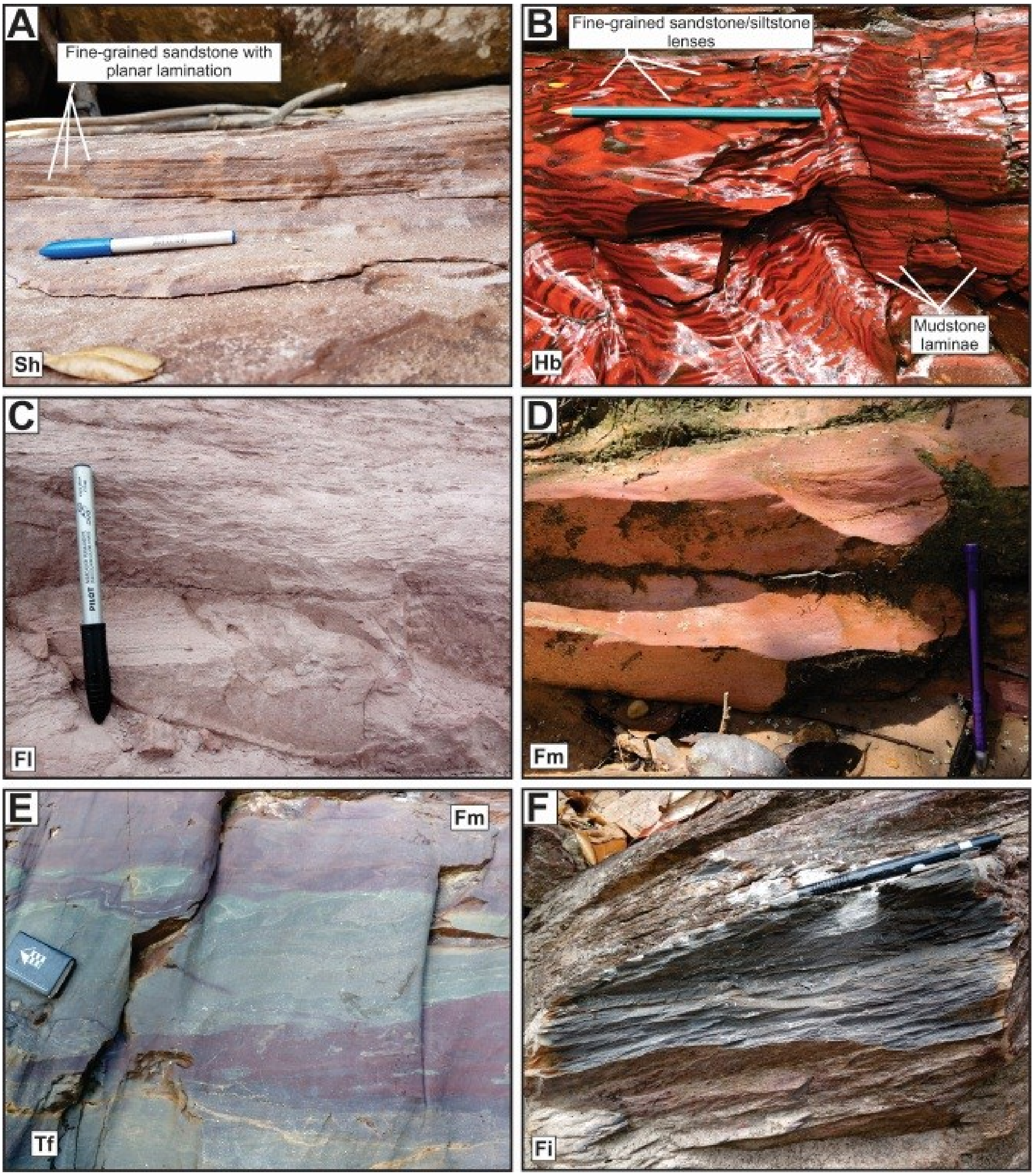
These channels possess a high rate of lateral migration, corroborated by incomplete and amalgamated fining-upward stacking pattern (ERIKSSON et al, 2006a; LONG, 2011; MIALL, 2006), that eroded the restricted interdistributary plains as demonstrated by clasts of mudstones immersed in sandy and gravelly beds in the form of lags (ERIKSSON et al, 2006a; LONG, 1978, 2006).

Figure 5 – Examples of facies from the Funil Member. (A) Massive oligomitic conglomerate (Gm facies) with pebbles that are predominantly quartz immersed in a matrix of fine to coarse sand, with occasional mudstone granules; (B) Plan view of oligomitic massive breccia (Bm facies) composed of mudstone gravel immersed in a matrix of fine to coarse sand; (C) Medium- to coarse-grained sandstone with trough cross-stratification (St facies) shown in planar view. Observe the paleocurrents in the SW direction; (D) Medium- to coarse-grained sandstone with tidal bundles (Stb facies) with foresets marked by mud drapes (Neap tide); (E) Fine- to medium-grained sandstone with foresets and sets marked by continuous mud drapes (Std facies); (F) Fine- to medium-grained sandy facies with a massive structure (Sm facies), tabular cross-stratification (Sp facies) and planar lamination (Sh facies)



Additionally, the hydrodynamic adjustments of these channels allowed for the remobilization of bedforms and a rapid deposition generating the Sm facies, or alternatively

Figure 6 – Examples of facies of the Funil Member. (A) Fine-grained sandstone internally structured by planar lamination (Sh facies); (B) Silicified heterolithic bedding (Hb facies) with internal variation between wavy and linsen; (C) Planar laminated mudstone (Fl facies); (D) Massive mudstone of the Fm facies; (E) Intercalation between massive mudstone (Fm facies) and ash-fall tuffs (Tf facies); (F) Phyllonite (Fi facies) presenting fine and homogenous texture, internally structured in thin, pervasive, sinuous to undulating laminae, furrowed and with a lustrous to silky luster

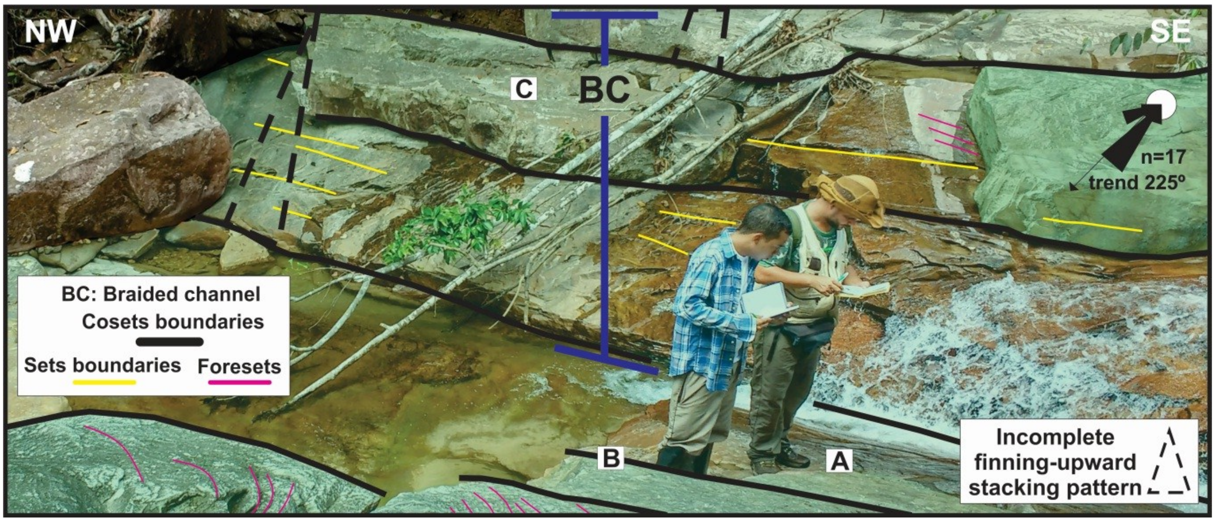


they can be associated with the liquification process of supersaturated sandy sediments (MIALL, 2006; MUKHOPADHYAY et al, 2016; SARKAR et al, 2012), as suggested by the convolutions in the St and Std facies. Furthermore, the massive sandstone of the Sm facies could be related to diagenetic processes that obliterated the primary structures (MAGALHÃES et al, 2014; SOUZA et al, 2019).

Table 2 – Summary of the interpreted depositional sub-environments of the tidal flats system of the Funil Member, Tepequém mountain

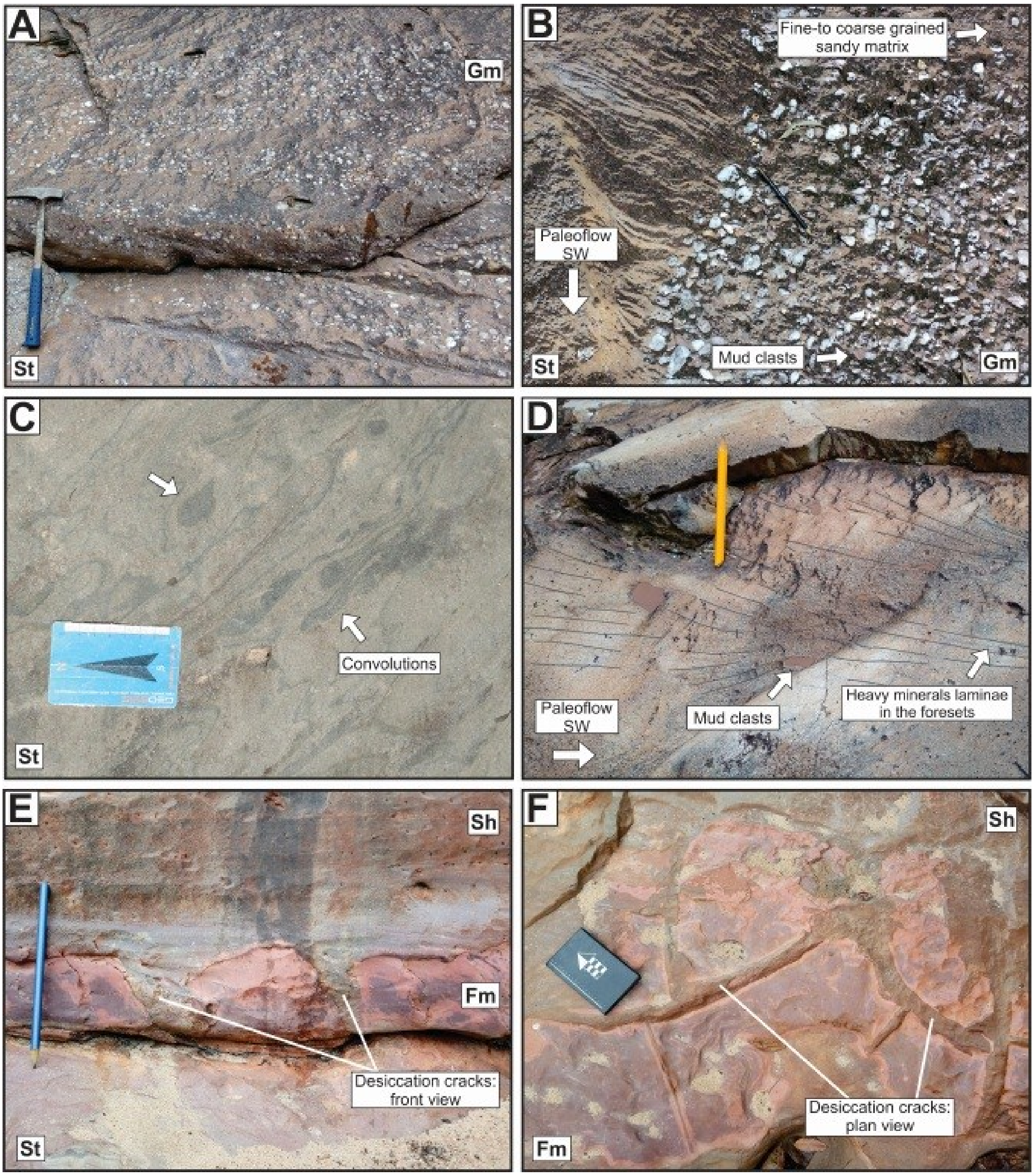
Facies Association		Description	Interpretation
Intertidal Deposits – AF1	**Intertidal: Upper Area – Iua**	Lenticular to tabular beds with an incomplete upward-fining pattern of up to 3 m in thickness. Internally composed by the Gm, Bm, St, Sp, Sh, Sm and rarely, Std facies. Paleocurrent pattern exclusively to the SW.	Braided fluvial channel deposits.
		Tabular layer of up to 1.5 m in thickness cut by shallow channels that mark the top of the layers with a complete upward-fining pattern of up to 4 m in thickness. These are composed of the Fl, Fm facies and eventual intercalations of ash-fall tuffs from the Fm/Tf facies.	Mud flats deposits.
	IIntertidal: Intermediate/Lower Area – Iia	Lenticular to tabular bodies with an incomplete upward-fining pattern of up to 3 m in thickness. These are composed of the facies Gm, Bm, St, Sp, Sh, Sm, besides Stb and an abundance of Std. Pattern of bidirectional sedimentary dispersion, with predominance to the SW and subordinate to the NE.	Channel deposits with total influence of tidal currents.
		Tabular beds of up to 1.5 m in thickness cut by deposits from channels with a complete upward-fining pattern of up to 4 m thick. Composed only by the Fl and Fm facies, which in contrast to the Iua flats, does not present pyroclastic materials.	Mud flats deposits.

Figure 7 – Lenticular to tabular amalgamated layers forming an incomplete fining-upward stacking pattern. Represent braided fluvial channel deposits with an elevated bedload, constituted exclusively by sandy and gravelly facies that migrated to the SW. Outcrop from profile 6. A, B and C represent details in Fig. 8A to C



The sedimentary stacking marked by weakly developed fining-upward pattern, associated with unimodal and low sedimentary dispersion to the W/SW in shallow channels with elevated hydrological variation and high contribution of bedload deposits, points to braided fluvial channels (BOSE et al, 2012; ERIKSSON et al, 2006a; SØNDERHOLM &

Figure 8 – Examples of facies from the intertidal upper area associated braided fluvial channel (A to D) and mud flats deposits (E and F). (A) Intercalation between medium- to coarse-grained sandstone with trough cross-stratification (St facies) and oligomitic conglomerates (Gm facies); (B) Planar view of the relationship of lateral contact between trough cross-stratified sandstone (St facies) and oligomitic conglomerates (Gm facies). Foresets of the St facies indicate paleoflux exclusively to the SW; (C) Planar view of concentration of heavy mineral grains showing convolutions of sandstone foresets with trough cross-stratification of the St facies; (D) Sandstone with trough cross-stratification (St facies) with foresets marked by heavy minerals grains, besides mudstone granules dispersed in the matrix; (E) Massive mudstone (Fm facies) with contraction cracks marked by vertical fissures in a ‘v’ format filled with sandy grains of the Sh facies. These mudstone fragments are commonly sources of sediments for generation of breccias (Bm facies); (F) Polygonal contraction cracks filled with sandstone at the top of the massive mudstone facies (Fm facies)



TIRSGAARD, 1998). The occurrence, even though restricted, of the Std facies in these channels suggests proximity to coastal regions and minimum influence of tidal currents, but rather there is a predominance of a dominant and unidirectional paleoflow (BHATTACHARYA et al, 2012; DEYNOUX et al, 1993; Eriksson & Simpson, 2012; GHOSH et al, 2005; MUELER et al, 2002).

Mud Flats – MF

Description: tabular deposits that are laterally continuous for more than 6 m, generally less than 1 m thick, which may occasionally reach 1.5 m. These occur intercalated with channel deposits from the upper area, delimited by abrupt, well-defined contacts which are bulging and erosive or sinuous. Stratigraphically, the mud flat deposits finalized the fining-upward stacking pattern, although incomplete patterns are more abundant.

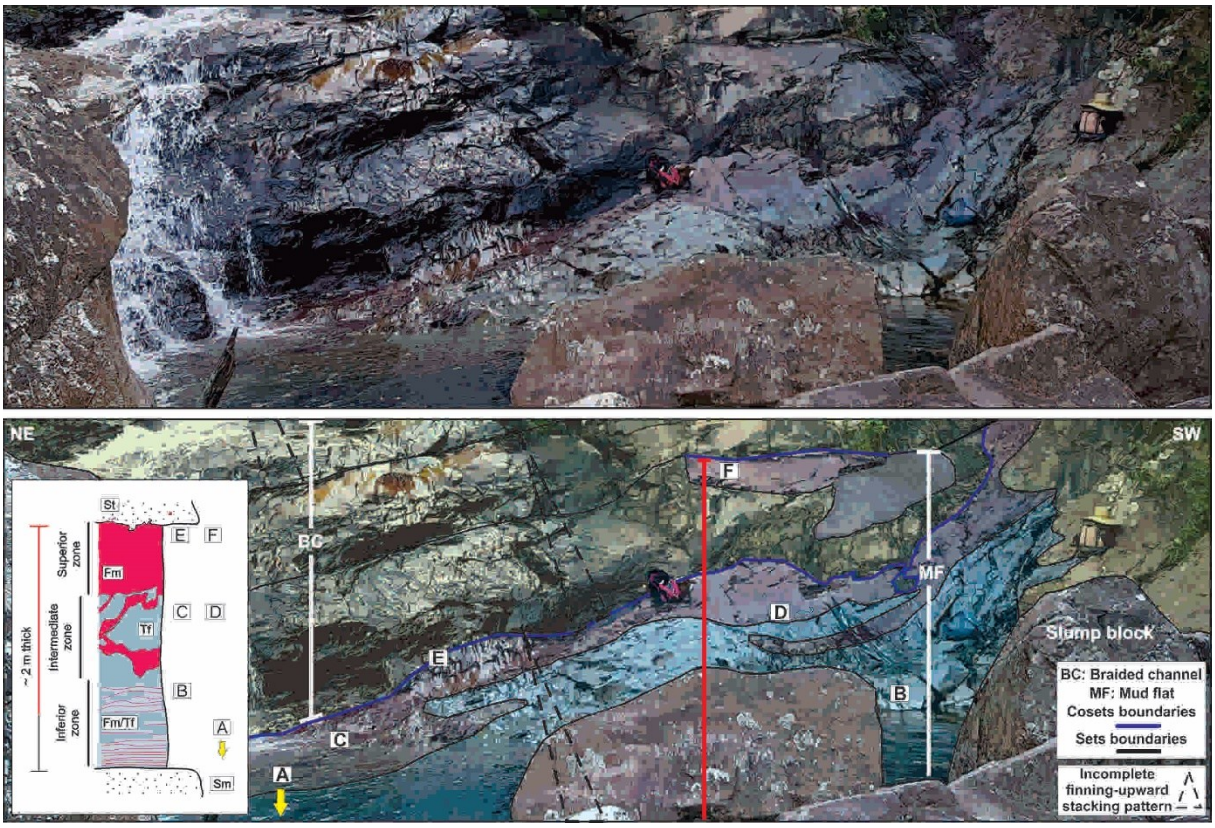
These deposits are composed of Fl and Fm facies (FIGURES 6C and D), wherein the top is eventually marked by dissection cracks characterized by sinuous and straight fissures up to 2 cm in width, organized in polygons that are greater than 40 cm in diameter and filled with massive fine- to medium-grained sandstone (FIGURE 8F). In transversal cuts the fissures are v-shaped and can be greater than 5 cm in depth (FIGURE 8E).

Besides these, there is a contribution from the Fm/Tf facies (FIGURE 6E), restricted to the Barata stream, represented by intercalation between massive red mudstone (Fm facies) and pyroclastic volcanic aphanitic rock that is grey to blue-green in color (Tf facies) (FIGURE 9). This occurs intercalated with sandy facies delimited by an lower surface that is abrupt and planar, while the upper limit has an erosive character which laterally becomes a sinuous and bulging surface that stands out due to flame and ball-and-pillow structures.

Internally, the Fm/Tf facies can be subdivided into 3 zones, identified here as inferior, intermediate, and superior. In the inferior zones there are intercalated laminations forming parallel plane bedding. These intercalations occasionally present irregular, sinuous limits, or form harmonic folds, besides having microfaults that are normal and inverse to centimeter-sized slips which truncate these intercalations (FIGURE 10A). Towards the top, these laminations develop disharmonic folds (FIGURE 10B) that gradationally pass to the intermediate zone, characterized by a reduction in the intercalated laminations and the appearance of layers of up to 30 cm in thickness, especially related to the volcanic rocks (FIGURE 10C).

In the intermediate zone the two lithologies present interdigitated lateral contact, with random forms that have a fluid aspect, generating disharmonic folds (FIGURE 10D). The superior zone is exclusively represented by massive red mudstone, whose upper limit is erosive

Figure 9 – Deposits of the upper mud flats highlighting the Fm/Tf facies at the waterfall of the Barata stream (Profile 6) organized with incomplete finning-upward stacking pattern. The Fm/Tf facies is constituted by intercalation between mudstone (red tones) and tuff (grey to blue-green tones), which is subdivided from the base to the top into three zones: inferior, intermediate and superior (see schematic drawing in the bottom left corner). A to F represent details of features of the 3 zones that are shown in Figure 10

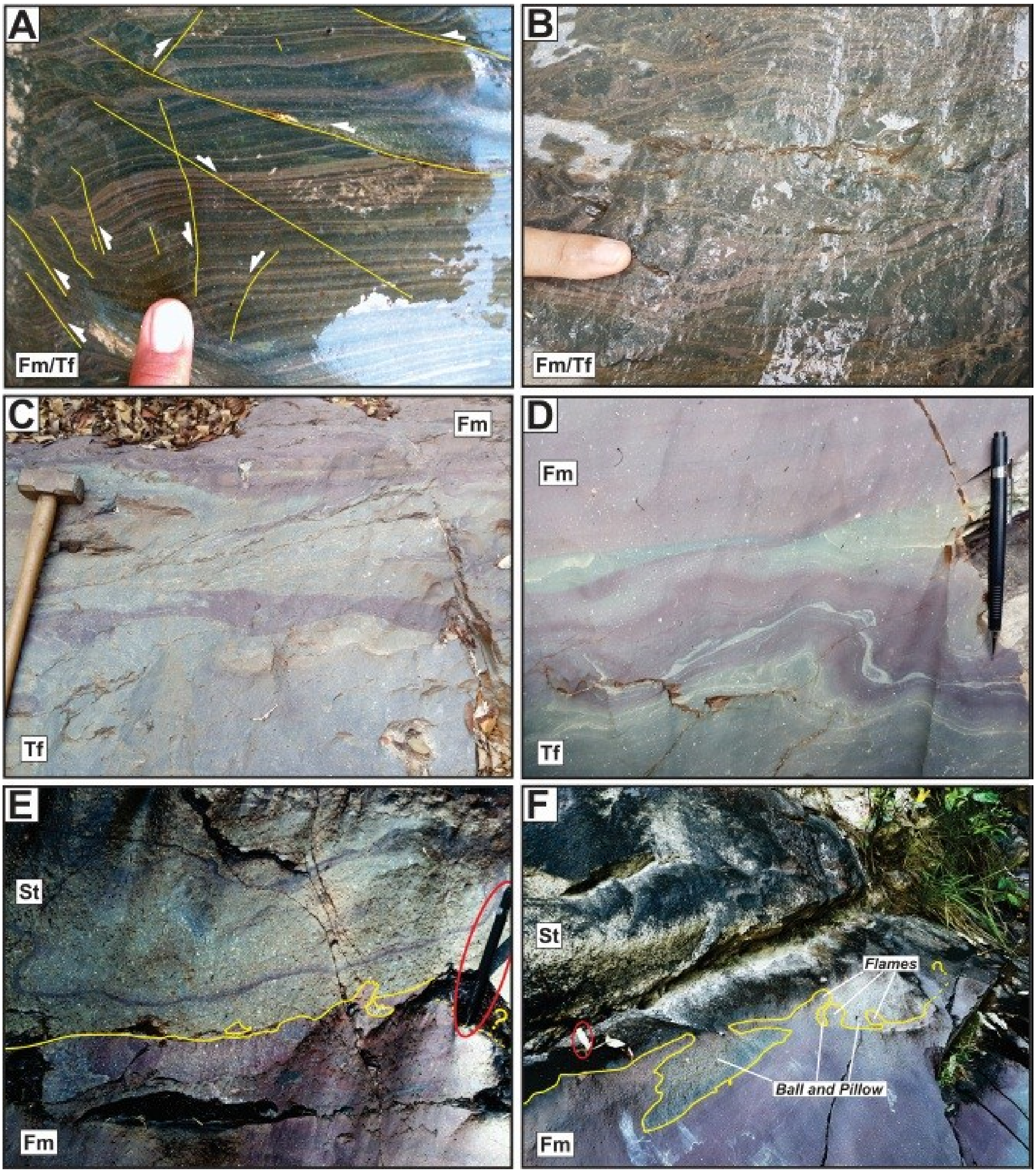


(FIGURE 10E), but laterally passes to contacts marked by ball-and-pillow centimeter-sized spheres and elliptic forms of massive sandstone, with sub-rounded to moderately-selected grains, immersed in mudstone either in an isolated form or still connected to the superimposed St facies (FIGURE 10F).

Occasionally these mud flats deposits of the Fm and Fl facies, when found near the principal structural lineaments of the mountain, such as below the waterfall of the Barata stream, take on a color that is more grey, with a very fine texture that is homogenous and internally structured by a slaty type of cleavage, attributed to facies of phyllonite (Fi) (FIGURES 6F and 11A, B).

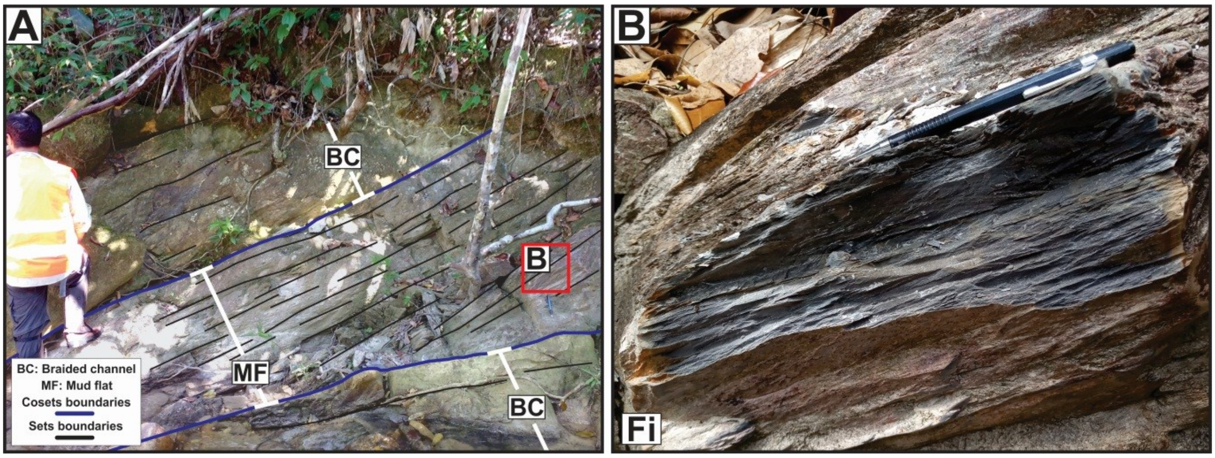
Interpretation: the association of the Fm and Fl facies, resulting from the deposition of clayey sediments via water through settling and with the absence of currents (SANTOS & OWEN, 2016; SCHEMIKO et al, 2014), marking the top of the layers with a complete fining-upward stacking pattern that is commonly eroded by channels suggests depositional sub-environments that are external to the channels, interpreted as restricted interdistributary plains (ERIKSSON et al, 1995; MIALL, 2006).

Figure 10 – Details of the characteristics of the inferior, intermediate, and superior zones of the Fm/Tf facies at the waterfall of the Barata stream (Profile 6). (A) Intercalation of thin planar laminae of mudstone with tuff. Observe the presence of microfaults that dislocate the laminae; (B) Sub-parallel intercalation of laminae of mudstone with tuff disharmonically deformed; (C) Planar view of intercalation of thicker layers between tuff and mudstone, which marks the intermediate zone of the Fm/Tf facies; (D) Syndepositional deformations in a plastic state forming asymmetrical folds between the intercalations; (E) Relationship of the upper contact marked by an erosive surface as indicated by clasts of mudstone immersed in the overlaying St facies. Scale is highlighted by an ellipse at the right; (F) Upper contact relationship between Fm facies and the overlying sandy facies (St) marked by a sinuous and bulging surface associated with the presence of deformational overload structures



These restricted plains were eventually submitted to subaerial exposition, as indicated by the dissection cracks (FEITOSA et al, 2019), which, in the defended paleoenvironmental context, are compatible with mud flats (Ojakangas, 1983; Eriksson et al., 1995; Dalrymple, 2010; Daidu et al., 2013; Bhattacharya et al., 2019).

Figure 11 – (A) Mud flats intercalated with braided channel deposits downstream of the waterfall of the Barata stream. (B) Detailed aspects of the phyllonite facies (Fi) constituted by penetrative millimetric planes, undulating to slightly arched, besides a lustrous shine associated with slaty cleavage



Tuff intercalated in these muddy deposits (Fm/Tf facies) suggests evidence of explosive felsic volcanic eruptions (SAHA & TRIPATHY, 2012; SAI, 2014). In this way, these tephras were dispersed by subaerial currents over an extensive area and were deposited only in the most distant portions of these eruptive scenarios. The distal environment of these volcanic deposits is shown by the fine texture of the sediments (grey) and by the absence of rocks associated with pyroclastic flow in the Funil Member (BYUN et al, 2019; ZHOU et al, 2017).

In this context, the fine siliciclastic sediments as well as the volcanic ash were deposited by water through settling processes in these restricted mud flats. The abundant presence of deformational structures such as laminae/layers deformed, flames, and ball-and-pillows related to processes of liquification and partial fluidization of supersaturated sediments (HILL & CORCORAN, 2018; OLIVEIRA et al, 2011), is consistent with this interpretation (ZHOU et al, 2017). Furthermore, brittle structures associated with ductile deformations suggests posterior microfaults in semi-consolidated sediments related to multiple pulses of tectonic and volcanic activity, which is confirmed by variations in the thickness of the tuff laminations (GAO et al, 2020; PERKINS & NASH, 2002).

The presence of rocks interpreted as phyllonite, restricted to the structural lineaments of the Barata stream mapped on the Tepequém mountain, and with a stratigraphic position similar to that of the mud flats, alludes to a process of recrystallization of clay facies through low-grade metamorphism in intense zones of deformation (FERNANDES et al, 1993; LENZ et al, 2011).

This, in turn, deformationally responded in a different way when compared to other, more competent rocks, such as sandy or conglomeratic ones.

4.1.2. Intertidal, Intermediate/Lower Area– Iia

The deposits of the intermediate/lower area present lenticular to tabular geometry, with expositions of up to 40 m in thickness and lateral extensions of more than 30 m. These occur in all the profiles, except for 6 and 9, constituting the largest part of the sedimentary record of this unit. This depositional area is characterized by tidal channels which cut mixed and mud flats, the latter described above.

Tidal Channels – TC

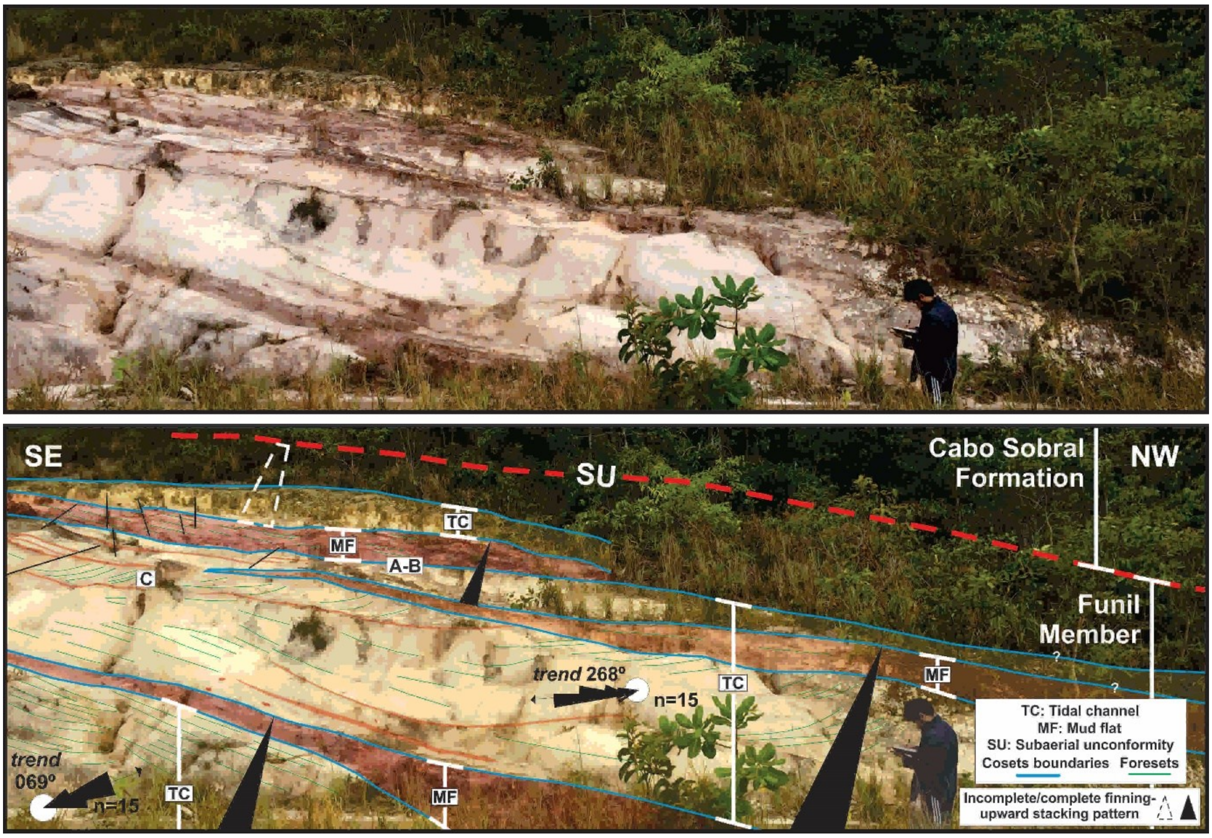
Description: a set of layers with lenticular to tabular geometry of up to 3 m in thickness with more than 6 m of lateral extension. When superimposed by deposits of the mixed or mud flats these form layers with a complete fining-upward stacking pattern of up to 4 m in thickness (FIGURE 12), marked at the base by gravelly beds from the Gm and Bm facies, characterized by an open framework, and predominantly composed of clay clasts. Eventually, the base of these deposits is also marked by the Std or Stb facies (FIGURE 13).

Laterally, the Stb facies presents foresets that regularly alternate between thicker and thinner, the latter being texturally finer and having continuous mud drapes up to 1 cm thick concentrated in the toe set. The thicker foresets have a coarser texture and rarely present mud drapes.

Towards the top of the layers with a complete fining-upward stacking pattern the Std (FIGURE 5E), Stb (FIGURE 5D), St, Sp, Sh (FIGURE 6A) and Sm facies occur, with special emphasis on the Std facies since it is the most prevalent one and presents asymmetrical ripple marks at the top of the sets (FIGURES 14A and B). Additionally, its tangentially-crossed foresets present millimeter-sized mud drapes, which regularly cover the foresets in a continuous and discontinuous form (FIGURE 14C), with the latter being partially fragmented in tabular clasts in the medium- and coarse-grained sand fractions. When preserved in a continuous form in the bottom set, the mud drapes are thicker and can present fine laminations with prominent micaceous grains.

The crossed foresets of the Stb and Std facies are sectioned by surfaces that are inclined in the same direction as its strata, however at an angle that is acute in relation to the base of the sets. The paleocurrent measurements obtained from the Std facies indicate a bidirectional paleoflow with principal trends to the SW and subordinately to the NE, the latter case being similar to that indicated by the ripple marks at the limit of the sets (FIGURE 14B).

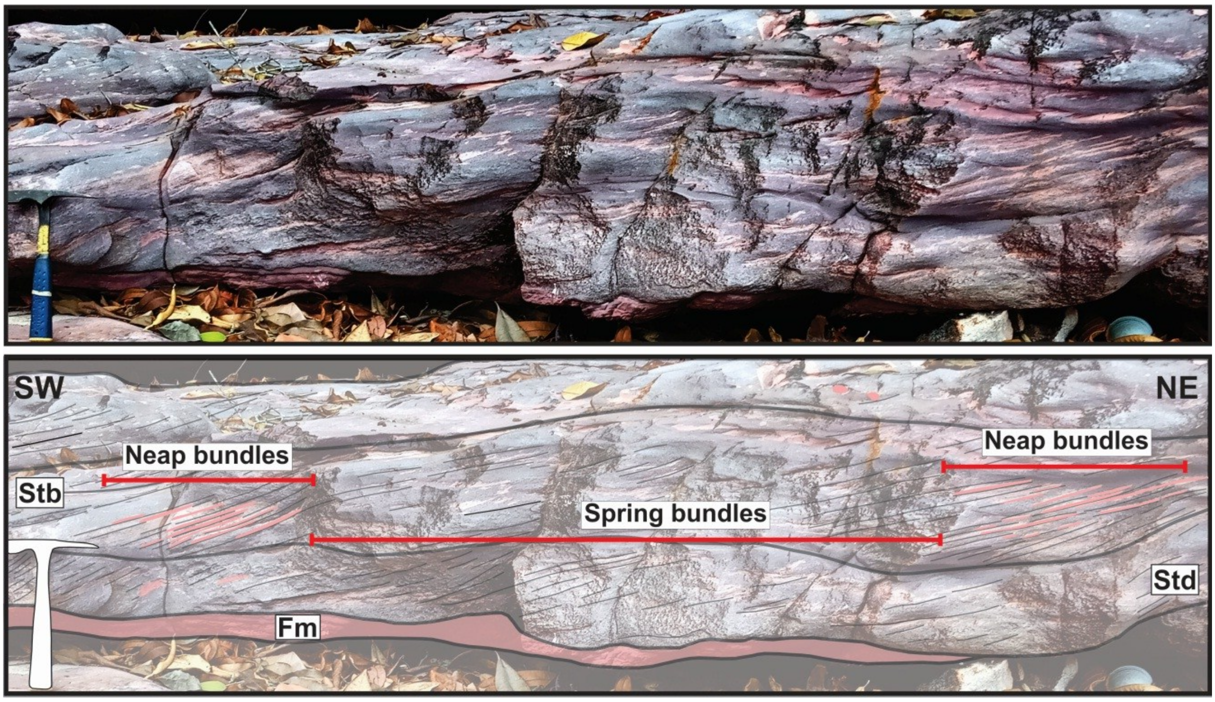
Figure 12 – Set of layers with lenticular to tabular geometry constituted by sandy facies interpreted as tidal channels intercalated with clayey facies of mud flats with a complete finning-upward stacking pattern. The tidal channel deposits (Std, St and Sm facies) show a bidirectional paleocurrent pattern and commonly cut the deposits of the mud flats (Fm and Fl facies). Observe that the top of the Funil Member is erosively covered by rocks of the Cabo Sobral Formation which has a surface interpreted as a subaerial unconformity, mappable throughout the area of Tepequém mountain. A, B and C represent details of Figure 14 A to C. Rock outcrop from profile 8



Interpretation: channels that form a set of layers with a tendency for fining-upward stacking pattern, occasionally at the base of deposits originating from pseudoplastic gravitational flow from the Gm and Bm facies, whose mudstone intraclasts indicate erosion of the clay substrate (ERIKSSON et al, 2006b; MIALL, 2006; SIMPSON et al, 2002).

Associated with these gravelly beds are sandy deposits in the facies St, Sp, Sh and Sm, which suggests hydrodynamic sedimentation conditions similar to those from the channels in the Iua. However, these are different due to the presence of the Stb facies and the abundance of the Std facies, which are strong indications of more transitional conditions in the channels and a strong influence of tidal currents (DALRYMPLE, 2010; ERIKSSON et al, 1995; MAZUMDER et al, 2015).

Figure 13 – Intertidal deposits with tidal bundled sandstone facies (Stb) characterized by a sequence with alternating lateral and regular bundles marked by mudstone drapes in the sigmoidally crossed foresets (Neap tide) and bundles with or without rare mudstone drapes (Spring tide). The Stb and Std facies overlay the massive mudstone (Fm facies) with deformed contacts. Rock outcrop from profile 7

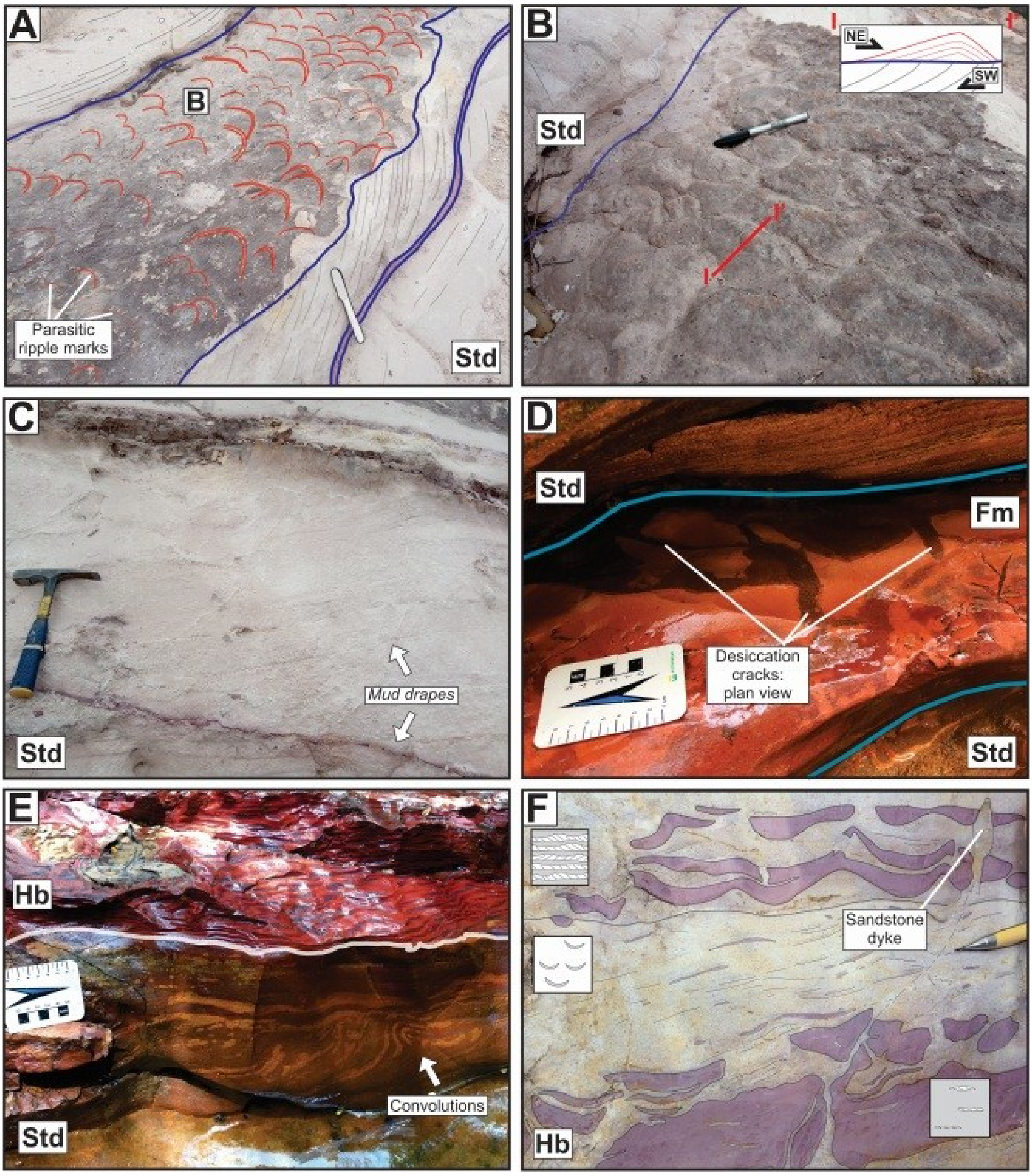


Tidal bundles (Stb facies) represent alternance between tractive depositional processes and settling associated with neap-spring cycles (DAVIS, 2012; FRIEDMAN & CHAKRABORTY, 2006; SHUKLA & SHUKLA, 2013; TAPE et al, 2003). These structures are compatible with tidal channels submitted to bidirectional currents, which are very common in intertidal/subtidal zones (DAIDU et al, 2013; ERIKSSON & SIMPSON, 2012;).

The bundles of the Stb facies (laterally accreted) are excellent registers of tidal periodicity (COUGHENOUR et al, 2009). The analysis of these records provides information about the Earth's rotation and paleolunar orbital period, however, the intense process of silicification in these facies obliterated and homogenized the majority of its structures, thus impeding an analysis.

The presence of the Std facies, a product of migration of sand dunes alternating with a period of stagnant water which allowed for the settling of fine sediments in crossed foresets (slack tide), were interpreted as records of semi-diurnal tide cycles (DALRYMPLE, 2010; DEYNOUX et al, 1993; MUELLER et al, 2002; STEEL et al, 2012). Crossed foresets of this facies indicate a bidirectionality in the current, whose predominance to the SW represents the low tide, which agrees with the paleoflow from the channels of the Iua.

Figure 14 – Facies from the intermediate/lower areas of the tidal flats of the Funil Member: tidal channel deposits (A to C), mud flats (D) and mixed flats (E to F). (A) Sandstone with cross-stratification with a mud drape (Std facies) with parasitic ripple marks that stand out in the sets. Observe that the crossed foresets are oriented to the SW quadrant, while the parasitic ripple marks indicate paleoflow to the NE. B shows the bedform detail; (B) Planar view of the parasitic ripple marks that highlight the sets of the Std facies; (C) Sandstone with cross-stratification with a mud drape (Std facies) covering the foresets (white mudstone) as well as the limit of the set (purple mudstone); (D) Massive mudstone (Fm facies) with contraction cracks on its top surface; (E) Heterolithic bedding (Hb facies) superimposed on cross-stratified sandstone with a mud drape (Std facies) delimited by bulging and deformed contacts. Observe restricted convolutions of the foresets of the Std facies; (F) Heterolithic bedding (Hb facies) marked by a gradation from the base to the top composed of linsen, flaser and wavy forms. These structures are truncated by sandstone dykes



Dispersion of subordinate sediments to the NE represents the high tide, consistent with the bedforms of a lower hierarchy indicated by parasitic ripple marks at the limit of the sets (BRADLEY et al, 2018; DALRYMPLE, 2010). These ripple marks of subordinate currents (set climbers) suggest indications of tidal activity, which, different than ripple marks from back-flow in unidirectional flow migrate in the opposite direction covering reactivation surfaces or even limits of sets (HERBERT et al, 2015; VAN DEN BERG et al, 2007).

The internal surface that section the foresets of the Stb and Std facies represent reactivation surfaces linked to the rejuvenation of currents and adjustment of the inclination of the lee side of the sandy bedform (DAVIS, 2012). Eventual convolutions of the strata of Std facies are suggestive of plastic deformation of partially liquified sediments soon after their deposition (BERRA & FELLETTI, 2011).

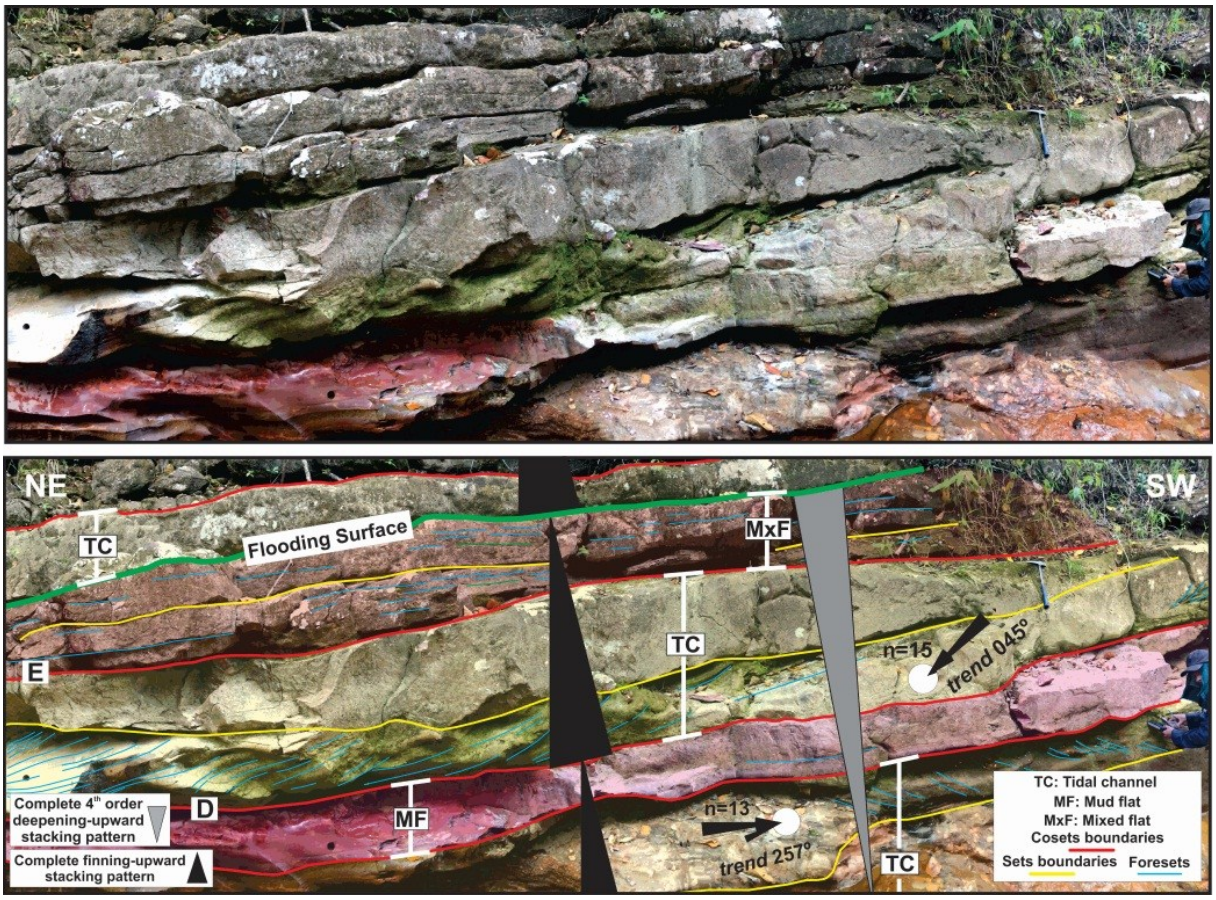
Mixed Flats – MxF

Description: a set of tabular layers of up to 1 m in thickness and laterally continuous for more than 10 m. These are delimited by surfaces that are sinuous and bulging, well-defined abrupt, or erosive when superimposed by deposits from tidal channels, marking the top of the layers with a tendency for a complete fining-upward stacking pattern up to 4 m thick (FIGURE 15). These deposits are primarily constituted by the Fl and Fm facies, eventually marked at the top by contraction fissures (FIGURE 14D), besides sandy and heterolithic bedding, respectively for the Sm and Hb facies (FIGURES 6B and 14E). The latter is internally characterized by flaser, wavy and linsen bedding in gradational, well-defined abrupt, or sinuous bulging contact.

Flaser bedding presents massive lenses of fine- to medium-grained sandstone that are centimeters thick and continuous, which are sometimes covered by continuous thin films of mudstone at the terminal ends, and discontinuous in the central portion of the lenses. Wavy bedding represents asymmetric ripple marks of fine- to very fine-grained sandstone, with maximum length and amplitude of 10 and 3 cm, respectively, and intercalated with mudstone laminae. The mudstone laminae cover the wavy bedding in a continuous manner and can reach 2 m in thickness, principally along the trough of the ripple marks, which diminish at the top of the crest. The linsen bedding is characterized by thin lenses of continuous, massive fine-grained sandstone of up to 1 cm in length and 0.5 cm in amplitude, dispersed in massive mudstone (FIGURE 14F).

Diapiric structures of millimeters to centimeters in size commonly deform and break the heterolithic bedding of the Hb facies. These features are characterized by cylindrical to oval forms, constituted by sand grains that are fine to very fine or silted-sized in texture, sub-rounded to rounded, and moderately selected (FIGURE 14F).

Figure 15 – Intercalation of tabular deposits attributed to mud and mixed flats with lenticular beds from tidal channels with a tendency of a fining to-deepening-upward stacking pattern delimited by marine flooding surface. The mud flats are characterized by the Fl and Fm facies, while the mixed flats are highlighted by the Hb and Fm facies. Sandy facies (Std) in the tidal channels present bidirectionality in the pattern of paleoflow. Outcrop relative to profile 1. See Figures 14D and E



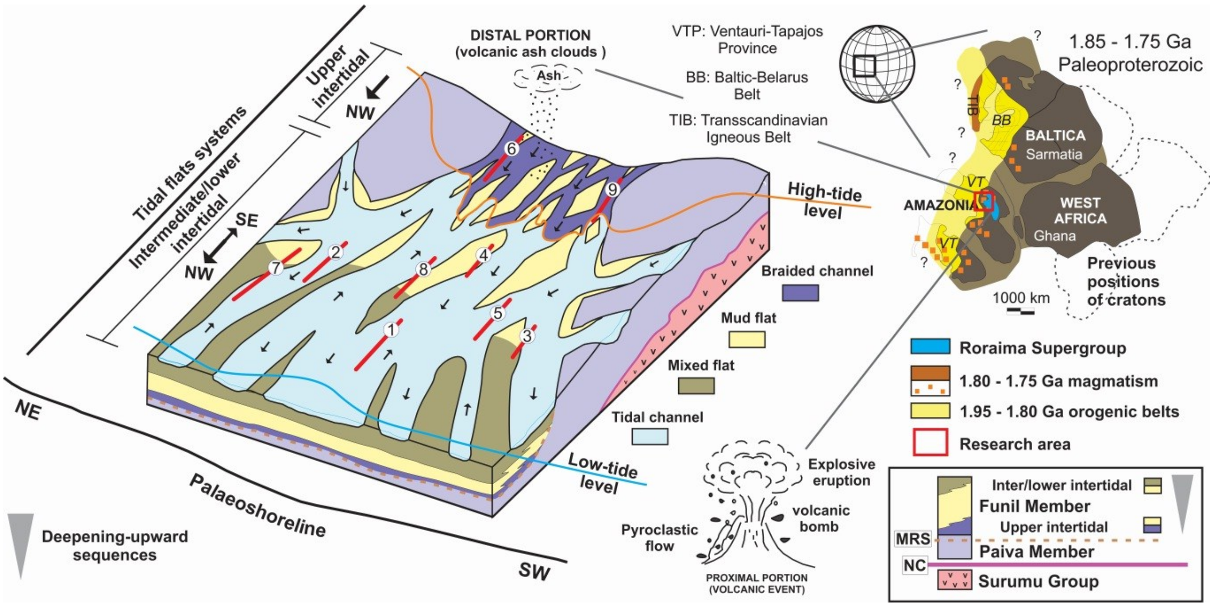
Interpretation: These are interdistributary plains wherein predominated processes of settling of fine sediments in suspension due to the Fm and Fl facies (ERIKSSON et al, 2006b; SHIERS et al, 2014), which eventually were exposed and submitted to dehydration of sediments thus forming fissures (SILVA JÚNIOR et al, 2007). However, the intercalation of centimeter-sized lenses of the Sm facies on these clay beds suggests the action of tractive forces on these plains, which is corroborated by the occurrence of heterolithic bedding in the Hb facies.

Even though heterolithic bedding occurs in lacustrine environments, fluvial plains, or through wave action, the presence of other features associated with tidal processes (mud drapes, bidirectionality of paleoflow, tidal bundles) discards this possibility (DALRYMPLE, 2010). In this context, these facies were interpreted as non-cyclic rhythmites, characterized by alternating tractive and settling processes deposited in mixed flats at the interface of inter- and subtidal zones (DAIDU et al, 2013; DALRYMPLE, 2010; ERIKSSON et al, 1995). Sandstone dykes that intersect these deposits result from the injection of fluid sediments in the direction of the top (ERIC et al, 2018; GHOSH et al, 2012).

4.2. Paleodepositional Model

Facies and stratigraphic analysis from the Funil Member allowed for the recognition of a depositional system with intertidal characteristics where there is interaction between fluvial conditions and tidal currents. These deposits are subdivided into two geomorphologic areas: upper and intermediate/lower (FIGURE 16).

Figure 16 – Depositional model suggested for the Funil Member, Arai Formation, Tepequém mountain. Represents a tidal flat depositional paleoenvironment with a paleocoastline oriented to the NE-SW. This depositional system was characterized by an intertidal zone (upper and intermediate/lower) that was eventually the target of distal felsic volcanic eruptions that were preserved in the upper deposits in this zone. Numbered red lines indicate the idealized positions of the columnar profiles designed in this study. The arrows indicate the direction of the sedimentary dispersion. Partial Paleoproterozoic model of the Columbia supercontinent with emphasis on the Amazon paleocontinent, modified from Johansson (2009)



The upper portion was represented by braided fluvial channels that cut restricted mud flats with evidence of subaerial exposition. These channels were shallow, filled predominantly with sandy-gravelly deposits and had a high rate of lateral migration, principally due to the lack of vegetation in Proterozoic fluvial systems (ERIKSSON et al, 2006a; LONG, 2011; TIRSGAARD, 1993). Furthermore, toward the top of the sedimentary succession these fluvial channels began to register a tidal influence during their sedimentation.

Paleoflow measurements obtained for these braided paleochannels indicate a unidirectional paleocurrent pattern exclusively for the SW quadrant. However, in the paleogeographic context of the Orosirian/Statherian the actual Amazon Craton was positioned at equatorial latitudes and integrated in the Amazonian Paleocontinent of the Supercontinent Columbia (BISPO-SANTOS et al, 2014; D'AGRELLA-FILHO et al, 2012; PESONEN et al, 2012), rotated about 60º clockwise when compared to the actual geographic context (JOHANSSON, 2009). Considering this, the rotation of the depositional trends associated with the principal paleoflow actually migrated to the NW.

The intermediate/lower area was characterized by tidal channels associated with deposits of mixed flats. In the intermediate area of the intertidal portion the tide level is more variable, thus allowing for a greater subaerial exposition in relation to downstream portions (DAIDU et al, 2013). In the lower area predominated mixed flats related to a greater contribution of tractive processes of tidal currents (DALRYMPLE, 2010).

Tidal channels, in contrast to the aforementioned braided channels, were marked by a bidirectional paleoflow pattern. The paleoflow was dominant to the NW, and coincided with the braided fluvial channels, but the subordinate currents demonstrated paleoflow to the opposite quadrant (SE), in the context of the Amazonian Paleocontinent. Furthermore, the tidal channels were predominantly filled with sandy-clayey deposits similar to the Phanerozoic tidal channels, which normally develop more stable drainage patterns with high internal sinuosity (DALRYMPLE, 2010; HUGHES, 2012).

Alluvial plains, as they existed before the rise of vegetation, were not favorable to the installation of fluvial patterns with high internal sinuosity (BOSE et al, 2012). However, even though this channeling was subjected to Proterozoic tidal currents that are known to have been more intense (WILLIAMS, 2000), when associated with favorable conditions that have more accommodation space, low to moderate gradients, and greater stability of margins due to an increase in fine sedimentation, the installation of more stable channels is possible (BOSE et al, 2012; IELPI, 2016; SØNDERHOLMA & TIRSGAARD, 1998). This is corroborated by a greater abundance of records associated with plains and preservation of strata with a complete fining-upward pattern, when compared to the upper portion.

Sedimentation conditions similar to deposition in the Funil Member occurred in the Precambrian, such as fluvial deposits of low sinuosity influenced by tidal currents in the Västervik basin, Sweden (SULTAN & PLINK-BJÖRKLUND, 2006), and braided channel deposits that were gradatively subjected to tidal influence and that accommodated intertidal and subtidal deposits in the Bayana Formation, Lalsot sub-basin (BHATTACHARYA et al, 2019).

The paleoenvironment of tidal flats that is proposed in this study, with the paleocoastline oriented to the NE-SW in the context of the Amazonian Paleocontinent, registered distal felsic volcanic events (volcanic ash) concomitant with siliciclastic sedimentation. This volcanism could be related to extrusive and intrusive interplate magmatism, which occurred in Amazonia during the Paleoproterozoic and is attributed to the Uatumã Magmatism (SANTOS et al, 2000).

This magmatic event is registered in the Surumu pyroclastic deposits (1.96 Ga) (SANTOS et al, 2000, 2003), besides the layers of tuff (ash-fall tuffs) intercalated with the rocks of the Roraima Supergroup (Uaimapué Formation), which is 1.87 Ga (SANTOS et al, 2003), both during the Orosirian. Despite the effusive volcanism having affected the entire tidal flats, the ash had greater potential to be preserved in depositional sites outside of the zone of influence of tidal variations, as, for example, the interdistributary deposits from settling of fine particles.

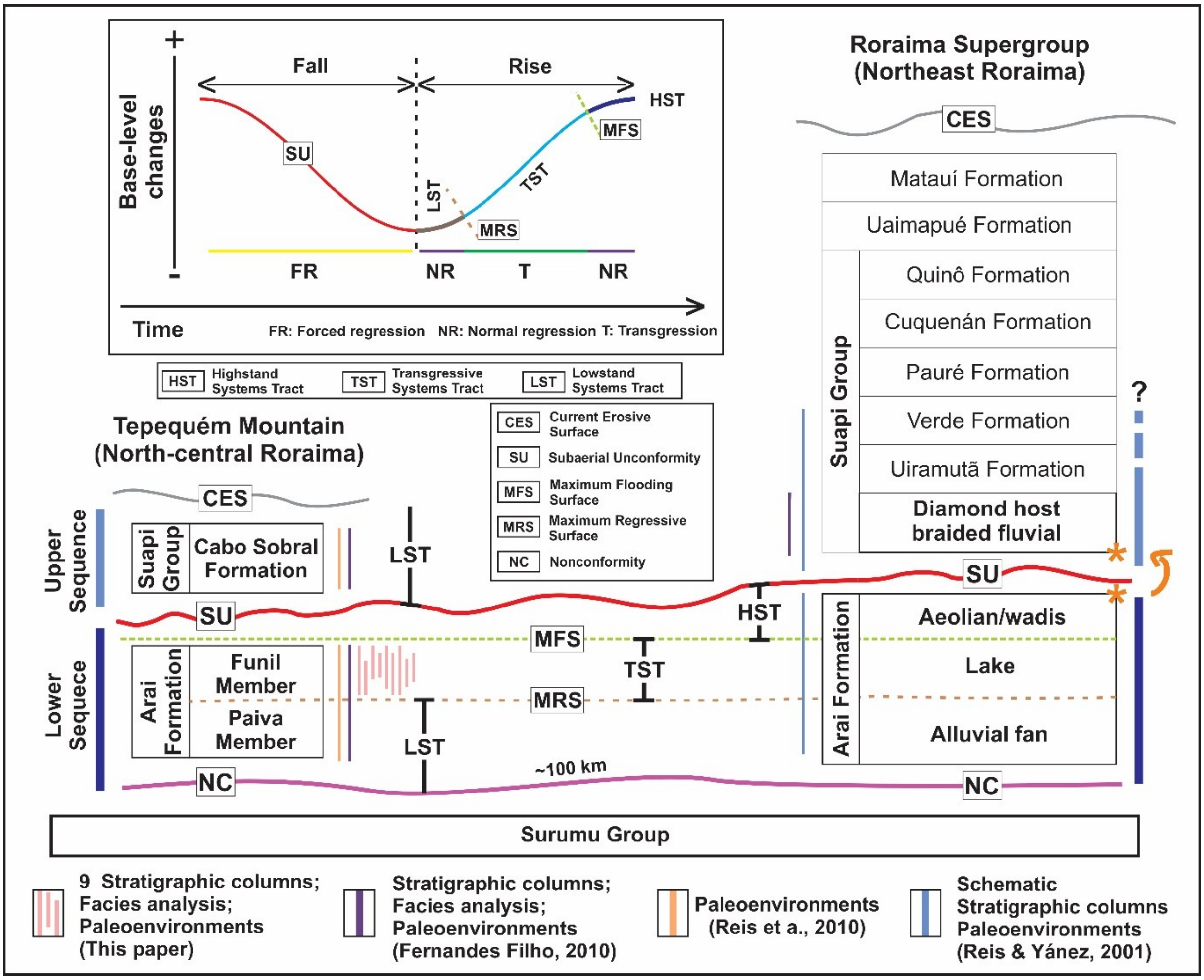
5. SEQUENCE STRATIGRAPHY AND PALEOENVIRONMENTAL CORRELATION

According to Catuneanu (2017, 2019), the hierarchy of stratigraphic sequences depends on factors such as geologic time, tectonic configuration of a basin, and the scale of resolution. In general, 1st order sequences are associated with complete sedimentary filling of a basin in a particular tectonic context. Additionally, 1st order sequences can be subdivided into lower hierarchies as a function of variations in the level of the regional base, which reflects the relationship between sedimentation rate and accommodation space, existing in several observational scales (CATUNEANU, 2019; MAGALHÃES et al, 2016).

In Precambrian successions, the low potential for preservation, the difficulty of biostratigraphic control, and post-depositional modifications hinder the criterious establishment and hierarchy of depositional sequences (MAGALHÃES et al, 2016). However, this problem is partially compensated by a solid knowledge of the facies and their associations, stacking patterns, and paleocurrent data (CATUNEANU et al, 2005; CATUNEANU & ERIKSSON, 2007). In this way, Precambrian successions have been consistently classified with a maximum resolution in sequences of the 3rd order at a regional scale (ALKMIM & MARTINS-NETO, 2012; ERIKSSON & CATUNEANU, 2004; MAGALHÃES et al, 2016; SAMANTA et al, 2016; SOUZA et al, 2019).

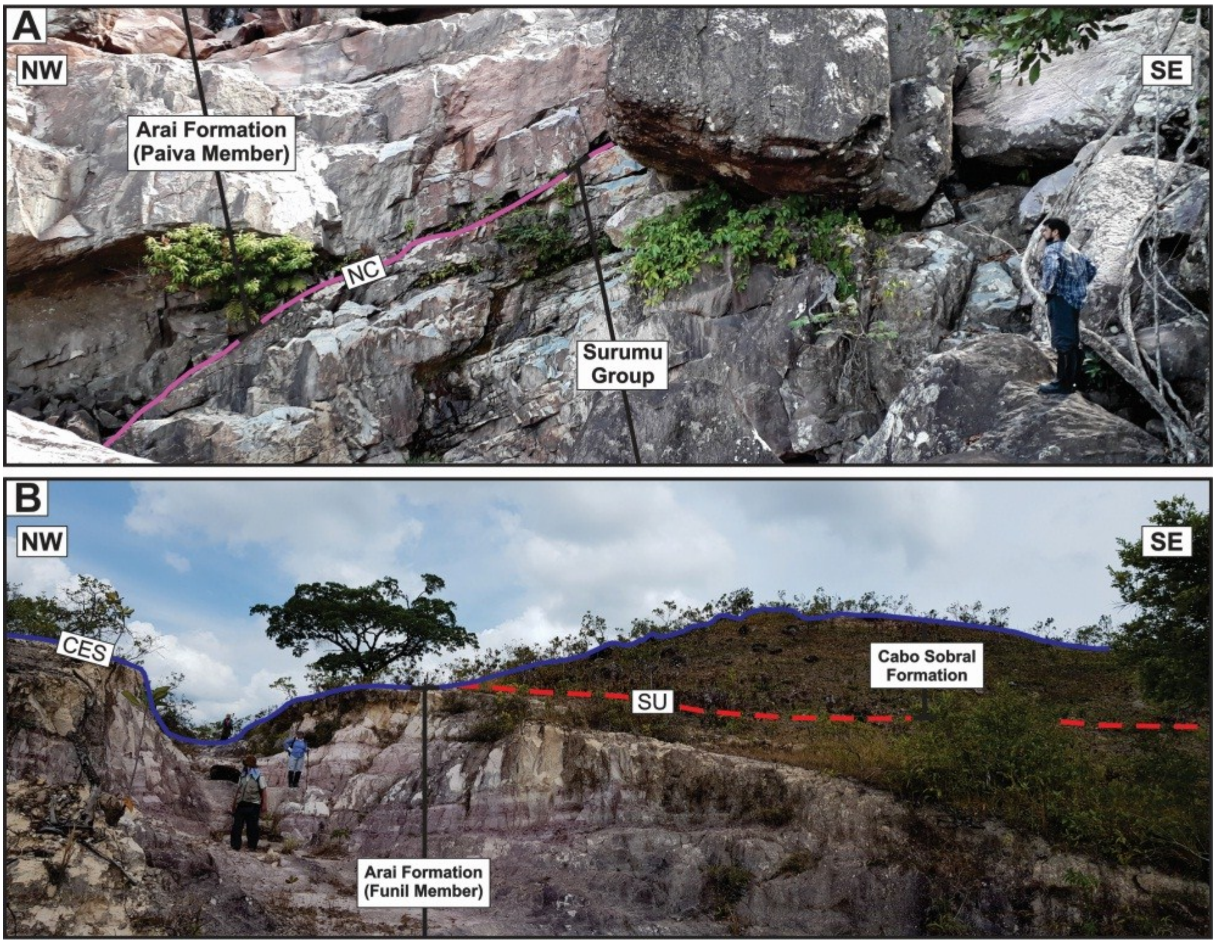
Siliciclastic succession of the Tepequém mountain, represented from the base to the top by the Arai Formation (Paiva and Funil Members) and the Cabo Sobral Formation (basal unit of the Suapi Group), is characterized by continental and coastal deposits (BORGES & D'ANTONA, 1988; FERNANDES FILHO, 2010; REIS et al, 2010) which maintain a direct correspondence with the basal units of the Roraima Supergroup, located approximately 100 km distant in the extreme northeast of the state of Roraima (Brazil). These rocks were placed in two depositional sequences of the 3rd order: lower (Arai Formation) and upper (Cabo Sobral Formation), based on faciological data, concepts of sequence stratigraphy, and the nature of the principal surfaces that separate these units (CATUNEANU, 2017, 2019; CATUNEANU et al, 2012; MARTINS-NETO, 2009) (FIGURE 17).

Figure 17 – Stratigraphic correlation of the Roraima Supergroup based on principles of sequence stratigraphy. The Funil Member, the upper unit of the Arai Formation, Tepequém mountain, constitutes the top of the lower sequence and represents the retrogradational deposits of the tidal flats (intertidal zone), associated with the initial stages of the transgressive system tract. This unit is interpreted as the distal portion correlated to the lacustrine continental deposits of the Arai Formation of the Roraima Supergroup, in the extreme northeast of Roraima state. The asterisk represents the movement of the braided fluvial system which previously had belonged to the upper portions of the Arai Formation described by Reis & Yánez (2001) for the base of the Suapi Group



The Paiva Member is characterized by deposits of alluvial and fluvial fans discordantly superimposed on volcanic rocks of the Surumu Group (FERNANDES FILHO, 2010; REIS et al, 2010), which, in the area of this study presents characteristics of a deepening of the water level towards the top, marked by more sinuous fluvial channel deposits which indicate an initial migration of the coastline in the direction of the continent and a reduction in the gradient of the fluvial profile (CASTRO, 2019). The surface that marks the beginning of this sedimentation in the basin and separates it from the volcanic basement (U1) is characterized by an unconformity (NC) (FIGURA 18A) (CATUNEANU, 2019; ZHANG et al, 2020), considered here as a key regional surface and the basal limit of the 1st order sequence of the Roraima Supergroup (CATUNEANU, 2017, 2019).

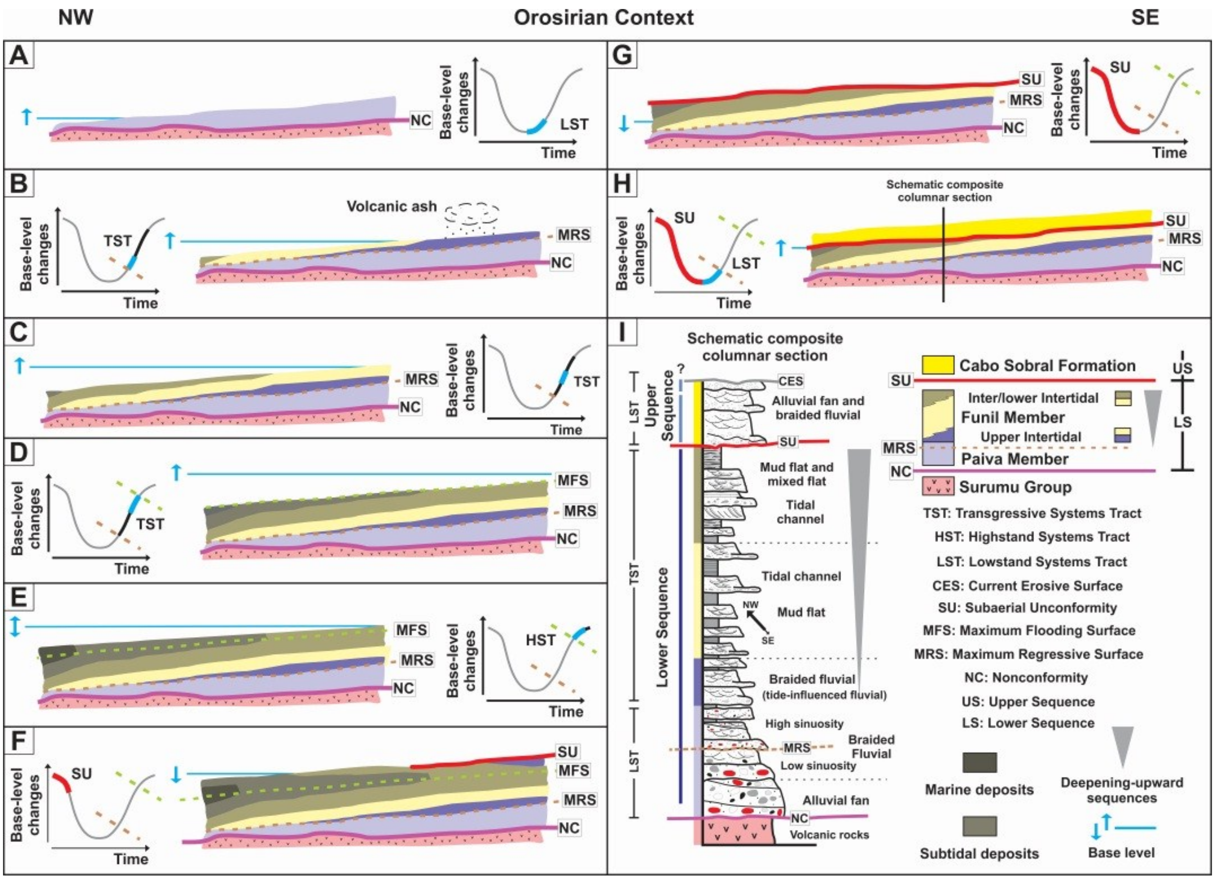
Figure 18 – (A) Outcrops of the Paiva Member discordantly superimposed on the deposits of the Surumu Group delimited by an unconformity (NC), which represents the basal limit of the 1st order sequence of the Roraima Supergroup. Outcrop at the base of the Paiva waterfall; (B) Intertidal deposits of the Funil Member (Arai Formation) delimited at the top by the subaerial unconformity (SU), base of the upper sequence constituted by the braided fluvial system of the Cabo Sobral Formation. Current erosive processes truncate each unit generating a current erosive surface (CES). Outcrop registered at profile 4



In the extreme northeast of the state of Roraima, this unconformity separates volcanic rocks of the Surumu Group from the proximal to intermediate alluvial fan deposits near the median at the base of the Arai Formation of the Roraima Supergroup (FERNANDES FILHO, 2010; REIS & YÁNEZ, 2001; REIS et al, 2017). In this scenario, the positive paleoenvironmental correlation and the overlapping of these deposits with the same stratigraphic surface indicates the implantation of active alluvial fans for more than 100 km.

These deposits are associated with the lowstand systems tract (LST) registered at Tepequém mountain as the final phase of normal regression of the coastline and a prelude for marine transgression through the maximum regressive surface (MRS) (FIGURA 19A) (CASTRO, 2019; CATUNEANU & ERIKSSON, 2002; MAGALHÃES et al, 2016; SOUZA et al, 2019). In this context, the continuous migration of the coastline suppressed the alluvial fans of the Paiva Member and generated basin conditions associated with tidal currents in the fluvial channels of the Funil Member superimposed with a transgressive tendency.

Figure 19 – Schematic evolution of the volcano-sedimentary succession at Tepequém mountain (Arai and Cabo Sobral Formations) relating the variation in the rise and fall of the base level. The rocky stacking of the Funil Member marked by an upward-deepening pattern presents an aggradational to retrogradational tendency associated with the transgressive system tract



At Tepequém mountain, in a scenario of gradual overlay of alluvial and fluvial fan deposits of the Paiva Member, there are tidal flats deposits (intertidal zone) that were examined in this study that are attributed to the Funil Member, and organized in a set of layers with fining to deepening upward stacking pattern (FIGURE 4).

Stacking patterns with a deepening upward tendency linked to allochthonous factors of up to 8 m were classified as 4th order, while patterns with a tendency of fining-upward of up to 4 m related to autochthonous factors were classified as bedsets (CATUNEANU, 2017, 2019;

ZECCHIN et al, 2017). Deepening-upward patterns are represented by strata deposited in conditions of mud flats (Iua deposits) which, in the direction towards the top, exhibit a pattern of deepening of the sea level and thickening of tidal channel deposits, which are systematically overlaid by deposits from mixed flats (Iia deposits) in abrupt contact. The thickening-upward stacking pattern of these deposits can also be observed laterally in the direction of the distal parts of the basin, which is to the NW in the Paleoproterozoic context (profiles 1, 7 and 3, FIGURE 4).

Fining-upward stacking patterns that are internal to the deepening upward patterns were divided into fluvial (profiles 6 and 9) and transitional (profiles 1-5, 7-9) domains, represented by strata deposited in conditions of mud flats that mark the top of the amalgamated braided fluvial channels (fluvial domain) and tidal channels (transitional domain), the latter also being finalized by mixed flats. Additionally, especially in the transitional domain, the bases of the fining upward patterns are also distinguished by the Gm facies which represent the erosion of mud flats.

Stacking patterns that are independent of allochthonous or autochthonous factors can be equivalent to sequences if they follow complete regressive-transgressive trajectories along the coastline, as, for example, deepening-upward patterns interpreted here as 4th order (CATUNEANU, 2019; CATUNEANU & ZECCHIN, 2013; KUNZMANN et al, 2020). In this sense, the top of the strata with a deepening-upward tendency represents a faciologic contact that marks an abrupt increase in the sea level and can be interpreted as delimiting marine flooding surfaces of these transgressive 4th order hierarchy sequences of the Funil Member (CATUNEANU, 2017; POSAMONTIER & ALLEN, 1999).

The fining-upward stacking patterns do not reflect the migration of the coastline, and for this reason were considered to be bedsets according to the definition of Zecchin et al. (2017), which could be related to, for example, a process of channel migration with no change in total energy and sedimentary supply in the depositional system. Despite the thinness of the deepening-upward stacking patterns of the Funil Member, the differentiation between sequences based solely on thickness is not a practical criterion for Precambrian successions, since sedimentation conditions were distinct from their modern analogs (CATUNEANU, 2019; CATUNEANU et al, 2012, ERIKSSON et al, 2013; ZECCHIN et al, 2017).

The overlaying of exclusively continental deposits of the Paiva Member by the tidal flats of the Funil Member demonstrates a progressive increase in the regional base level, and consequently greater accommodation space in a basin with a low gradient, thus preserving part of a retrogradational stacking (FIGURES 19B to D) (BEYER et al, 2015; CATUNEANU, 2017; DALRYMPLE, 2010; GALLOWAY & HOBDAY, 1996; STRAND, 2012).

Indications of aggradational stacking are evident only in profile 6 due to amalgamation of the braided fluvial channel deposits and an elevated internal migration shown by incomplete fining-upward stacking pattern, which could reflect the stability at the base level (CATUNEANU, 2019; ZECCHIN et al, 2017). The records of processes of tidal currents in these fluvial channels reaffirm a transgressive tendency in this unit (SHANLEY & MCCABE, 1993).

In the extreme northeast of Roraima state, the unit that is superimposed on alluvial fans of the Arai Formation of the Roraima Supergroup are characterized by lacustrine deposits (REIS & YÁNEZ, 2001; REIS et al, 2017), interpreted here as correlated with the Funil Member at Tepequém mountain. Therefore, the marine transgression in the direction of the interior of the basin flooded the fluvial paleochannels and consequently created the lacustrine systems associated with the transgressive systems tract (TST) (BENVENUTI & DEL CONTE, 2013; SHANLEY & MCCABE, 1994).

Even though the definition of key surfaces of lower hierarchical order in Proterozoic sequences is problematic, such as the maximum regressive surface (MRS), it is not always possible to identify this in the field taking into consideration Precambrian depositional configurations and the data available for analysis (CATUNEANU, 2017; KUNZMANN et al, 2020).

Erosively superimposed on the Funil Member are continental deposits of the Cabo Sobral Formation, the basal unit of the Suapi Group, which is highlighted by a mappable surface along the entire Tepequém mountain, while the top is marked by the current erosive surface (CES) (FIGURE 18B) (SOUZA et al, 2019). In this light, the Cabo Sobral Formation indicates a rejuvenation of a braided fluvial system (FERNANDES FILHO, 2010) that is strongly progradational over an erosive discordance of regional character (U2), in which conglomeratic, oligomitic facies are sources of alluvial diamond and gold (BORGES & D'ANTONA, 1988; FERNANDES FILHO, 2010) and considered here as a key surface and a correlation guide layer.

This same stratigraphic configuration was registered in the upper portions of the Arai Formation of the Roraima Supergroup in outcrops in the extreme northeast of the state of Roraima (REIS & YÁNEZ, 2001; FERNANDES FILHO, 2010; REIS et al, 2017). The discordant overlay of exclusively continental deposits on those of a transgressive nature of the Funil Member at Tepequém mountain suggests a lowering of the regional base level which allowed for the beginning of sedimentary succession of the Cabo Sobral Formation, attributed to the lowstand systems tract (LST) of the upper sequence (FIGURES 19F to H) (CATUNEANU & ERIKSSON, 2002). In this scenario, the erosive surface that separates these deposits is attributed a sequence limit of the 3rd order, since it indicates changes in sedimentation due to a brusque drop in sea level and changes in the sediment source area (CATUNEANU, 2017; MAGALHÃES et al, 2016; MARTINS-NETO, 2009).

This sequence limit and basal surface of the tract of the upper system is interpreted as a subaerial unconformity (SU) that registered erosive or non-depositional events related to a fluvial incision (CATUNEANU & ERIKSSON, 2002; CHAKRABORTY & PAUL, 2008). This discordance reached its maximum extension in the direction of the deepest parts of the basin during the period of regression, separating strata that were genetically unrelated (CATUNEANU, 2017; CATUNEANU et al, 2005).

Consequently, the transgressive deposits of the Funil Member were exposed to the processes of fluvial incision due to a hydrodynamic adjustment in the basin caused by a reduction in the base level (CATUNEANU, 2017; CHAKRABORTY et al, 2012; MUKHOPADHYAY et al, 2016). The absence of subtidal to deep marine deposits which would mark a purely retrogradational succession at the top of the Funil Member suggests that superimposed fluvial erosion was extreme to the point of erasing the records of this sedimentation, along with the maximum flooding surface (MFS) and the deposits from the highstand systems tract (HST) at Tepequém mountain (CATUNEANU & ERIKSSON, 2002) (FIGURES 19D to F), the last two being registered only in the extreme northeast of Roraima state.

Although the preservation of transgressive succession is compromised principally by erosion associated with waves and tides (CATTANEO & STEEL, 2003; CATUNEANU & ERIKSSON, 2007), the stratigraphic configuration described in this study demonstrated correlated records in Precambrian as well as Phanerozoic foreland basins, as in the Vingerbreek Member (Nudaus Formation) of the Nama Basin, Namibia (GRESSE & GERMS, 1993) and in the Aspelintoppen Formation of the Central Eocene Basin of Spitsbergen (PLINK-BJÖRKLUND, 2005), respectively.

Based on the occurrence of a basal erosive discordance of the diamantipherous braided fluvial system present at Tepequém mountain (Cabo Sobral Formation) as well as in the northeast portion of the state of Roraima that erosively sectioned the Arai Formation of Reis & Yánez (2001), this study suggests that this fluvial unit be moved to the base of the superimposed Suapi Group. This new placement is justified by the fact that this discordance represents a sequence limit that separates this genetically unrelated fluvial system from the other underlying paleoenvironments (FIGURE 17, observe the asterisk).

Beyer et al. (2015) conducted a subsurface analysis of rocks of the Roraima Supergroup in Guyana and subdivided stacking into three regressive-transgressive depositional sequences constituted at their base by amalgamated braided fluvial systems related to a slow creation of accommodation space, while the top is represented by deltaic-lacustrine deposits which reflect a rapid creation of accommodation space. This depositional architecture is similar to that described in the current study for the strata of Tepequém mountain (FIGURE 19I), since the lower sequence (Arai Formation), delimited from the volcanic basement by an unconformity, is constituted at the base by alluvial fans of the Paiva Member, while the top is defined by intertidal deposits of the Funil Member. The base of the upper sequence at the mountain is constituted by the Cabo Sobral Formation, which represents the installation of a braided fluvial system, whose base defines the limit of the top of the lower sequence. In this way, the upper sequence defined at Tepequém mountain corresponds only to the basal portion of the second complete sequence of Beyer et al. (2015).

Santos et al. (2003) reject the idea that source of the detritic diamonds present in the braided fluvial system of the Cabo Sobral Formation is the rocks that come from the West African Craton, based on paleoflow data obtained in these braided channels in the NE of the state of Roraima, which indicate paleocurrents dominant to the S/SW (REIS & YÁNEZ, 2001). Fernandes Filho (2010) also suggest a preferential orientation of the paleoflow to the S-SW for the braided fluvial system at Tepequém mountain (Cabo Sobral Formation), similar to the trend for dominance to the SW shown in the current study for the underlying unit, the Funil Member. These data give reason to believe that the area that is the source of the detritic diamonds is located to the NE of the Amazon Craton.

However, in the paleogeographic context of the Orosirian/Statherian, the West African Paleocontinent was agglutinated to the Amazon Craton (JOHANSSON, 2009), which was rotated 60º clockwise compared to its current orientation, therefore suggesting a NW depositional trend and consequently a source area to the SE, where Paleoproterozoic meta-volcano-sedimentary rocks (2.3-1.9 Ga) were located in the West African Craton, which could be possible source areas. These rocks belong to the Birimian Supergroup and contain alluvial gold and diamonds, which represent sources of revenue for African countries such as Ghana, Ivory Coast, and Mali (CHIRICO et al, 2010; SMITH et al, 2016).

6. CONCLUSIONS

The facies and stratigraphic analysis of the Funil Member at Tepequém mountain revealed 13 facies grouped in an association representative of intertidal deposits. These deposits were subdivided into upper and intermediate/lower, which encompass sub-environments characteristic of braided fluvial channels, mud flats, tidal channels, and mixed flats.

Paleoenvironmental data suggest a partial record of a retrogradational tidal flats with a paleocoastline oriented to the NE-SW, perpendicular to the bidirectional sedimentary dispersion trend, with a principal paleoflow to the NW and subordinate to the SE, in the context of the Amazonian Paleocontinent during the Paleoproterozoic.

Sedimentary succession of the Funil Member is organized into 4th order sequences limited by marine flooding surfaces, characterized by a deepening-upward stacking pattern, and internally organized by a fining-upward stacking pattern of fluvial and transitional domains. This configuration of strata reflects a progressive increase in accommodation space and implantation of marine conditions associated with migration of the coastline in the direction of the continent as part of the transgressive systems tract (TST). In the context of the Roraima Supergroup, these intertidal deposits represent correlates of a distal environment of lacustrine deposits of a more continental nature of the Arai Formation in the extreme northeast of the state of Roraima.

The paleoenvironmental analysis of the Funil Member as described in this study, allied with identification of sedimentary stacking patterns and the principal stratigraphic surfaces, allowed for understanding of how allochthonous and autochthonous processes influenced the establishment of transgressive sequences in Precambrian sedimentation conditions. Furthermore, these results enabled a reexamination of a portion of the Proterozoic sedimentary record in the light of sequence stratigraphy principles, and in this manner provide an improved correlation between the deposits of Tepequém mountain and the Roraima Supergroup, in the central portion of the Amazon Craton.

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CAPÍTULO 5 CONSIDERAÇÕES FINAIS

A análise de fácies e estratigrafica do Membro Funil permitiu identificar 13 fácies: conglomerado maciço, brecha maciça, arenito com estratificação cruzada acanalada, arenito com estratificação cruzada com *mud drapes*, arenito com bandamento de maré, arenito com estratificação cruzada tabular, arenito com laminação plano-paralela, arenito maciço, acamamento heterolítico, argilito laminado, argilito maciço, filonito e intercalação argilito/tufo.

Essas fácies representam o registro de depósitos de uma planície de maré transgressiva implantada no Escudo das Guianas no Paleoproterozoico. A planície de maré era caracterizada por canais *braided* que recortavam planícies lamosas e mistas, com registros de correntes de maré nos canais, especialmente nas porções superiores da sucessão estratigráfica. O padrão de dispersão sedimentar deste sistema no contexto do Paleoproterozoico indica bipolaridade, com paleofluxo dominante para NW e suborinado para SE. Além disso, a planície de maré foi alvo de sedimentação vulcanoclástica distal (tufos de queda) associada a fácies argilosas e preservada exclusivamente na planície lamosa. O vulcanismo pode estar relacionado com os eventos do Grupo Surumu, que incluem os depósitos piroclástico de idade 1.96 Ga (SANTOS et al, 2000, 2003) e camadas de tufos intercaladas com rochas do Supergrupo Roraima (Formação Uaimapué), de idade 1.87 Ga (SANTOS et al, 2003).

O evento transgressivo no Membro Funil foi interpretado pela identificação de sequências *deepening-thickening upward* de 4ª ordem separadas por superfícies de inundação marinha, faciologicamente representadas pela sobreposição dos depósitos de planície lamosa por mistas e pelo espessamento dos depósitos de canais de maré, englobados no trato de sistema transgressivo. As sequências de 4ª ordem são organizadas internamente por camadas com padrão *finning upward* de domínio fluvial e transicional relacionados a fatores autóctones.

A análise faciológica aliada ao reconhecimento do padrão estratal e das principais superfícies estratigráfica no Membro Funil, permitiu uma releitura estratigráfica do Supergrupo Roraima. Assim na Serra do Tepequém, a estratigrafia do Supergrupo Roraima seria representada na sequência inferior pelos membros Paiva e Funil, incluídas na Formação Arai correlata à de Reis & Yánez (2001), depositados respectivamente sobre uma não conformidade. A unidade mais continental correlata aos depósitos do Membro Funil, no extremo nordeste de Roraima, é representada por depósitos lacustres da Formação Arai de Reis & Yánez (2001).

Já o registro da sequência superior na serra é representado pelo Membro Cabo Sobral, que indica a diminuição do nível de base e a implantação de um sistema fluvial *braided* portador de diamante aluvionar depositado erosivamente sobre os depósitos do Membro Funil. A superfície erosiva mapeável por toda a serra e que limita a base desse sistema fluvial é atribuída a uma discordância subaérea e limite de sequência de 3ª ordem do Supergrupo Roraima. Este mesmo sistema fluvial é correlato ao que ocorre nas porções superiores da Formação Arai de Reis & Yánez (2001). Desta forma, essa pesquisa propõe a elevação de membro para Formação Cabo Sobral e deslocamento para a base do Grupo Suapi, unidade sobreposta.

A presença de restitos filonitos no Membro Funil intercalados com fácies arenosas e conglomeráticas sugere processos de metamorfismo de baixo grau concentrado em abundantes lineamentos que truncam rochas com diferentes graus de competências. Contudo, em áreas não influenciadas por essas estruturas tectônicas seria necessário aplicar técnicas petrográficas e de microtextura para determinar se os processos metamórficos ocorreram de forma ampla por toda a Serra do Tepequém.

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