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LITOESTRATIGRAFIA E PALEOGEOGRAFIA DO CARBONÍFERO NA BACIA DE SERGIPE-ALAGOAS

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Orientador:

Dr. Wagner Souza-Lima

DISSERTAÇÃO DE MESTRADO

Programa de Pós-Graduação em Geociências e Análise de Bacias

São Cristóvão – SE

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ANANDA LIMA CARNEIRO

LITOESTRATIGRAFIA E PALEOGEOGRAFIA DO CARBONÍFERO NA BACIA DE SERGIPE-ALAGOAS

Dissertação submetida ao Programa de Pós-Graduação em Geociências e Análise de Bacias, da Universidade Federal de Sergipe, como requisito para obtenção do título de Mestre em Geociências.

Orientador: Dr. Wagner Souza-Lima

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por:

Ananda Lima Carneiro

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RESUMO

Apesar do crescente reconhecimento das glaciações no Carbonífero do Gondwana nos últimos anos, há uma escassez de estudos detalhados sobre questões paleoclimáticas, faciológicas e paleogeográficas na região central deste paleocontinente. A seção carbonífera da bacia de Sergipe-Alagoas, Nordeste do Brasil, representada pela Formação Batinga, apresenta feições geológicas importantes para a compreensão dos processos sedimentares que ocorreram durante este período. Com base na análise integrada de dados litoestratigráficos de poços e afloramentos desta seção e de seções coetâneas em bacias adjacentes, este estudo fornece uma interpretação paleogeográfica para o Carbonífero da região central do Gondwana. A Formação Batinga teve sua deposição relacionada a seis estágios paleoclimáticos glaciais e interglaciais, refletindo o avanço e recuo de geleiras. O primeiro estágio representou um evento glacial, com extensa deposição de diamictitos, enquanto os quatro estágios seguintes estiveram representados por uma intercalação de eventos interglaciais e glaciais associados a um sistema provavelmente glaciolacustre, com influência de rios, deltas e fluxo de detritos. O último estágio representou o final da glaciação e o retrabalhamento dos depósitos glaciais. A reconstrução paleogeográfica proposta para a região consiste em vales glaciais controlados por cadeias de montanhas brasilianas, de direção preferencial NW-SE, que agiram como limitadoras das bacias. Vales glaciais, entre essas montanhas, foram delimitados pelos registros do Membro Mulungu da Formação Batinga encontrados em poços e afloramentos. Nos períodos glaciais, esses vales acomodaram geleiras, enquanto, nos períodos interglaciais, foram, em parte, preenchidos por água e se tornaram lagos. Ambos teriam tido seus deságues em um vale principal de direção NE-SW, definido pela ação de sistemas fluviais pretéritos de provável idade siluro-devoniana. Na porção central do Gondwana, a glaciação teve início por volta de 337 Ma, se estendendo para o centro-leste até aproximadamente 320 Ma. Então, os continentes se distanciaram do Polo Sul, dando início ao degelo e, em 290 Ma, a glaciação diminuiu consideravelmente nessa região, de modo que na porção da bacia de Sergipe-Alagoas já dominavam condições quentes e áridas, o que propiciou a deposição dos sedimentos da Formação Aracaré, já no início do Permiano. A idade indicada pelos palinomorfos para as rochas da Formação Batinga, na bacia de Sergipe-Alagoas, sugere que os últimos eventos glaciais nesta porção do Gondwana ocorreram no Westphaliano.

Palavras-chave: Carbonífero. Gondwana. Glaciação. Formação Batinga. Ambientes deposicionais.

ABSTRACT

Despite the increasing recognition of glaciations in Carboniferous Gondwana in recent years, there is a lack of detailed paleoclimatic, faciological, and paleogeographical studies in the central region of this paleocontinent. The Carboniferous section of the Sergipe-Alagoas basin, Northeast Brazil, represented by the Batinga Formation, presents geological features that are significant for understanding the sedimentary processes that occurred during this period. Based on integrated analysis of lithostratigraphic data from boreholes and outcrops from this and coeval sections in adjacent basins, this study provides a paleogeographic interpretation for the Carboniferous of central Gondwana. The deposition of the Batinga Formation was related to six glacial and interglacial paleoclimatic stages, reflecting the advance and retreat of glaciers. The first stage represented a glacial event, with extensive diamictite deposition, while the following four stages were represented by an intercalation of interglacial and glacial events associated with a probably glaciolacustrine system, with the influence of rivers, deltas, and debris flows deposits. The final stage represented the end of glaciation and the reworking of glacial deposits. The paleogeographic reconstruction proposed for the region consists of glacial valleys controlled by Brazilian-age mountain chains, with a preferential NW-SE direction, which acted as basin boundaries. Glacial valleys, between these mountains, were delimited by records of the Mulungu Member of the Batinga Formation found in boreholes and outcrops. In glacial periods, these valleys accommodated glaciers, while in interglacial periods, they were partly filled with water and became lakes. Both would have drained into a main valley with a NE-SW direction, defined by the action of previous river systems of probable Siluro-Devonian age. In the central portion of Gondwana, glaciation began around 337 Ma, extending to the central-east until approximately 320 Ma. After this, the continents moved away from the South Pole, and the ice began to melt and, by 290 Ma, glaciation decreased considerably in this region. This resulted in hot and arid conditions already prevailing in the Sergipe-Alagoas basin, which led to the deposition of sediments from the Aracaré Formation at the beginning of the Permian. The age indicated by palynomorphs for the rocks of the Batinga Formation, in the Sergipe-Alagoas basin, suggests that the last glacial events in this portion of Gondwana occurred in the Westphalian.

Key-words: Carboniferous. Gondwana. Glaciation. Batinga Formation. Depositional environments.

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CAPÍTULO 01: INTRODUÇÃO

1.1. APRESENTAÇÃO

O registro geológico é repleto de evidências que permitem a individualização de eventos significativos de aumento e diminuição da temperatura que ocorreram no planeta ao longo da sua história. Durante o Paleozoico, múltiplos centros glaciais, de variadas dimensões, se propagavam pelo Gondwana, influenciando a sedimentação nas suas bacias sedimentares (Mottin & Vessely, 2021).

Segundo algumas reconstruções paleogeográficas (p. ex., Torsvik & Cocks, 2011; Cao *et al*., 2017), durante o final do Paleozoico, o supercontinente Gondwana estava deslocado para o hemisfério sul, sendo afetado por intensas glaciações, que deixaram suas evidências amplamente distribuídas em todos os fragmentos do antigo supercontinente: América do Sul, África, Península Arábica, Antártica, Austrália e sudoeste da Ásia (Crowell & Frakes, 1975; Caputo & Crowell, 1985; Isbell *et al*., 2003; Rosa & Isbell, 2021).

No contexto do Gondwana central, onde está inserida a bacia de Sergipe-Alagoas, são poucos os estudos que esclarecem questões paleoclimáticas, faciológicas e paleogeográficas, principalmente no que diz respeito ao Carbonífero. Durante este período, esta porção do Gondwana encontrava-se geograficamente situada em altas latitudes no hemisfério sul, sofrendo os efeitos das glaciações. Nesse contexto, a bacia de Sergipe-Alagoas estaria numa posição periglacial (Souza-Lima, 2006b; figura 1), sendo confirmada pelas rochas sedimentares da Formação Batinga e em unidades contemporâneas, como as da Formação Curituba, na bacia de Tucano Norte (Rocha-Campos *et al*., 2003).

As rochas da Formação Batinga contêm evidências geológicas e climáticas que permitem interpretar a evolução dos processos sedimentares, os paleoambientes, bem como a paleogeografia do Carbonífero nesta região. Com isso, o entendimento detalhado desta seção da bacia de Sergipe-Alagoas é peça-chave para a compreensão desta porção central do Gondwana.

A Formação Batinga está dividida em dois membros: Mulungu e Boacica. O Membro Mulungu é constituído predominantemente por diamictitos, enquanto o Membro Boacica, que representa a seção sedimentar dominante da unidade, é constituído por arenitos, siltitos e folhelhos, que foram depositados por leques deltaicos em sistemas lacustres (Campos Neto *et al*., 2007).

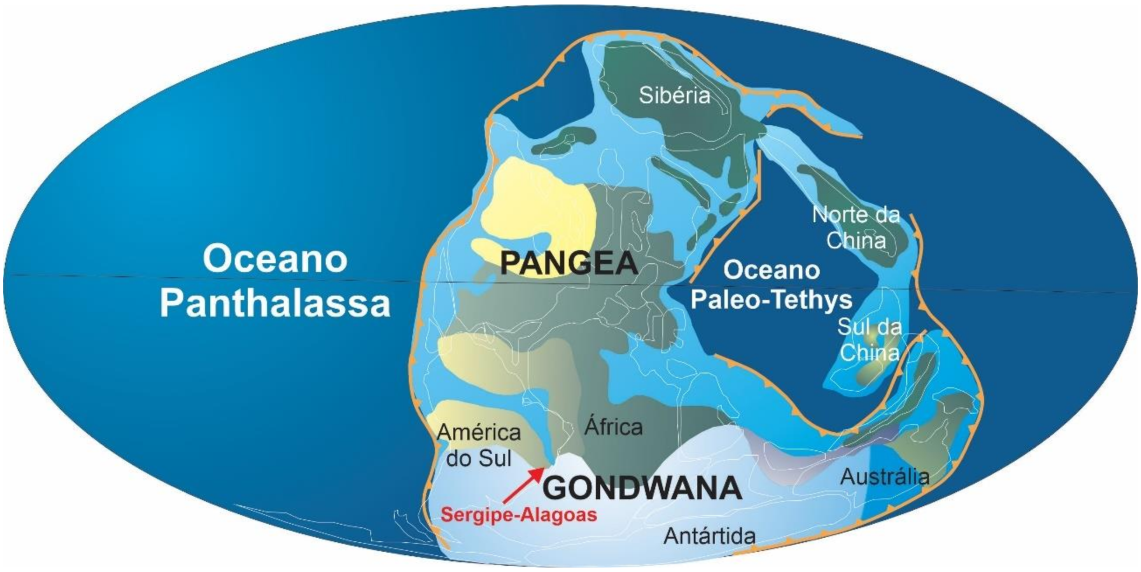

Figura 1: Reconstrução paleogeográfica para o Carbonífero (cerca de 300 Ma). Nessa época o Gondwana estaria ocupando a região austral do planeta, enquanto a bacia de Sergipe-Alagoas estaria numa posição periglacial (Souza-Lima, 2006b).

As rochas do Membro Mulungu teriam seus depósitos relacionados a um contexto geográfico periglacial, por ação direta das geleiras. Os ritmitos do Membro Boacica são típicos da intercalação de folhelhos e siltitos prodeltaicos e folhelhos lacustres, com níveis de arenitos de frentes deltaicas. Observa-se um aumento do registro de arenitos em relação aos folhelhos para o topo da seção, refletindo a progradação do sistema no corpo aquoso (Souza-Lima & Farias, 2006b).

O presente estudo consistiu em analisar poços e afloramentos da Formação Batinga, na bacia de Sergipe-Alagoas, com o intuito de interpretar sequências sedimentares, entender a dinâmica paleoclimática durante os depósitos das sequências e reconstruir a paleogeografia do Carbonífero na bacia e no contexto do Gondwana central.

Os resultados desta dissertação estão apresentados no **Capítulo 2**, e foram ajustados ao formato de um artigo científico, intitulado: “A bacia de Sergipe-Alagoas, nordeste do Brasil, como peça-chave para a compreensão paleogeográfica do Carbonífero do Gondwana central”, o qual foi submetido à revista “Gondwana Research”, de nível A1 do Qualis CAPES.

1.2. OBJETIVOS

O objetivo geral desta dissertação foi apresentar a caracterização litoestratigráfica e a reconstrução paleogeográfica a partir da análise integrada de dados de poços e dados faciológicos dos afloramentos da bacia de Sergipe-Alagoas, para o intervalo Carbonífero, em relação ao contexto do Gondwana e suas relações com os registros coetâneos definidos na literatura.

Como objetivos específicos podem-se listar:

- Elaborar seções de correlação estratigráfica para integração de dados;
- Elaborar mapas de isópacas e isólitas para a seção carbonífera da bacia;
- Interpretar os ambientes deposicionais para os membros da Formação Batinga;
- Definir a paleogeografia carbonífera para a bacia;
- Integrar a paleogeografia carbonífera no contexto do Gondwana central.

1.3. LOCALIZAÇÃO E CONTEXTUALIZAÇÃO DA ÁREA DE ESTUDO

A bacia de Sergipe-Alagoas está localizada na margem continental do nordeste brasileiro, abrangendo a região costeira dos estados de Sergipe e Alagoas. Os poços e afloramentos utilizados para essa pesquisa contemplam a seção carbonífera desta bacia (Formação Batinga). As seções aflorantes localizam-se na porção central da bacia, enquanto os poços estão distribuídos ao longo da mesma, conforme figura 2. O apêndice 1 contém as coordenadas e informações sobre cada poço e afloramento.

A bacia de Sergipe-Alagoas teve sua origem diretamente relacionada ao processo de rifteamento do supercontinente Gondwana e à separação das placas africana e sul-americana, que culminaram com a formação do Oceano Atlântico Sul a partir do Mesozoico (Campos Neto *et al*., 2007).

Uma particularidade que se observa ao longo das bacias marginais brasileiras é que a bacia de Sergipe-Alagoas apresenta seções aflorantes de quase todos os seus estágios evolutivos: pré-*rift*, *rift*, transicional e *drift* (Souza-Lima *et al*., 2002). Além disso, também afloram significativos remanescentes das sinéclises paleozóicas, que ocuparam grandes extensões da América do Sul durante esta era.

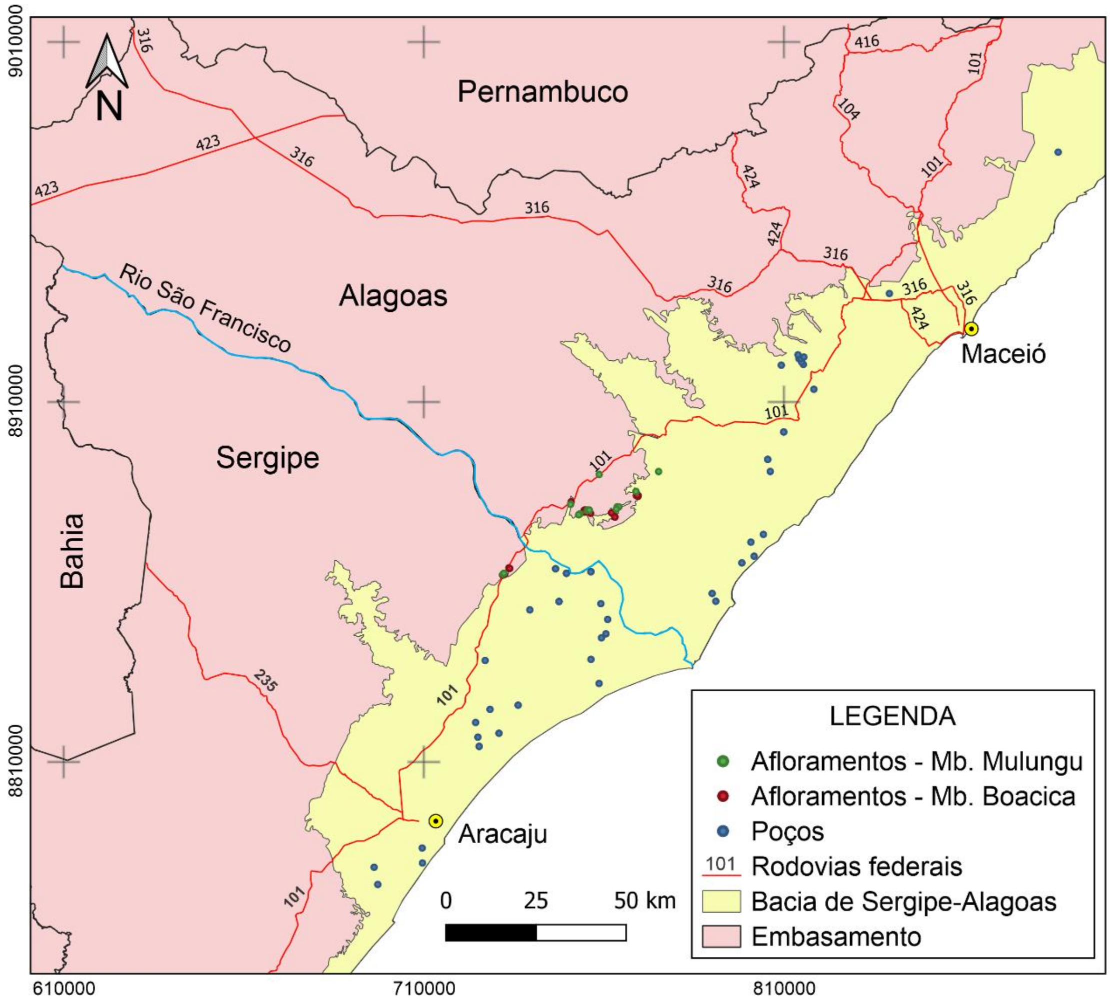

Figura 2: Mapa de distribuição de poços e afloramentos que contemplam a seção carbonífera da bacia de Sergipe-Alagoas.

A evolução estratigráfica proposta por Campos Neto *et al*. (2007) subdividiu os depósitos da bacia em cinco supersequências. O embasamento é constituído por rochas metamórficas proterozóicas da Faixa de Dobramentos Sergipana, granitóides proterozóicos do Maciço Pernambuco-Alagoas e metassedimentos supostamente cambrianos do Grupo Estância.

A Supersequência Paleozoica (figura 3) compreende o registro sedimentar depositado no estágio de sinéclise intracratônica (Campos Neto *et al*., 2007). Os registros mais antigos desse estágio possuem idade provável siluro-devoniana e receberam o nome de Formação Karapotó (Souza-Lima *et al*., 2017). Durante o Carbonífero, o continente Gondwana passou por uma intensa glaciação, resultando em depósitos interpretados como de origem glacial, que estão representados pela Formação Batinga. Durante o Permiano, foi depositada a última sequência da sinéclise paleozoica, representada pela Formação Aracaré, em clima quente e seco.

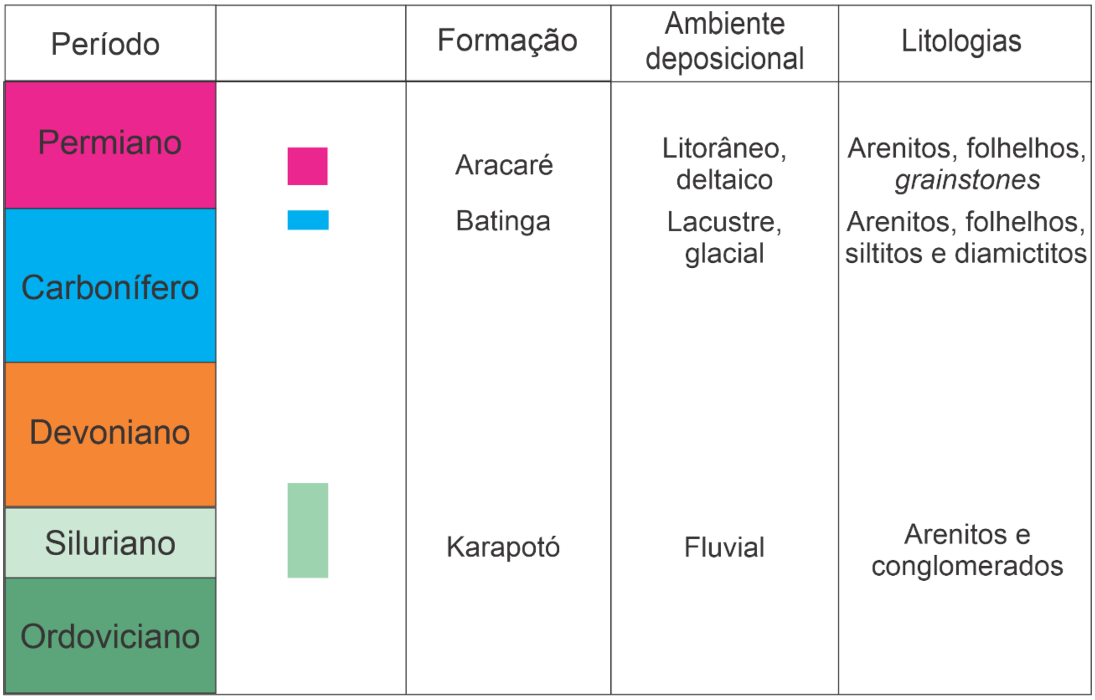

Figura 3: Estratigrafia dos remanescentes paleozoicos preservados na bacia de Sergipe-Alagoas.

Todas as outras supersequências são relacionadas ao processo de rifteamento do supercontinente Gondwana e à separação das placas africana e sul-americana, com a formação do Oceano Atlântico Sul a partir do Mesozoico (Campos Neto *et al*., 2007).

1.4. MÉTODOS DE TRABALHO

Para a realização desta pesquisa foram utilizados dados litoestratigráficos e litofaciológicos dos membros Mulungu e Boacica, da Formação Batinga, em 40 afloramentos, onde 6 puderam ser levantados perfis, e 41 poços localizados ao longo da bacia de Sergipe-Alagoas. Este projeto consistiu nas seguintes etapas:

- Revisão bibliográfica

Foi realizado um levantamento bibliográfico sobre a bacia de Sergipe-Alagoas, com foco na sua sequência paleozoica, especialmente na seção carbonífera. Além disso, as demais seções coetâneas de bacias sedimentares que sofreram ação glacial, no contexto do Gondwana, também foram estudadas.

- Trabalhos de campo

Trabalhos de campo foram efetuados para o levantamento de perfis estratigráficos, com o intuito de auxiliar a correlação dos poços na seção carbonífera da bacia de Sergipe-Alagoas, bem como entender os processos sedimentares envolvidos na sua formação. Além disso, foram utilizados dados de campo já levantados, disponíveis no banco de dados da Fundação Paleontológica Phoenix (Aracaju, Sergipe, Brasil), bem como dados publicados. Afloramentos da Formação Curituba, na bacia de Tucano Norte, foram estudados, a fim de melhorar o modelo paleogeográfico para o Carbonífero.

- Análise petrográfica dos diamictitos

Lâminas delgadas dos diamictitos da Formação Batinga foram analisadas com o intuito de observar a diferença textural e composicional entre eles. Para a realização da análise petrográfica, foi utilizado microscópio petrográfico com luz transmitida e refletida do Laboratório de Microscopia Ótica e Metalografia do Condomínio de Laboratórios Multiusuários da Geociências (CLGeo) na Universidade Federal de Sergipe (UFS).

- Seleção e revisão litológica dos poços

Com base em dados litoestratigráficos, foram selecionados os poços terrestres que contemplam a seção carbonífera, na bacia de Sergipe-Alagoas. Esses poços estão disponíveis pelo consórcio da Agência Nacional de Petróleo, Gás e Biocombustíveis (ANP) e Companhia de Pesquisa dos Recursos Minerais (CPRM), no site https://reate.cprm.gov.br/anp/TERRESTRE. Após a seleção, foi feita a revisão litológica da seção carbonífera de cada poço, ajustando os litotipos conforme padrões dos perfis geofísicos (principalmente perfil de raio gama, sônico e resistividade), integrado aos dados da descrição litológica disponíveis para os poços.

- Interpretação de sequências sedimentares e cômputo de litotipos

Foram interpretadas sequências sedimentares transgressivo-regressivas para o Membro Boacica, baseadas nos padrões dos perfis radioativo (raios gama, nêutron e densidade), elétrico (resistividade e potencial espontâneo) e acústico (sônico) conforme a disponibilidade para cada poço. Posteriormente, foi computada a contribuição litológica (espessura) das litofácies simplificadas (diamictito/conglomerado, arenito, siltito e folhelho) que compõem cada sequência sedimentar. O poço 1CO 0001 AL apresenta a maior espessura da seção estudada, por esse motivo foi utilizado como referência para a correlação e delimitação das sequências nos outros poços. Isto permitiu interpretar quatro sequências sedimentares. O levantamento computado foi inserido em uma planilha *Excel* (apêndice 1), integrado às litofácies identificadas nas seções aflorantes, a qual possui os dados necessários para a confecção dos mapas faciológicos.

- Confecção de seções estratigráficas

Foram confeccionadas oito seções estratigráficas (apêndice 2), sendo duas *strike* (paralelas as falhas de borda da bacia) e cinco *dip* (seguindo o mergulho deposicional/tectônico da bacia), com ênfase no Membro Boacica. Estas seções foram necessárias para definir e correlacionar marcos elétricos e radioativos da unidade (padrões semelhantes nos perfis). Além disso, uma seção do Membro Mulungu foi realizada a fim de melhor entender o comportamento faciológico desta unidade e seu controle geográfico. Para a correlação litoestratigráfica entre poços nas seções foi utilizado o *datum* definido no topo da Formação Batinga, com distância constante entre os poços e perfis estratigráficos.

- Confecção de mapas

Mapas estruturais foram feitos a partir da delimitação das profundidades de ocorrência dos membros Mulungu e Boacica da Formação Batinga, e do embasamento, representando a estruturação atual na área da bacia. Mapas de isópacas foram confeccionados conforme parâmetros definidos na caracterização de topo e base das unidades (apêndice 3). Mapas de isólitas de folhelhos, arenitos e siltitos foram gerados, representando o Membro Boacica, e mapa de isólita de diamictitos para o Membro Mulungu. Os mapas paleoambientais representam os ambientes deposicionais da unidade, baseados na integração com dados de afloramentos, enquanto os mapas paleogeográficos representam estes paleoambientes, no contexto da bacia e desta porção do Gondwana, à época da deposição.

Todos os mapas, com exceção dos paleogeográficos, foram gerados no *software* QGis, através do complemento *contour* e posteriormente editados no CorelDRAW. Para a confecção dos mapas paleogeográficos foram utilizados como base os mapas descritos anteriormente. No CorelDRAW foram feitos os desenhos e ajustes necessários, conforme interpretação dos dados de poços e afloramentos. Todos os mapas foram confeccionados com o sistema de referência espacial: *Datum* Sirgas 2000 e coordenada UTM – Fuso 24S.

Para a reconstrução do mapa paleogeográfico do Gondwana central foi utilizado o mapa global proposto para o intervalo de 310 Ma, reconstruído a partir dos dados disponibilizados por Matthews *et al*. (2016) e Cao *et al*. (2017). No *software* GPlates, foram inseridos os dados disponíveis e exportado o mapa reconstruído para a idade de 310 Ma, no formato *shapefile*. No *software* QGis, o arquivo foi importado e exportado no formato DXF. Posteriormente, utilizando este arquivo, foi possível realizar modificações e adicionar dados ao mapa no *software* CorelDRAW, com base na integração com a literatura e nos resultados obtidos neste estudo. Por fim, estes mapas retornaram ao GPlates para exibição das visualizações apresentadas.

O fluxograma abaixo resume a ordem dos métodos utilizados nesta pesquisa (figura 4).

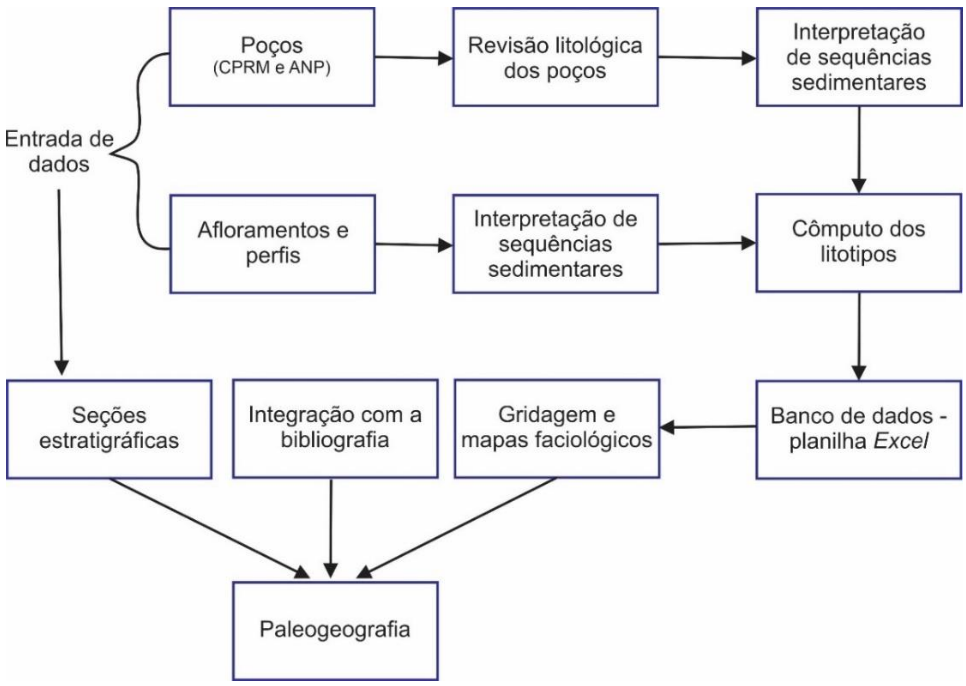

Figura 4: Fluxograma de aplicação dos métodos utilizados na pesquisa.

1.5. REFERÊNCIAS BIBLIOGRÁFICAS

CAMPOS NETO, O. P. A., SOUZA-LIMA, W., CRUZ, F. E. G. 2007. Bacia de Sergipe-Alagoas. Boletim de Geociências da PETROBRAS, 15 (2): 405-415.

CAO, W., ZAHIROVIC, S., FLAMENT, N., WILLIAMS, S., GOLONKA, J., MULLER, R. D. 2017. Improving global paleogeography since the late Paleozoic using paleobiology. Biogeosciences, 14: 5425-5439.

CAPUTO M.V. & CROWELL J.C. 1985. Migration of glacial centers across Gondwana during Paleozoic Era. GSA Bulletin, 96: 1020-1036.

CROWELL J.C. & FRAKES L.A. 1975. The Late Paleozoic Glaciation. Gondwana Geology, 3: 313-331.

ISBELL, J. L., MILLER, M. F., WOLFE, K. L., LENAKER, P. A. 2003. Timing of late Paleozoic Glaciation in Gondwana: Was glaciation responsible for the development of northern hemisphere cyclothems? In: Chan M.A., Archer A.W. (eds) Extreme depositional environments: Mega end members in geologic time. GSA Special Paper, 370: 5-24.

MATTHEWS, K. J., MALONEY, K. T., ZAHIROVIC, S., WILLIAMS, S. E., SETON, M., MÜLLER, R. D. 2016. Global plate boundary evolution and kinematics since the late Paleozoic, Global Planet. Change, 146: 226-250.

MOTTIN, T. E. & VESSELY, F. F. 2021. Formação Taciba: última manifestação glacial no Paraná. Boletim Paranaense de Geociências, 78: 65-82.

ROCHA-CAMPOS, A. C., SANTOS, P. R. DOS, SALVETTI, R. A. P, 2003. Iceberg scours and associated subglacial furrows and striae on sandstones of the Late Paleozoic Curituba Formation, NE Brazil. Latinamerican Congress of Sedimentology, 3, Museu Paraense Emilio Goeldi. Universidade Federal do Pará. Abstract Book, p. 142–144.

ROSA, E. L. M. & ISBELL, J. L. 2021. Late Paleozoic Glaciation. In: Alderton D., Elias S.A. (eds.). Encyclopedia of Geology 2nd edition, Elsevier, p. 534-545.

SOUZA-LIMA, W. 2006b. Litoestratigrafia e evolução tectono-sedimentar da bacia de Sergipe-Alagoas – O Paleozoico: considerações paleogeográficas. Phoenix, 92: 1-4.

SOUZA-LIMA, W. & FARIAS, R. M. 2006b. Litoestratigrafia e evolução tectono-sedimentar da bacia de Sergipe-Alagoas – O Paleozóico: a sequência carbonífera (II). Phoenix, 96: 1-6.

SOUZA-LIMA, W., ANDRADE, E. DE J., BENGTSON, P. & GALM, P. C. 2002. A bacia de Sergipe-Alagoas: evolução geológica, estratigrafia e conteúdo fóssil. Fundação Paleontológica Phoenix, Aracaju, edição especial, 34p.

SOUZA-LIMA, W., BORBA, C., RANCAN, C.C., CANGUSSU, L.P., COSTA, M.N.C., SANTOS, M.R.F.M., RIBAS, N., PIERINI, C., BEZERRA, C.P.V.,

2017. Formação Karapotó – uma nova unidade estratigráfica paleozoica na Bacia de Sergipe-Alagoas. Boletim de Geociências da PETROBRAS, 22 : 83-112.

TORSVIK, H. T. & COCKS, L. R. M. 2011. The Palaeozoic palaeogeography of central Gondwana. The Geological Society, London, Special Publications, v. 357: 137-166.

CAPÍTULO 02: ARTIGO SUBMETIDO À REVISTA “GONDWANA RESEARCH”

THE SERGIPE-ALAGOAS BASIN, NORTHEASTERN BRAZIL, AS A KEY FOR THE PALEOGEOGRAPHIC UNDERSTANDING OF THE CENTRAL GONDWANA CARBONIFEROUS

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ABSTRACT: Despite the increasing recognition of glaciations in Carboniferous Gondwana in recent years, there is a lack of detailed paleoclimatic and paleogeographic studies in the central region of this paleocontinent. The Carboniferous section of the Sergipe-Alagoas Basin, Northeastern Brazil presents geological features that are significant for understanding the sedimentary processes that occurred during this period. Based on integrated analysis of lithostratigraphic data from boreholes and outcrops from this and coeval sections in adjacent basins, this study provides a paleogeographic interpretation for the Carboniferous of this region. The deposition of tis section was related to six glacial and interglacial paleoclimatic stages, reflecting the advance and retreat of glaciers. The first stage represented a glacial event, with extensive diamictite deposition, while the following four stages were represented by the intercalation of interglacial and glacial events probably associated with a glaciolacustrine system, with the influence of rivers and deltas. The final stage represented the end of glaciation and the reworking of glacial deposits. The paleogeographic reconstruction proposed for the region consists of glacial valleys controlled by Brazilian-age (Pan-African) mountain chains, with a preferential NW-SE direction. Glacial valleys, between these mountains, were delimited by records of the Mulungu Member of the Batinga Formation found in boreholes and outcrops. In glacial periods, these valleys accommodated glaciers, while in interglacial periods, they were partly filled with water and became lakes. In the central portion of Gondwana, glaciation began around 337 Ma, extending to the central east until approximately 320 Ma. After this, the continents moved away from the South Pole, and the ice began to melt and, by 290 Ma, glaciation decreased considerably in this region. The age defined for the Batinga Formation, in the Sergipe-Alagoas Basin, suggests that the last glacial events in this portion of Gondwana occurred in the Westphalian.

Keywords: Carboniferous. Gondwana. Glaciation. Batinga Formation. Depositional environments.

1. INTRODUCTION

The Paleozoic Era was characterized by the tectonic reconfigurations of large continental masses, which, when grouped together, gave rise to supercontinents. The formation of Gondwana began at the end of the Proterozoic and continued until the end of the Carboniferous, when it collided with Laurasia to form the supercontinent Pangea. These movements had a significant impact on the Earth's climate, influencing the characteristics of the Earth's surface, the oceans and the planet's atmospheric circulation (Stampfli et al., 2013).

The supercontinent Gondwana occupied different latitudinal positions throughout the Paleozoic Era (Torsvik & Cocks, 2011). When it was located at low latitudes (0° to 30°), a warm climate prevailed. However, as it moved towards medium to high latitudes (30° to 90°), part of Gondwana became susceptible to colder climates and the occurrence of glaciations.

During the late Paleozoic, Gondwana drifted towards the South Pole, remaining geographically at high latitudes. These conditions provided environments with the temperatures ranges and precipitation rates necessary for the formation of extensive ice masses that spread over the continent (Rosa & Isbell, 2021).

Multiple glacial regions of varying sizes were stablished across Gondwana, influencing sedimentation in the Paleozoic sedimentary basins (Mottin & Vessely, 2021). Records of these events have been preserved in deposits throughout South America, Africa, the Arabian Peninsula, Antarctica, Australia and southwest Asia (Crowell & Frakes, 1975; Caputo & Crowell, 1985; Isbell et al., 2003; Rosa & Isbell, 2021).

Paleogeographic reconstructions for the different stages of the Paleozoic have been proposed by several authors (Ziegler et al., 1979; Rowley et al., 1985; Torsvik & Cocks, 2011; Cao et al., 2017). Nonetheless, for the Carboniferous period, there are few studies that clarify paleoclimatic, facies and paleogeographic issues in the central region of Gondwana, where the Sergipe-Alagoas Basin is located.

The paleogeographic reconstructions, at the end of the Carboniferous, show that the Gondwana occupied the southern region of the planet. The Sergipe-

Alagoas Basin would have been in a periglacial position (Souza-Lima, 2006b; figure 1), evidenced by the sedimentary rocks of the Batinga Formation and in contemporary units, such as those of the Curituba Formation, in the adjacent North Tucano Basin (Rocha-Campos et al., 2003).

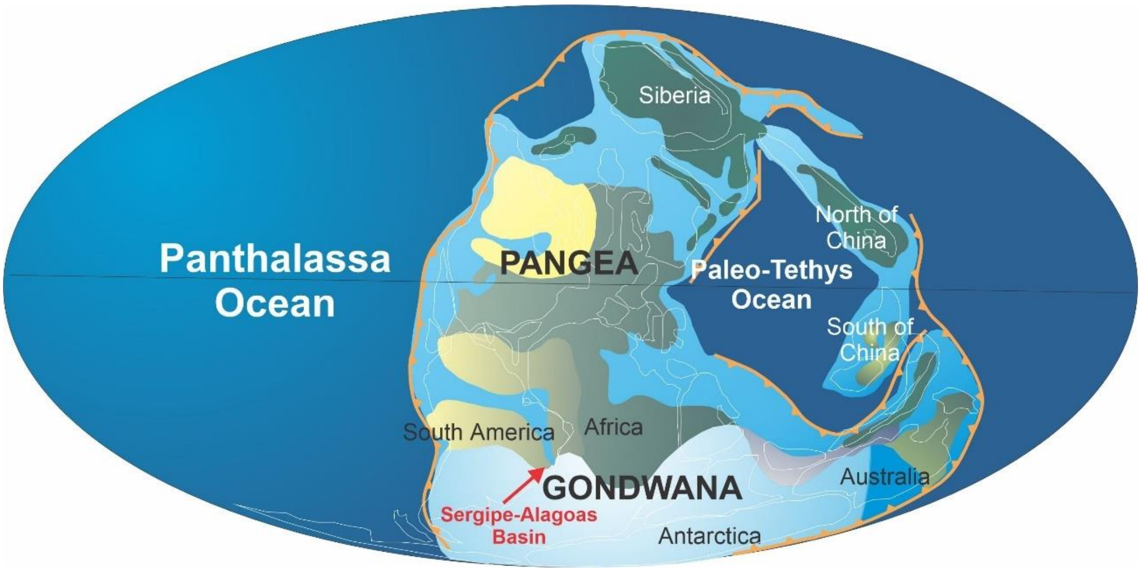

Figure 1: Paleogeographic reconstruction for the Carboniferous (around 300 Ma). At that time, Gondwana was occupying the southern region of the planet, with the Sergipe-Alagoas Basin in a periglacial position (Souza-Lima, 2006b).

The rocks of the Batinga Formation contain geological and climatic evidence that allows the interpretation of the evolution of sedimentary processes, paleoenvironments and the paleogeography of the Carboniferous in this central part of Gondwana. In this context, a detailed understanding of this section of the Sergipe-Alagoas Basin is an important key to understanding this part of Gondwana.

The Batinga Formation is subdivided into two members, Mulungu and Boacica. The Mulungu Member consists exclusively of diamictites, characteristic of subglacial deposition, while the Boacica Member contains sandstones, siltstones and shales, which were deposited in lacustrine environments influenced by deltaic fans (Souza-Lima & Farias, 2006a, b).

Cao et al. (2017) presented several proposals for global paleogeographic reconstructions, carried out by integrating paleobiology with a set of pre-existing maps. However, the maps presented for the Carboniferous (348; 328 and 302 Ma) have little detail in the region where the Sergipe-Alagoas Basin is located.

With the data resulting from this research, it was possible to contribute to a more detailed understanding of this central area of Gondwana.

The aim of this study was to present a lithostratigraphic characterization and a paleogeographic reconstruction proposal based on the integrated analysis of well data and facies data from the outcrops of the Sergipe-Alagoas Basin, for the Carboniferous interval, in relation to the context of Gondwana and its relations with the coetaneous records defined in the literature.

2. MATERIALS AND METHODS

This research was based on lithostratigraphic data from sections of the Mulungu and Boacica members of the Batinga Formation in 40 outcrops, on which stratigraphic profiles were carried out, and 41 wells located throughout the Sergipe-Alagoas Basin (figure 2).

Bibliographic data referring to the Carboniferous of the Sergipe-Alagoas and other coeval basins that were affected by glacial action in the context of Gondwana were also used to establish correlations between these regions.

Stratigraphic profiles were constructed to help correlate the wells and understand the sedimentary processes involved in their formation. In addition to the surveyed profiles, information available in the database of the Phoenix Foundation (Aracaju, Sergipe, Brazil) and published data were used. Subsequently, outcrops of the Curituba Formation in the North Tucano Basin, located to the west of the Sergipe-Alagoas Basin, were also studied to improve the paleogeographic model for the Carboniferous.

Petrographic thin sections were analyzed aiding observation the textural and compositional differences of the rocks. The petrographic analysis was carried out using a petrographic microscope with transmitted light at the Laboratory of Optical Microscopy and Metallography of the Condomínio de Laboratórios Multiusuários da Geociências (CLGeo) at the Federal University of Sergipe (UFS).

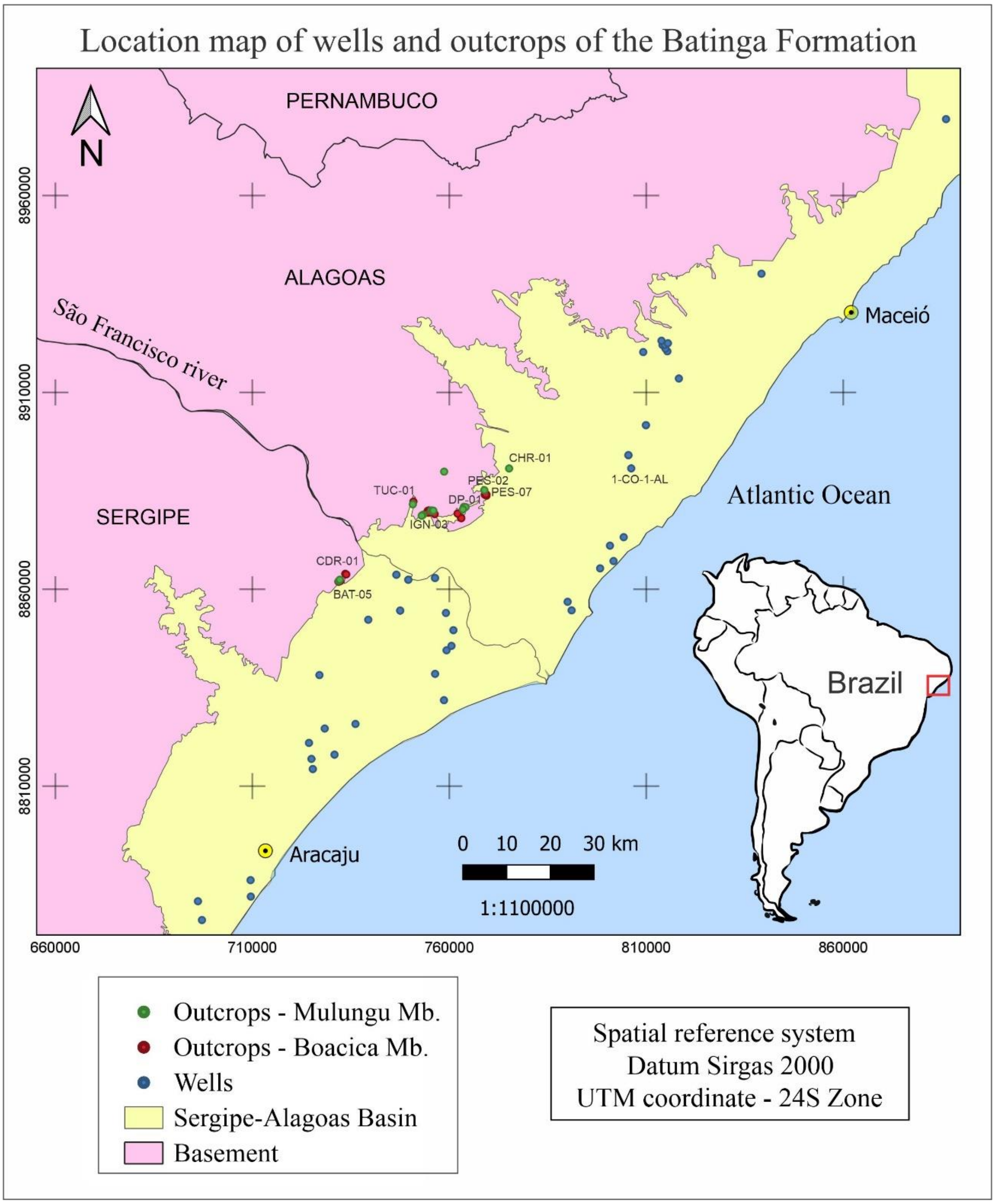

Figure 2: Map showing the location of wells and outcrops in the carboniferous section of the Sergipe-Alagoas Basin. The outcrops and wells mentioned in the text have been named.

For each well, the carboniferous section was reviewed, adjusting the lithotypes based on the indications of the electrical and radioactive profiles, as well as the cuttings recovered during the drilling, whose information is available in the used databases.

For each well Transgressive-regressive sequences were interpreted, based on patterns distinguishable on the radioactive (gamma rays, neutron and density), electrical (resistivity and spontaneous potential), and acoustic (sonic) logs, as available. Then, the lithological contribution (thickness) of simplified lithofacies (diamictite/conglomerate, sandstone, siltstone and shale) that make up each of these sequences was computed. As the well 1 CO 0001 AL has the greatest thickness in the studied section, it was used as a reference for the correlation and delimitation of the sequences in the other wells. The computed data were transferred to an Excel spreadsheet that, integrated with the lithofacies identified in the cropping out sections, composed the data needed to construct the facies maps.

Eight stratigraphic cross-sections were drawn, two strikes (parallel to the basin's border faults) and five dips (following the depositional/tectonic dip). These sections were necessary to define and correlate electrical and radioactive marks of the carboniferous sequence using patterns of similarities in the well-logs, and thus understand the facies distribution and its geographical distribution. For reference datum, it was defined the top of the Batinga Formation, with a constant distance between the wells and stratigraphic profiles.

Structural maps were constructed by delimiting the depths of the occurrence of the Mulungu and Boacica members of the Batinga Formation, and of the basement, representing the current structure in the basin area. Isopach maps were made following the parameters defined in the characterization of the top and bottom of the units. Isolith maps of shales, sandstones and siltstones were generated, representing the Boacica Member, and an isolith map of diamictites for the Mulungu Member. The paleoenvironmental maps integrated the predominant facies for each sequence, and the correlation of these facies to cropping out data, permitted representing the depositional environments of the unit. On the other hand, the paleogeographic maps represent these paleoenvironments, in the context of this region of Gondwana, at the time of deposition.

All the maps, except for the paleogeographic maps, were generated in the QGis software using the Contour add-on and then edited in CorelDRAW. To make the paleogeographic maps, these previous maps were used as a base. The necessary drawings and adjustments were made in CorelDRAW, according to the interpretation of well and outcrop data. All the maps were made using the spatial reference datum Sirgas 2000 and UTM coordinate at 24 S zone.

To reconstruct the paleogeographic map of central Gondwana, it was used the global map proposed for the 310 Ma interval, reconstructed from the data provided by Matthews et al. (2016) and Cao et al. (2017). The available data was opened in the GPlates software and the reconstructed map for the age of 310 Ma was exported in shapefile format. This file was imported into the QGis program, and then exported in DXF format. This file can then be imported into vector editing programs, such as CorelDraw, where it was modified and updated with data obtained from the literature and this study. Finally, these maps were opened again in GPlates to generate the projections shown here.

The flowchart below summarizes the steps followed in this process (figure 3).

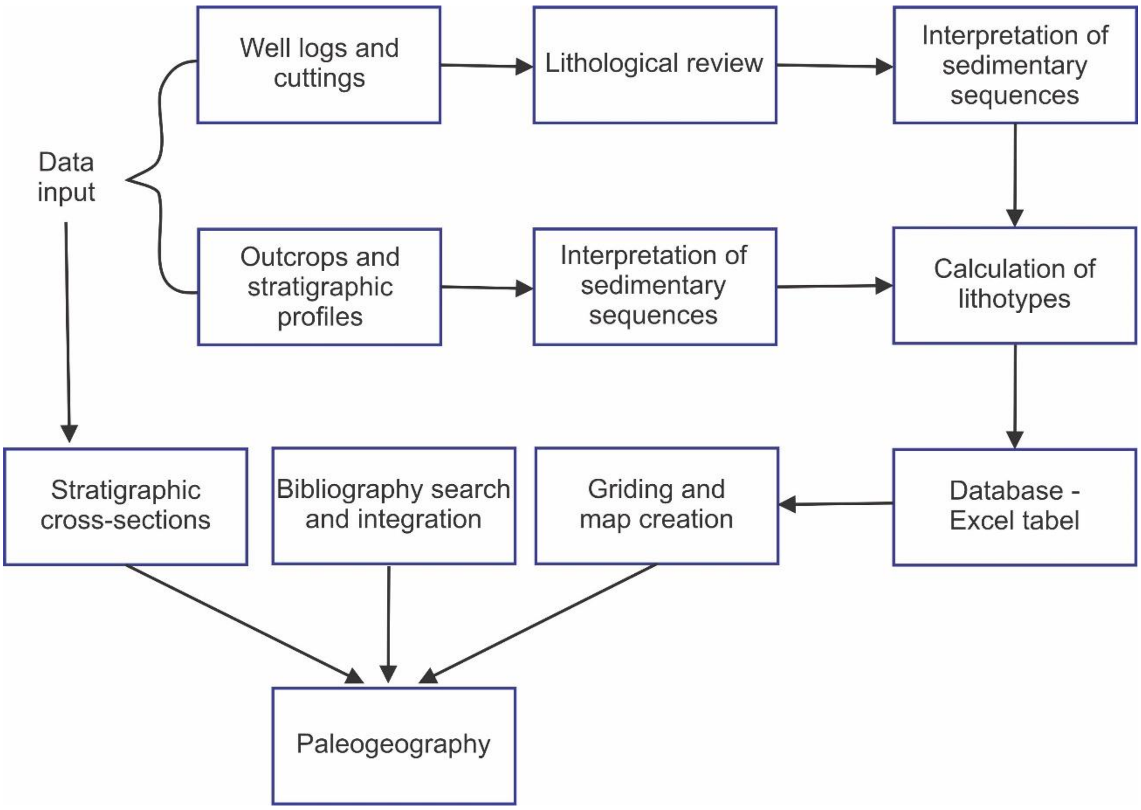

Figure 3: Schematic flowchart of the steps followed in this study.

3. CARBONIFEROUS SEQUENCES OF GONDWANA SEDIMENTARY BASINS: A SYNTHESIS

During the Carboniferous, the Gondwana was affected by several glaciation episodes. The geological record of this ice age is widely distributed along the continent’s relicts (figure 4), in the form of glacial deposits and erosional features, in various South America sedimentary basins such as Solimões, Amazonas, Parnaíba, North Tucano, Jatobá, Paraná, Paganzo, Río Blanco and Sergipe-Alagoas, the subject of this study (figures 5 and 6).

Figure 4: Location map of the main sedimentary basins (in yellow) with records of Carboniferous glaciation on South American.

The Solimões Basin has a Devonian-Carboniferous supersequence that includes the marine and glaciomarine sedimentary rocks of the Marimari Group (Uerê and Jandiatuba formations; Eiras et al., 1994). The overlying Carboniferous-Permian supersequence consists of clastic rocks, carbonates and marine and continental evaporites of the Tefé Group (Juruá, Carauari and Fonte Boa formations), which were deposited in a hot, dry climate.

The Amazonas Basin has an Ordovician-Devonian supersequence composed of alternating glaciomarine sections of the Autás-Mirim, Nhamundá, Pitinga and Manacapuru formations, which make up the Trombetas Group (Cunha et al., 2007). The Devonian-Carboniferous supersequence is constituted by the Urupadi and Curuá groups. The Urupadi Group encompasses the Maecuru and Ererê formations, which represent fluvial-deltaic and neritic sedimentation. The Curuá Group, with the Barreirinha, Curiri and Oriximiná formations, represents a shallow marine depositional stage with glacial incursions, of Tournaisian age (Eocarboniferous).

The stratigraphic succession of the Parnaíba Basin shows four glacial stages. The oldest glaciogenic deposits are of Silurian age, represented by the diamictites of the Ipu Formation. The second glaciation event is recorded by the glaciomarine and glaciofluvial deposits, which occur in the upper portion of the Cabeças Formation, of Devonian age. The last two glaciations of the Paleozoic correspond to the Mississippian (Early Carboniferous) and are represented by diamictites of the Longá and Poti formations, of Tournaisian and Visean age, respectively (Caputo & Santos, 2019).

The North Tucano and Jatobá basins had their Paleozoic record beginning with the Siluro-Devonian sequence of the Jatobá Group (Tacaratu and Inajá formations; Costa et al., 2007). The Carboniferous sequence is represented by the Curituba Formation, (diamictites, clayey sandstones, vuggy shales and limestones), correlated with the Poti Formation, in the Parnaíba Basin, of Tournaisian to Visean age (Caputo, 1984). Rocha-Campos et al. (1997) described striated surfaces and grooves produced by ice masses in sandstone and conglomerate outcrops from this unit. The Permian sequence (Costa et al., 2007) is represented by the Santa Brígida Formation, with sandstones, calcareous siltstones and dolomites, from an aeolian and transitional to shallow marine environment.

The stratigraphic record of the Parecis Basin begins with the Cacoal Formation, of Late Ordovician age, consisting of conglomerates, dolomitic claystones, conglomeratic and feldspathic sandstones, siltstones and shales. It is overlain by the Paraná Group, with the Furnas and Ponta Grossa formations, of Devonian age, with rocks characteristic of shallow to deep marine environments (Bahia et al., 2006). During the Late Mississippian, sediments of the Pimenta Bueno Formation were deposited, consisting of shales, sandstones, siltstones and diamictites, characteristic of glacial and shallow marine environments. The Fazenda da Casa Branca Formation, of Meso-Pennsylvanian to Early Permian age, is made up of conglomerates, arkoses, graywacke and pelites, characteristic of a shallow marine and lacustrine environment, in a periglacial context (Caputo, 1984).

The Paleozoic remnants of the Sanfraciscana Basin consist of Permo-Carboniferous sedimentary rocks from the Santa Fé Group). The Santa Fé Group is constituted by the Floresta (Late Carboniferous) and Tabuleiro (Early Permian) formations, which present diamictites/tillites facies and basal shales with dropstones, that suggest a correlation with the glacial permo-carboniferous sediments of the Itararé Group, in the Paraná Basin (Zalán & Silva, 2007).

The Itararé Group (Westphalian to Sakmarian; Vesely & Assine, 2006), in the Paraná Basin, encompasses the Lagoa Azul, Campo Mourão and Taciba formations. Sedimentation occurred mainly in glaciomarine environments and consists of five deglaciation sequences marked by subglacial diamictites at the base of each sequence, followed by conglomerates and sandstones. Shales occur at the top of these sequences, representing ice retreat. Striated and grooved surfaces are common.

The stratigraphic record of the Paganzo Basin in Argentina is represented by the Paganzo Group, which includes the Guandacol, Tupe and Patquia formations. Sedimentation began at the end of the Carboniferous, in continental environments, where alluvial sediments and tillites were covered by shales, interpreted as a glaciolacustrine setting. Later, conglomerates and sandstones, characteristic of anastomosed rivers, were deposited. At the beginning of the Permian, the sea level dropped, and sedimentation occurred in arid and semi-arid environments (Limarino et al., 2002).

The Río Blanco Basin, in Argentina, has three Mississippian units, from bottom to top: Agua de Lucho Formation (Tournaisian), composed of shales and sandstones intercalated with glacial diamictites; Cerro Tres Cóndores Formation (Visean), consisting of thick sandstones and polymict conglomerates intercalated with diamictites; and Punta del Agua Formation, of Visean age, consisting of thick volcano-sedimentary deposits intercalated with glacial diamictites. The Río del

Peñón Formation (Pennsylvanian) covers the earlier Mississippian successions (Ezpeleta et al., 2020).

The Sergipe-Alagoas Basin, the object of this study, has a Paleozoic supersequence (Campos Neto et al., 2007) that encompasses the Karapotó, Batinga and Aracaré formations. The Karapotó Formation consists is fluvial sandstones of probable Siluro-Devonian age (Souza-Lima et al., 2017). Later, glacial diamictites, silty-clay rhythmites and sandstones were deposited, composing the Batinga Formation, of Carboniferous age, probably Westphalian (Dino et al., 2002). During the Permian (Sakmarian-Artinskian), the sediments of the Aracaré Formation were deposited, represented by limestones, sandstones, siltstones and shales in a coastal environment (Brito et al., 1985).

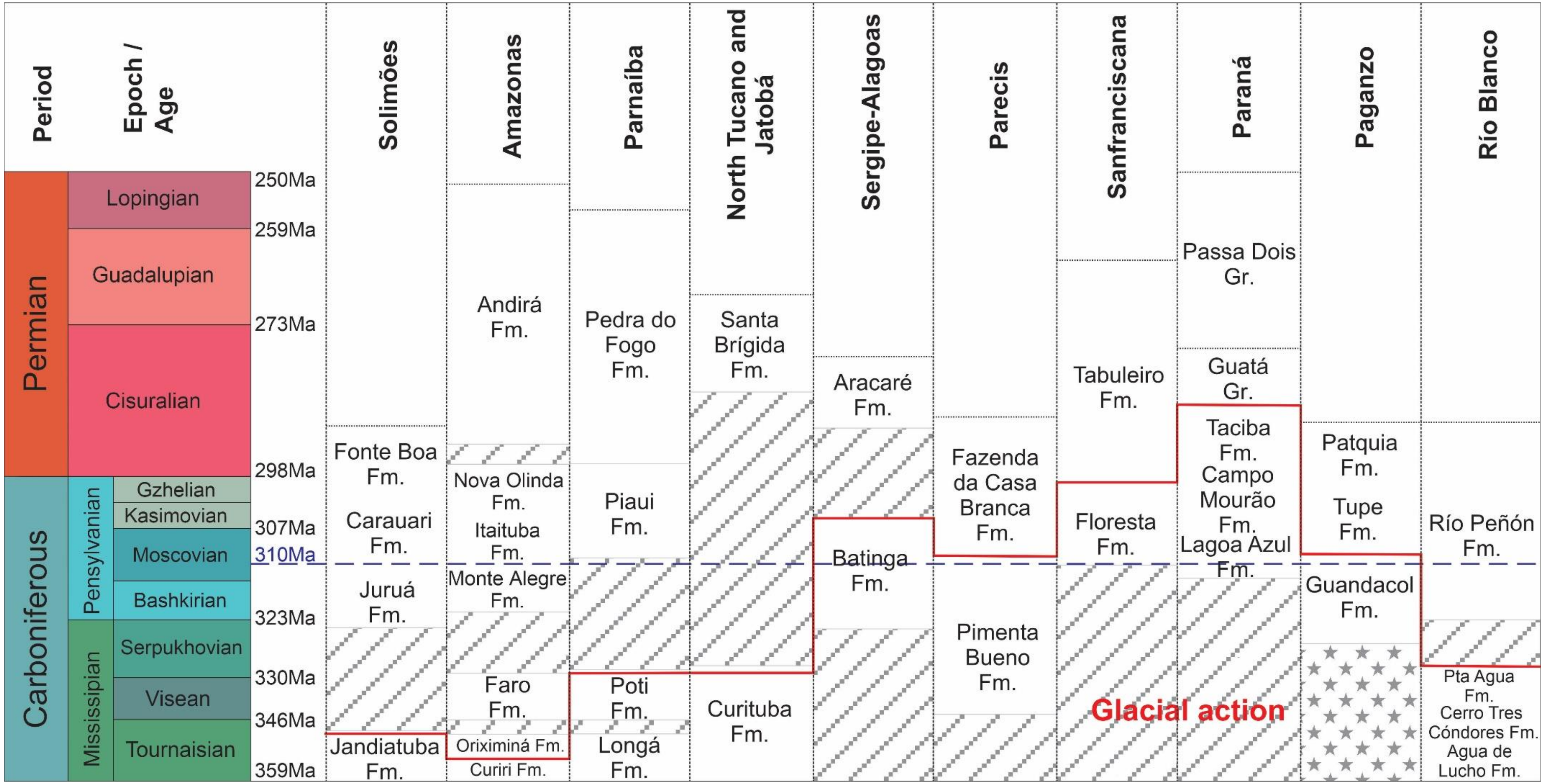

Figure 5: Correlation of permo-carboniferous sedimentary records in Paleozoic basins of Gondwana. The blue dashed line represents the age used to reconstruct the Carboniferous paleogeography in central Gondwana; the red line represents the upper limit of glacial action in each basin (ages according to “The ICS International Chronostratigraphic Chart” - 2021; Cohen et al., 2013).

4. THE SERGIPE-ALAGOAS BASIN

The Sergipe-Alagoas Basin is located on the continental margin of northeastern Brazil, in the coastal region of the states of Sergipe and Alagoas (figure 6). It is an important basin for understanding the evolution of the continental margins of South America and Africa, as it presents the most complete stratigraphic succession exposed on both sides of the South Atlantic. The cropping-out sections represent all the evolutionary stages characteristic of passive margin basins: pre-rift, rift, transitional and drift (Souza-Lima et al., 2002). There are also significant remnants of the Paleozoic syneclesis, which occupied large portions of South America during this era.

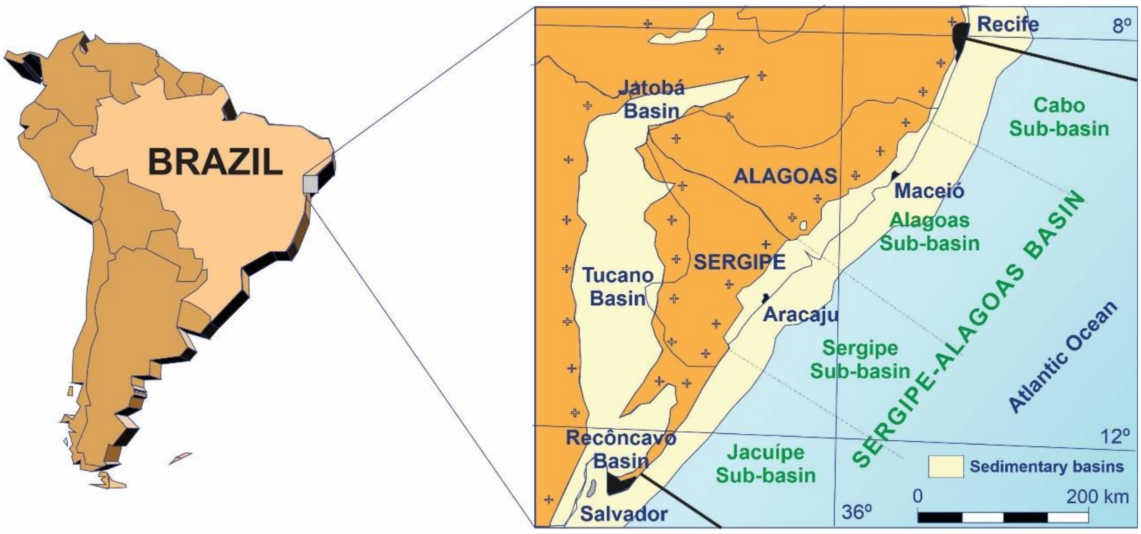

Figure 6: Location of the Sergipe-Alagoas Basin (Souza-Lima et al., 2002).

The basin's basement is made up of Proterozoic metamorphic rocks from the Sergipano Folded Belt, Proterozoic granitoids from the Pernambuco-Alagoas Massif and supposedly Cambrian metasediments from the Estância Group. The stratigraphic evolution proposed by Campos Neto et al. (2007) subdivided the basin's deposits into five supersequences.

The Paleozoic Supersequence (figure 7) comprises the sedimentary record deposited in the syneclesis stage (Campos Neto et al., 2007). The oldest records of this stage have a probable Siluro-Devonian age and is represented by the Karapotó Formation (Souza-Lima et al., 2017). During the Carboniferous, the Gondwana continent underwent intense glaciation, and the resulting deposits, interpreted as being of glacial origin, are represented by the Batinga Formation (Brito et al., 1985; Souza-Lima & Farias, 2006a, b). During the Permian, the last

Paleozoic sequence was generated, represented by the Aracaré Formation, at a hot and dry climate (Brito et al., 1985).

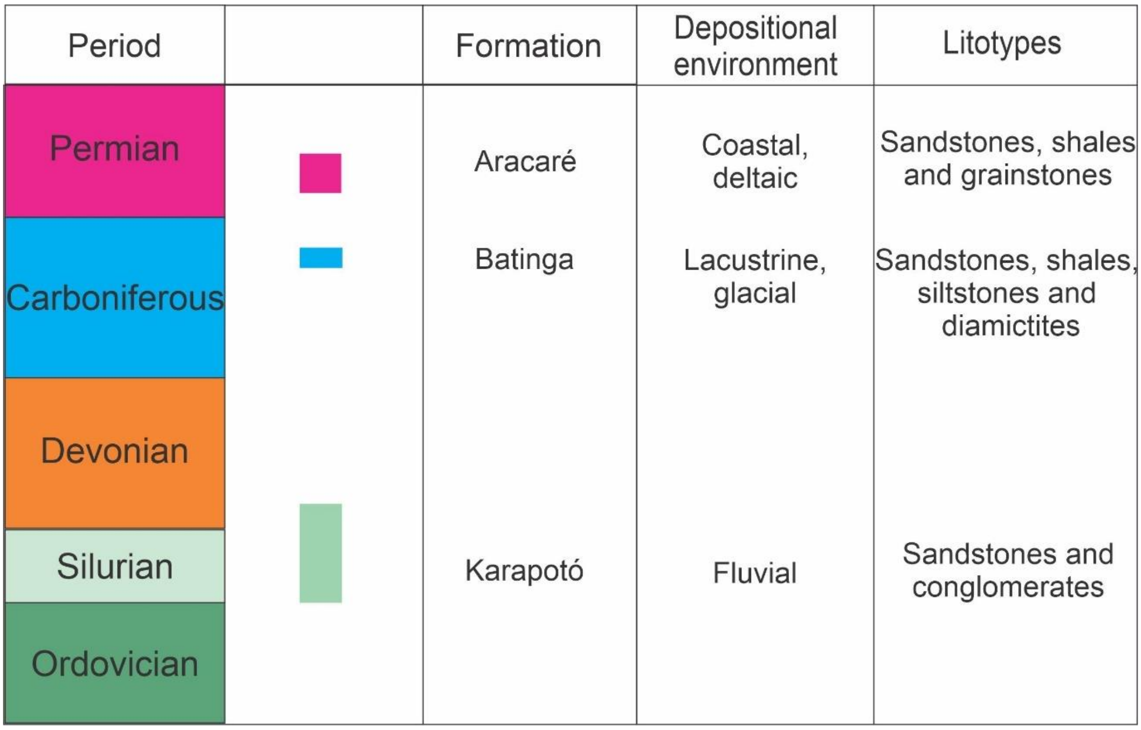

Figure 7: Stratigraphy of the preserved Paleozoic remains in the Sergipe-Alagoas Basin.

All the other supersequences are related to the rifting process of the supercontinent Gondwana and the separation of the African and South American plates, which culminated in the formation of the South Atlantic Ocean from the Mesozoic onwards (Campos Neto et al., 2007).

The Sergipe-Alagoas Basin tectonic framework was established by the various stages of the rifting process that caused this rupture. This process generated a series of half-grabens dipping approximately 10–15° SE (figure 8), crossed by NW transcurrent zones that can be traced to the West African conjugate basins (Meyers et al., 1996). This framework is characterized by an asymmetrical rift, elongated in a NE-SW direction, defined mainly by faults in NE-SW, N-S and NNE-SSW directions (Aquino & Lana, 1990).

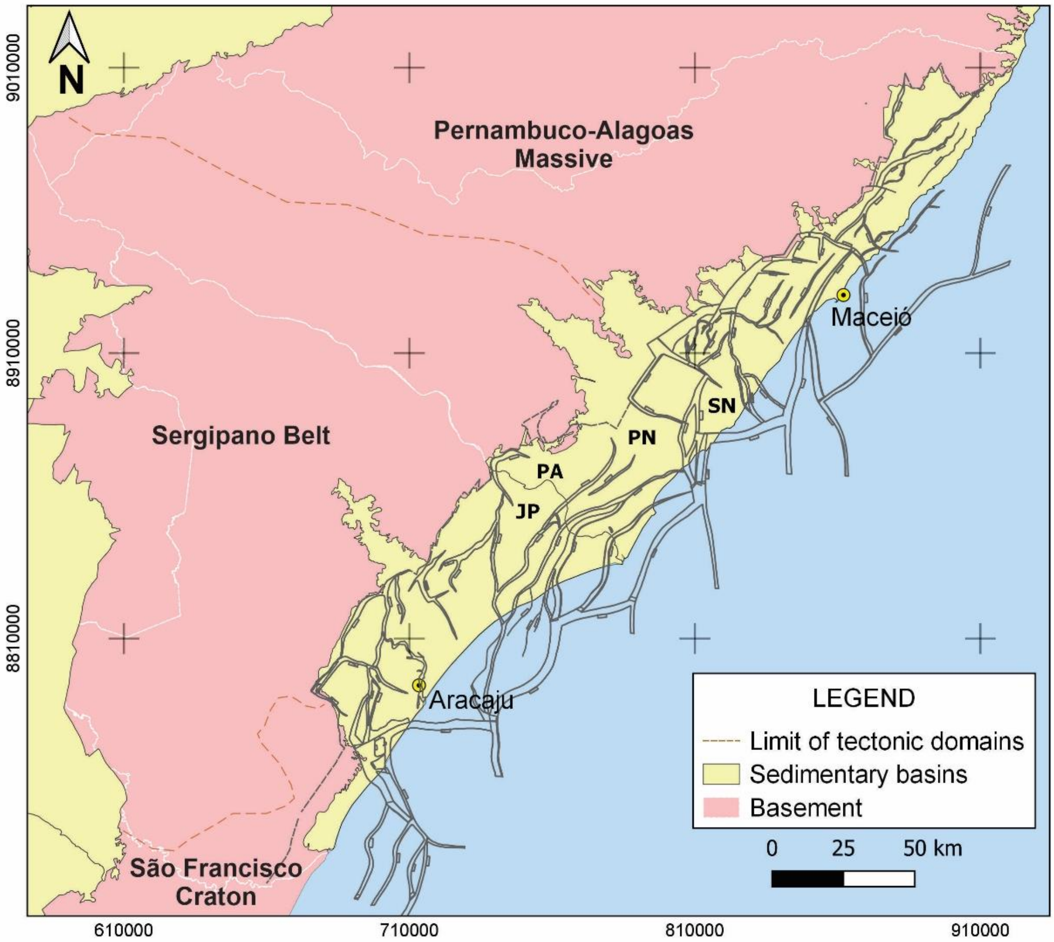

Figure 8: Tectonic framework of the Sergipe-Alagoas Basin, with the structural compartments mentioned in this study: Palmeira Alta High (PA), Japoatã High (JP), Penedo High (PN), and Sinimbu Low (SN), which delimit the thickest portion of the Batinga Formation. Modified from Falkenhein, 1996 and Souza-Lima et al., 2002.

During the syneclesis stage, the tectonic framework that controlled this depositional phase was inherited mainly from the basement. This internal structuring was thus the result of the distinct compositional character of the basement over which the basin was installed. In the northern, the basement is represented by granitoids (granite-gneisses and migmatites) of the Pernambuco-Alagoas Massive, while in the southern part, the basement is mainly represented by the Sergipano Folded Belt, made up of folded metasediments, with metamorphism ranging from greenschist to amphibolite facies (Almeida et al., 1977).

Four preferential structural directions can be identified: NE-SW, N-S, NW-SE and E-W. Among these, the NW-SE direction is one of the most pronounced, being controlled by the transcurrent shear zones activated during the Neoproterozoic, mainly in the Brasiliano (Pan-African) cycle, the last event that deformed the Sergipano Folded Belt, also oriented in a NW-SE direction (Souza-Lima, 2006a).

5. THE BATINGA FORMATION

The first studies on the Batinga Formation were carried out in 1943, with the recognition of a sedimentary section that was grouped into the “Vaza Barris Series”, of supposed Silurian age, in Sergipe (Oliveira, 1943). The name “Batinga Formation” was proposed as a new unit by Bender (1957), in an internal Brazilian petroleum company PETROBRAS report (Souza-Lima & Farias, 2006a).

The Batinga Formation is divided into two members: Mulungu, consisting of diamictites and medium-thick to conglomeratic sandstones, and Boacica, which represents the dominant sedimentary section of the formation, consisting mainly by fine to very fine sandstones, siltstones and shales, deposited by deltaic fans and lacustrine systems (Campos Neto et al., 2007).

The rocks of the Mulungu Member had their deposits interpretated as related to a periglacial geographical context, with the direct action of glaciers. The rhythmites of the Boacica Member are typical of the intercalation of prodeltaic and lacustrine shales and siltstones, interbedded with sandstones from deltaic fronts. There is an increase in the ratio sandstones/shales towards the top of the section, reflecting the progression of the system in the water body (Souza-Lima & Farias, 2006b).

The deposits of the Batinga Formation crops out in the central part of the basin, over the structural highs of Japoatã, Penedo and Palmeira Alta (Souza-Lima & Farias, 2006a). The formation presents extensive thickness variation, with a maximum of ca. 320 meters (figure 9). The Mulungu Member occurs more restrictively, with greater expression at the center of the basin, mainly in Alagoas (Souza-Lima & Farias, 2006b).

The age of the basal Mulungu Member of the Batinga Formation is unknown, however, palynomorphs characteristic of a Late Carboniferous age, probably Westphalian (Meso-Pennsylvanian), have been recovered in siltstones of the Boacica Member, the overlying unit (Dino et al., 2002).

Classically, the Batinga Formation is related to subaqueous glacial environments (Souza-Lima & Farias, 2006b; Campos-Neto et al., 2007; Farias, 2013). Farias (2013) studied the ichnofossils in the Boacica Member and defined that their association displays elements that characterize a subaqueous, muddy, relatively calm and shallow environment, which may represent both the Mermia (lacustrine) and Scoyenia (transitional continental) ichnofacies. The study carried out by Dino et al. (2002) identified the significant presence of woody organic matter, which provided evidence of a deposition in continental conditions, and have not identified elements of marine paleoplankton in the recovered association. Therefore, for the paleogeographic reconstruction of the Carboniferous in this study, interglacial lacustrine environments were considered for the deposition of this unit.

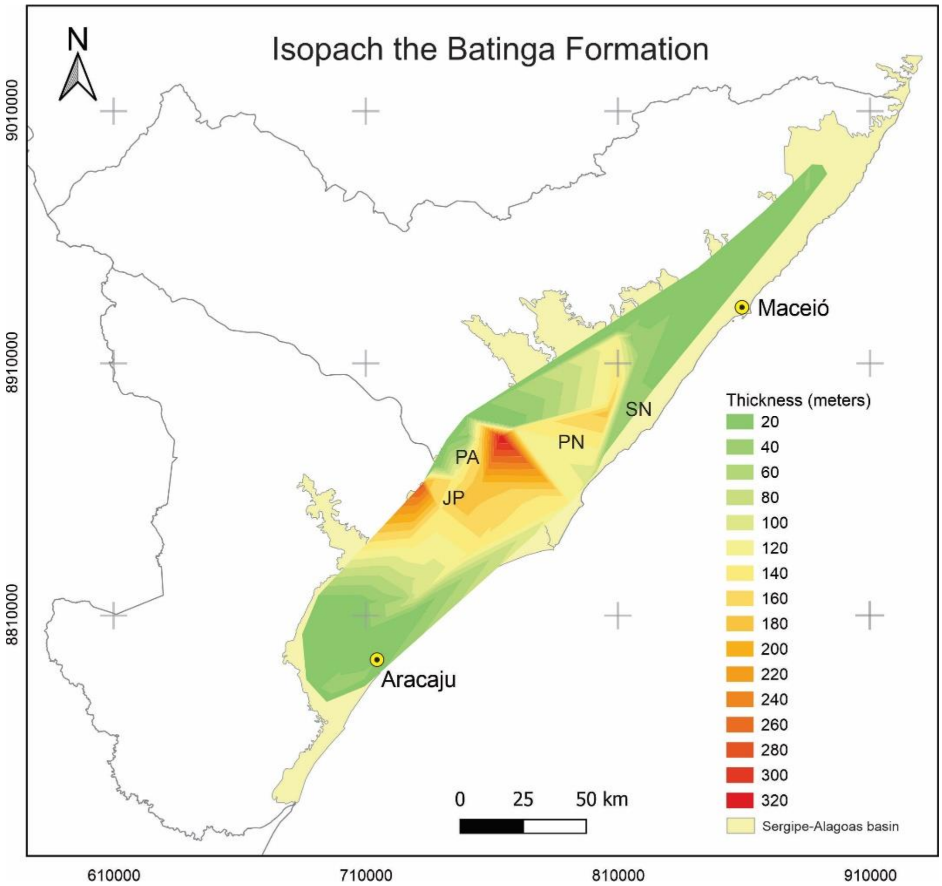

Figure 9: Isopach map of the Batinga Formation based on wells and outcrops data. The greatest thicknesses are found at the Japoatã (JP), Penedo (PN) and Palmeira Alta (PA) highs, and at the Sinimbu Low (SN).

5.1. Stratigraphic profiles

Many outcrops in the Boacica Member are extensive and well preserved, which made it possible to carry out almost continuous stratigraphic surveys. For this study, six profiles were surveyed, named according to the location where they were constructed: Igreja Nova, Batinga, Cedro, Chã do Remígio, Pescocinho and Mulungu. The stratigraphic profiles helped with the lithological review and were important for interpreting the sedimentary sequences. The Cedro profile represents a rather continuous cropping out section, about 170 meters thick, in Sergipe (figure 10).

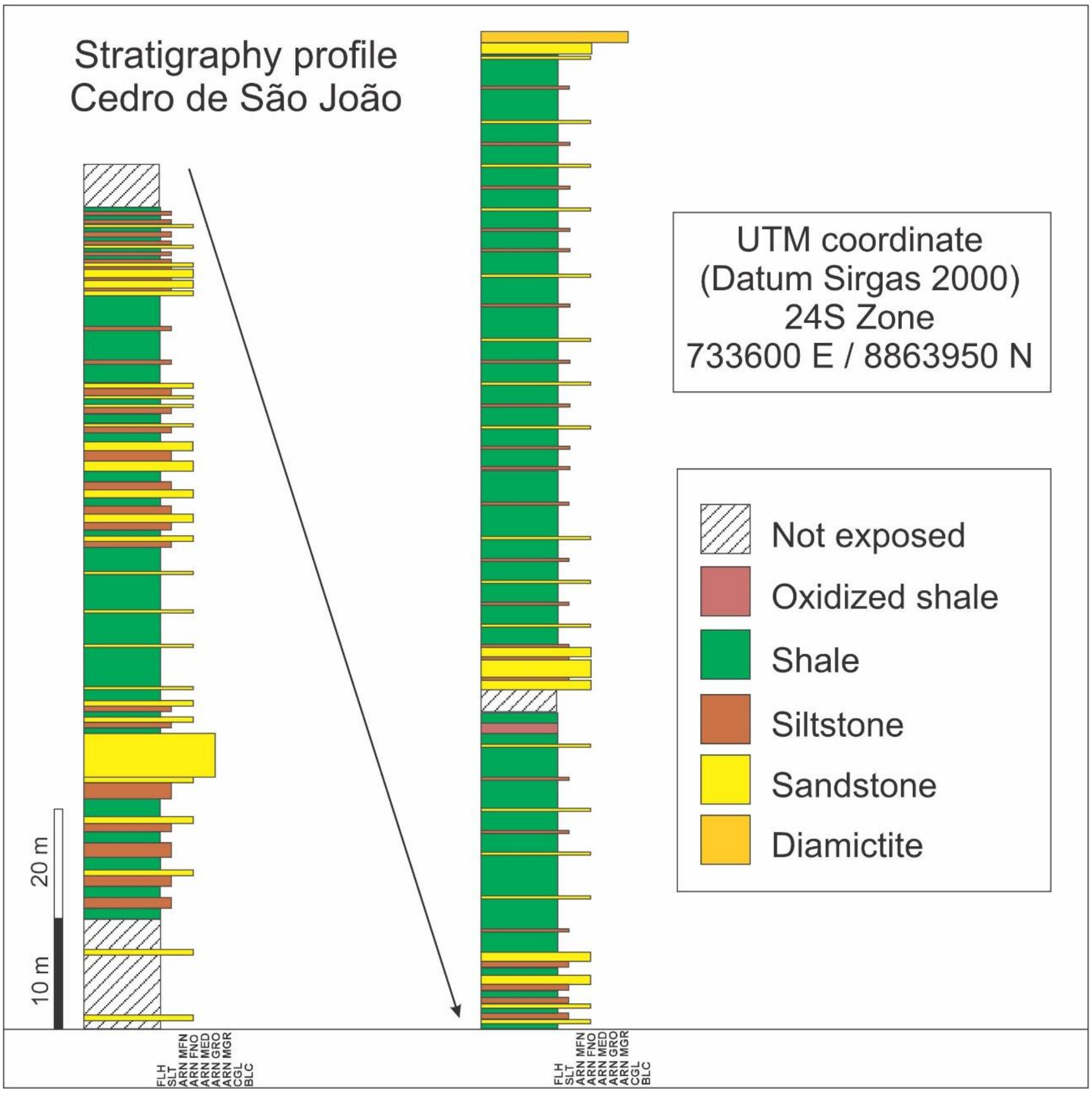

Figure 10: Stratigraphic profile of the cropping out section of the Boacica Member, located east of the city of Cedro de São João, SE (CDR-01).

5.2. Sedimentary facies

As most of the data for this study came from wells, making it impossible to identify the facies directly, the facies analysis of the Batinga Formation was carried out using a compositional approach, based on the identification of basic lithotypes, not representing the facies discrimination sensu Eyles et al. (1983) or

Miall (1996). Four basic facies were considered in this study: diamictite, for the Mulungu Member, and sandstone, siltstone and shale, for the Boacica Member. The total thickness of each of these basic facies, for each sequence, was computed and entered a spreadsheet for later analysis.

The diamictite facies represents rocks with clasts and blocks varying in shape, size and composition, immersed in a fine, silty-clay or sandy matrix. Two diamictites were interpreted for the Mulungu Member: one basal and another superior. The basal diamictite (figure 11) is represented by texturally immature rocks, a greenish-gray to dark-gray sandy matrix, mainly quartz, and a large concentration of clasts and blocks of polymict composition with varying shapes and sizes (granites, schists, gneisses, quartzites, phyllites, fragments of white quartz, etc.), which characterize subglacial deposits, subject to the direct action of glaciers, where deposition occurred during their advance and retreat.

Figure 11: Compositional facies of the basal Mulungu Member: rocks with polymitic clasts and blocks of varying shape and size immersed in a sandy matrix. A - (TUC-01); B - (DP-01); C - (IGN-03); D - (TUC-01); E - (DP-01); F - (DP-01). For location, see figure 2.

Petrographically, the basal diamictite has a mineralogical composition dominated by angular to subrounded monocrystalline quartz of varying sizes. Subordinately, lithic fragments, polycrystalline quartz, iron oxide, potassium feldspar (microcline), plagioclase and biotite altering to chlorite are observed. All the grains are surrounded by a predominantly quartz matrix and, locally, silty clay (figure 12).

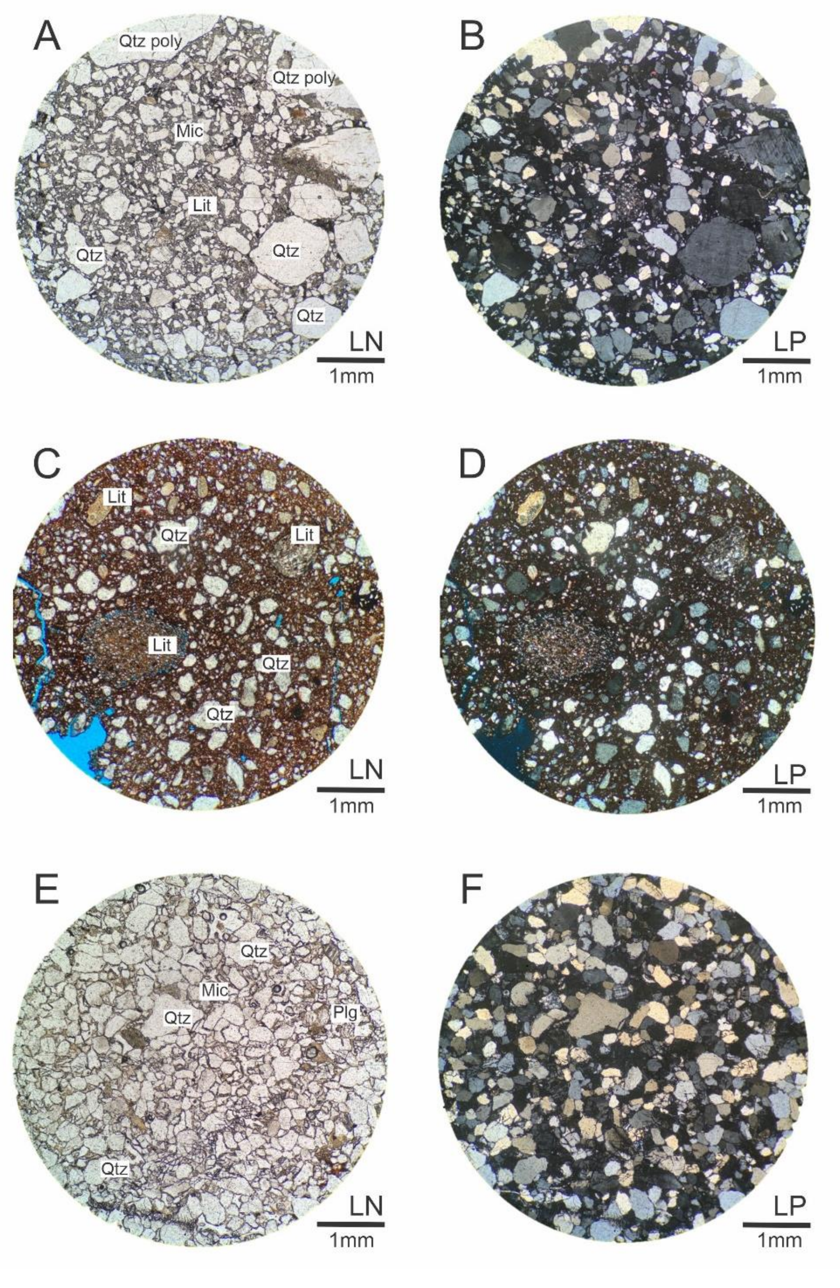

Figure 12: Petrographic characterization of the basal diamictite: A and B (GTE-01) - diamictite of the Curituba Formation, Tucano Norte Basin; C and D (ONÇ-09) - diamictite of the basal Mulungu Member, Sergipe-Alagoas Basin; E and F (LGS-01) - diamictite of the Curituba Formation, Tucano Norte Basin. LN - natural light; LP - polarized light; Qtz - quartz; Qtz poly - polycrystalline quartz; Plg - plagioclase; Mic - microcline; Lit - lithic fragment.

The upper diamictite (figure 13) occurs in the upper portion of the Batinga Formation, overlying the Boacica Member, and represents the final collapse of the glaciation. It occurs as rocks with a high percentage of sandy and carbonate matrix, smaller and sparse clasts (figure 13A), with a less diverse composition than the basal diamictite, constituted mainly by white quartz, quartzite and metasiltite, and possibly granite (figure 13F), containing, in its lower portion, dropstones immersed in a sandy-clay matrix (figure 13C). It characterizes deposits from a fluvial-deltaic environment, with glacial influence, where the sediments were transported and deposited by thaw currents, with intense fluidization.

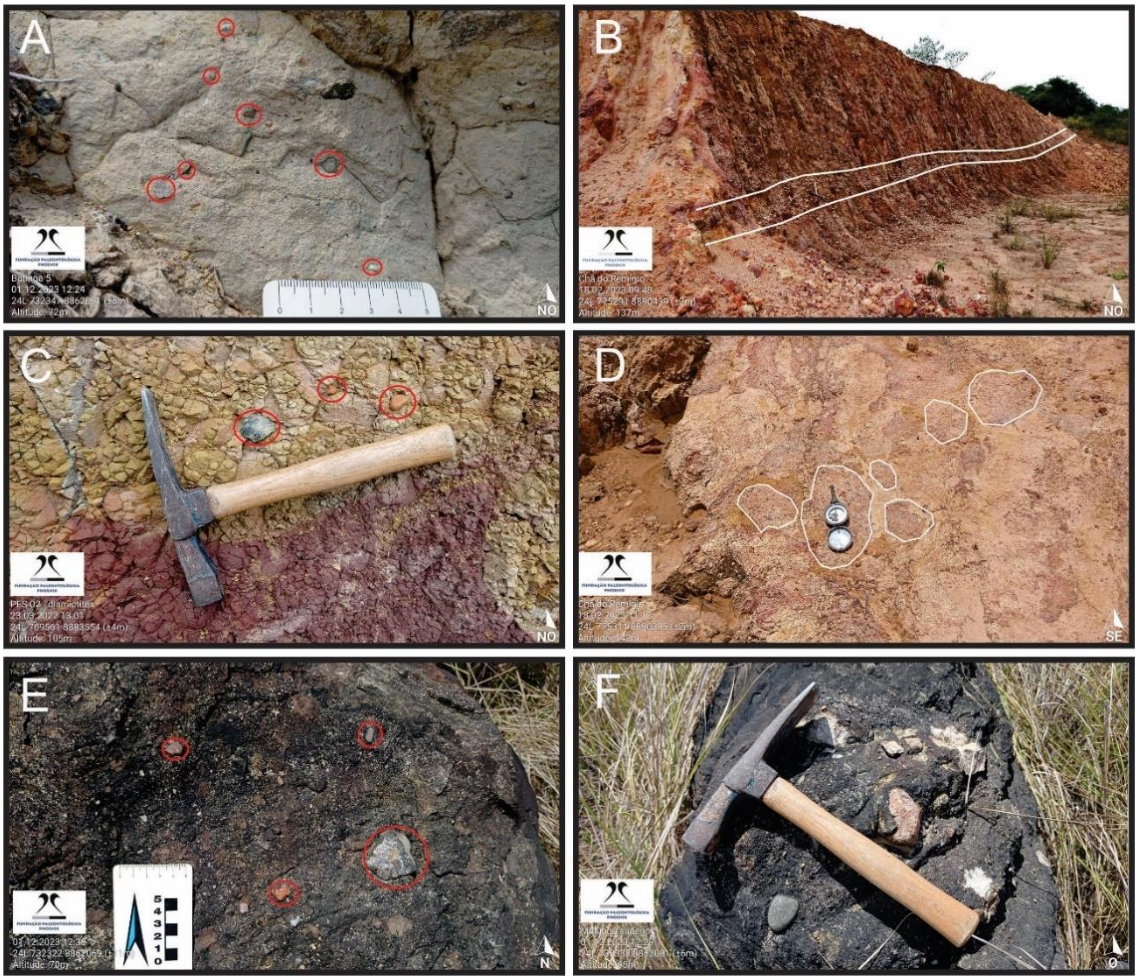

Figure 13: Compositional facies of the upper Mulungu Member: A – diamictite with clasts varying in size and composition, usually rounded, immersed in a sandy matrix (BAT 05); B - sandy-clay diamictite with sparse clasts, predominantly granitic in composition, showing a lenticular layer rich in white quartz clasts, resulting from debris flow, probably reworked from the immediately underlying Karapotó Formation (CHR 01); C – sandy-clay rocks with dropstones (PES 02); D - detail of B, showing sandy clay matrix rock with sparse clasts (CHR 01); E - sandy matrix diamictite with sparse clasts (BAT 05); F - diamictite with clasts varying in size and composition, immersed in a sandy matrix (BAT 05). For location, see figure 2.

Petrographically, the upper diamictite has a mineralogical composition dominated by subrounded to subangular monocrystalline quartz. Subordinately, lithic fragments, polycrystalline quartz, iron oxide, potassium feldspar (microcline), plagioclase and biotite changing to chlorite are observed. All the grains are surrounded by a matrix made up of earthy mudstones/marls (figure 14).

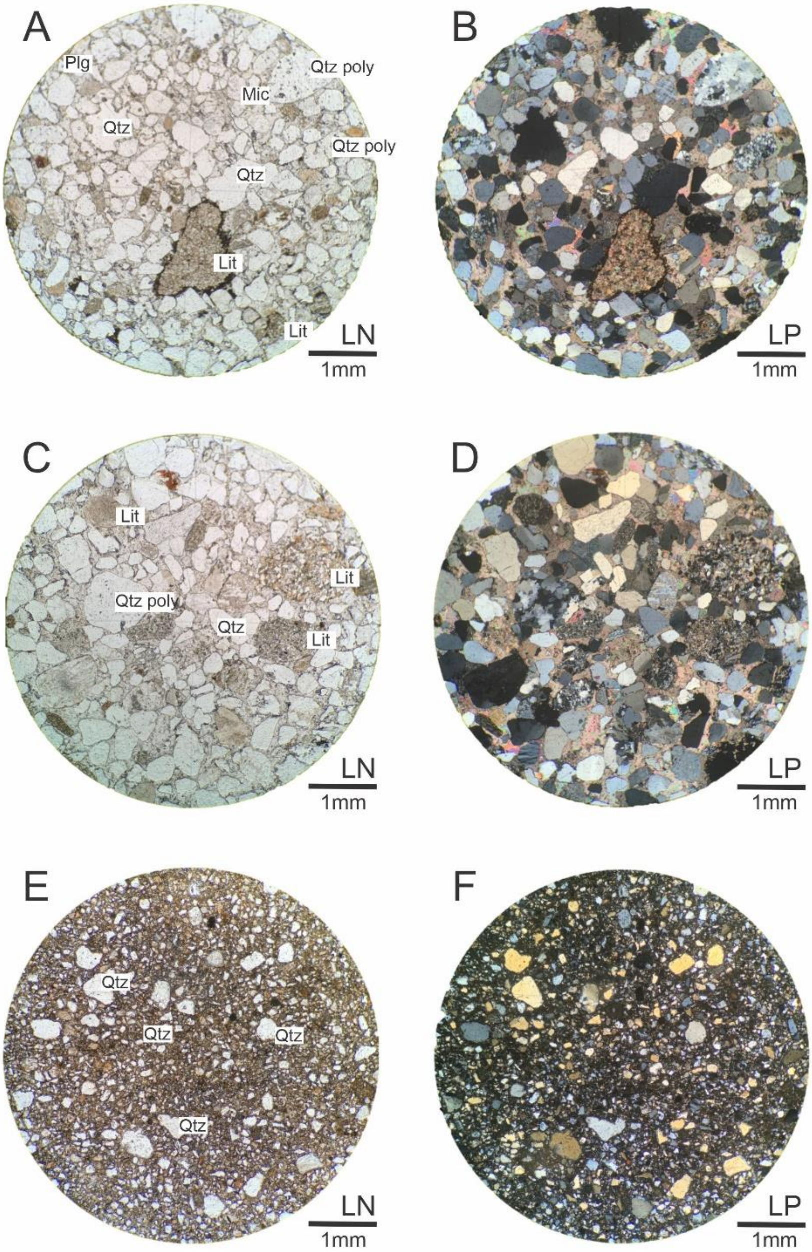

Figure 14: Petrographic characterization of the diamictites from the upper Mulungu Member, Sergipe-Alagoas Basin: A, B, C and D (BAT-05D); E and F (BAT-05C). LP - polarized light; Qtz - quartz; Qtz poly - polycrystalline quartz; Plg - plagioclase; Mic - microcline; Lit - lithic fragment.

The shale, siltstone and sandstone facies represent the glaciolacustrine deposits with deltaic influence from the Boacica Member. The shale and siltstone facies make up rhythmites, characterized by the intercalation of fine-grained prodeltaic sediments, where the suspended sedimentary particles (silt and clay) were gradually deposited, in a hyperpycnal flow, in the prodelta area (figure 15D and 15E). The sandstone facies represent the deltaic fronts. In this sub-environment, in the most distal part (near the prodelta), in a clay-silt context, fine-grained sands are deposited in climbing ripples and lenticular and undulating beds (figure 15A and 15B). In the proximal regions of the deltaic fronts, thicker sands are deposited with tabular and trough cross-stratification, or even massive (figure 15C), locally showing combined flow structures resulting from the coexistence of currents and waves (figure 15F).

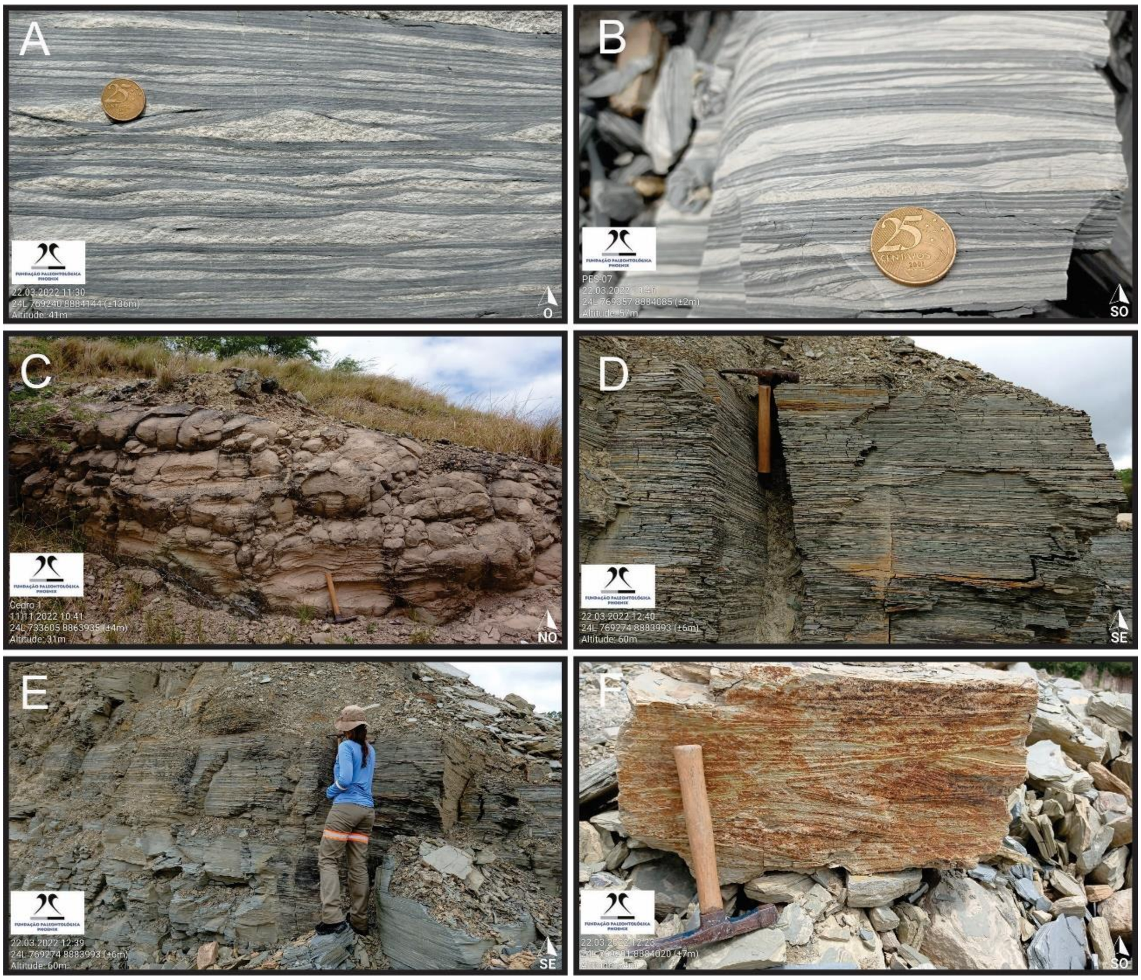

Figure 15: Characteristic facies of the Boacica Member: A and B - Rhythmic intercalations of shales and siltstones, with levels of fine-grained sandstones exhibiting climbing ripples and lenticular and undulating bedding (PES 07); C - Thick sandstone with stratification masked by fluidization (CDR 01); D and E - Pro deltaic papyraceous shale (PES 07); F - Sandstone with combined flow structure (currents and waves) (PES 07). For location, see figure 2.

5.3. Reference section

The Boacica Member, of the Batinga Formation, occurs characteristically as rhythmic intercalations of shales and siltstones, with levels of fine to very fine-grained sandstones. The sandstone/shale ratio tends to increase towards the top of the section. As the well 1 CO 0001 AL (figure 16) has the greatest thickness of this member, it was chosen as a reference for the delimitation of four transgressive-regressive sedimentary sequences, based on the patterns of the geophysical logs, that was replicated to all the other selected wells.

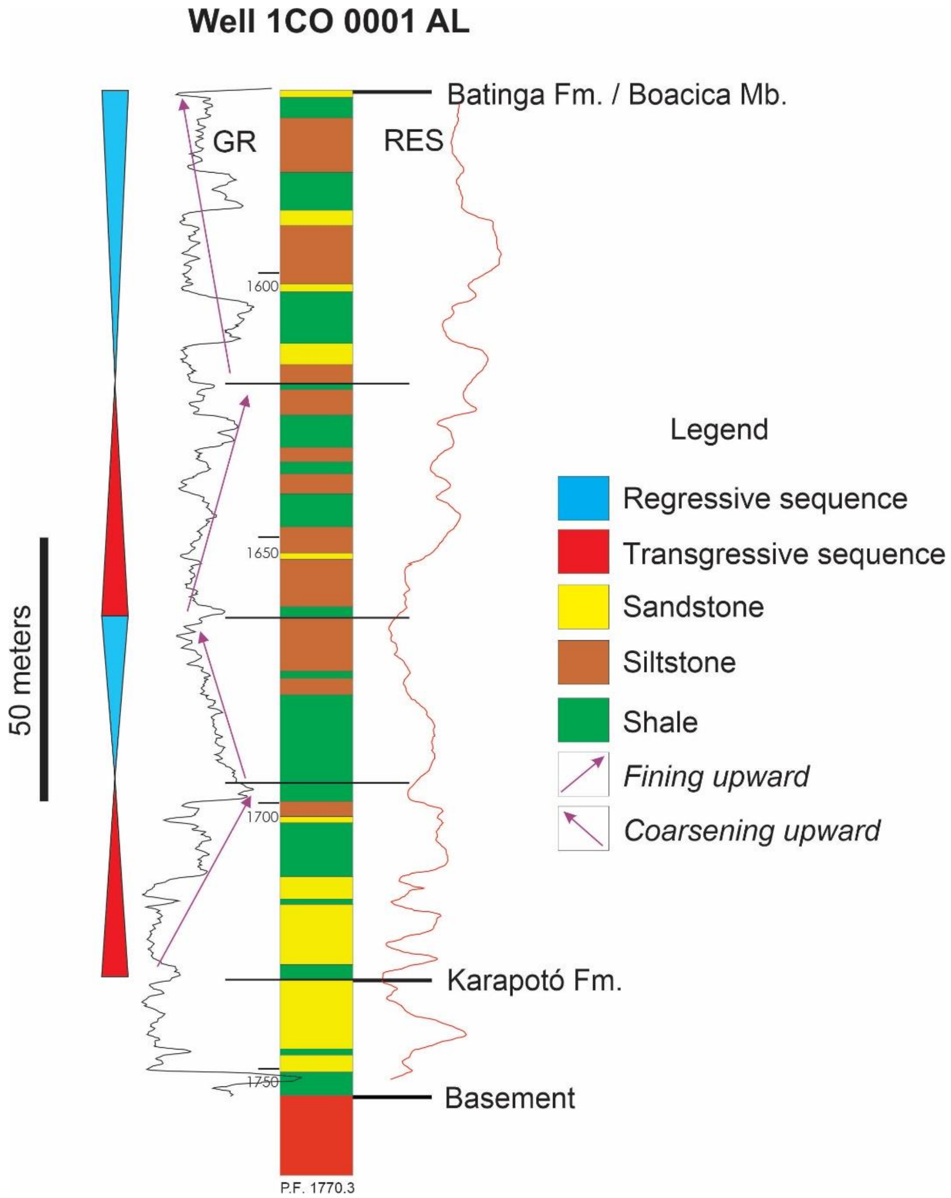

Figure 16: Reference section for the Boacica Member, Batinga Formation, in well 1-CO-1-AL (southeast Alagoas). The section is defined at the interval 1,565 - 1733 m and shows the four transgressive-regressive sequences defined for this member. GR - gamma ray log; RES - resistivity log. For location, see figure 2.

5.4. Sedimentary sequences

Six sedimentary sequences were defined for the Batinga Formation: one for the basal Mulungu Member, four transgressive-regressive sequences for the Boacica Member, and one for the upper Mulungu Member. Subsequently, the simplified lithofacies (sandstone, siltstone and shale) were computed for each sequence. The diamictite lithotype was computed for the Mulungu Member. Isolith (facies) maps were generated for each facies and each sequence. The maps were constructed by stacking the lithofacies in shale-siltstone-sandstone order, discarding the lower classes, the resulting maps illustrated in figures 17 and 18. The thicknesses variation for each lithotype is shown in table 1.

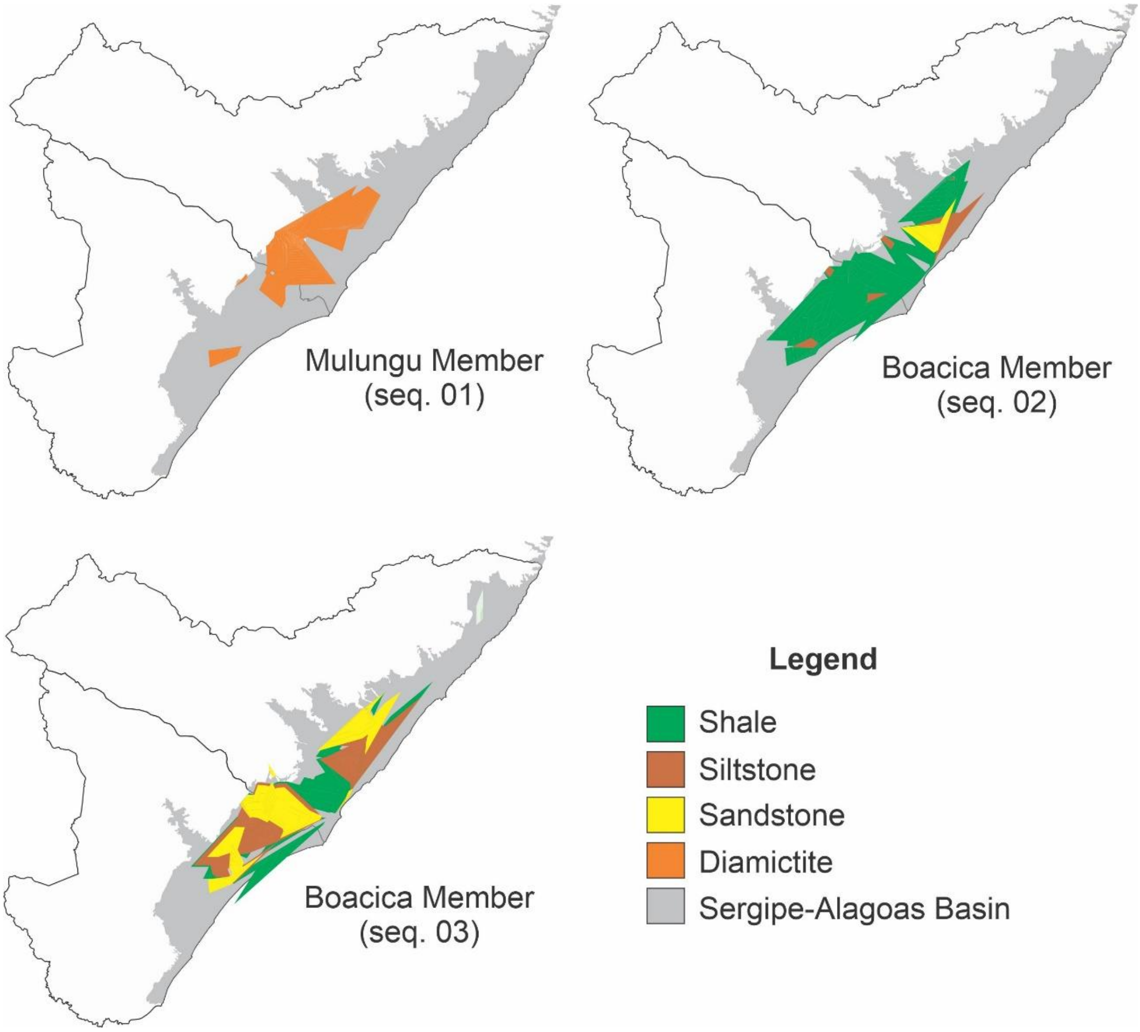

Figure 17: Lithofacies maps of the Mulungu and Boacica members (sequences 1, 2 and 3) generated by gridding the facies thicknesses.

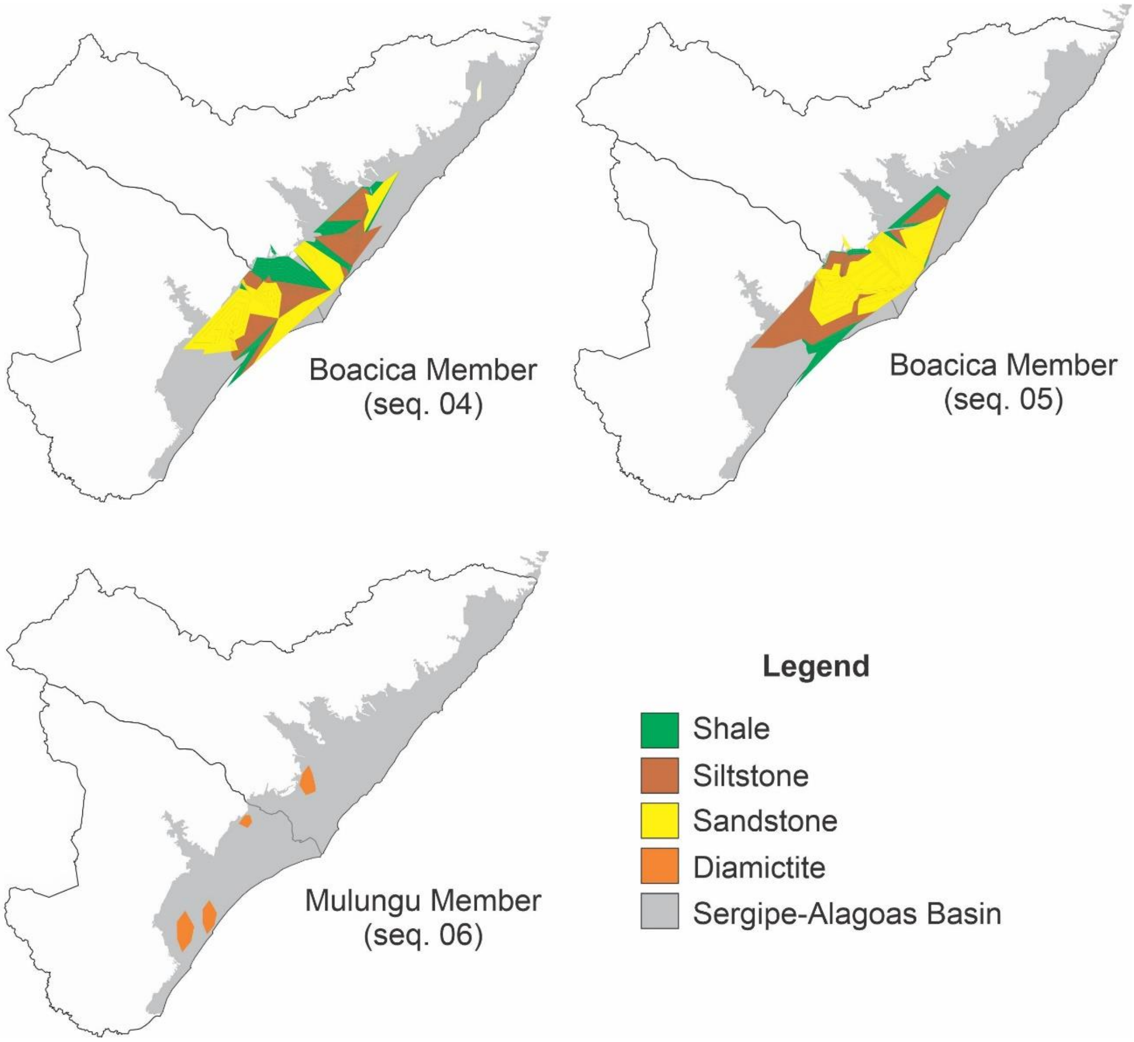

Figure 18: Lithofacies maps of the Mulungu and Boacica members (sequences 4, 5 and 6) generated by gridding the facies thicknesses.

Table 1: Variation in the contribution (thickness) of the lithofacies defined for the members Mulungu and Boacica by sequence.

	Mulungu (seq. 01)	**Boacica (seq. 02)**	**Boacica (seq. 03)**	**Boacica (seq. 04)**	**Boacica (seq. 05)**	**Mulungu (seq. 06)**
Diamictite	0 – 75 m	0 m	0 m	0 m	0 m	0 – 150 m
Sandstone	0 m	0 – 16 m	0 – 29 m	0 – 22 m	0 – 50 m	0 m
Siltstone	0 m	0 – 8 m	0 – 21 m	0 – 31 m	0 – 49 m	0 m
Shale	0 m	2 – 28 m	0 – 25 m	0 – 50 m	0 – 60 m	0 m

5.5. Lithostratigraphic correlation sections

Stratigraphic cross sections were carried out through the correlation between wells and outcrops, to understand the geometric and faciological subsurface behavior of the Batinga Formation. The correlations were based on similar patterns of the radioactive and electrical logs, reflecting mainly the sedimentary composition. The analysis of the constructed sections allows to recognize a mildly synclinal character at a time prior to the deposition of the Permian section (e.g., Figure 19), as well as suggesting the continuity of deposition beyond the current limits of the basin, particularly towards the east (e. g., Figure 20).

Furthermore, the stratigraphic sections show the thickness variation of the transgressive and regressive sedimentary sequences, which provided support for the paleogeographic reconstruction. The deformation of the Carboniferous section, which preceded the deposition of the Permian section, caused the erosion of the marginal portions of some of the sedimentary sequences here defined, in particular 4 to 6, as can be seen in the maps presented below.

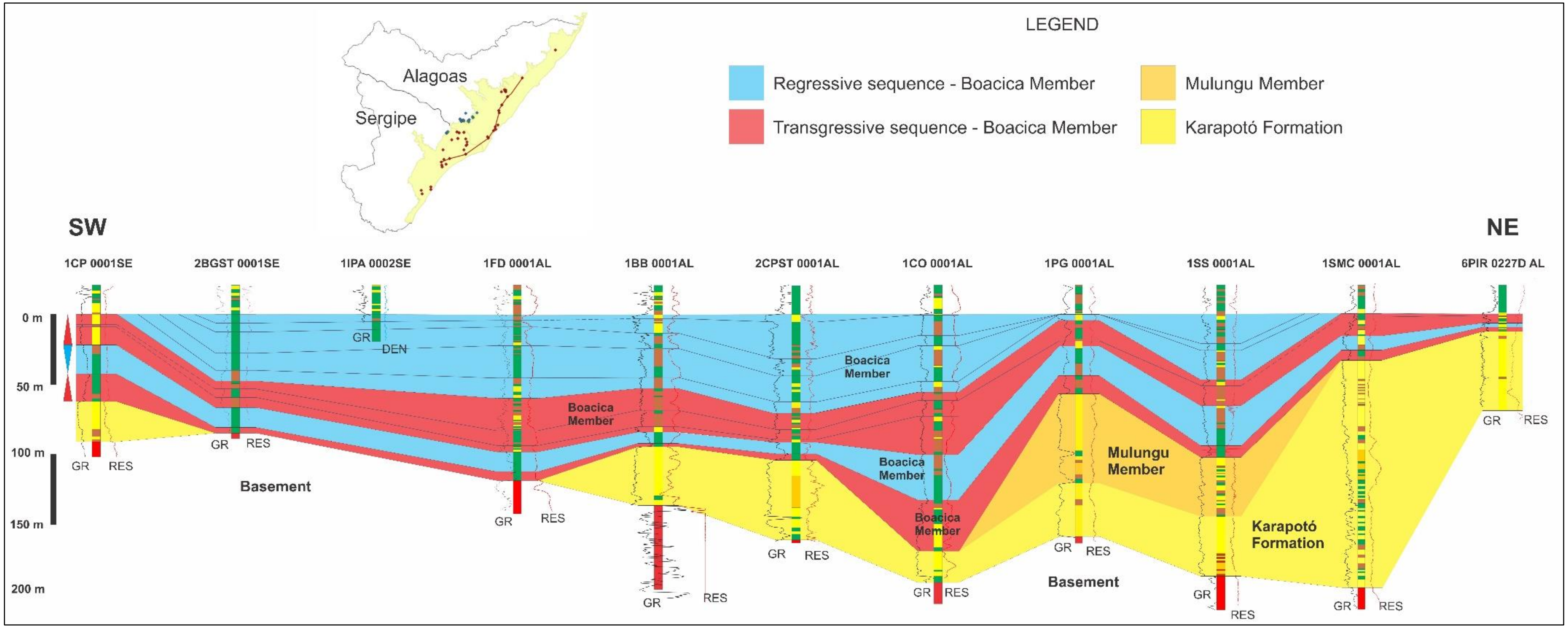

Figure 19: Well correlation stratigraphic SW-NE cross section. Datum defined at the top of the Batinga Formation and constant distance between wells. In the section it is possible to observe the thickness variation of the sequences and for the underlying Karapotó Formation, and the more restricted distribution of the Mulungu Member. The transgressive (in red) and regressive (in blue) sedimentary sequences (Boacica Member) are exhibited, as well as internal correlation marks (lines in dark blue) and the GR (gamma ray) and RES (resistivity) logs for each well.

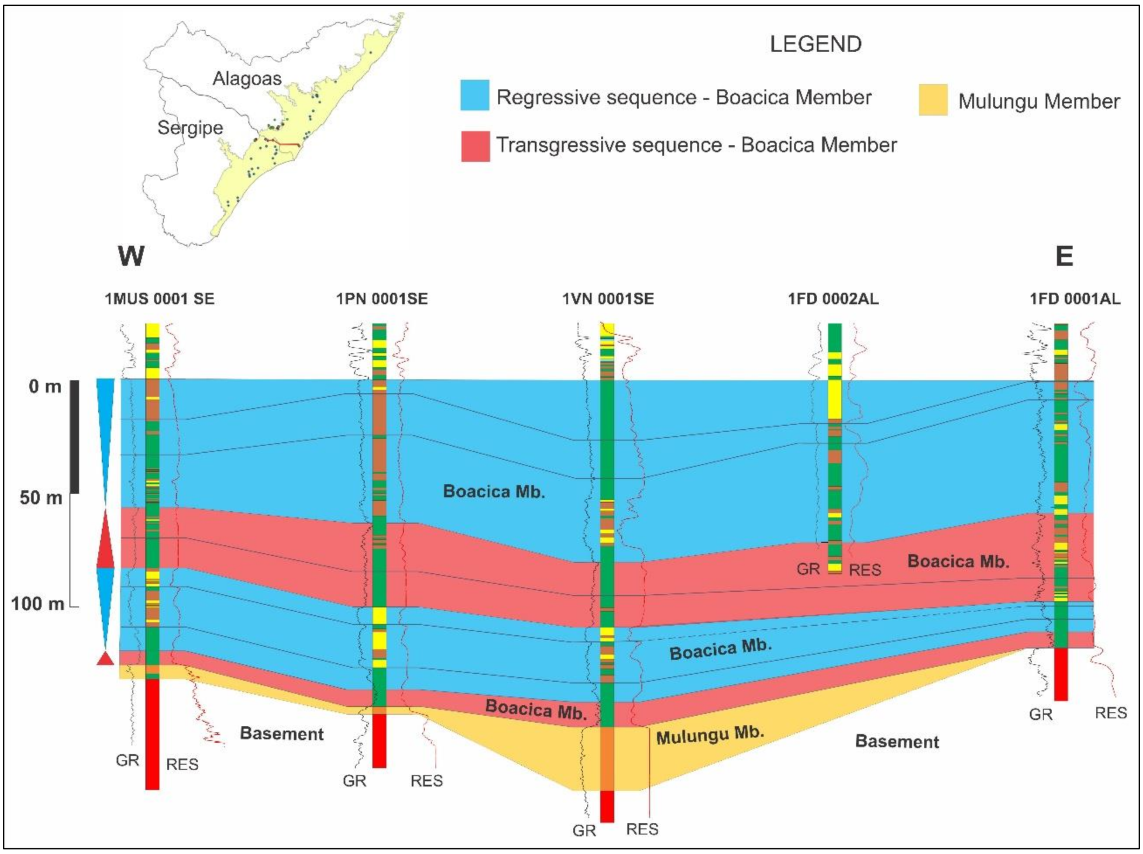

Figure 20: Well correlation stratigraphic W-E cross section, with datum defined at the top of the Batinga Formation and constant distance between wells. In the section it is possible to observe the thickness variation of the sequences and members of the Batinga Formation. The transgressive (in red) and regressive (in blue) sedimentary sequences (Boacica Member) are presented, as well as internal correlation landmarks (lines in dark blue) and the GR (gamma ray) and RES (resistivity) logs for each well.

6. PALEOGEOGRAPHIC EVOLUTION OF THE CARBONIFEROUS SEQUENCE IN THE SERGIPE-ALAGOAS BASIN

The Carboniferous sequence in the Sergipe-Alagoas Basin is marked by a series of glacial and interglacial episodes. Several evidences suggesting this origin are recorded in the Batinga Formation: diamictites with polymict clasts, striations into bedrock by abrasion, faceted (flat-iron type) and striated clasts, grooving and rhythmites with dropstones (Souza-Lima & Farias, 2006b). The detailed study of this sedimentary succession enabled the interpretation of these episodes in different paleoclimatic contexts, making it possible to reconstruct the changes in paleogeography during the deposition of this sequence.

During the Carboniferous, the region of Sergipe and Alagoas would have had a much higher topography than today, represented by mountain ranges resulting from the collision of the Pernambuco-Alagoas Massif to the north, with the São

Francisco Craton, to the south, which generated the Sergipano Folded Belt, with a preferential NW-SE direction and vergence to the SW (Van Schmus et al., 1995).

Paleogeographic maps were drawn up to represent the evolution of the deposition of the Carboniferous Batinga Formation. In order to make these maps, the higher areas that still exist today, and represent residual reliefs of this paleotopography, were preserved and slightly expanded. On the other hand, the interpretation of the low areas (valleys) was based on the occurrences of diamictites found in wells and outcrops, which represented the action of glaciers confined to glacial valleys. The distribution of shales, siltstones and sandstones were also used to delimit areas where the glaciolacustrine deposition occurred, either along valleys or in intermountain depressions.

Six paleogeographic-paleoclimatic stages were defined: three glacial (I, III and V), two interglacial (II and IV) and the end of glaciation (VI), each of them associated, respectively, with the previously defined sedimentary sequences.

6.1. Stage I (glacial – Sequence 1: basal Mulungu)

The paleogeographic map representing stage I (glacial; figure 21) had its lower areas, occupied by glaciers, delimited by the occurrences of the basal glacial diamictites (tillites) in the studied section. These diamictites, here referred as basal Mulungu, are found both in wells and outcrops.

The deposition of these diamictites corresponds to a subglacial context, mostly interpreted as lodgment tillites, due to the direct action of glaciers confined to valleys, where deposition occurred during their advance. Some exposed sections suggest that they could also represent frontal moraines, which, in certain contexts, would serve to dam up the meltwater in the form of small lakes, particularly at higher altitudes. Souza-Lima & Farias (2006b) carried out measurements of the major axes of diamictite clasts and noted that they present good coherence in indicating glacial flows, differentiating glacial valleys in NW-SE and NE-SW directions. This methodology was applied to the new sedimentary sections now studied, providing similar directions.

Souza Lima (2017) studied the sedimentary section underlying the Carboniferous sequence, of probable Siluro-Devonian age, called Fm. Karapotó. Based on paleocurrent measurements, they interpreted that the preferential direction of the river system that gave rise to this unit was SW-NE. The main valley of this river, in the paleogeographic interpretation of these authors, was preserved in the reconstructions presented here for the Carboniferous. This valley would have acted as a convergence zone for glacial flow, which would have had its direction, however, opposite to the ancient Siluro-Devonian drainage, as indicated by the paleocurrents measured for the Carboniferous sequence.

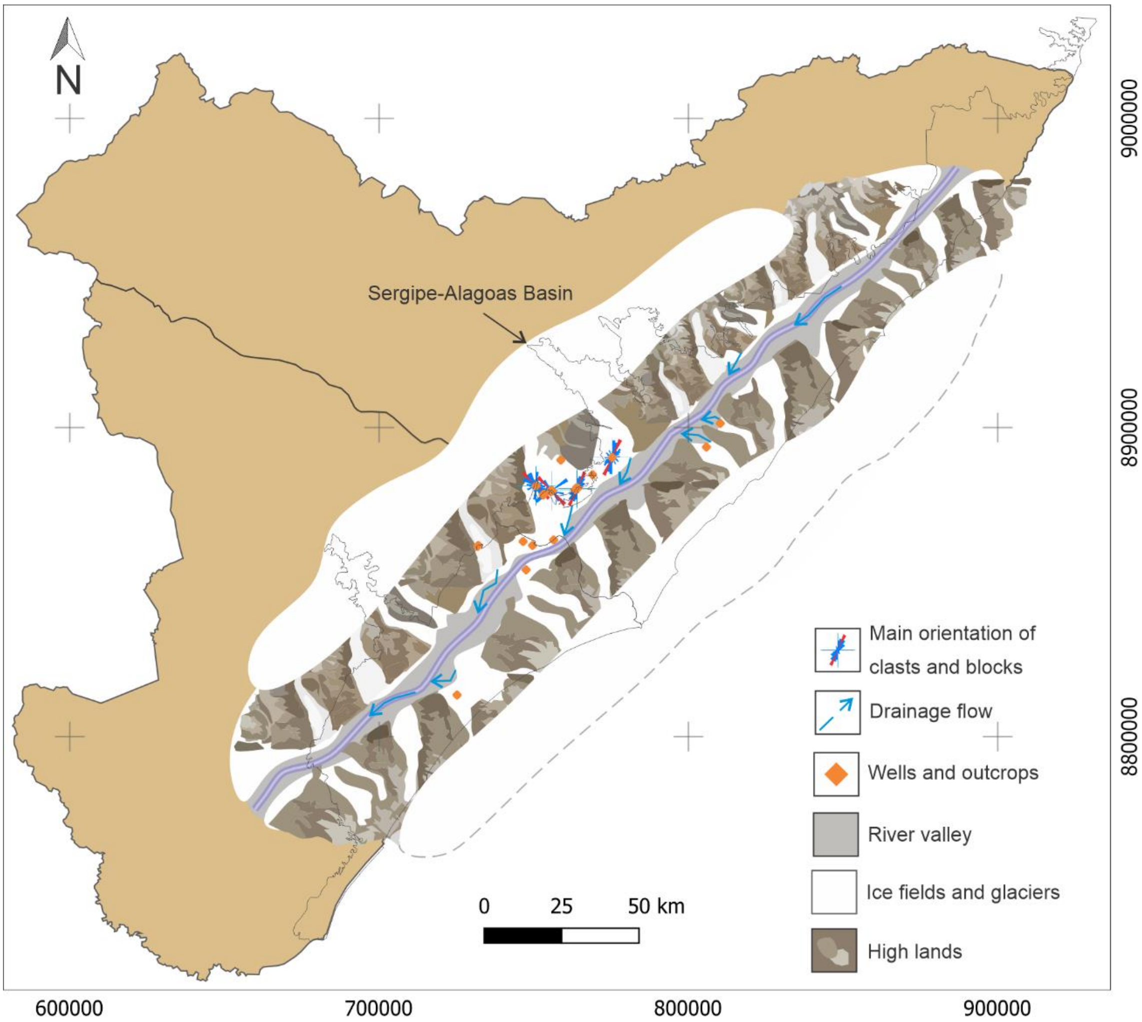

Figure 21: Paleogeographic map at the area of the Sergipe-Alagoas Basin corresponding to the interval of deposition of the diamictites of the basal portion of Batinga Formation, represented by the basal Mulungu Member.

6.2. Stage II (interglacial – Sequence 2, transgressive)

The transgressive Sequence 2 (figure 22) was formed as glaciation decreased, causing ice to melt and consequently the formation of lakes in the valleys, some of which were more continuous. At higher altitudes, mountain lakes (intermontane) formed in small depressions, also fed by gravitational flows from the adjacent higher areas. This sequence is represented in wells and outcrops mainly by shales and siltstones, with a coarsening upward pattern, which had their sediments deposited in a lacustrine context, influenced by small rivers and their deltas.

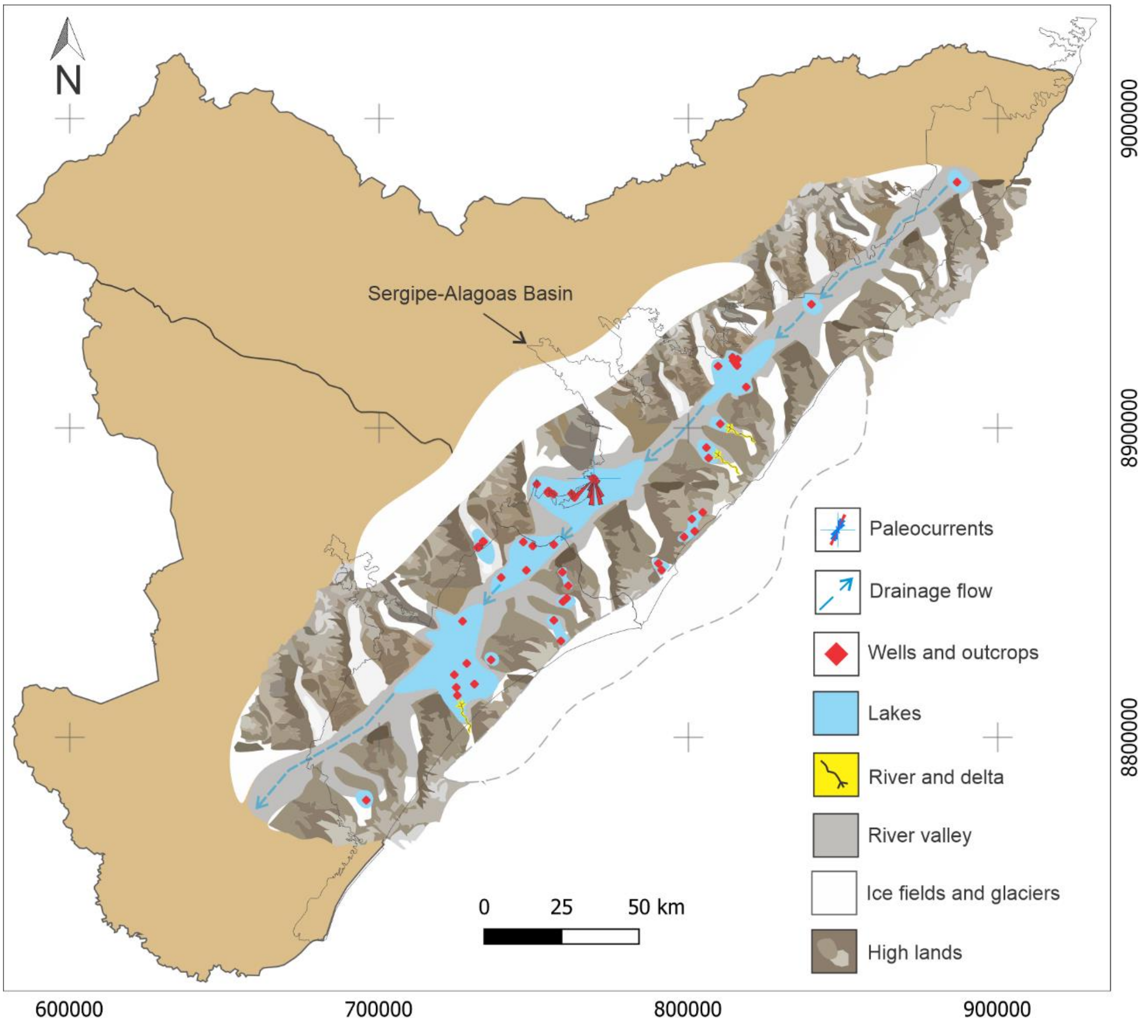

Figure 22: Paleogeographic map at the area of the Sergipe-Alagoas Basin corresponding to the interval of deposition of the rhythmites in sequence 2 (transgressive).

6.3. Stage III (glacial – Sequence 3, regressive)

The regressive Sequence 3 (figure 23) represents a resumption of glaciation and the consequent advance of glaciers and reduction of water bodies. This sequence is represented in the wells and outcrops by shales, siltstones and sandstones, with a coarsening upward pattern, which had their sediments deposited in a lacustrine context, with greater influence from rivers, deltas and debris flows, whose sediments prograded over the lacustrine system.

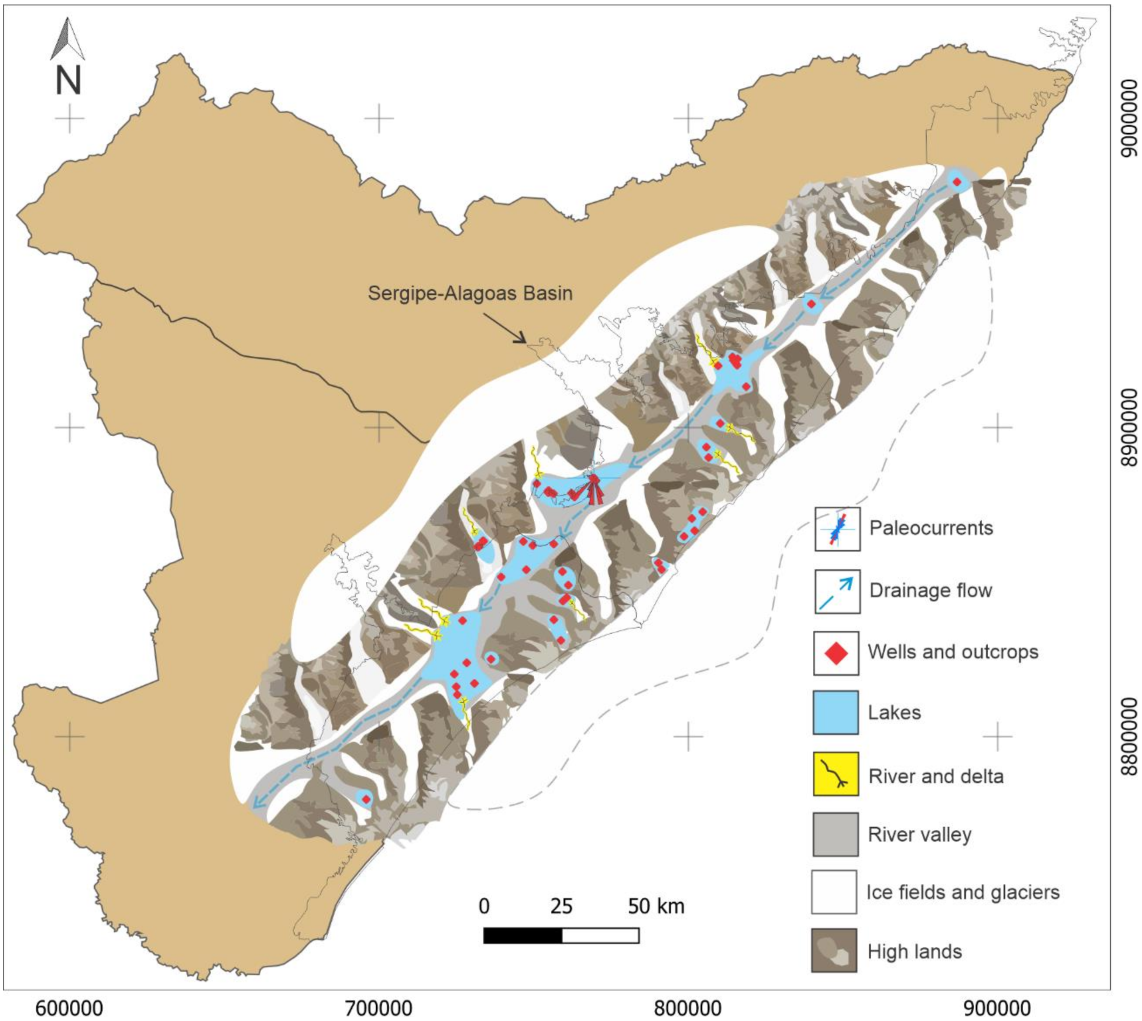

Figure 23: Paleogeographic map at the area of the Sergipe-Alagoas Basin corresponding to the interval of deposition of the rhythmites in sequence 3 (regressive).

6.4. Stage IV (interglacial – Sequence 4, transgressive)

A further decrease in glaciation led to a reduction in ice bodies and an increase in the water levels of the lakes, generating the transgressive sequence 4 (figure 24). These lakes were fed by glaciofluvial systems and gravity flows. This sequence is represented by shales, siltstones and sandstones, which had their sediments deposited in a lacustrine context, influenced by rivers, deltas and debris flows. The southwestern region does not have this sequence preserved, due to later erosion.

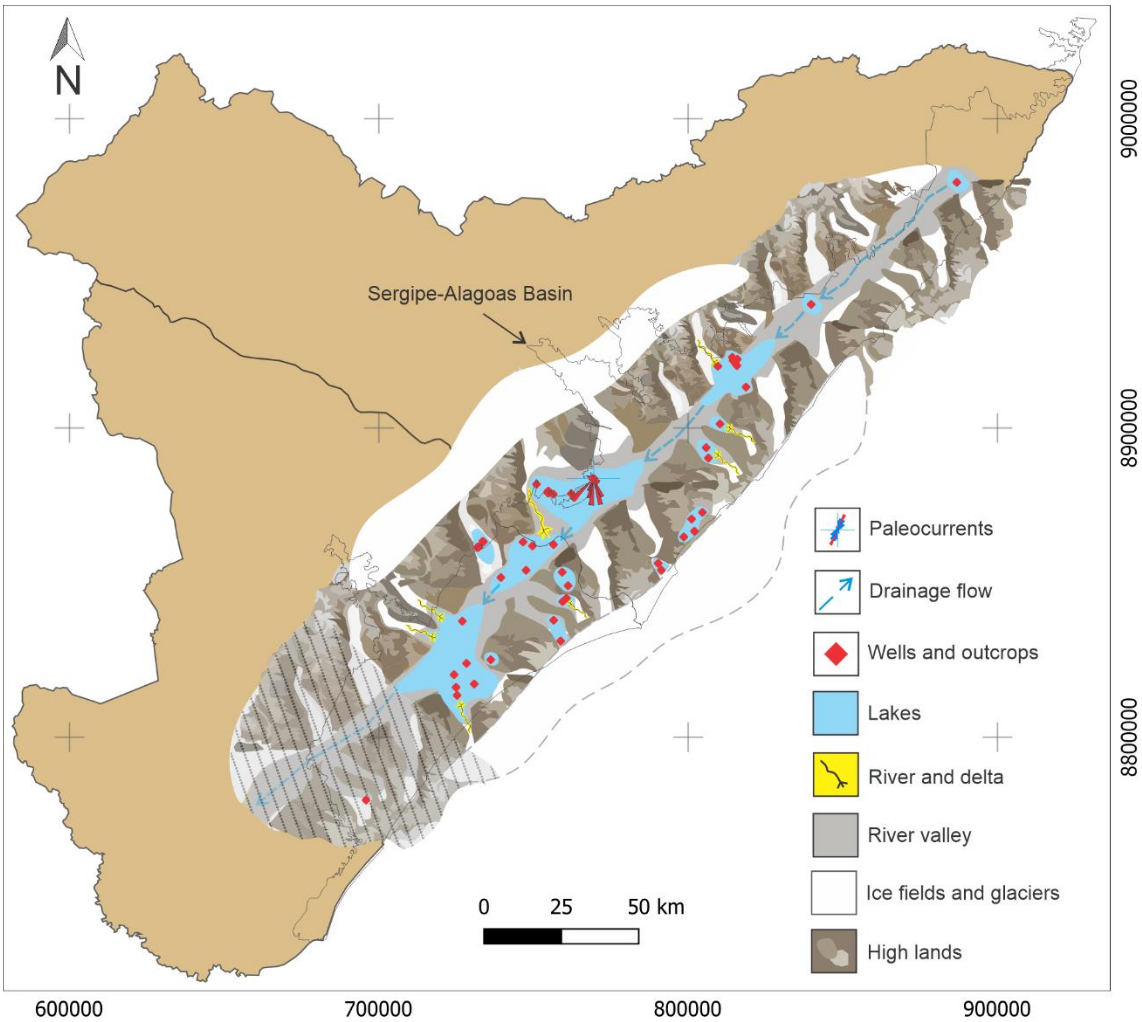

Figure 24: Paleogeographic map at the area of the Sergipe-Alagoas Basin corresponding to the interval of deposition of the rhythmites in sequence 4 (transgressive).

6.5. Stage V (glacial – Sequence 5, regressive)

Sequence 5, regressive (figure 25), occurred as glaciation increased again, causing the glaciers to advance and consequently lowering lake levels. This sequence is represented by shales, siltstones and sandstones, which had their sediments deposited in a lacustrine context, with the influence of rivers, deltas and debris flows, prograding over the lacustrine system. The northeast and southwest regions do not have this sequence preserved, due to later erosion.

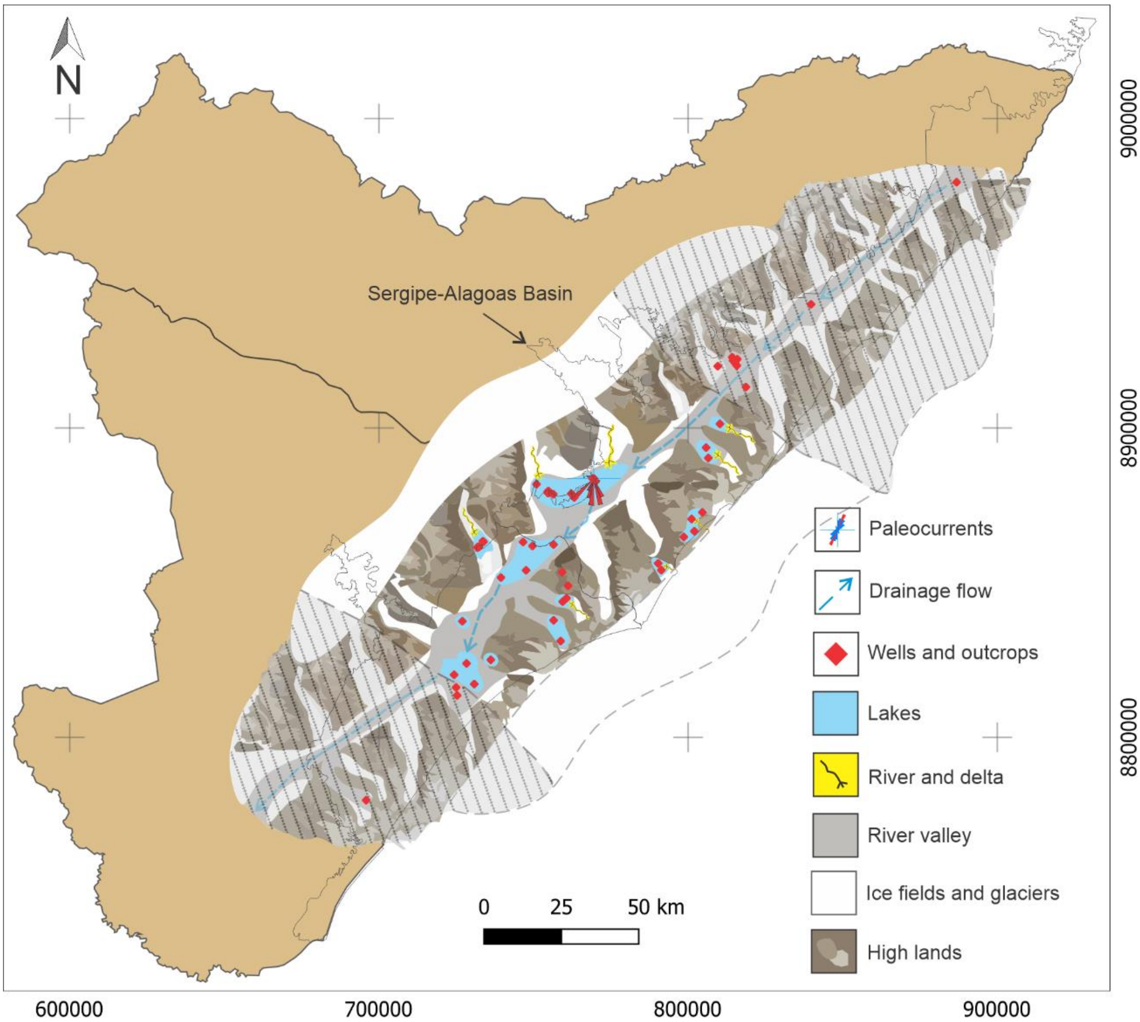

Figure 25: Paleogeographic map at the area of the Sergipe-Alagoas Basin corresponding to the interval of deposition of the rhythmites in sequence 5 (regressive).

6.6. Stage VI (end of glaciation – Sequence 6: upper Mulungu)

Stage VI (figure 26), the last stage defined for the study section, probably characterized by high humidity and moderate temperatures, when the glaciers melted significantly, and the sediments were transported and deposited by thaw currents. At this stage, the deposition of the upper diamictite occurred, corresponding to an episode of rapid resedimentation, mainly due to the reworking of the earlier diamictites, on deltaic fronts inside the lakes. These diamictites are characterized by a high percentage of sandy matrix, with sparser, smaller and rounded clasts, with a less diverse composition than that of the basal diamictite, and the absence of blocks. They also have a carbonate matrix that provides cohesion to the quartz framework, indicating a warmer climate than the previous stages.

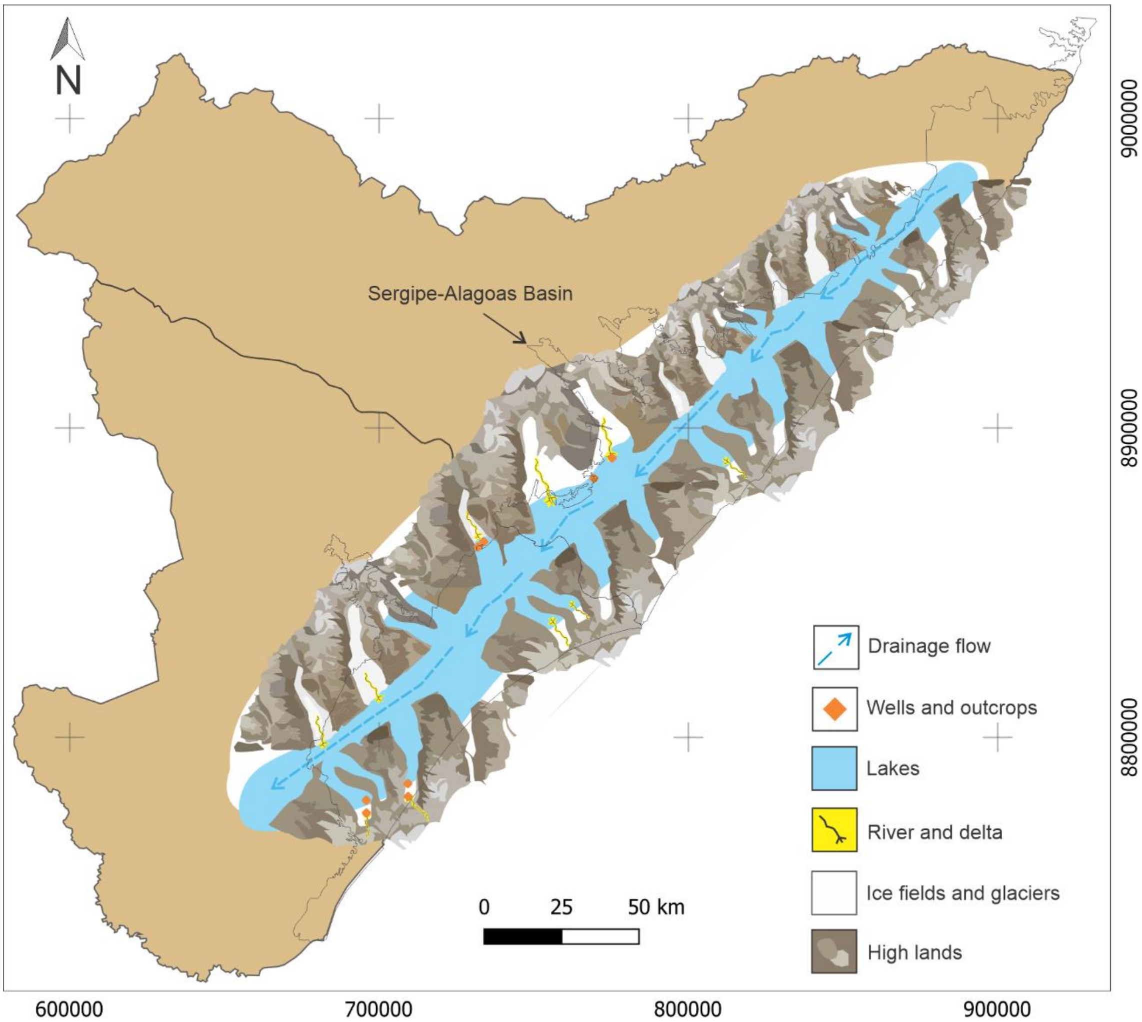

Figure 26: Paleogeographic map at the area of the Sergipe-Alagoas Basin corresponding to the interval of deposition of the diamictites of the upper portion of the Fm. Batinga, represented by the upper Mulungu Member.

7. CARBONIFEROUS PALEOGEOGRAPHY OF CENTRAL GONDWANA

Frakes (1979) suggested that at the apogee of the Permo-Carboniferous glaciation, a huge ice sheet, generated by the union of various ice sheets and ice caps, occupied a large part of Antarctica, southern Africa, Australia, and parts of South America. He identified three phases of glacial activity in the Neopaleozoic, within a single global glacial epoch. The first glacial phase would have started in the Pennsylvanian, with glaciation in high altitude regions, then an Eopermian phase, where continental ice sheets covered large areas of Gondwana and during the late Permian would have decayed and disappeared.

Therefore, the Gondwana glaciation was considered an uninterrupted event throughout the Carboniferous and Permian periods (Frakes et al., 1992).

However, new studies, mainly in South American sedimentary basins, have reported that glacial episodes occurred at specific intervals during these periods (Caputo et al., 2008; Limarino et al., 2014).

Torsvik & Cocks (2011) stated that the central portion of Gondwana was considerably affected by the Permo-Carboniferous glaciation, with different glacial episodes. The geological record of this ice age is distributed throughout the Gondwana continent, as detailed in the synthesis of the correlation between the sedimentary basins presented in this study (figure 5), in the form of erosional features and glacial deposits, which provide important information on paleogeography and paleoclimate. The wide distribution of these deposits and erosional features is mainly related to the drift of Gondwana across the South Pole, reflecting the changes in their palaeolatitudinal position.

The emergence of glaciers in a basin does not have to be associated only with poleward drift, although the displacement of the pole roughly defines the general trajectory of glacial occurrences (Limarino et al., 2014). The glaciations that affected the supercontinent Gondwana requires additional factors to explain their formation, not just paleolatitude.

Recent studies on the evolution of the Neopaleozoic glacial event (Limarino et al., 2014; Rosa, 2015; Vesely et al., 2015) suggested the presence of smaller ice masses (ice caps, ice fields and glaciers valleys) located in regions of high altitude and controlled mainly by topographic conditions and secondarily by climatic conditions. Rosa (2015) also concluded that glacial influence reached approximately 40° latitude when Gondwana was in great part displaced towards the South Pole. This extent is also like that observed today.

Around 310 Ma ago, the South Pole was located east of Antarctica (Torsvik & Cocks, 2011). During this period, the central portion of Gondwana, where the Sergipe-Alagoas Basin is located, was positioned between latitudes 45° S and 30° S, which made it susceptible to glaciation events.

The Sergipano Folded Belt was structured during the Brasiliano cycle (Pan-African orogeny), between 650-500 Ma (Van Schmus et al., 1995) and would probably still be a region of high altitudes during the Carboniferous. This scenario, coupled with a favorable latitudinal position, provided ideal conditions for the formation of glaciers in the Sergipe-Alagoas Basin region, thus promoting glaciation in this central portion of Gondwana.

A paleoclimatic review of the southernmost basins of South America by Limarino et al. (2014) showed some paleoclimatic intervals in the region, ranging from a glacial to a semi-arid stage, along the Visean (Mid Mississippian) - Lopingian (Late Permian). They defined four paleoclimatic stages: glacial, terminal glacial, post-glacial and semi-arid. The glacial stage began at the end of the Visean and extended until the beginning of the Bashkirian (Early Pensilvanian) in almost all the region. During the terminal glacial stage (Bashkirian - Late Cisuralian; Mid-Permian), the glacial centers located to the east remained, while in the western basins the glacial deposits gradually disappeared.

The basal diamictites of the Mulungu Member of the Batinga Formation, although possibly not datable, are probably associated with the glacial stage proposed by Limarino et al. (2014) in South America, i.e., Late Mississippian to Early Pensilvanian. The rhythmites of the Boacica Member are possibly associated with the terminal glacial stage, corroborating the biostratigraphic dating carried out by Dino et al. (2002), who defined the age of this member as Late Carboniferous, probably Westphalian (Late Bashkirian-Moskovian). Like these rhythmites, the upper Mulungu diamictites are also possibly associated with the terminal glacial stage, since they indicate the endmost glaciation in the Sergipe-Alagoas Basin.

The presence of carbonate in the matrix of the upper diamictite suggests that the climate was already relatively warm at the time of deposition. This change in climate is also recorded in several South American basins, whose sedimentation was dominated by fluvial deposits actions alternating with marine transgressions (Limarino et al., 2014). Therefore, the end of the Kasimovian to the beginning of the Permian corresponded to a time interval characterized by seasonally dry climates and a progressive improvement in humidity (López-Gamundí et al., 1992; Limarino et al., 2014).

Recently, Caputo & Santos (2019) suggested that the glacial event in the Sergipe-Alagoas Basin occurred during the Llandoverian (Eosilurian), correlating the glacial diamictites of the Mulungu Member with the glacial diamictites of the Ipu Formation, in the Parnaíba Basin. They considered that the Boacica Member, dating from the Westphalian, would correspond to a globally warmer period, unrelated to a glacial action. However, not only are the paleocurrent directions obtained for the Boacica Member compatible with the alignment directions of the clasts in the Mulungu Member (Souza-Lima & Farias, 2006b and this study), but there are also levels with dropstones within the Boacica Member, denoting glacial processes. In addition, there is a recurrence of diamictites "sensu Mulungu" in the upper part of the Carboniferous section, as visualized on the surface and interpreted in wells, for the first time described in this study. The high-energy conditions of the Mulungu diamictites makes dating this section improbable, so it is inferred that its age is equal to or slightly younger than the Westphalian, the age interpreted for the Boacica Member (Dino et al., 2002). The reconstructions presented by Cao et al. (2017) concluded that glaciation began around 337 Ma (Visean), corroborating the interpretation presented here. Thus, in this study, the interpretation that the Mulungu and Boacica members are genetically associated is maintained.

Evidence of Carboniferous glaciation in the central portion of Gondwana can also be found in the North Tucano Basin, adjacent to Sergipe-Alagoas (Rocha-Campos et al., 2003; Caputo & Santos, 2019). The Carboniferous of this basin, represented by the Curituba Formation, is faciologically very similar to the Batinga Formation of the Sergipe-Alagoas Basin. The study of outcrops of diamictites and sandstones with grooves created by the glacial action helped the improvement of a proposal of the paleogeographic model for this region (figure 27).

The global paleogeographic maps reconstructed by Cao et al. (2017) present paleogeographic information, such as ice sheets, shallow seas, mountains and deep seas, since the Paleozoic, based on paleobiological integrations. These maps were generated from the data of Matthews et al. (2016), which present global tectonic reconstructions with plate boundaries ranging from 410 to 0 Ma.

Evaluating these data in the GPlates software, it was possible to observe the continental drift and the variation of the South Pole throughout the Permo-Carboniferous. As a result, it was observed that, in the South American region, according to the interpretations presented, the Carboniferous glaciation began around 337 Ma, in its central portion, extending to the center east until approximately 320 Ma. Since then, the Gondwana moved away from the South Pole, and the ice sheets and glaciers began to thaw. Around 290 Ma ago, glaciation would have diminished considerably in these regions (figure 28). However, the 337 Ma map shows little extent of glaciation on the current area of South American continent, which would be expected, given it was positioned at an approximately 45-50º S latitude and there are glacial records in some basins in this region (figure 5). As a result, the probable limit reached by glaciation during the ages presented has been highlighted with a dashed line.

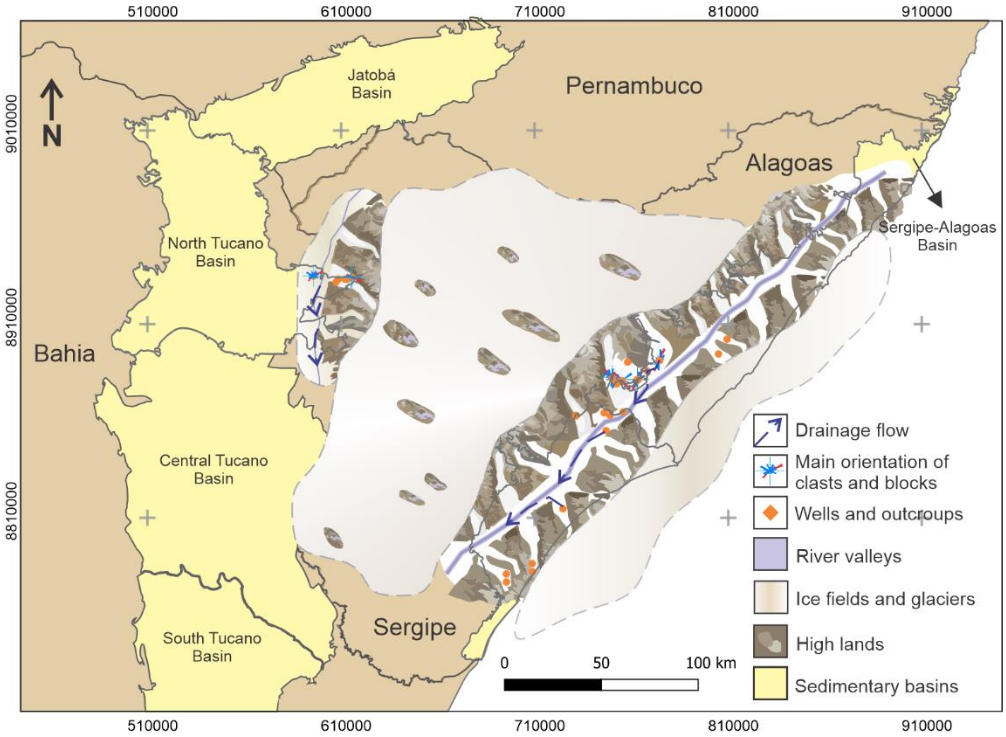

Figure 27: Paleogeographic map for the Carboniferous at the area of the Sergipe-Alagoas Basin expanded to the North Tucano Basin.

Considering the relative age obtained for the Batinga Formation, the global paleogeographic map proposed for the 310 Ma was extracted from these reconstructions. This age is a key to understanding this part of the Carboniferous, as it presents records for almost all related basins. Thus, the extracted map served as the basis for incorporating the stratigraphic data from the various sedimentary basins shown in figure 5. Cao et al. (2017) interpreted ice sheets in the Sanfranciscana and Paraná in Brazil, as well as a shallow sea in the Amazon and Solimões. In other Brazilian basins, including Sergipe-Alagoas and Tucano Norte, only continental masses were interpreted.

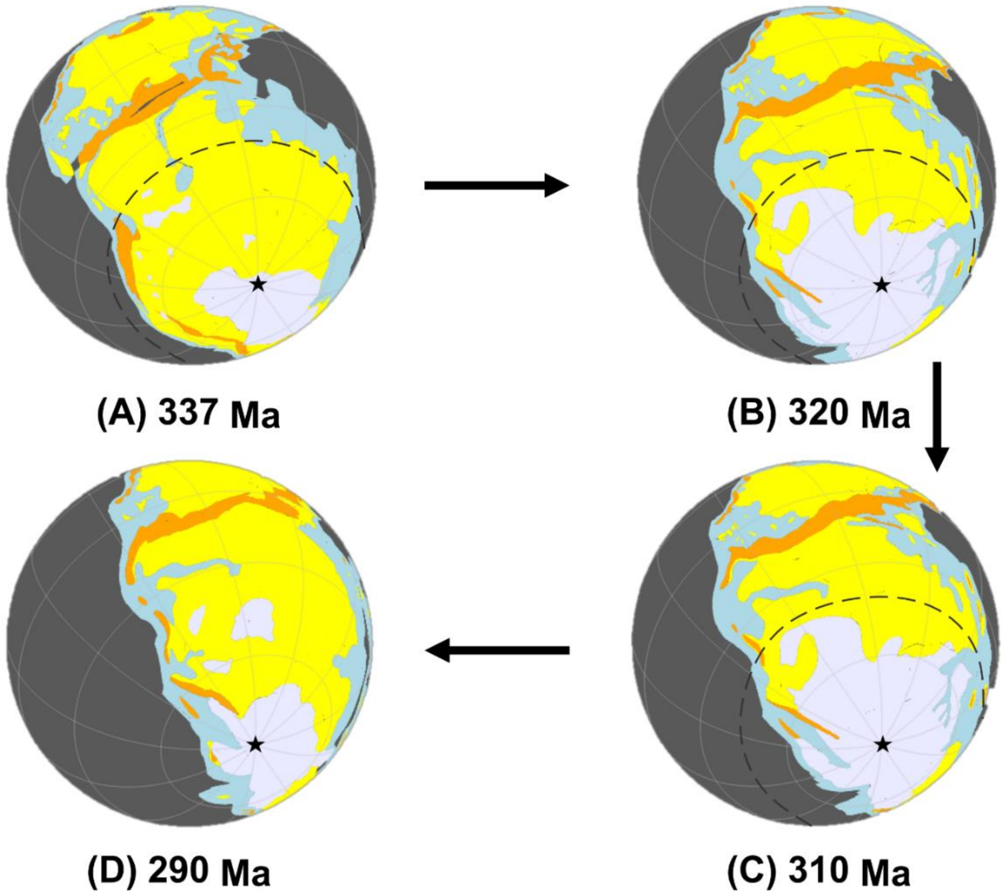

Figure 28: Series of schematic maps illustrating the continental drift around the south pole (star) between 337 and 290 Ma. The dashed lines indicate the possible range for glaciations as currently observed (40° S), similar to the interpretation by Rosa (2015). (A) Beginning of glaciation on the south Gondwana continent. (B) Gondwana continent moves away from the south pole, marking the beginning of the glacial thaw. (C) Reference map used in this study. (D) End of glaciation in most of Gondwana, leaving the continent subject to a warmer climate. Maps extracted and modified from Cao et al. (2017), view: 3D orthographic.

In this way, it was possible to delimit ice sheets positioned around the latitude 40° S, including the Sergipe-Alagoas and North Tucano basins, with the south pole in east Antarctica. In addition, information about other South American basins was included (figure 29), using data from the stratigraphic charts and literature (Caputo, 1984; Brito et al., 1985; Eiras et al., 1994; Rocha-Campos et al., 1997; Dino et al., 2002; Limarino et al., 2002; Bahia et al., 2006; Vesely and Assine, 2006; Costa et al., 2007; Campos Neto et al., 2007; Cunha et al., 2007;

Zalán and Silva, 2007; Souza-Lima et al., 2017; Dino et al., 2018; Caputo and Santos, 2019; Ezpeleta et al., 2020).

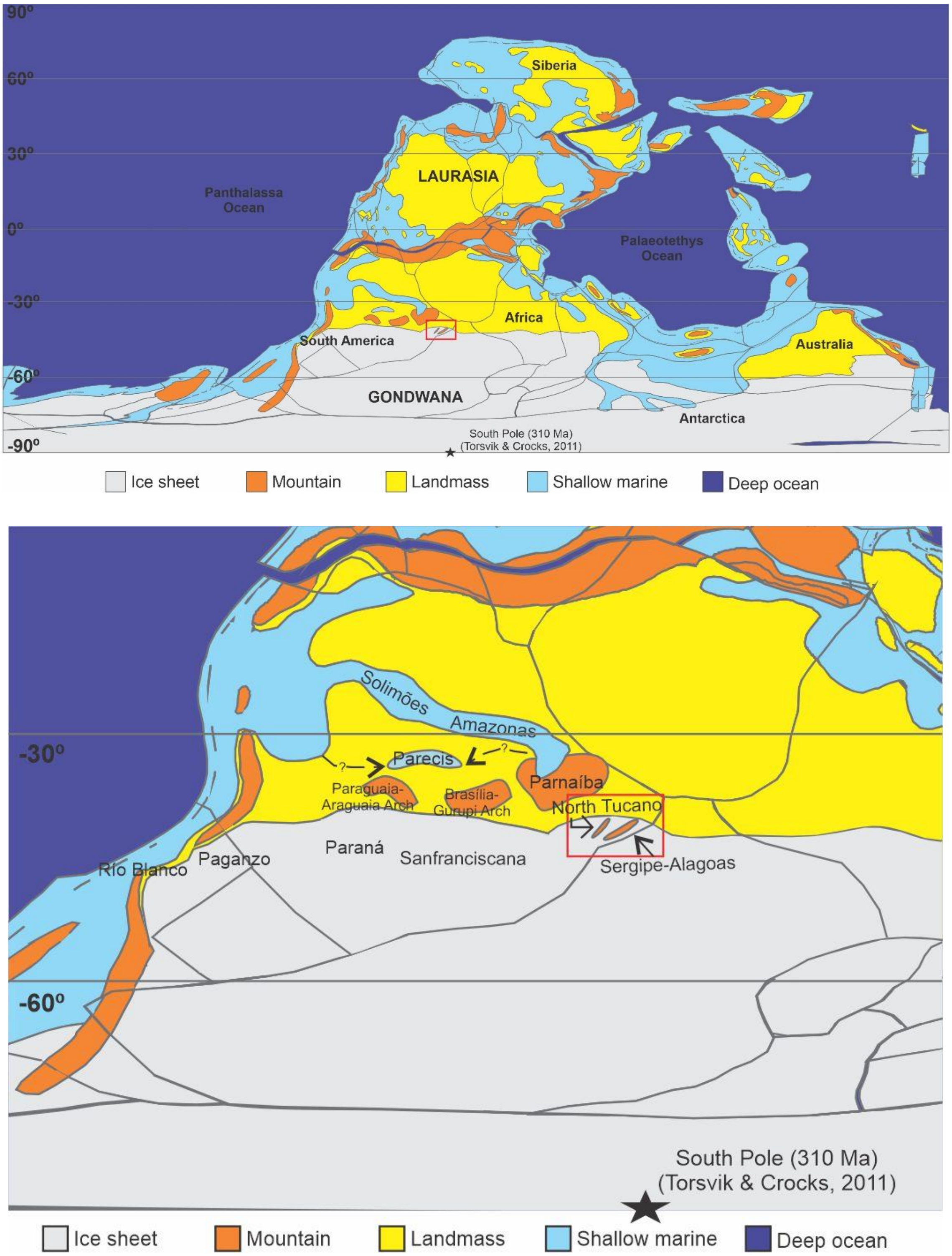

Figure 29: Paleogeographic reconstruction of Central Gondwana and extended to South America at around 310 Ma, with data updated in this study for the Brazilian sedimentary basins. The Sergipe-Alagoas and Tucano Norte basins are highlighted by the red rectangle. Map extracted and modified from Cao et al., 2017, view: rectangular.

8. CONCLUSIONS

The glacial and interglacial intervals that occurred during the Carboniferous, recorded in the Sergipe-Alagoas Basin, in the central part of Gondwana, consist of glaciolacustrine systems with increasing and decreasing glacial activity. Six stages have been identified that characterize the deposition of this section. The first stage represents a glacial event, with the deposition of diamictites, followed by transgressive (interglacial) and regressive (glacial) stages, with the deposition of shales, siltstones and sandstones, characteristic of a lacustrine system, influenced by rivers, deltas and debris flows. The last stage represents a recurrence of diamictites that apparently resulted from the reworking of deposits from the previous stages, after the significant melting of the glaciers, where the sediments were transported and deposited by a fluvial-deltaic system.

The history of the Batinga Formation lakes started with a transgression caused by glacial thawing, with the deposition of silt and clay by hyperpycnal flows. Over time, glaciers advanced and retreated, influencing the rise and fall of water levels, related to the changing of glacial and interglacial periods. An increase in the contribution of coarser sediments brought to the lakes by fluvial processes generated the sandiest section at the top of the carboniferous section, demonstrating the progressive increase in melting, as well as aerial gravitational deposits resulting from erosion of slopes probably represented by Siluro-Devonian rocks of the Karapotó Formation.

The Carboniferous paleogeography interpreted for the central region of Gondwana would consist of chains of Brasiliano (Pan-African orogeny) mountains that acted as basin boundaries. Glacial valleys between these mountains were delimited by diamictites. For this time, these valleys would accommodate glaciers, while in warmer periods they could be occupied by more or less expressive lakes. Both had their outfalls in a main valley running NE-SW, delineated and inherited by the action of past fluvial systems.

In the central portion of Gondwana, the glacial events possibly began approximately from the Visean to the beginning of the Baskirian (Limarino et al., 2014; Cao et al., 2017), corresponding to stage I (basal Mulungu Member). Throughout the period from the Bashkirian to the end of the Gzhelian, the glacial centers gradually disappeared, but progressively earlier for the basins furthest from the pole, marking the beginning of the thawing process. During the Westphalian, sedimentation occurred for most of the carboniferous section, covering the entire Boacica Member, as well as the upper diamictite. From the Cisuralian onwards, the central region of Gondwana was at progressively lower latitudes, subjected to hot and dry climates, as evidenced by the rocks of the Aracaré Formation in the Sergipe-Alagoas Basin and their equivalents in adjacent coetaneous basins, which mark the definitive end of glaciations in this portion of Gondwana.

9. ACKNOWLEDGMENTS

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10. BIBLIOGRAPHICAL REFERENCES

ALMEIDA, F. F. M., HASUI, Y., BRITO NEVES, B. B., FUCK, R. A. 1977. Províncias estruturais brasileiras. In: VIII Simpósio de Geologia do Nordeste, Campina Grande, 363-391.

AQUINO, G. G., LANA, M. C. 1990. Exploração na bacia de Sergipe-Alagoas: “o estado da arte”. Boletim de Geociências da PETROBRAS, 4 (1): 75-84.

BAHIA, R. B. C., MARTINS-NETO, M. A., BARBOSA, M. S. C. & PEDREIRA, A. J. 2006. Revisão estratigráfica da bacia dos Parecis - Amazônia. Revista Brasileira de Geociências, 36 (4): 692-703.

BENDER, F. 1957. North-east Sergipe Coastal Basin: progress report of Sergipe geological field party TG-6. Relatório interno da PETROBRAS, 45, 28p., 5 mapas.

BRITO, I. M., QUADROS, L. P., CARDOSO, T. R. M. 1985. A idade das formações Batinga e Aracaré da bacia de Sergipe-Alagoas. Anais da Academia Brasileira de Ciências, 57(2): 209-215.

CAMPOS NETO, O. P. A., SOUZA-LIMA, W., CRUZ, F. E. G. 2007. Bacia de Sergipe-Alagoas. Boletim de Geociências da PETROBRAS, 15 (2): 405-415.

CAO, W., ZAHIROVIC, S., FLAMENT, N., WILLIAMS, S., GOLONKA, J., MULLER, R. D. 2017. Improving global paleogeography since the late Paleozoic using paleobiology. Biogeosciences, 14: 5425–5439.

CAPUTO, M. V. 1984. Stratigraphy, tectonics, paleoclimatology and paleogeography of northern basins of Brazil. Dissertação de doutorado, Universidade da California, Santa Barbara, 586p.

CAPUTO M.V. & CROWELL J.C. 1985. Migration of glacial centers across Gondwana during Paleozoic Era. GSA Bulletin, 96: 1020–1036.

CAPUTO, M.V., GONCALVES DE MELO, J.H., STREEL, M., ISBELL, J.L., 2008. Late Devonian and Early Carboniferous glacial records of South America. In: Fielding, C.R., Frank, T. D., Isbell, J. L. (Eds.), Resolving the Late Paleozoic Age in Time and Space: Geological Society of America, 441: 97–114.

CAPUTO, M. V. & SANTOS, R. O. B. 2019. Stratigraphy and ages of four Early Silurian through Late Devonian, Early and Middle Mississippian glaciation events in the Parnaíba Basin and adjacent areas, NE Brazil. Earth-Science Reviews, 207: 103,002.

COHEN, K. M., FINNEY, S. C., GIBBARD, P. L., FAN, J. X. (2013; updated) The ICS International Chronostratigraphic Chart. Episodes 36: 199–204.

COSTA, I. P., BUENO, G. V., MILHOMEM, P. S., SILVA, H. S.R.L., KOSIN, M. D. 2007. Sub-bacia de Tucano Norte e Bacia de Jatobá. Boletim de Geociências da PETROBRAS, 15(2): 445-453.

CROWELL J.C. & FRAKES L.A. 1975. The Late Paleozoic Glaciation. Gondwana Geology, 3: 313–331.

CUNHA, P.R.C., MELO, J. H. G., SILVA, O. B. 2007. Bacia do Amazonas. Boletim de Geociências da PETROBRAS, 15(2): 227-251.

DINO, R., ANTONIOLI, L., SEVERIANO RIBEIRO, H.J.P., CONCEIÇÃO, U.C.F.F. DE B. 2018. Palinoflora eopermiana da Formação Santa Brígida (Membro Ingá) – borda leste da sub-bacia de Tucano Norte. In: Congresso Brasileiro de Geologia, 49, Sociedade Brasileira de Geologia, Boletim de Resumos.

DINO, R., ANTONIOLI, L., BERGAMASCHI, S., RODRIGUES, M. A. C. 2002. Palinologia de depósitos aflorantes da Formação Batinga, Membro Boacica, Carbonífero superior da bacia de Sergipe. In: 41º Congresso Brasileiro de Geologia, Sociedade Brasileira de Geologia, Boletim de Resumos, p.659.

EIRAS, J.F., BECKER, C.R., SOUZA, E.M., GONZAGA, J.E.F., SILVA, L.M., DANIEL, L.M.F., MATSUDA, N.S., FEIJÓ, F.J. 1994. Bacia do Solimões. Boletim de Geociências da PETROBRAS, 8(1): 17-45.

EYLES, N., EYLES, C. H., MIALL, A. D. 1983. Lithofacies types and vertical profile models; an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences. Sedimentology. 30(3): 393–410.

EZPELETA, M., RUSTÁN, J. J., BALSEIRO, D., DÁVILA, F. M., DAHLQUIST, J. A., VACCARI, N. E., STERREN, A. F., PRESTIANNI, C., CISTERNA, G. A. BASEI, M. 2020. Glaciomarine sequence stratigraphy in the Mississippian Río Blanco Basin, Argentina, southwestern Gondwana. Basin analysis and palaeoclimatic implications for the Late Paleozoic Ice Age during the Tournaisian. Journal of the Geological Society, 177 (6): 1107–1128.

FALKENHEIN, F. U. H. 1986. Análise da bacia de Sergipe-Alagoas. PETROBRAS/DEPEX/CENPES. Relatório interno da PETROBRAS, p. 210, 9 volumes com mapas.

FARIAS, R. M. 2013. Caracterização litoestratigráfica e paleontológica do Membro Boacica da Formação Batinga, Neocarbonífero da Bacia de Sergipe-Alagoas. Dissertação de Mestrado, Universidade Federal de Sergipe, São Cristóvão - SE, 98p.

FRAKES, L.A. 1979. Climates throughout geologic time. Elsevier, Amsterdam, 310p.

FRAKES, L.A., FRANCIS, J.E., SYKTUS, J.I. 1992. Climate modes of the Phanerozoic. The History of the Earth’s climate over the past 600 million years. Cambridge University Press, 271p.

ISBELL, J. L., MILLER, M. F., WOLFE, K. L., LENAKER, P. A. 2003. Timing of late Paleozoic Glaciation in Gondwana: Was glaciation responsible for the development of northern hemisphere cyclothems? In: Chan M.A., Archer A.W. (eds) Extreme depositional environments: Mega end members in geologic time. GSA Special Paper, 370: 5–24.

LIMARINO, C. O. CÉSARI, S. N. NET, L. I. MARENSSI, S. A. GUTIERREZ, R. P., TRIPALDI, A. 2002. The Upper Carboniferous postglacial transgression in the Paganzo and Río Blanco basins (northwestern Argentina): facies and stratigraphic significance. Journal of South American Earth Sciences, 15(4): 445–460.

LIMARINO, C. O., CÉSARI, S. N., SPALLETTI, L. A., TABOADA, A. C., ISBELL, J. L. GEUNA, S., GULBRANSON, E. L. 2014. A paleoclimatic review of southern South America during the late Paleozoic: A record from icehouse to extreme greenhouse conditions. Gondwana Research, 25(4): 1396–1421.

LÓPEZ-GAMUNDÍ, O. R., LIMARINO, C. O., CÉSARI, S. N. 1992. Late Paleozoic paleoclimatology of central west Argentina. Palaeogeography, Palaeoclimatology, Palaeoecology, 91: 305–329.

MATTHEWS, K. J., MALONEY, K. T., ZAHIROVIC, S., WILLIAMS, S. E., SETON, M., MÜLLER, R. D. 2016. Global plate boundary evolution and kinematics since the late Paleozoic, Global Planet. Change, 146: 226–250.

MEYERS, J. B., ROSENDAHL, B. R., GROSCHEL-BECKER, H., AUSTIN Jr, J. A. & RONA, P. A. 1996. Deep penetrating MCS imaging of the rift-to-drift transition, offshore Douala and North Gabon basins, West Africa. Marine and Petroleum Geology, 13(7): 791–835.

MIALL, A. D. 1996. The Geology of Fluvial Deposits. Sedimentary Facies, Basin Analysis, and Petroleum Geology. Geological Magazine, 134 (3): 409–421.

MOTTIN, T. E. & VESSELY, F. F. 2021. Formação Taciba: última manifestação glacial no Paraná. Boletim Paranaense de Geociências, 78: 65-82.

OLIVEIRA, A. I. 1943. Geologia de Sergipe. Mineração e Metalurgia, 16p., 15 estampas, 1 mapa.

ROCHA-CAMPOS, A. C., CRUZ, F. E., SATO, P. E. S., SAITO, M. M. 1997. Late Paleozoic glacial and floating ice striated surfaces in northeastern Brazil. Academia Brasileira de Ciências, 69: 2.

ROCHA-CAMPOS, A. C., SANTOS, P. R. DOS, SALVETTI, R. A. P, 2003. Iceberg scours and associated subglacial furrows and striae on sandstones of the Late Paleozoic Curituba Formation, NE Brazil. Latinamerican Congress of Sedimentology, 3, Museu Paraense Emilio Goeldi. Universidade Federal do Pará. Abstract Book, p. 142–144.

ROSA, E. L. M. 2015. Paleogeografia da Era Glacial Neopaleozoica na porção ocidental do Gondwana: resgate e análise crítica dos dados existentes. Trabalho de Conclusão de Curso, Universidade Federal do Paraná, Curitiba - PR, 77p.

ROSA, E. L. M. & ISBELL, J. L. 2021. Late Paleozoic Glaciation. In: Alderton D., Elias S.A. (eds.). Encyclopedia of Geology 2nd edition, Elsevier, p. 534–545.

ROWLEY, D. B., RAYMOND, A., PARRISH, J. T., LOTTES, A. L., SCOTESE, C. R., ZIEGLER, A. M. 1985. Carboniferous paleogeographic, phytogeographic, and paleoclimatic reconstructions. International Journal of Coal Geology, 5: 1–2.

SCHALLER, H. 1970. Revisão estratigráfica da Bacia de Sergipe-Alagoas. Boletim técnico da PETROBRAS, 12 (1): 21–86.

SOUZA-LIMA, W. 2006a. Litoestratigrafia e evolução tectono-sedimentar da bacia de Sergipe-Alagoas – Introdução Phoenix, 89: 1-10.

SOUZA-LIMA, W. 2006b. Litoestratigrafia e evolução tectono-sedimentar da bacia de Sergipe-Alagoas – O Paleozoico: considerações paleogeográficas. Phoenix, 92: 1–4.

SOUZA-LIMA, W. & FARIAS, R. M. 2006a. Litoestratigrafia e evolução tectono-sedimentar da bacia de Sergipe-Alagoas – O Paleozóico: a sequência carbonífera (I). Phoenix, 95: 1–4.

SOUZA-LIMA, W. & FARIAS, R. M. 2006b. Litoestratigrafia e evolução tectono-sedimentar da bacia de Sergipe-Alagoas – O Paleozóico: a sequência carbonífera (II). Phoenix, 96: 1-6.

SOUZA-LIMA, W., ANDRADE, E. DE J., BENGTSON, P. & GALM, P. C. 2002. A bacia de Sergipe-Alagoas: evolução geológica, estratigrafia e conteúdo fóssil. Fundação Paleontológica Phoenix, Aracaju, edição especial, 34p.

SOUZA-LIMA, W., BORBA, C., RANCAN, C.C., CANGUSSU, L.P., COSTA, M.N.C., SANTOS, M.R.F.M., RIBAS, N., PIERINI, C., BEZERRA, C.P.V., 2017. Formação Karapotó – uma nova unidade estratigráfica paleozoica na Bacia de Sergipe-Alagoas. Boletim de Geociências da PETROBRAS, 22 : 83-112.

STAMPFLI, G.M., HOCHARD, C., VÉRARD, C., WILHEM, C., VONRAUMER J. 2013. The formation of Pangea. Tectonophysics, 593: 1–19.

TORSVIK, H. T. & COCKS, L. R. M. 2011. The Palaeozoic palaeogeography of central Gondwana. The Geological Society, London, Special Publications, v. 357: 137–166.

VAN SCHMUS, W.R., DE BRITO NEVES, B.B., HACKSPACHER, P., BABINSKI, M., 1995. UPb and SmNd geochronologic studies of the eastern Borborema Province, Northeastern Brazil: initial conclusions, Journal of South American Earth Sciences, 8: 267–288.

VESELY, F. F., TRZASKOS, B., KIPPER, F., ASSINE, M. L., SOUZA, P. A. 2015. Sedimentary record of a fluctuating ice margin from the Pennsylvanian of western Gondwana: Paraná Basin, southern Brazil. Sedimentary Geology, 326: 45–63.

VESELY, F. F. & ASSINE, M. L. 2006. Deglaciation sequences in the Permo-Carboniferous Itararé Group, Paraná Basin, southern Brazil. Journal of South American Earth Sciences, 22: 156–168.

ZALÁN, P. V., SILVA, P. C. R. 2007. Bacia do São Francisco. Boletim de Goeciências da PETROBRAS, 15(2): 561-571.

ZIEGLER, A. M., SCOTESE, C. R., MCKERROW, W. S., JOHNSON, M. E., BAMBACH, R. K. 1979. Paleozoic paleogeography. Earth Planet, 7: 473–502.

CAPÍTULO 03: CONCLUSÕES

CONCLUSÕES

A bacia de Sergipe-Alagoas apresenta feições geológicas importantes para a compreensão dos processos sedimentares que ocorreram durante o Carbonífero, pois registra intervalos glaciais e interglaciais que ocorreram na porção central do Gondwana durante este período. Este registro está representado na bacia pela Formação Batinga, que teve sua deposição associada à seis estágios paleoclimáticos: o primeiro estágio representa um evento glacial, com deposição de diamictitos, seguido por estágios transgressivos (interglaciais) e regressivos (glaciais), com deposição de folhelhos, siltitos e arenitos, característicos de um sistema lacustre, com influência de rios, deltas e fluxo de detritos. O último estágio representa uma ocorrência de diamictitos que aparentemente foram resultantes do retrabalhamento de depósitos dos estágios anteriores, após o degelo significativo das geleiras, onde os sedimentos foram transportados e depositados por um sistema flúvio-deltaico com influência glacial.

A paleogeografia carbonífera interpretada para a região central do Gondwana consistiria em cadeias de montanhas brasilianas que agiram como limitadoras das bacias. Vales glaciais, entre essas montanhas, foram delimitados pelos diamictitos encontrados em poços e afloramentos. Por ora, esses vales acomodariam geleiras, enquanto, em períodos mais quentes, poderiam ser ocupadas por lagos mais ou menos expressivos. Ambos tiveram seus deságues em um vale principal de direção NE-SW, delineado pela ação de sistemas fluviais pretéritos.

Na porção central do Gondwana, é provável que os eventos glaciais tenham tido início aproximadamente do Viseano ao início do Baskiriano, conforme proposto por Limarino *et al*. (2014) e Cao *et al*. (2017), correspondendo ao estágio I (Membro Mulungu basal). Ao longo do período que abrange o Bashkiriano até o final do Gzheliano, os centros glaciais gradualmente desapareceram, porém de forma progressivamente mais cedo para as bacias mais afastadas de polo, marcando o início do processo de degelo. Durante o Westphaliano teriam sido depositados os sedimentos que abrangem as quatro sequências preservadas no Membro Boacica (estágios II a V) e a porção superior da unidade, Membro Mulungu superior (estágio VI), refletindo o degelo total. A partir do Cisuraliano, a região central do Gondwana encontrava-se a latitudes progressivamente menores, submetidos a climas quentes e secos, como evidenciado pelas rochas da Formação Aracaré na bacia de Sergipe-Alagoas e suas equivalentes nas bacias coetâneas adjacentes.

ANEXOS

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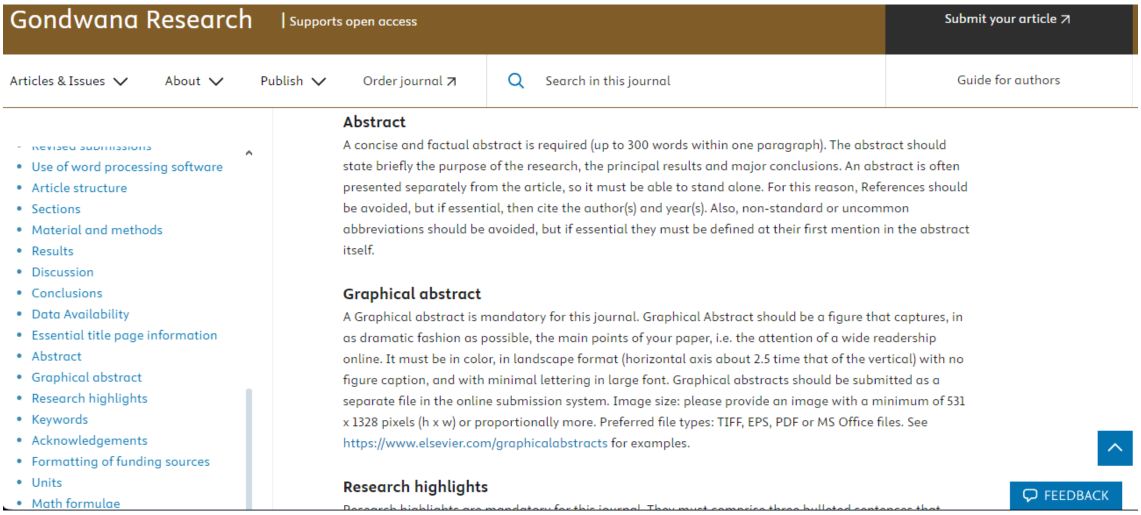
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Abstract

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Graphical abstract

A Graphical abstract is mandatory for this journal. Graphical Abstract should be a figure that captures, in as dramatic fashion as possible, the main points of your paper, i.e. the attention of a wide readership online. It must be in color, in landscape format (horizontal axis about 2.5 time that of the vertical) with no figure caption, and with minimal lettering in large font. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: please provide an image with a minimum of 531 x 1328 pixels (h x w) or proportionally more. Preferred file types: TIFF, EPS, PDF or MS Office files. See https://www.elsevier.com/graphicalabstracts for examples.

Research highlights

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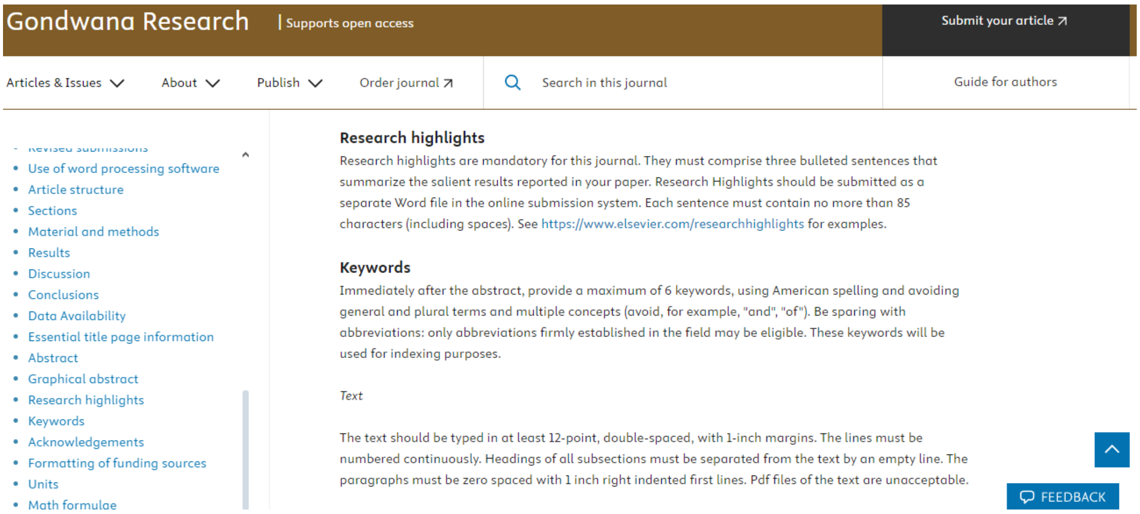

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Research highlights

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Keywords

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Text

The text should be typed in at least 12-point, double-spaced, with 1-inch margins. The lines must be numbered continuously. Headings of all subsections must be separated from the text by an empty line. The paragraphs must be zero spaced with 1 inch right indented first lines. Pdf files of the text are unacceptable.

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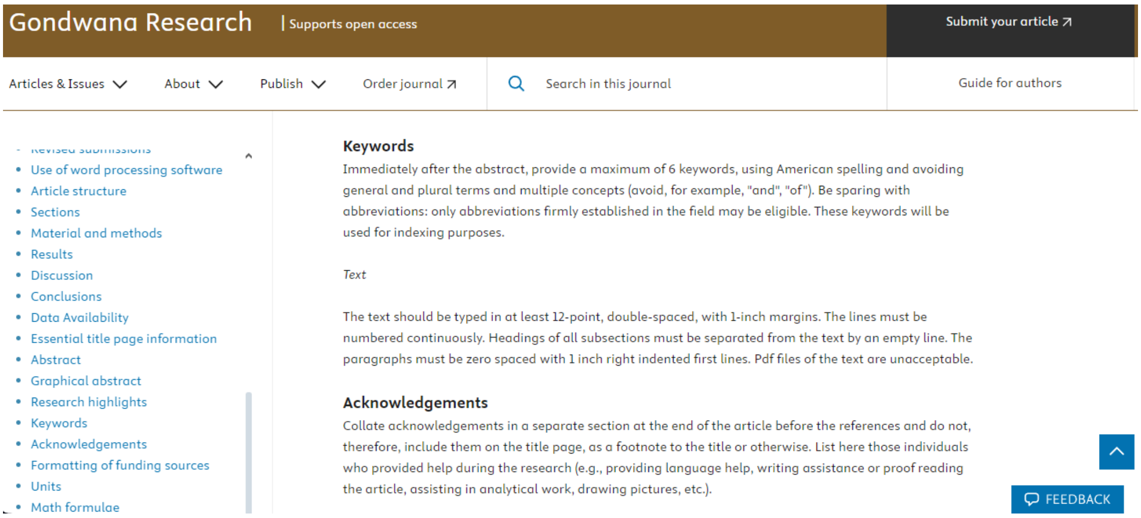

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Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, assisting in analytical work, drawing pictures, etc.).

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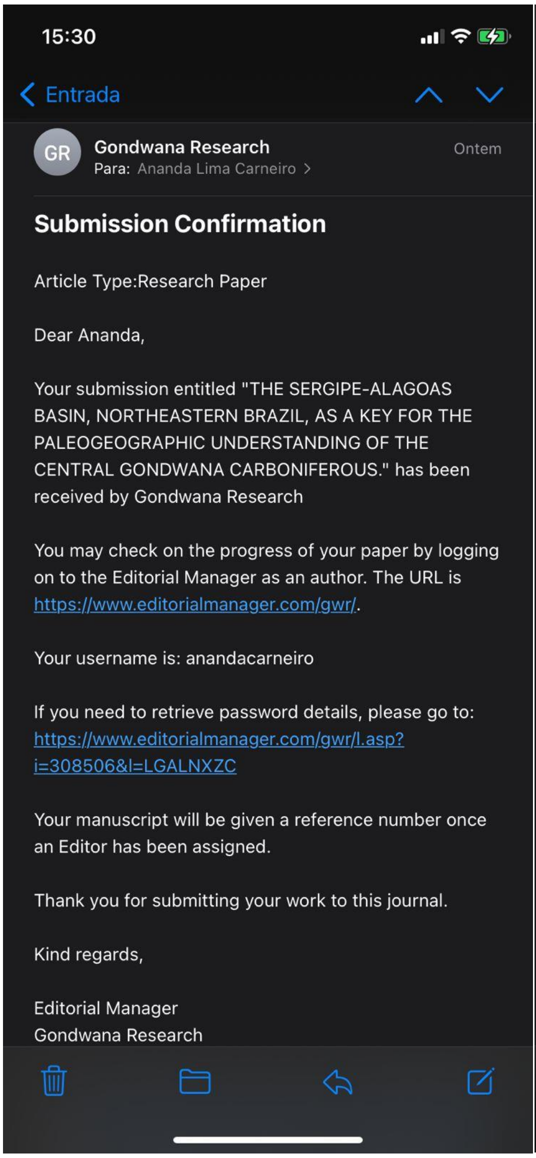

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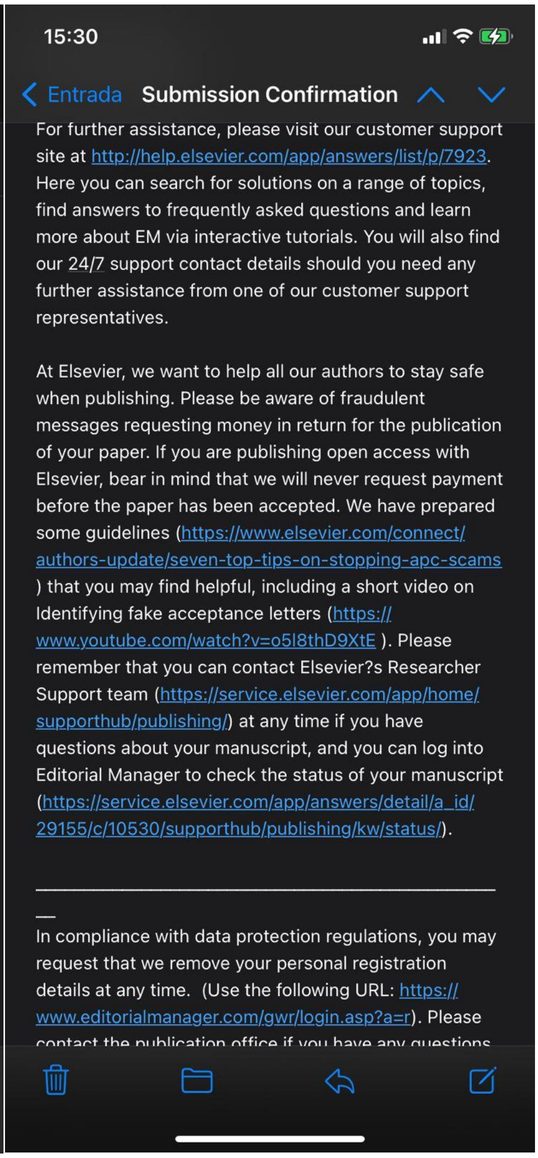

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POÇOS E AFLORAMENTOS	UTM N	UTM E	BOA	MUL	KAR	EMB	ESP_BOA	ESP_MUL_S	ESP_MUL_B	ESP_BAT	S1_DIA	S1_ARN	S1_SLT	S1_FLH	S1_TOTAL	S2_DIA	S2_ARN	S2_SLT	S2_FLH	S2_TOTAL	S3_DIA	S3_ARN	S3_SLT	S3_FLH	S3_TOTAL	S4_DIA	S4_ARN	S4_SLT	S4_FLH	S4_TOTAL
4ATS 0014 SE	8781966	709619	-1	-2530	-1	-2538	0	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AG 0001 SE	8818014	730863	-1625	-1	-1	-1716	91	0	0	91	0	1.168	0	6.737	7.905	0	7.007	12.513	15.183	34.703	0	2.819	18.067	15.578	36.464	0	3.027	2.111	7.233	12.371
BAR 0001 AL	8873253	804279	-598	-1	-625	-636	27	0	0	27	0	0	5.624	3.184	8.808	0	0	7.324	9.348	16.672	0	0	4.233	2.386	6.619	0	0	0	0	0
BB 0001 AL	8865332	798294	-848	-1	-941	-984	93	0	0	93	0	0	0	2.669	2.669	0	0	0	7.677	7.677	0	3.818	21.887	4.92	30.625	0	10.646	29.867	12.513	53.026
BGST0001 SE	8825812	736183	-2258	-1	-1	-2345	87	0	0	87	0	0	0	4.054	4.054	0	0	0	13.974	13.974	0	0	11.01	7.958	18.968	0	0	7.598	39.887	47.485
CBO 0001 SE	8838226	727030	-304	-1	-1	-429	125	0	0	125	0	1.736	0	15.977	17.713	0	5.862	8.508	9.161	23.531	0	17.872	7.928	11.252	37.052	0	0	24.899	24.266	49.165
1CO 0001 AL	8890728	806192	-1525	-1	-1693	-1715	168	0	0	168	0	16.861	2.895	17.371	37.127	0	0	13.308	18.198	31.506	0	1.192	25.264	17.908	44.364	0	9.963	25.035	20.948	55.946
1CP 0001 SE	8821000	724381	-1192	-1	-1254	-1283	62	0	0	62	0	0	3.481	15.465	18.946	0	0	6.525	14.697	21.222	0	20.527	1.78	0	22.307	0	0	0	0	0
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2CPST0001 AL	8871100	800800	-532	-1	-635	-692	103	0	0	103	0	0	0	5.032	5.032	0	0	0	7.701	7.701	0	2.038	0	18.445	20.483	0	5.246	5.313	59.002	69.561
1CSC 001 SE	8780782	696192	-1	-2626	-1	-2656	0	30	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1FD 0001 AL	8854669	791058	-2981	-1	-1	-3100	119	0	0	119	0	0	0	6.896	6.896	0	0	0	13.418	13.418	0	8.655	11.475	18.095	38.225	0	8.402	14.006	36.268	58.676
1FD 0002 AL	8856842	790049	-2564	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	3.141	2.971	6.791	12.903	0	19.223	18.208	35.295	72.726
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3FTD 0002 AL	8921148	814887	-1448	-1	-1501	-1	53	0	0	53	0	2.372	7.268	10.113	19.753	0	4.894	5.537	6.218	16.649	0	1.603	0.716	14.067	16.386	0	0	0	0	0
3FTD 0005 AL	8922066	814141	-1376	-1	-1414	-1	38	0	0	38	0	1.168	0	19.557	20.725	0	4.379	4.931	0	9.31	0	0	0	7.823	7.823	0	0	0	0	0
3FU 0064 AL	8922102	814729	-1238	-1	-1276	-1	38	0	0	38	0	6.445	2.836	7.147	16.428	0	6.807	3.487	6.446	16.74	0	0	0	4.631	4.631	0	0	0	0	0
3FU 0081 AL	8922517	815508	-1299	-1	-1323	-1	24	0	0	24	0	0.629	0.998	10.232	11.859	0	0	1.098	6.217	7.315	0	0	0	4.995	4.995	0	0	0	0	0
4FU 0082 AL	8923151	813874	-1612	-1	-1641	-1	29	0	0	29	0	0	0	9.645	9.645	0	9.762	0.591	9.629	19.982	0	0	0	0	0	0	0	0	0	0
4FU 0129 AL	8920265	809240	-773	-1	-888	-1	117	0	0	117	0	3.38	2.028	28.65	34.058	0	18.169	10.894	9.155	38.218	0	2.197	9.93	31.901	44.028	0	0	0	0	0
1IP 002 SE	8776003	697213	-1	-2242	-1	-2256	0	14	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1IPA 0002 SE	8831842	758657	-3428	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	1.736	14.705	16.441
1JP 0001 SE	8852284	739432	-269	-1	-1	-406	137	0	0	137	0	0	0	8.814	8.814	0	2.542	16.356	0	18.898	0	5.085	6.356	31.864	43.305	0	15.932	42.626	7.543	66.101
1MUS 0001 SE	8863713	746573	-819	-945	-1	-951	126	0	6	132	0	0	0	5.924	5.924	0	9.259	13.774	12.189	35.222	0	0.898	2.529	23.732	27.159	0	5.788	21.912	28.49	56.19
1NFD 0001 AL	8867191	801702	-1207	-1	-1271	-1	64	0	0	64	0	3.525	3.417	5.587	12.529	0	16.671	13.645	7.141	37.457	0	0.89	2.924	10.394	14.208	0	0	0	0	0
1PC 0001 AL	8979436	886120	-2200	-1	-2227	-2287	27	0	0	27	0	0	1.441	2.157	3.598	0	3.709	2.379	8.408	14.496	0	5.264	0	3.847	9.111	0	0	0	0	0
1PDA 0001 SE	8849632	761049	-1044	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	29.937	11.012	40.949
1PG 0001 AL	8894080	805480	-990	-1046	-1069	-1147	56	0	63	119	0	0	6.101	6.916	13.017	0	2.71	8.644	10.423	21.777	0	2.71	4.14	10.495	17.345	0	5.007	0	0	5.007
6PIR 0227D AL	8940169	839256	-2980	-1	-2991	-1	11	0	0	11	0	1.957	0.467	0.797	3.221	0	2.208	0	0.679	2.887	0	2.74	1.25	2.717	6.707	0	0	0	0	0
1PL 0002 SE	8814362	725356	-1248	-1285	-1	-1313	37	0	28	65	0	0	3.037	24.799	27.836	0	9.429	0	0	9.429	0	0	0	0	0	0	0	0	0	0
1PN 0001 SE	8862439	749595	-809	-952	-1	-955	143	0	3	146	0	0	0	17.119	17.119	0	18.595	5.254	2.534	26.383	0	0	4.21	32.796	37.006	0	1.356	49.512	12.439	63.307
1PTA 0001 SE	8838534	756405	-2488	-1	-1	-2623	135	0	0	135	0	0	0	8.66	8.66	0	0	3.396	23.045	26.441	0	3.311	3.65	50.126	57.087	0	2.461	13.523	27.026	43.01
1PTA 0003 SE	8844522	759312	-1558	-1	-1	-1697	139	0	0	139	0	0	0	6.145	6.145	0	0	7.627	20.04	27.667	0	0	29.998	23.644	53.642	0	0	27.795	24.066	51.861
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2SJST0001 SE	8824651	728379	-1844	-1	-1	-1922	78	0	0	78	0	0	1.505	5.305	6.81	0	13.159	5.72	15.076	33.955	0	3.313	4.414	4.836	12.563	0	0	7.054	17.563	24.617
1SMC0001 AL	8913559	818292	-2927	-1	-2960	-2937	33	0	0	33	0	0	2.749	4.581	7.33	0	6.413	3.666	0	10.079	0	6.378	2.977	6.079	15.434	0	0	0	0	0
1SS 0001 AL	8901704	809930	-220	-319	-363	-405	99	0	43	142	0	0	0	8.341	8.341	0	1.615	4.763	21.93	28.308	0	0	3.104	13.181	16.285	0	2.721	9.165	38.315	50.201
1TN 0001 SE	8854605	747538	-695	-836	-1	-867	141	0	31	172	0	0	0	8.543	8.543	0	4.425	6.942	7.355	18.722	0	18.675	21.47	7.894	48.039	0	17.104	31.462	18.385	66.951
1VN 0001 SE	8862880	756380	-1201	-1354	-1	-1381	153	0	27	180	0	0	0	10.57	10.57	0	7.457	11.209	14.397	33.063	0	0	1.525	27.117	28.642	0	6.375	12.077	60.845	79.297
Perfil BAT	8862100	732350	60	-205	-1	-209	265	0	6	271	0	2.5	2.5	3.9	8.9	0	29.22	21.5	21.5	72.22	0	22.43	22.43	44.875	89.735	0	46.34	23.17	23.17	92.68
Perfil PES	8884150	769300	170	-1	50	40	120	6	0	120	0	1.19	4.168	4.168	9.526	0	1.358	1.344	1.498	4.2	0	8.59	8.59	8.59	25.77	6.864	29.07	8.5	9	53.434
Perfil DP	8880900	763700	15	20	20	40	240	0	80	320	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Perfil IGN	8880054	754788	162	43	27	20	119	0	15.5	134.5	0	1	1.6	6	8.6	0	27	0	0	27	0	0	0	10	10	0	50	10	10	70
Perfil MUL	8889900	758700	199	195	160	60	4	0	34.65	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Perfil CDR	8863800	733850	30	-1	-1	30	170	5	0	170	0	1.658	5.516	5.721	12.895	0	10.495	6.479	25.281	42.255	0	2.008	22.932	18	40.3	0	6.094	4.185	53.773	64.052

Af. BAT-01	8861100	731300	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. BAT-09	8862000	731850	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. BAT-20	8862136	732082	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. BAT-21	8861925	731925	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. BAT-22	8862110	732020	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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Af. CDR-01	8863800	733550	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. DP-03	8878250	762950	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. DP-04	8878200	762975	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. DP-05	8878100	763050	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. DP-06	8878075	763050	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. DP-12	8879250	762100	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. IGN-01	8879925	754500	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. IGN-12	8879100	756300	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. IGN-03	8880050	754800	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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Af. PES-02	8883800	769450	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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Af. PES-04	8884050	769000	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. SJO-01	8879450	754700	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. SJO-03	8879500	754550	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. TUC-02	8882300	750900	100	70	-1	-1	30	0	10	40	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Af. BAT-07	8862250	732000	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. BAT-08	8862150	731950	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. BAT-10	8862450	732200	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. CBP-02	8885200	768900	-1	-1	-1	-1	0	0	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. CHR-01	8890710	775185	-1	-1	-1	-1	0	150	17	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. ONÇ-14	8878950	753350	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. ONÇ-07	8878900	753250	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. ONÇ-08	8878750	753050	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. ONÇ-09	8878700	753000	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. DP-01	8880950	763700	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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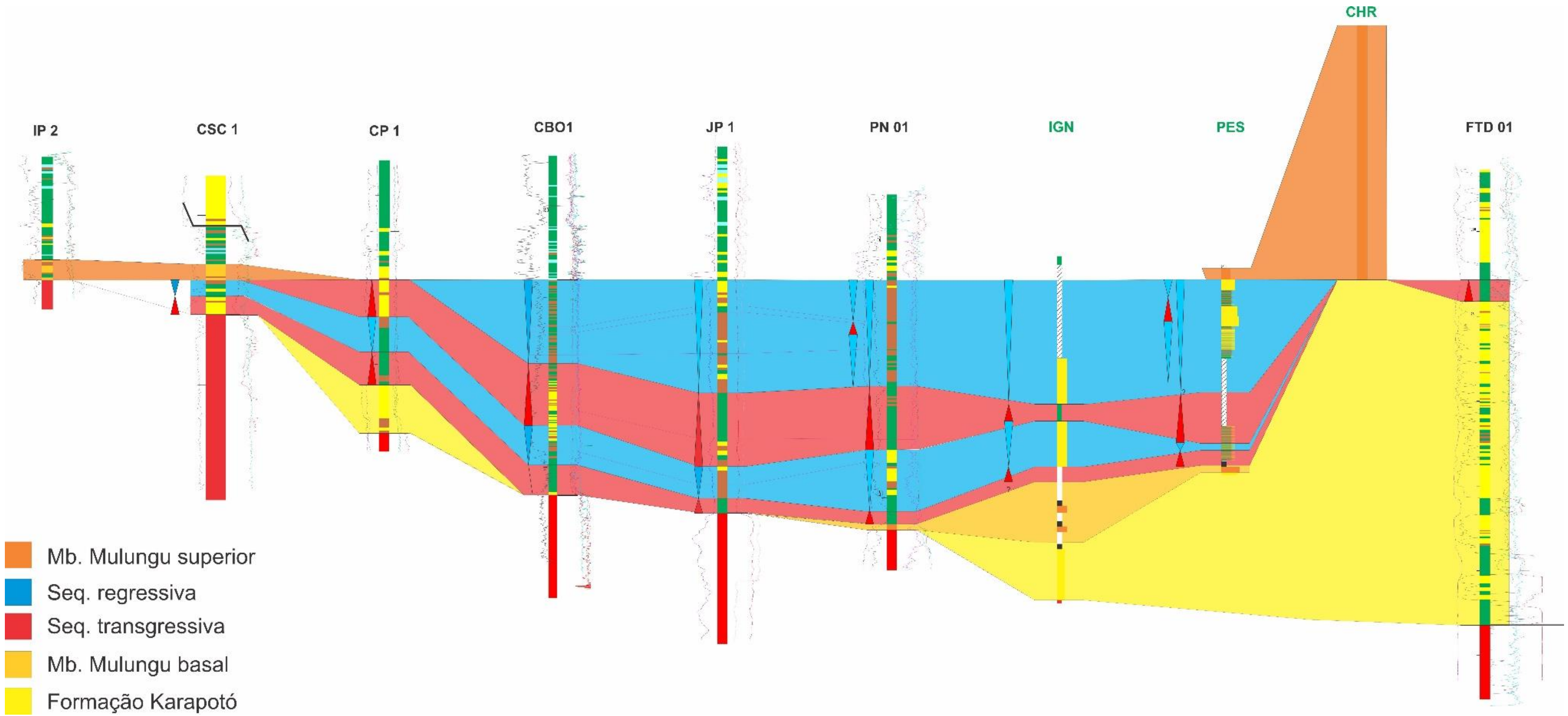
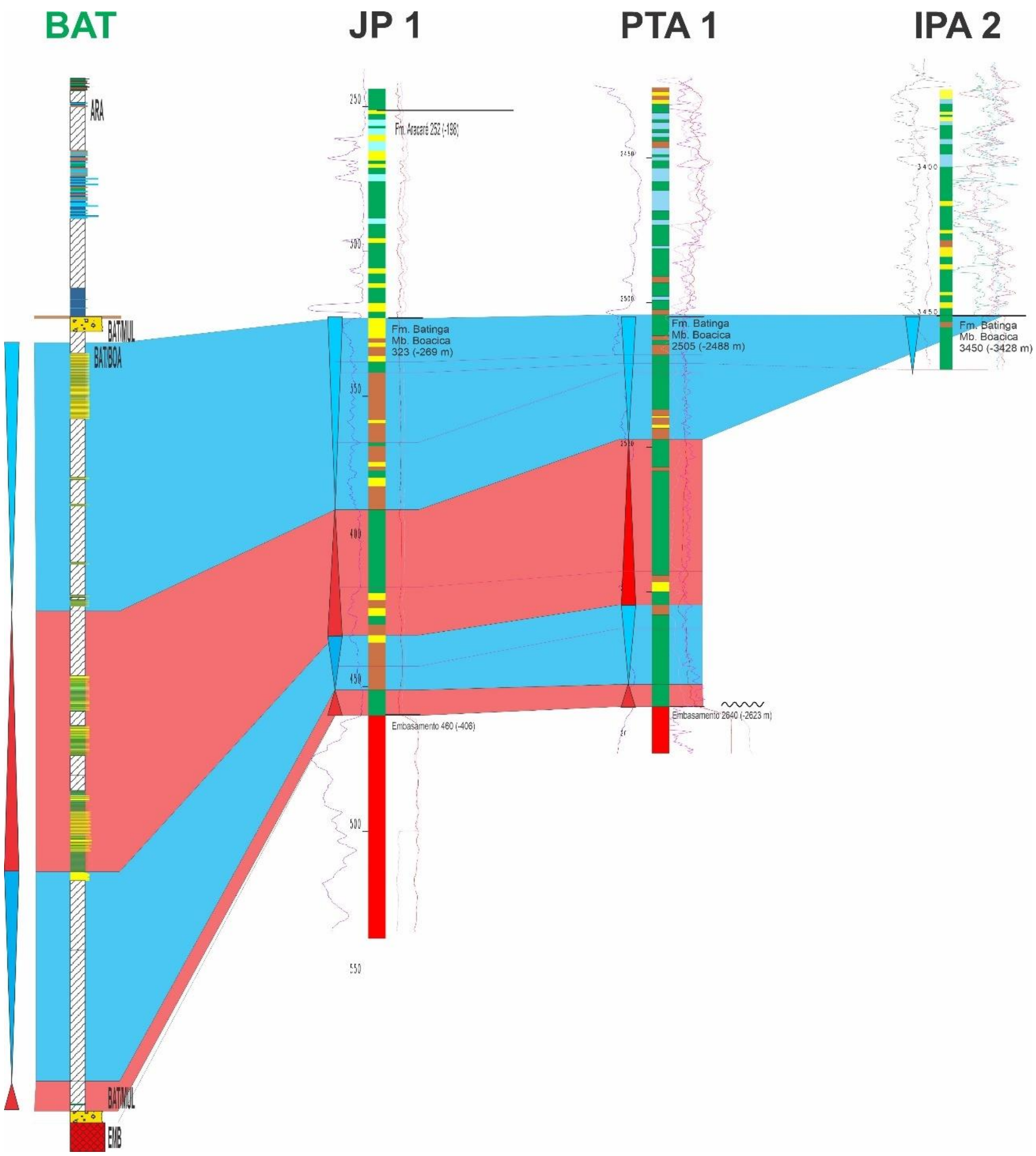
Af. DP-13	8880300	763450	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. IGN-11	8879950	755900	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. IGN-13	8879900	755450	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. IGN-14	8880050	755450	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. IGN-02	8880000	755900	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. IGN-04	8880000	755950	-1	-1	-1	-1	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Af. TUC-01	8881600	750750	-1	77	-1	-1	0	14	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CDR-03	8864200	733450	-1	-1	-1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PMR-01	8814550	687900	-1	-1	-1	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRP-01	8869950	738400	-1	-1	-1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ponto 17	8938150	829050	-1	-1	-1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUN-01	9009900	886100	-1	-1	-1	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SMC-11	8923400	810000	-1	-1	-1	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MRB-01	8889050	749450	-1	-1	-1	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EMB	8879850	742100	-1	-1	-1	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MTZ-04	8986150	879450	-1	-1	-1	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MTZ-07	8993250	879450	-1	-1	-1	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FLX-02	8973300	879350	-1	-1	-1	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ITA-05	8782500	684550	-1	-1	-1	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CN 0001 SE	8801497	706419	0	0	0	-1477	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MG 0018 SE	8814469	705204	0	0	0	-661	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PU 0002 SE	8810034	727409	0	0	0	-1421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC 0001 SE	8796931	708093	0	0	0	-1836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2. Seções: *strike*

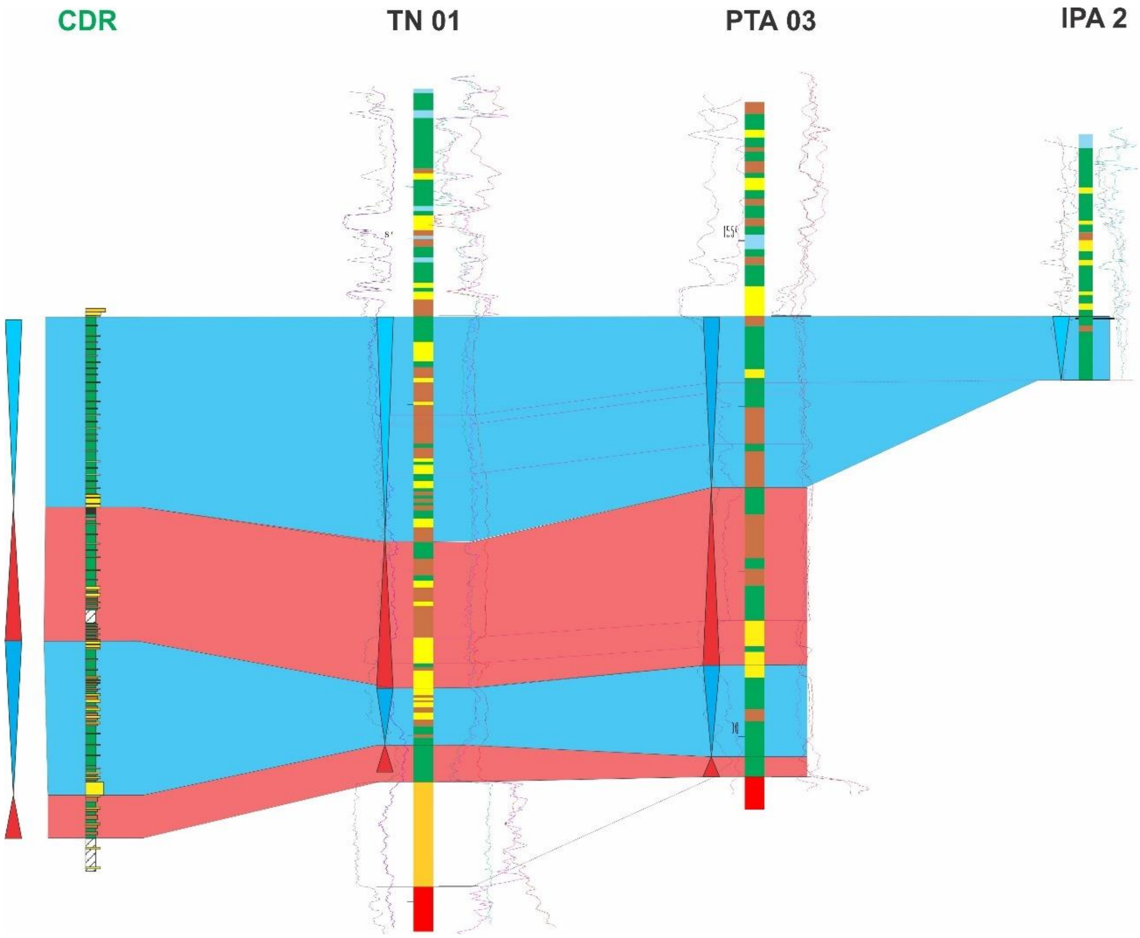


Seções: *dip*

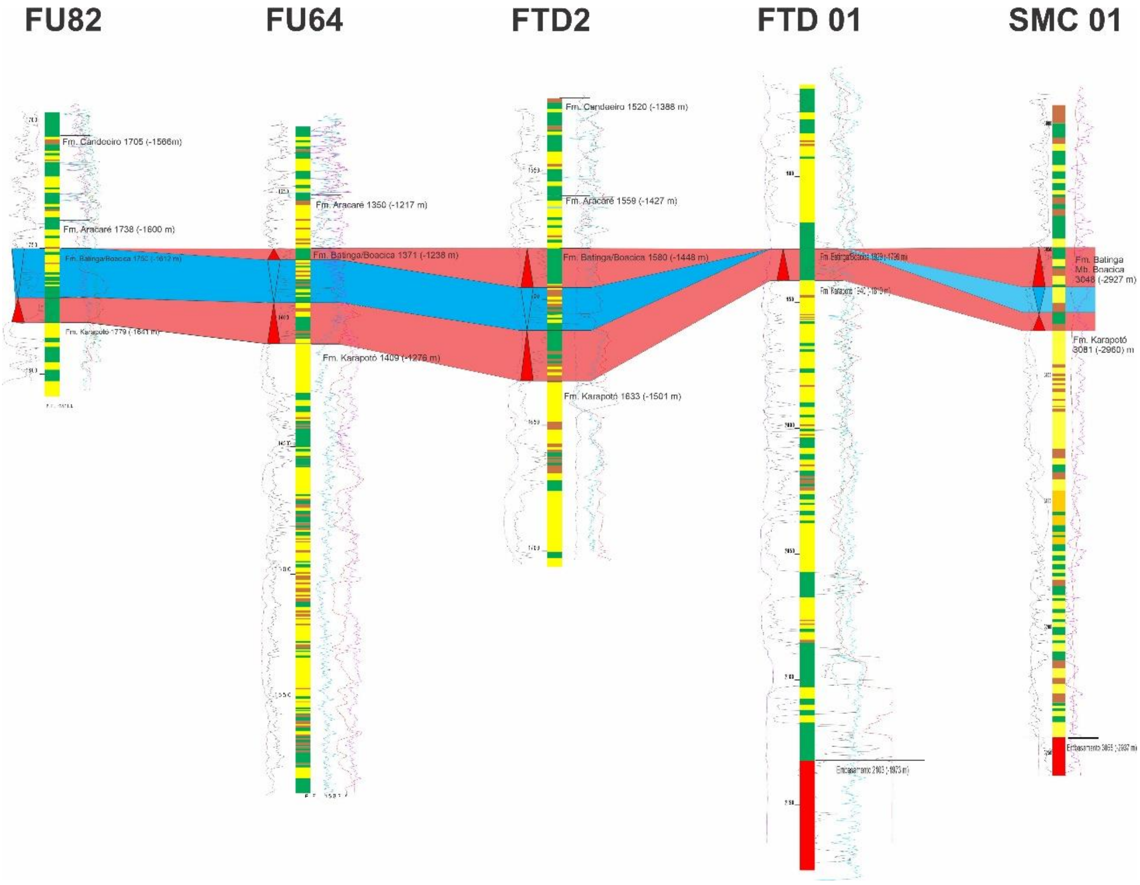


BAT
JP 1
PTA 1
IPA 2
ARA
BATMUL
BATBOA
BATMUL
EMB
Fm. Aracaré 252 (-198)
Fm. Batinga
Mb. Boacica
323 (-269 m)
Embasamento 460 (-406)
Fm. Batinga
Mb. Boacica
2505 (-2488 m)
Embasamento 2640 (-2623 m)
Fm. Batinga
Mb. Boacica
3450 (-3428 m)

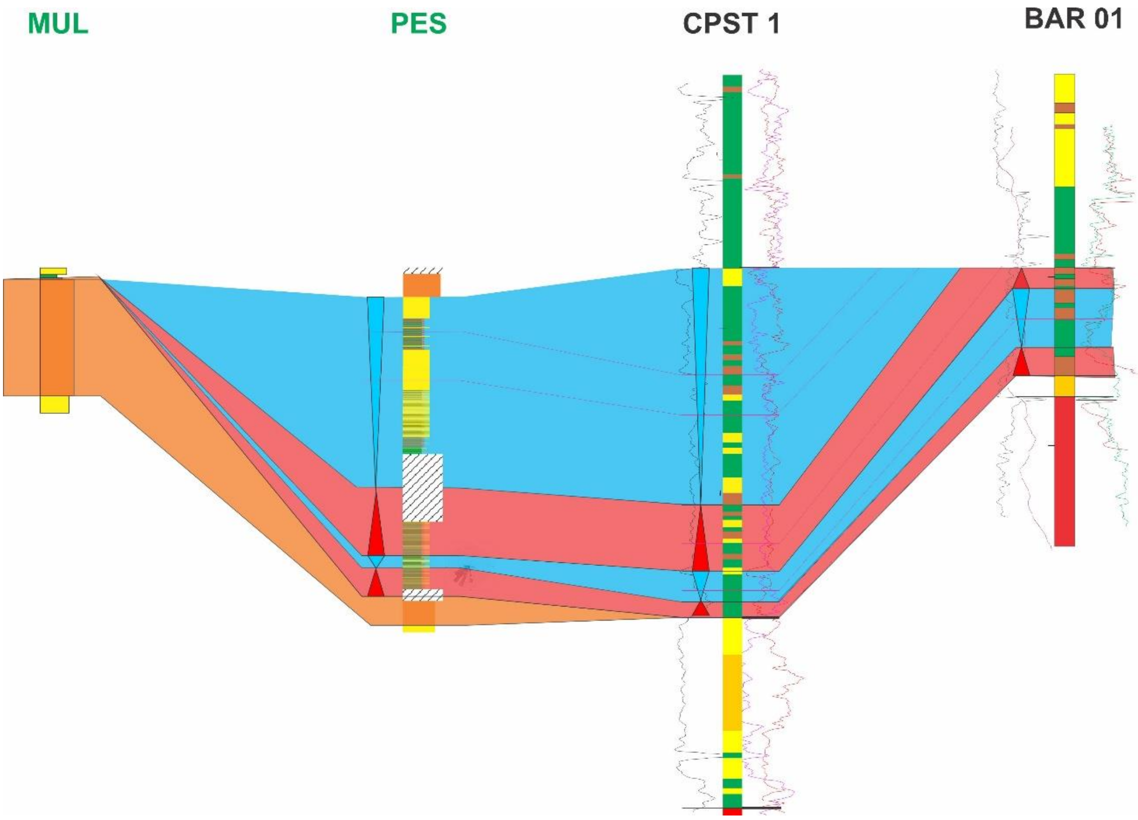
Seções: *dip*



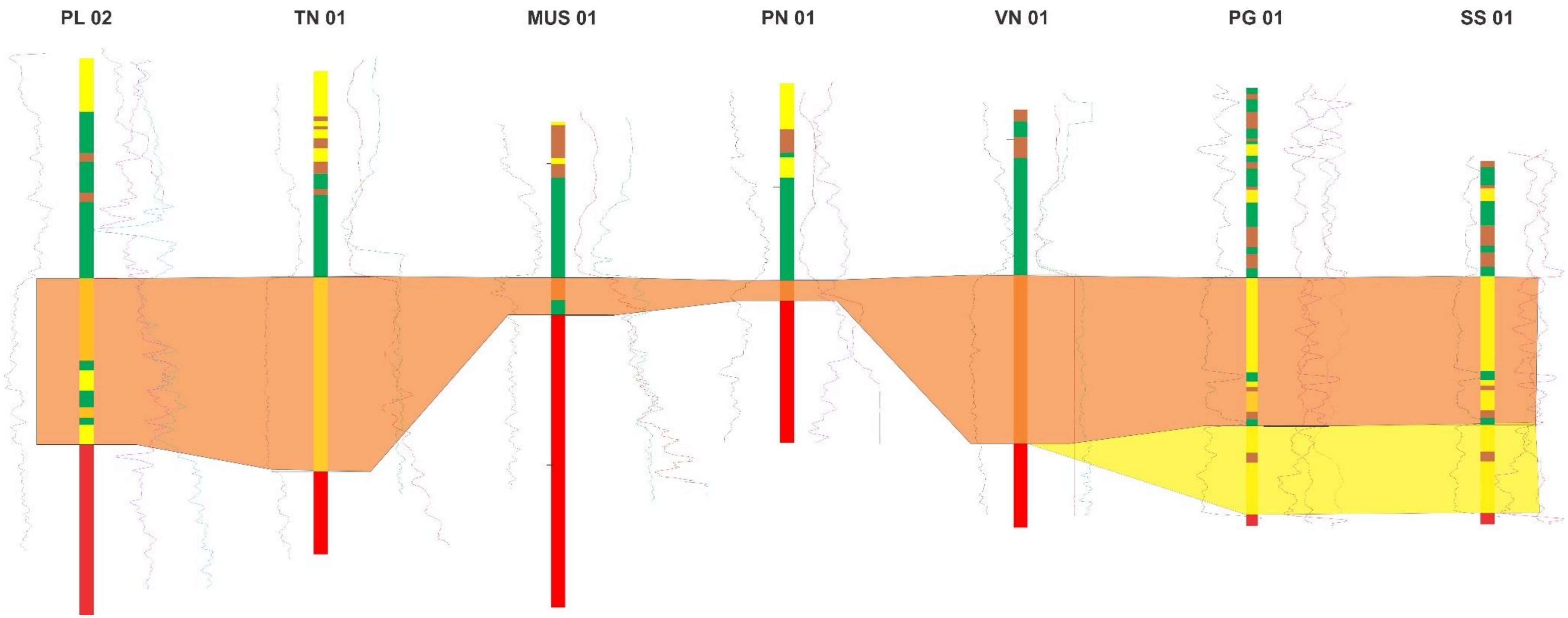
Seções: *dip*


FU82
FU64
FTD2
FTD 01
SMC 01
Fm. Candeeiro 1705 (-1586m)
Fm. Aracaré 1738 (-1600 m)
Fm. Aracaré 1350 (-1217 m)
Fm. Batinga/Boacica 1371 (-1238 m)
Fm. Karapotó 1409 (-1276 m)
Fm. Candeeiro 1520 (-1388 m)
Fm. Aracaré 1559 (-1427 m)
Fm. Batinga/Boacica 1580 (-1448 m)
Fm. Karapotó 1633 (-1501 m)
Fm. Batinga
Mb. Boacica
3048 (-2927 m)
Fm. Karapotó
3081 (-2960) m

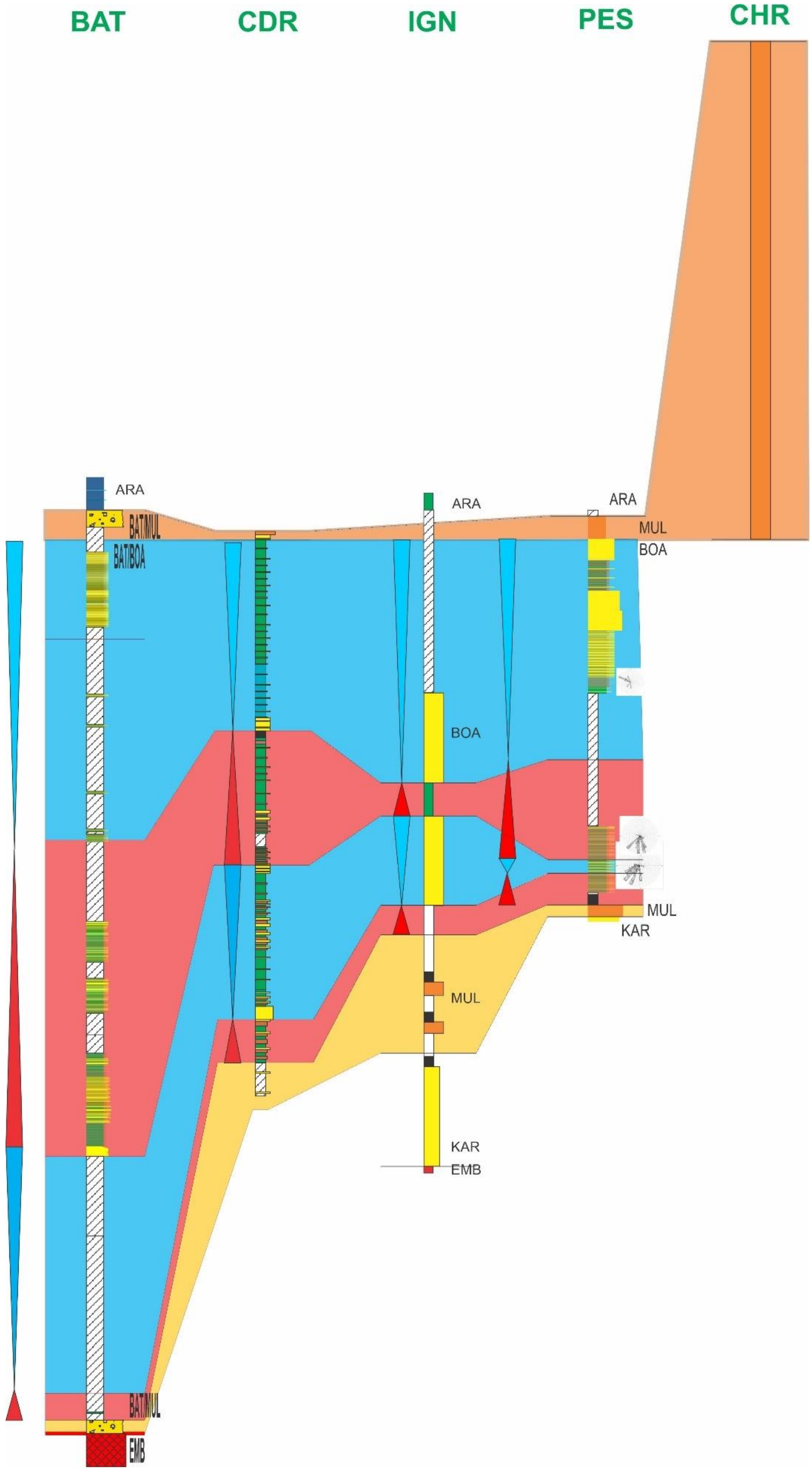
Seções: *dip*



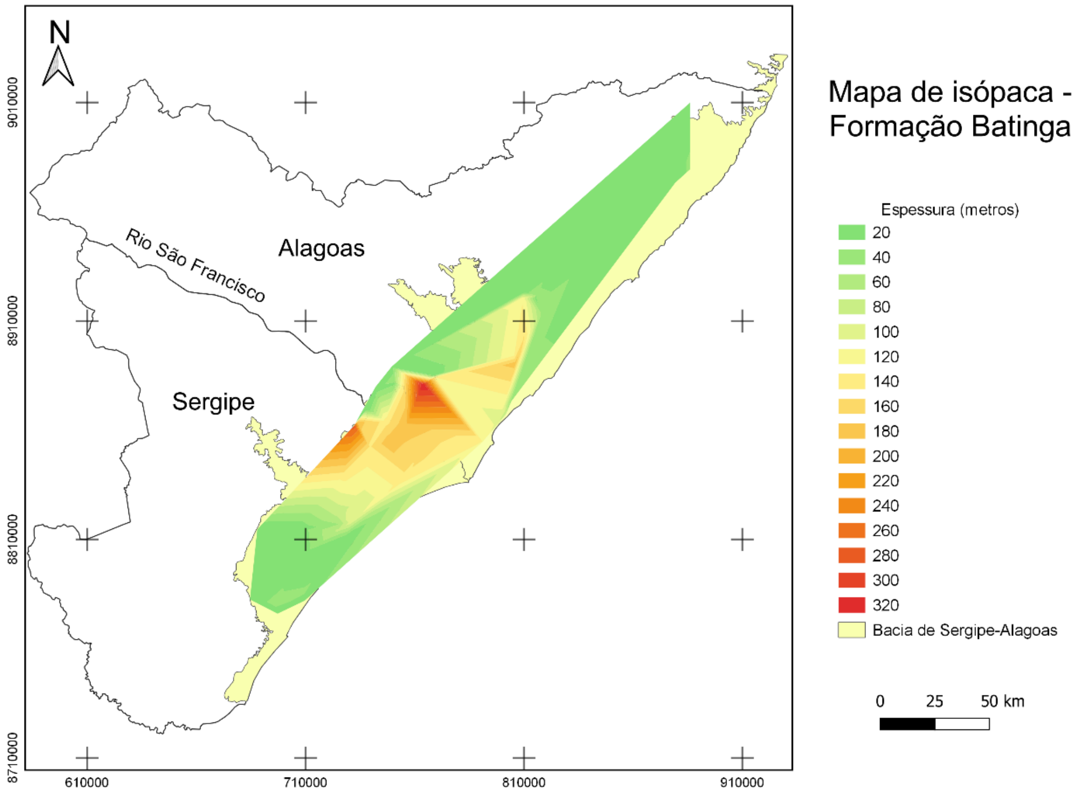
Seções: Mulungu basal



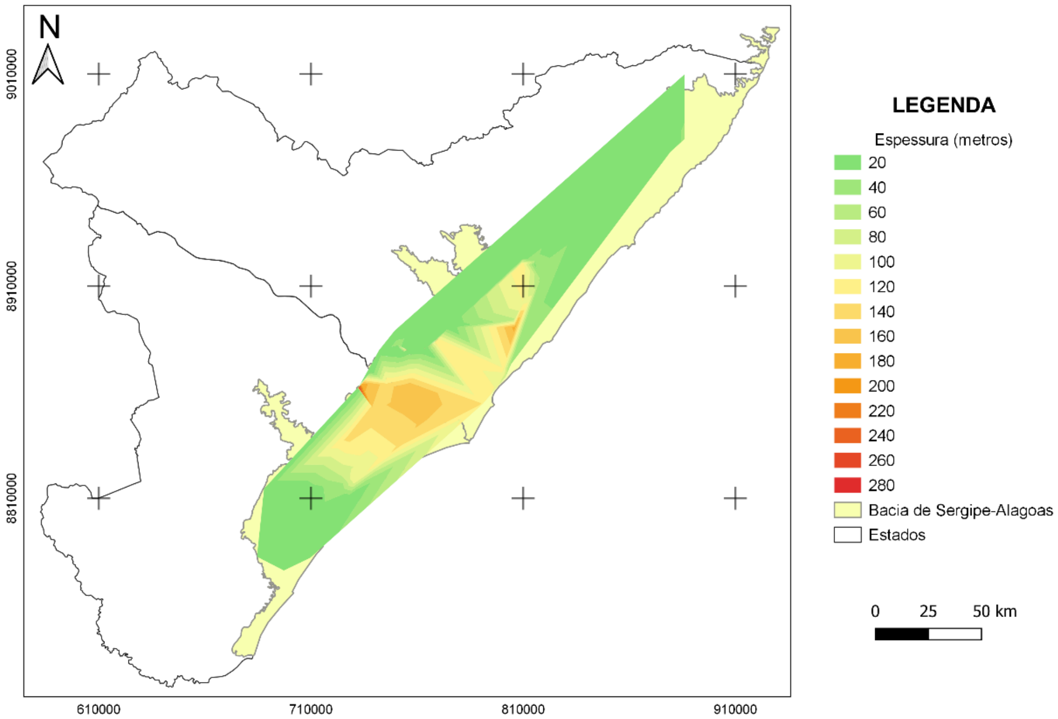
Seções: perfis



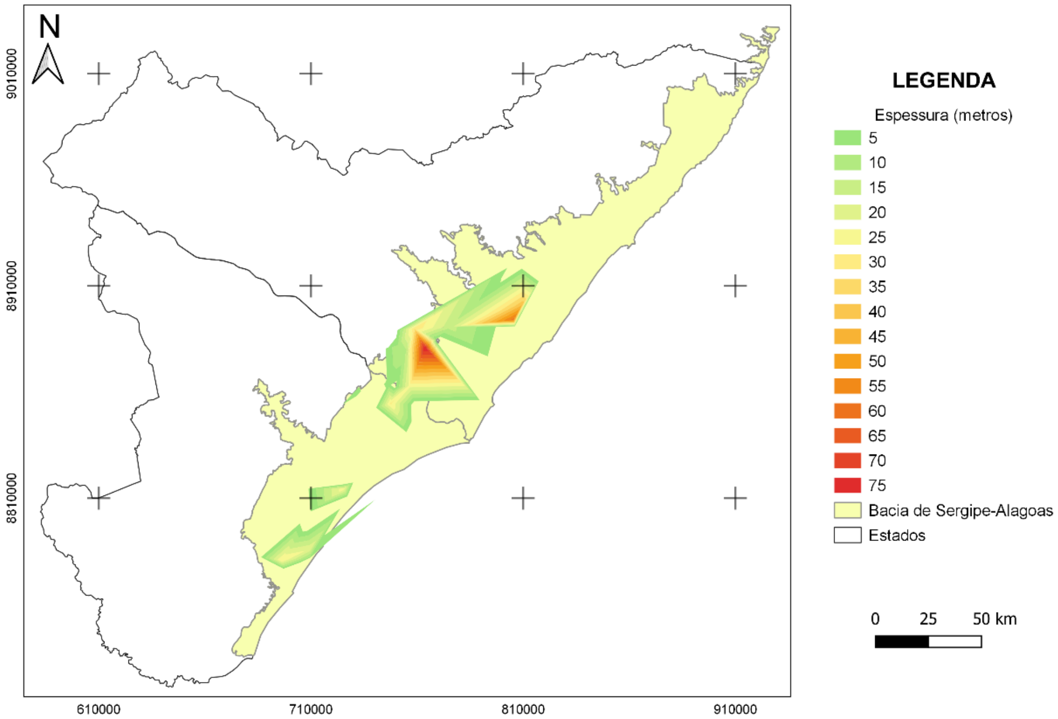
3. Mapas de isópacas e mapas de contorno estrutural do topo.



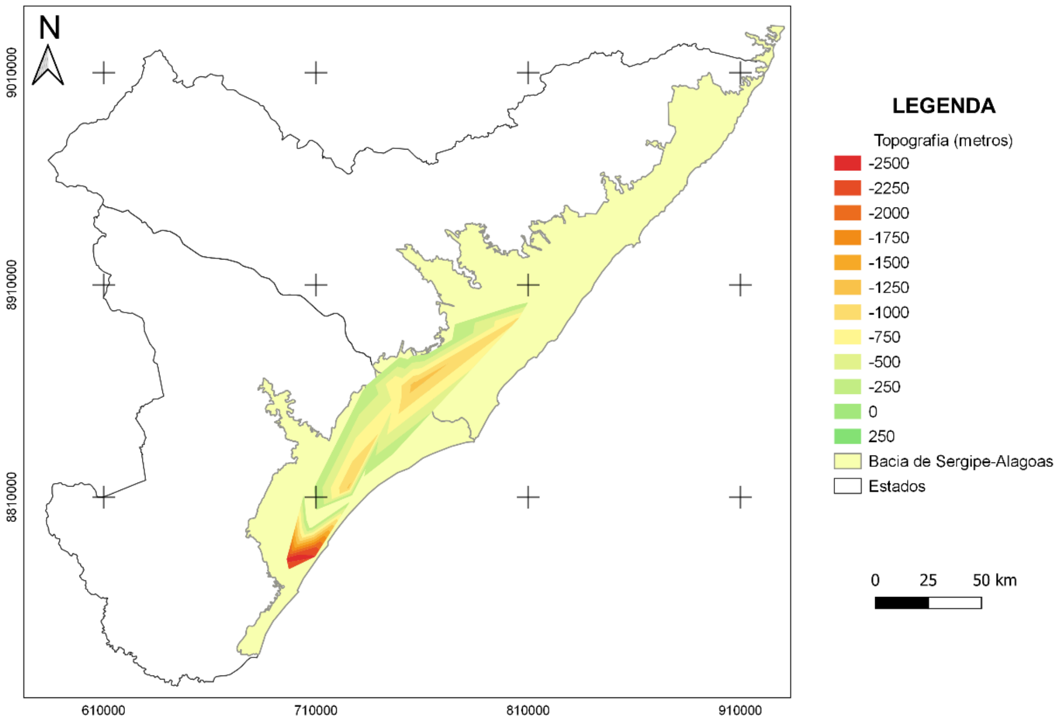
Mapa de isópaca - Membro Boacica



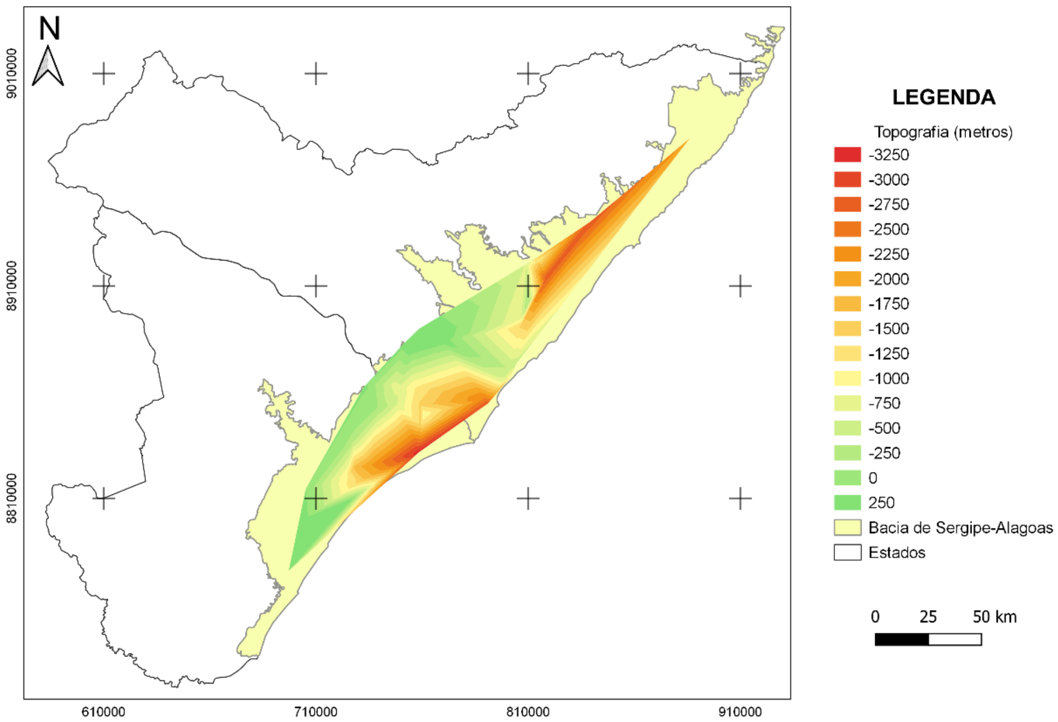
Mapa de isópaca - Membro Mulungu



Mapa de contorno estrutural do topo – Membro Mulungu



Mapa de contorno estrutural do topo – Membro Boacica



Mapa de contorno estrutural do topo – Embasamento