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OROGÊNESE ACRESCIONÁRIA NA MARGEM NORTE DO CRÁTON DO SÃO FRANCISCO: A FAIXA SERGIPANA

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Gabriela Menezes Almeida

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GABRIELA MENEZES ALMEIDA

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Discente:
Gabriela Menezes Almeida

Orientador:
Prof. Dr. Reinhardt A. Fuck
Co-orientador:
Prof. Dr. Elton Luiz Dantas

Banca examinadora:
Prof. Dr. Reinhardt A. Fuck (Orientador)
Prof. Dr[a]. Maria de Lourdes da Silva Rosa (DGEOL/UFS)
Prof. Dr. Ticiano José Saraiva dos Santos (DGRN/Unicamp)
Prof. Dr[a]. Eliza Inês Nunes Peixoto (IG/UnB)

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Aos caminhos que percorri, aos erros e acertos que me tornaram a pessoa que sou, às escolhas que me trouxeram até aqui.

“O conhecimento científico é um corpo de afirmativas com graus variados de certezas: algumas muito incertas, outras quase certas, nenhuma absolutamente certa.”

“De todos os seus muitos valores, o maior deles deve ser a liberdade de duvidar”

– Sobre o valor da Ciência

Richard P. Feynman

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RESUMO

A Faixa Sergipana está localizada na porção meridional da Província Borborema e é uma região chave para o estudo dos processos atuantes na aglutinação do Supercontinente Gondwana durante a Orogenia Brasiliana. Entretanto, ainda há muitas lacunas no conhecimento que dificultam o entendimento de sua evolução geotectônica. Ao longo dos anos, diversos modelos foram propostos para a formação da Faixa Sergipana: colagem de domínios litoestratigráficos distintos, inversão de uma bacia de margem passiva e, mais recentemente, um ciclo de Wilson completo. Nesta tese busco entender os processos tectônicos atuantes nesse orógeno por meio de um estudo sistemático, abrangendo geofísica aérea, mapeamento estrutural detalhado, petrografia e química mineral da Zona de Cisalhamento São Miguel do Aleixo, estrutura que limita os domínios Vaza Barris e Macururé da Faixa Sergipana. Os dados obtidos apontam que um modelo evolutivo acrescionário é o mais adequado para a evolução da Faixa Sergipana. Com base na magnetometria, foi possível inferir que o domínio Poço Redondo é um provável microcontinente que foi acrescionado à paleo-margem do São Francisco durante a colisão. Esses dados apontam também a presença de dois prováveis limites entre terrenos representados pelas zonas de cisalhamento São Miguel do Aleixo e Belo Monte-Jeremoabo e uma região de alta intensidade magnética localizada no Complexo Arapiraca seria a provável zona de sutura principal da colisão entre a Paleoplaca do São Francisco e o Superterreno Pernambuco-Alagoas. O mapeamento estrutural detalhado reforça a importância da Zona de Cisalhamento São Miguel do Aleixo como limite crustal. Além disso, indicadores cinemáticos e arcabouço estrutural mostram que durante a colisão essa zona atuou como transpurrão, em que a componente direcional teve papel maior do que a compressional. As assembleias minerais encontradas para os domínios Vaza Barris e Macururé são distintas, indicando metamorfismo na zona da clorita e granada, respectivamente. Para a zona da granada foram encontradas temperaturas de até 564 °C. A deformação também atuou de maneira heterogênea através da zona de cisalhamento. O Domínio Vaza Barris é interpretado como um cinturão de dobras e cavalgamentos em *foreland* onde dominou deformação tipo rúptil-dúctil em regime tectônico *thin skinned* com envolvimento de porções do embasamento. Já o Domínio Macururé foi deformado ductilmente em provável regime tectônico *thick-skinned*. A justaposição desses domínios é similar à estruturação do Orógeno Tasmanides, o que suporta a hipótese de orogênese acrescionária para a Faixa Sergipana.

Palavras-chave: Província Borborema, Gondwana Ocidental, magnetometria, zona de cisalhamento, *thin-skinned*, *thick-skinned*

ABSTRACT

The Sergipano Belt is located in the Southern portion of the Borborema Province and is a key area for the study of the acting processes during the agglutination of the Gondwana Supercontinent in the Brasiliano Orogeny. However, there are still many gaps in knowledge that make it difficult to understand its geotectonic evolution. Over the years, several models have been proposed for the formation of the Sergipano Belt: collage of distinct lithostratigraphic domains, inversion of a passive margin basin and, more recently, a complete Wilson cycle. This thesis sought to understand the tectonic processes acting in this orogen through a systematic study relying on airborne geophysics, detailed structural mapping, petrography and mineral chemistry of the São Miguel do Aleixo Shear Zone, a structure that limits the Vaza Barris and Macururé domains of the Sergipano Belt. Our data indicate that an accretionary evolutionary model is the most adequate for the evolution of the Sergipano Belt. Through magnetometry it was possible to infer that the Poço Redondo Domain is a probable ribbon continent accreted to the São Francisco paleo-margin during the collision. These data also point to the presence of two probable boundaries between terrains represented by the São Miguel do Aleixo and Belo Monte-Jeremoabo shear zones and a region of high magnetic intensity located in the Arapiraca Complex would be the probable main suture zone of the collision between the the São Francisco Paleoplate and the Pernambuco-Alagoas Superterrane. Through detailed structural mapping, the importance of the Shear Zone as a crustal boundary is reinforced. In addition, the kinematic indicators and structural framework show that during the collision this zone acted as a transpressive thrust, in which the directional component played a greater role than the compressional one. The mineral assemblages found for the Vaza Barris and Macururé domains are distinct, indicating metamorphism in the chlorite and garnet zones, respectively. For the garnet zone, temperatures of up to 564 °C were found. Deformation across the shear zone is also heterogeneous. The Vaza Barris Domain is interpreted as a forelend fold-and-thrust belt with dominant basement-involved thin-skinned brittle-ductile deformation. The Macururé Domain was ductilely deformed in a probable thick-skinned tectonics regime. The juxtaposition of these domains is similar to the structure of the Tasmanides Orogen, which supports the hypothesis of accretionary orogeny for the Sergipano Belt.

Keywords: Borborema Province, Western Gondwana, magnetometry, shear zone, thin-skinned, thick-skinned

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CAPÍTULO 1 – Introdução

1. Apresentação e justificativa

A Faixa Sergipana está incluída na porção sul da Província Borborema, Nordeste do Brasil, abrangendo a totalidade do estado de Sergipe, além de parte dos estados de Alagoas e Bahia. A faixa apresenta forma triangular, com *trend* ESE-WNW, e acredita-se ter sido formada pela colisão entre a Paleoplaca do São Francisco, a sul, e o Superterreno Pernambuco-Alagoas, a norte, durante a Orogenia Brasiliana, que culminou com o amálgama de blocos continentais e formação Gondwana Ocidental. Essa faixa faz parte de orógeno de escala continental, que apresenta extensão E-W superior a 2.000 km, abrangendo as faixas Rio Preto, Riacho do Pontal e Sergipana, na América do Sul, e continua no Orógeno Oubanguides, no noroeste da África, bordejando o Cráton do Congo (e.g. Nzenti et al., 1988; Egydio da Silva et al., 1989; Gomes, 1990; Jardim de Sá et al., 1992; Trompette, 1997, 2000; Oliveira et al., 2006; Caxito et al., 2016, 2017; Fig. 1).

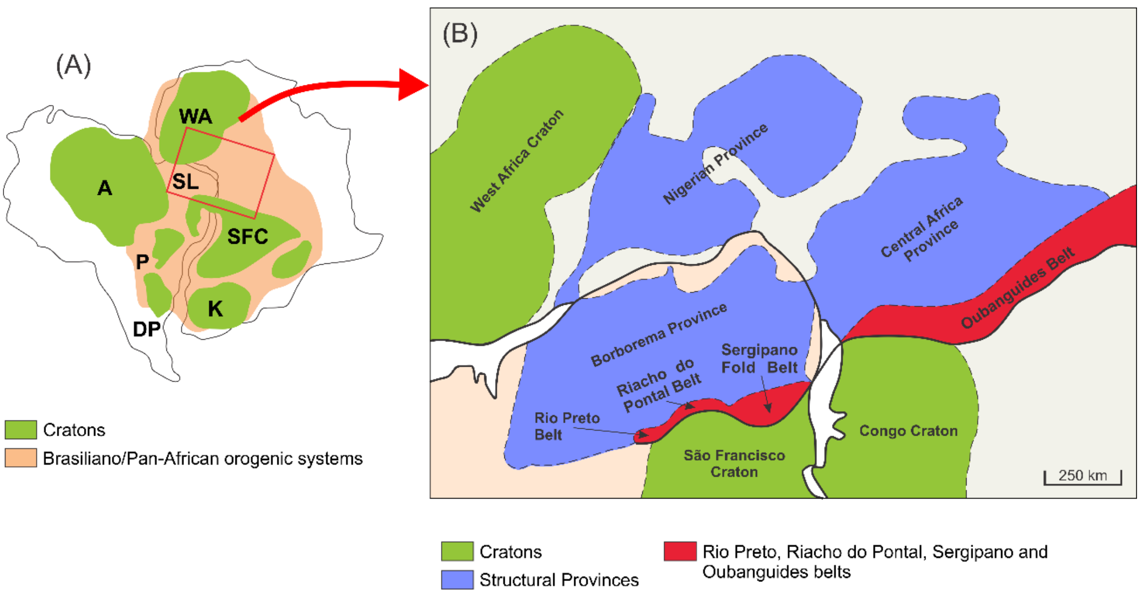

Figura 1: (A) Crátons e sistemas orogênicos brasilianos/pan-africanos do Gondwana Ocidental (América do Sul e África) e contexto geotectônico do território brasileiro, que abrange quase todos núcleos pré-cambrianos da América do Sul (modificado de Heilbron et al., 2017); A: Cráton Amazônico; WA: Cráton do Oeste Africano; SL: Cráton São Luís; P: Bloco Paranapanema; SFC: Cráton do São Francisco-Congo; K: Cráton Kalahari; DP: Cráton Rio de La Plata. (B) Porção de destaque da Figura 1A (Quadrado vermelho), salientando o orógeno transcontinental constituído pelas faixas Rio Preto, Riacho do Pontal, Sergipano e Oubanguides no limite entre os crátons São

Francisco e Congo a sul e as províncias Borborema e África Central, a norte (modificado de Brito Neves et al., 2001).

A evolução geodinâmica da Faixa Sergipana ainda não está bem elucidada e estudos específicos devem ser feitos para solucionar questões pendentes. Uma dessas questões refere-se à continuidade ou não entre os domínios Vaza-Barris e Macururé, os quais constituem boa parte da faixa, sendo compostos majoritariamente por rochas metassedimentares e situados, respectivamente, a sul e norte da Zona de Cisalhamento São Miguel do Aleixo (Fig. 2). Essa questão é importante não só para um melhor e mais completo entendimento da evolução da Faixa Sergipana, como também da implicação desta para a formação do Gondwana Ocidental.

Atualmente, existem dois modelos principais para a evolução desse orógeno, divergentes com relação à continuidade crustal entre os domínios Vaza-Barris e Macururé. Com base em dados litoestruturais regionais, metamorfismo e geofísica, D'el-Rey Silva (1992, 1995, 1999) descreve a continuidade desses domínios, que representariam o preenchimento sedimentar de uma bacia da margem passiva na borda norte do paleo-continente São Francisco-Congo. Em uma tal evolução, a Zona de Cisalhamento São Miguel do Aleixo representa feição intraplaca tardia devida à forte transpressão regional, como outras importantes falhas regionais da Faixa Sergipana. Já Oliveira et al. (2010, 2015), com base especialmente em dados isotópicos e idades U-Pb em zircão detrítico de rochas em praticamente toda a faixa, preconizam que as rochas do Domínio Macururé representariam a sedimentação da paleo-margem na borda sul do Superterreno Pernambuco-Alagoas, enquanto as rochas do domínio Vaza-Barris seriam representativas de sedimentação da paleo-margem do São Francisco. Neste sentido, a Zona de Cisalhamento São Miguel do Aleixo faria o papel de sutura entre as duas paleo-margens.

Uma sutura *sensu stricto* marca o estágio final de uma colisão continental e é caracterizada por uma superfície de cisalhamento que limita blocos crustais ou de dimensões continentais (Dewey, 1977; Brito Neves, 2011). Zona de sutura, por sua vez, é mais abrangente e engloba, além da linha de sutura principal, o cinturão colisional gerado em torno do amálgama de terrenos (Moores, 1981). Dessa forma, torna-se necessário caracterizar a região da Zona de Cisalhamento São Miguel do Aleixo como sutura ou simplesmente uma falha regional intraplaca.

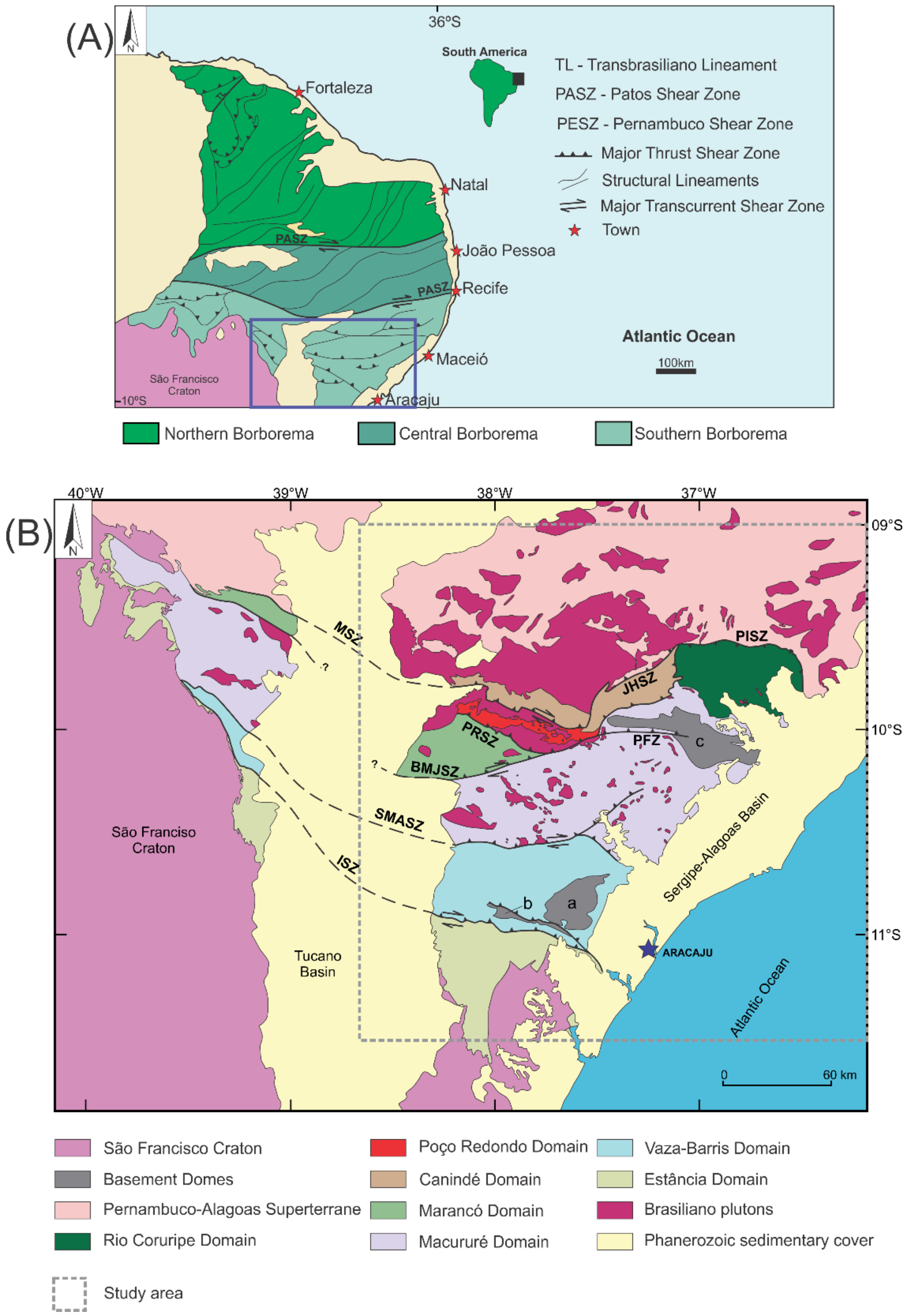

Figura 2: (a) Mapa esquemático da Província Borborema exibindo as três subprovíncias, com ênfase na Faixa Sergipana (modificado de Brito Neves et al., 2000); (b) Mapa geológico da Faixa Sergipana modificado de Pinho Neto (2018). Domos do embasamento: a – Itabaiana; b – Simão Dias, c – Jirau do Ponciano. Zonas de Cisalhamento: ISZ – Itaporanga; SMASZ – São Miguel do Aleixo; BMJSZ – Belo Monte-Jeremoabo; PFSZ – Porto da Folha; PRSZ – Poço Redondo; MSZ – Macururé; JHSZ – Jacaré dos Homens, PISZ – Palmeira dos Índios.

2. Objetivo

Compreender a evolução tectônica da Faixa Sergipana através de um extenso trabalho de caracterização e interpretação do arcabouço magnético da região e entender quais processos levaram à formação da da Zona de Cisalhamento São Miguel do Aleixo, um importante limite de terreno que seapara os domínios Vaza Barris e Macururé por meio de caracterização geofísica, litoestrutural, metamórfica e petrográfica das sequências metassedimentares, bem como entender qual o papel dessa zona de cisalhamento na evolução da Faixa Sergipana no contexto da Orogenia Brasiliana.

3. Localização da área

Geologicamente, a área de estudo compreende a porção central da Faixa Sergipana Oriental (a leste da Bacia do Tucano), com cerca de 2800 km², e geograficamente abrange parte dos estados de Sergipe e da Bahia (Fig. 3). A área envolve parte dos municípios baianos de Coronel João Sá, Sítio do Quinto, Adustina, Paripiranga e dos municípios sergipanos Carira, Frei Paulo, Nossa Senhora Aparecida, Ribeirópolis, Nossa Senhora das Dores, Nossa Senhora da Glória, São Miguel do Aleixo, Feira Nova, Gracho Cardoso, Aquidabã, Cumbe, Siriri e Moita Bonita. Essa área faz parte da mesorregião do Nordeste Baiano e Agreste Sergipano, inserindo-se em quatro folhas cartográficas: Carira, Gracho Cardoso, Aracaju e Simão Dias.

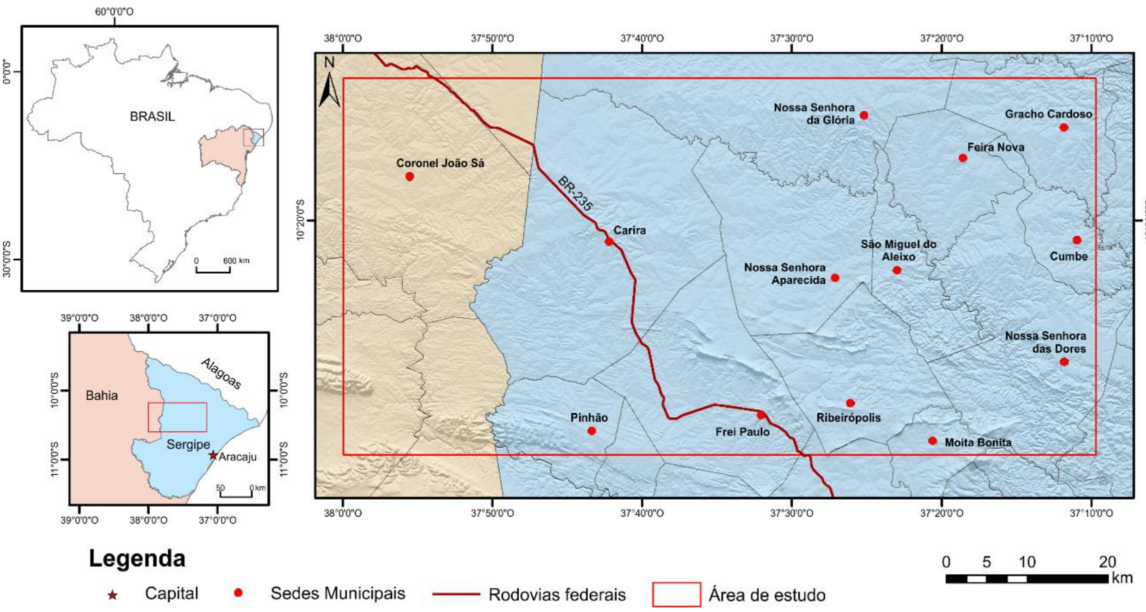

Figura 3: Mapa político simplificado mostrando a localização da área de estudo.

4. Materiais e métodos

4.1. Levantamento bibliográfico

Foi realizado levantamento bibliográfico sobre a área de estudo, bem como sobre as ferramentas utilizadas neste trabalho, em dissertações, teses e periódicos nacionais e internacionais.

4.2. Geofísica aérea

Foram usados dados de geofísica aérea, visando a caracterização magnética da Faixa Sergipana e seu embasamento mediante a identificação e traçado de alinhamentos e separação de domínios magnéticos, além de estimativas de profundidade. Os dados aeromagnéticos foram obtidos pela CPRM por meio dos projetos aerogeofísicos 1102 (Estado de Sergipe) e 1104 (Paulo Afonso–Teotônio Vilela) executados em 2014. O levantamento areogeofísico foi realizado com espaçamento entre linhas de voo e controle de 500 m e 10 km, respectivamente. Os produtos geofísicos utilizados foram o campo magnético anômalo (CMA) e o sinal analítico para delimitação de domínios magnéticos e identificação de zonas de cisalhamento, a derivada *tilt* para traçar os principais lineamentos e a Deconvolução de Euler e o *Matched Filter* para estimativa de profundidade. O detalhamento dessa metodologia encontra-se nos capítulos 3 e 4.

4.3. Trabalho de campo

O mapa geológico base pré-campo foi confeccionado a partir da integração de mapas geofísicos, imagens Landsat 8 e imagem de radar SRTM para separação dos principais litotipos e estruturas. Foram realizadas duas etapas de campo, a primeira com 18 dias entre os dias 05 e 23 de fevereiro de 2018, e a segunda de três dias, entre 17 e 19 de novembro de 2019. O mapeamento teve como base os mapas geológicos de Sergipe e da Bahia em escala 1:250.000 e 1:1.000.000, respectivamente, elaborados pela CPRM (Teixeira et al. 2014 e Dalton Souza et al. 2003, respectivamente), as folhas cartográficas de Aracaju, Simão Dias, Gracho Cardoso e Carira, confeccionadas pela Superintendência de Desenvolvimento do Nordeste – SUDENE (SUDENE, 1973a, 1973b, 1974, 1989) e o mapa litogeofísico elaborado com base na imagem RGB (K-Th-U) obtida no banco de dados do Projeto Aerogeofísico de Sergipe (1102) da CPRM. O objetivo foi a observação em maior detalhe das relações entre os principais litotipos e das suas características estruturais. Também foram coletadas amostras para estudos petrográficos e isotópicos. Posteriormente ao trabalho de campo, o mapeamento foi refinado com o auxílio de imagens LANDSAT 8 (composição 654), SRTM e dados aerogamaespectométricos para delimitação de unidades litológicas e das principais estruturas regionais.

4.4. Petrografia

Foram descritas 51 lâminas delgadas, correspondentes aos principais litotipos da área de estudo, utilizadas para caracterização das rochas em microescala, incluindo determinação de paragêneses minerais e microestruturas associadas. Foi utilizado o microscópio óptico de luz polarizada modelo Zeiss Axio Imager.A2M do Laboratório de Microscopia de Pós-Graduação (M-Pós) da Universidade de Brasília.

4.5. Química mineral

Das 51 lâminas petrográficas descritas, 8 foram separadas para análise de química mineral em microssonda eletrônica (EPMA). Os minerais analisados foram granada, biotita, muscovita, clorita e ilmenita. A composição química das fases minerais foi determinada por meio da microssonda eletrônica JEOL® JXA-8230 Superprobe, operando em modo WDS (*Wavelength Dispersive X-Ray Spectrometry*), no Laboratório de Microssonda Eletrônica da Universidade de Brasília. Condições analíticas foram voltagem de aceleração 15 kV, corrente de 10nA e um tempo de análise de 10 segundos. Os efeitos de matriz foram corrigidos pelo método ZAF. Os padrões usados foram minerais naturais: andradita (SiO_2 e CaO), albita (Na_2O), forsterita (MgO), topázio (F), coríndon (Al_2O_3), microclínio (K_2O), vanadinita (Cl e V_2O_3), pirofanita (TiO_2 e MnO) e hematita (Fe_2O_3). A redução dos dados foi feita utilizando o pacote de software da microssonda eletrônica e posteriormente no software Qmin (Silva et al., 2021).

5. Contexto Geológico

5.1. Supercontinente Gondwana e o Orógeno Brasiliano

O orógeno transcontinental, composto pelas faixas Rio Preto, Riacho do Pontal, Sergipana e pelo Orógeno Oubanguides, foi formado durante o amálgama do Supecontinente Gondwana, resultante da colagem de fragmentos do antigo Supercontinente Rodínia (Trompette, 1997, 2000). Gondwana formou-se em duas aglutinações distintas: oriental e ocidental. A porção oriental de Gondwana era formada pelos terrenos atuais da Austrália, Índia, Leste da Antártica, Sri Lanka, e Madagascar, enquanto Gondwana Ocidental era composto pela América do Sul e toda ou a maior parte da África (Rogers e Santosh, 2004, Fig. 3). Rogers e Santosh (2004) apontam que as duas porções de Gondwana se diferenciam pela idade de cratonização (arqueana para Gondwana Oriental e proterozóica para Gondwana Ocidental) e atividade orogênica, com orógenos greenvilianos (1250 a 980 Ma, aproximadamente) preservados em Gondwana Ocidental enquanto a Orogenia Pan-Africana obliterou as estruturas greenvilianas na contraparte oriental. Para os autores o amálgama de Gondwana ocorreu devido aos eventos orogenéticos da Orogenia Brasiliana/Pan-Africana que se estendeu por quase todo o Neoproterozóico (~1000 Ma a ~500 Ma).

Segundo Brito Neves et al. (2014), os eventos orogenéticos do Brasiliano ocorreram em quatro pulsos principais: (i) Eo-Criogeniano (800–740 Ma); (ii) Neo-Criogeniano a Eo-Ediacarano (650–600 Ma); (iii) Eo- a Meso-Ediacarano (590–560 Ma) e (iv) Neo-Cambriano (520–500 Ma). Tais eventos deixaram registros na evolução da porção de Gondwana Ocidental, englobando os blocos continentais Amazônico, São-Francisco-Congo, Oeste Africano e outros menores, além dos oceanos intermediários (Fig. 4B) como Goiás, Adamastor e Borborema, e o braço deste que separava o Superterreno Pernambuco-Alagoas da Paleoplaca do São Francisco, designado Mar Canindé por D’el-Rey Silva (1992, 1995, 1999) e cujo fechamento resultou no Orógeno Sergipano-Oubanguides há cerca de 610-600 Ma.

No intervalo entre 800 e 600 Ma, o fechamento dos oceanos Goiás e Adamastor (Fig. 4B) deu origem às outras faixas dobradas em torno das margens oeste e sul-sudeste do Cráton do São Francisco (faixas Brasília, Ribeira, Araçuaí-Congo), mas a formação das faixas bordejando a margem leste do Cráton Amazônico (faixas Araguaia e Paraguai) e consequente amalgamação final de Gondwana Ocidental, envolveu ainda o ciclo de abertura e fechamento (em torno de 750 e 540 Ma) do Oceano Climene (não mostrado na Fig. 4B, Alves et al. 2019).

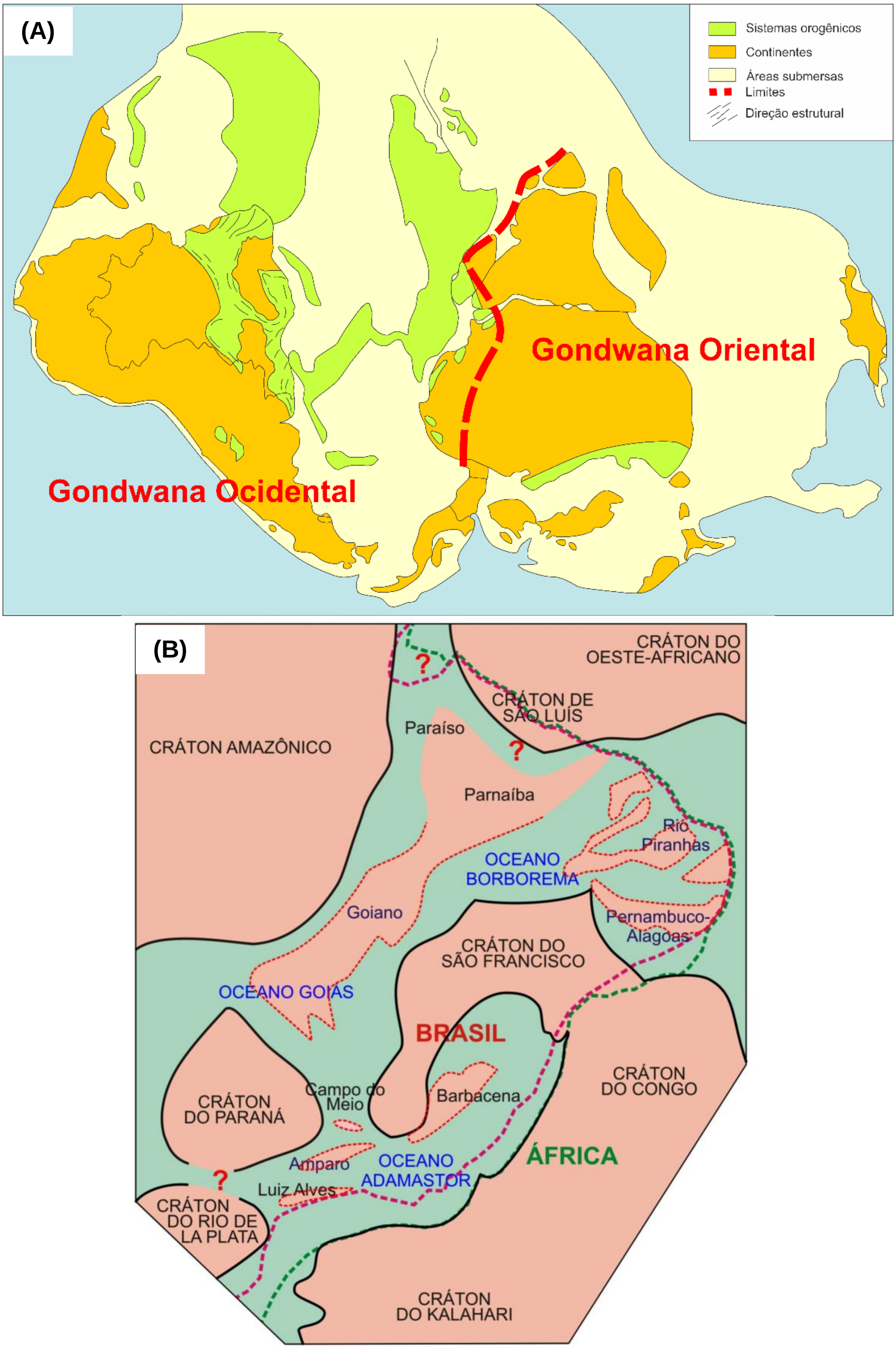

Figura 4: (A) Croqui esquemático mostrando as massas continentais que compunham Gondwana Ocidental e Oriental (Hasui, 2010). (B) Esboço de cenário paleogeográfico do fecho do Ciclo Brasiliano-Pan Africano, mostrando os principais segmentos colidentes (placas, microplacas, terrenos) e os principais sistemas orogênicos gerados.

5.2. A Faixa Sergipana

A Faixa Sergipana está inserida na Subprovíncia Meridional da Província Borborema (Fig. 2) e sua origem está estritamente ligada à Orogenia Brasiliana, ocorrida no Neoproterozóico. Foi inicialmente denominada de "Geossinclinal de Sergipe" ou "Propriá" (Humphrey e Allard, 1967), e, no advento da tectônica de placas passou a ser chamada de "Faixa Sergipana" (Brito Neves, 1975).

Davison e Santos (1989) interpretaram a Faixa Sergipana como colagem de cinco domínios tectono-estratigráficos distintos, separados por zonas de cisalhamento, de sul para norte: Vaza Barris, Macururé, Marancó, Poço Redondo e Canindé. A evolução teria começado com a colagem do Vaza Barris ao domínio cratônico ou Estância, situado a Sul (Silva Filho, 1982) e teria progredido gradualmente com os demais terrenos sendo colados sucessivamente a norte do anterior. Segundo Davison e Santos (1989), os domínios Vaza Barris e Macururé são constituídos principalmente por rochas metassedimentares, mas o último apresenta também litotipos vulcânicos subordinados e suas rochas foram intrudidas por diversos corpos graníticos. Os domínios Marancó e Canindé são constituídos majoritariamente por sequências metavulcanossedimentares intrudidas por corpos graníticos e o Domínio Poço Redondo é caracterizado por paragnaisses e ortognaisses migmatizados.

Para D'el-Rey Silva (1992, 1995, 1999) a Faixa Sergipana teria sido formada pela inversão de uma bacia de margem passiva, depositada na Paleoplaca do São Francisco, na colisão com o Superterreno Pernambuco-Alagoas durante o amálgama de Gondwana. Silva Filho e Torres (2002) e Silva Filho et al. (2003) propuseram mais dois domínios: Rio Coruripe e Viçosa, ainda pouco estudados. O Domínio Rio Coruripe, segundo os autores, é formado por uma sequência vulcanossedimentar associada a rifte com metabasaltos e formações ferríferas, intrudida por um complexo máfico-ultramáfico acamadado. O Domínio Viçosa (não individualizado na Fig. 2) seria composto por uma sequência metavulcanossedimentar intrudida por plútons graníticos de idade meso- a neoproterozóica. Por outro lado, alguns autores consideram que os domínios Poço Redondo e Marancó formam um domínio único, devido à sua estreita associação genética e à falta de evidência, em imagens de satélite LANDSAT e em trabalhos de campo, de zona de cisalhamento a separá-los (Carvalho, 2005; Oliveira et al., 2010, 2014, 2015, 2017).

No presente trabalho é adotada a classificação adaptada dos trabalhos mais recentes do Serviço Geológico do Brasil para o Estado de Sergipe (Teixeira et al., 2014) e para a folha Arapiraca (Mendes e Brito, 2017): domínios Estância, Vaza-Barris, Macururé, Marancó, Poço Redondo, Canindé e Rio Coruripe. Com exceção do Domínio Rio Coruripe, que é sobreposto por rochas metassedimentares do Domínio Macururé, todos os outros domínios são separados por zonas de cisalhamento, conhecidas de sul para norte como: Itaporanga, São Miguel do Aleixo, Belo Monte-Jeremoabo, Poço Redondo e Macururé. Para Silva Filho e Torres (2002) e Silva Filho et al. (2003), a Zona de Cisalhamento Belo Monte-Jeremoabo divide a Faixa Sergipana nos cinturões Sergipano, a sul, e Alagoano, a norte.

5.2.1. Evolução estrutural

Em termos da evolução estrutural da Faixa Sergipana, a correlação de fases de deformação entre domínios tem-se mostrado difícil, tendo em vista o provável diacronismo da deformação ao longo da faixa, bem como a possibilidade de que eventos deformacionais encontrados em um domínio podem não ser reconhecidos em outro (Oliveira et al., 2010). Para melhor entendimento, a deformação na Faixa Sergipana pode ser dividida em deformação das rochas dos domínios externos e deformação dos domínios internos (Oliveira et al., 2010, 2017).

Nos domínios externos são identificados quatro eventos deformacionais principais. O evento D_1 é caracterizado principalmente por dobras centimétricas a métricas isoclinais e recumbentes, com vergência SSW, que afetam tanto as rochas sedimentares quanto seu embasamento. O evento D_2 é o mais penetrativo e está associado à principal fase de colisão da Orogenia Brasiliana e transpõe fortemente as estruturas D_1. O evento D_3 é não penetrativo e ocorre em continuidade cinemática a D_2. O último estágio (D_4) é marcado pela continuação do soerguimento do orógeno, apresentando estruturas de regime rúptil a dúctil-rúptil, ou reativações das fábricas D_2 e D_3 (Oliveira et al. 2010).

Já nos domínios internos a deformação é mais complexa. Nos domínios Marancó e Poço Redondo é reconhecida uma história deformacional pretérita (D_{n-1}), relacionada à anatexia que gerou os migmatitos desses domínios. Esse evento foi superimposto por D_n, caracterizada principalmente por dobras isoclinais. Estruturas anteriores a D_{n-1} são reconhecidas em xenólitos anfibolíticos nos migmatitos. Carvalho (2005) descreve a presença de dois eventos deformacionais posteriores a D_n: D_{n+1}, caracterizado por foliação penetrativa com direção NW e dobras assimétricas com vergência para SSW. O evento D_{n+2} ocorre em continuidade cinemática a D_{n+1}. O Domínio Canindé apresenta deformação similar aos domínios Marancó e Poço Redondo. Nas rochas metassedimentares (Unidade Novo Gosto) são reconhecidas as deformações D_1 a D_4, enquanto nos anfibolitos do Complexo Gabróico há uma deformação anterior (D_n, Oliveira et al., 2010).

5.2.2. Evolução tectônica

Ainda não há consenso sobre a evolução geodinâmica da Faixa Sergipana. Conforme mencionado, há dois modelos atuais, ambos bem embasados, diferindo principalmente quanto à continuidade dos domínios Vaza Barris e Macururé.

O modelo geotectônico mais recente (Oliveira et al., 2010) considera que durante a ruptura do Supercontinente Rodínia, no Neoproterozóico, o Superterreno Pernambuco-Alagoas sofreu distensão, formando uma margem passiva onde foram depositados sedimentos concomitantemente à atividade vulcânica e posterior granitogênese, pertencentes ao Domínio Poço Redondo-Marancó, bem como os sedimentos do Domínio Macururé. Simultaneamente, ocorreu a formação de margem passiva oposta, no nordeste da Paleoplaca do São Francisco, com deposição de sedimentos correspondentes ao Domínio Vaza-Barris. Os blocos começaram a colidir por volta de 980-960 Ma, durante o Evento Cariris Velhos, formando o arco magmático Poço Redondo, na margem do Superterreno Pernambuco-Alagoas, junto com uma bacia de retroarco, sedimentando as sequências correspondentes ao Domínio Canindé (rifte Canindé). Esse rifteamento prosseguiu até cerca de 640 Ma, com intrusão de rochas magmáticas bimodais (características de ambientes de rifte) em 715 Ma, e outros magmatismos na margem passiva do Superterreno Pernambuco-Alagoas, além de evidência de assoalho oceânico no Domínio Canindé.

A convergência entre a Paleoplaca do São Francisco e o Superterreno Pernambuco-Alagoas levou à deformação da plataforma sedimentar do arco magmático durante a Orogenia Brasiliana, nos domínios Macururé, Poço Redondo-Marancó e Canindé, com presença de vários corpos graníticos sin-colisionais. Enquanto o fechamento ocorria, as formações superiores do Domínio Vaza-Barris e as rochas do

Domínio Estância estavam sendo depositadas na margem da Paleoplaca do São Francisco e, concomitantemente, deformadas. O fechamento da paleobacia continuou até por volta de 605 a 540 Ma, quando ocorreu a colisão continental, com duplicação da crosta e formação da Faixa Sergipana na configuração atual, como esquematizado na Fig. 5.

Segundo o modelo proposto anteriormente por D'el-Rey Silva (1992, 1995, 1999), a evolução da Faixa Sergipana pode ser interpretada similarmente a um orógeno clássico, resultante do fechamento de um oceano (Mar Canindé) onde os domínios Estância, Vaza-Barris e Macururé formariam uma cunha única de sedimentação proximal, intermediária e distal, desenvolvida em bacia assimétrica que evoluiu para bacia de margem passiva. Com relação aos domínios mais ao norte, o autor não dá uma interpretação única, porém todas são compatíveis com um episódio de subducção tipo B ao norte, talvez com um ambiente de *back-arc*. Em seu modelo é coerente classificar o Domínio Marancó como arco magmático que se desenvolveu no processo de subducção de crosta oceânica sob um fragmento continental (Domínio Poço Redondo) como também, em uma outra interpretação válida, o Domínio Marancó seria o registro de vulcanismo félsico-intermediário dentro da própria bacia precursora, que sofreu extensão sin-deposicional em larga escala. Nessa interpretação o Domínio Poço Redondo seria uma porção retrabalhada e soerguida da margem norte da Paleoplaca do São Francisco. A Fig. 6 mostra o modelo evolutivo proposto pelo autor.

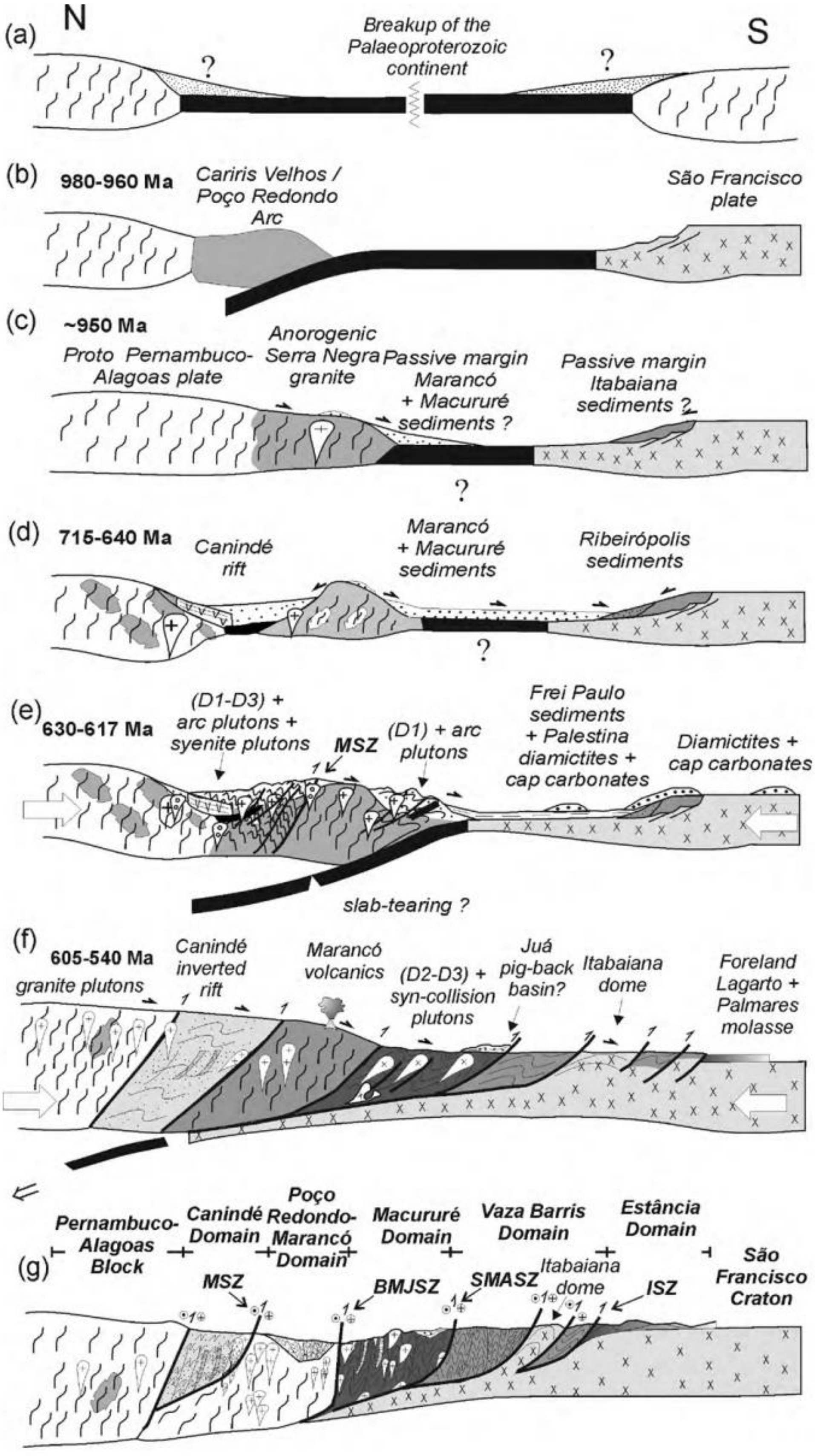

Figura 5: Modelo esquemático da evolução geotectônica da Faixa Sergipana proposto por Oliveira et al. (2010).

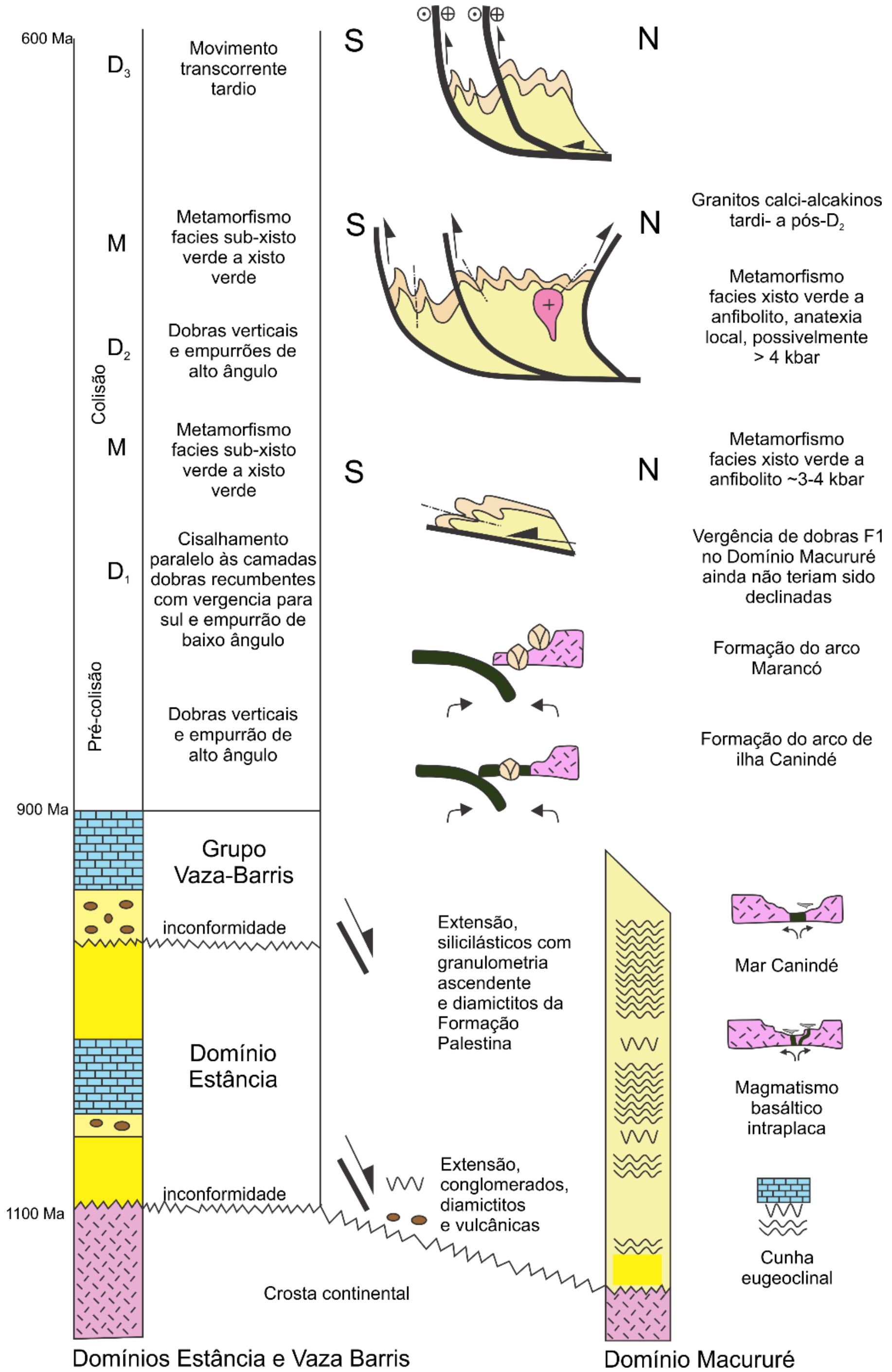

Figura 6: Modelo evolutivo para a Faixa Sergipana proposto por D'el-Rey Silva (1992).

5.2.3. Domínio Vaza-Barris

O Domínio Vaza-Barris possui estratigrafia um tanto controversa, havendo discordâncias entre o posicionamento cronológico bem como as subdivisões de suas unidades entre os principais autores que estudaram a região (Sial et al., 2010 e referências contidas). Neste trabalho será adotada a divisão do mapa geológico do Estado de Sergipe

(Teixeira et al. 2014). Os autores dividem esse domínio em dois grupos: Miaba e Vaza-Barris.

D'el-Rey Silva (1992) interpreta o Domínio Vaza-Barris como dois ciclos deposicionais representados por uma sucessão basal siliciclástica continental a marinha rasa, seguida por uma sequência carbonática. O primeiro ciclo deposicional é representado pelo Grupo Miaba, em que as formações Itabaiana e Ribeirópolis representam a sequência siliciclástica e a Formação Jacoca a sequência carbonática. O segundo ciclo deposicional compreende as formações do Grupo Vaza-Barris, cuja sequência siliciclática é representada pelas formações Frei Paulo e Palestina e a carbonática pela Formação Olhos d'Água. Uhlein et al. (2011) também consideram que a deposição do domínio aconteceu em dois ciclos deposicionais, associando-os à estratigrafia de sequências.

O Grupo Miaba, basal, é composto pelas formações Itabaiana, Ribeirópolis e Jacoca. A Formação Itabaiana, basal, encontra-se em não conformidade com o embasamento gnáissico-migmatítico e engloba quartzitos puros e impuros associados a metaconglomerados, metarenitos e metapelitos subordinados. A Formação Ribeirópolis, sobreposta à Formação Itabaiana, compreende filitos, metagrauvacas, metargilitos, metaconglomerados e, em menor proporção, metavulcanitos ácidos a intermediários. Sobrepondo essa sequência siliciclástica, encontra-se a Formação Jacoca, composta por dolomito sustentado por estromatólitos, intercalado com calcário e camadas subordinadas de metachert. A Formação Frei Paulo, base do Grupo Vaza-Barris, compreende filitos, metarenitos impuros, metarritmitos, metagrauvacas e metassiltitos. A Formação Palestina é formada por metadiamictitos, filitos subordinados e lentes locais de quartzitos. Já a Formação Olhos d'Água compreende metacarbonatos, metapelitos, metachert subordinados e metarritmitos.

5.2.4. Domínio Macururé

O Domínio Macururé, separado do Domínio Vaza-Barris pela Zona de Cisalhamento São Miguel do Aleixo, é formado basicamente por metapelitos (provavelmente de origem turbidítica) ricos em granada e micaxistos feldspático-aluminosos, intercalados por porções menores de quartzito, mármore e rochas metavulcânicas, com lentes de anfibolito, granada-anfibolito e clorita-xisto, todos na fácies metamórfica anfibolito (Bueno et al. 2009; Oliveira et al., 2010), depositado em não-conformidade com o embasamento (Domo Jirau do Ponciano).

Destacam-se duas formações: Santa Cruz (basal), caracterizada por quartzitos não ferruginosos que teriam sido depositados sobre o Domo Jirau do Ponciano, e Juá, essa provavelmente correlacionada à Formação Palmares, do Domínio Estância. A principal proveniência desse domínio foi a Província Borborema, e a idade de zircão detrítico mostra que as áreas fontes são mais antigas que as da Orogenia Brasiliano-Pan-Africana.

Teixeira et al. (2014) subdividem o Domínio Macururé na área do estado de Sergipe em unidades de micaxistos granadíferos, localmente ricos em quartzo; muscovita quartzitos cinza, finos a médios, bandados, muscovita-quartzo-(cianita) xistos e metaconglomerados subordinados; metarritmitos finos com lentes de dacitos; metagrauvacas e metarenitos finos; metassiltitos maciços; clorita-quartzo xistos milonitizados e metagabros, metabasaltos, metaperidotitos e talco xistos.

De grande importância nesse domínio é a presença de múltiplas intrusões graníticas. Conceição et al. (2016 e referências contidas) identificaram quatro tipos de plutonismo granítico na Faixa Sergipana: (1) granodiorítico cálcio-alcalino de alto potássio, representado por seis intrusões de idades entre 618±4 Ma e 625±2 Ma (Silva 2014; Long et al. 2005, respectivamente), tendo como principais representantes os batólitos Santa Helena, Coronel João Sá e *stock* Lagoa do Roçado; (2) monzonítico shoshonítico, com cerca de 11 *stocks* cartografados com idade de 588±5 Ma (Lisboa, 2014) para o *stock* Monzonítico Glória Norte (representante típico dessa granitogênese); (3) sienogranítico leucocrático cálcio-alcalino de alto potássio, granitogênese mais abundante na Faixa Sergipana com idades de magmatismo variando entre 571±9 Ma e 584±10 Ma (Bueno et al. 2009). É representado por cerca de duas dezenas de *stocks*, e as melhores exposições são os *stocks* Glória Sul, Pedra Furada, Angico e Lagoas; (4) granítico cálcio-alcalino com textura rapakivi, representado pelos *stocks* Propriá, Fazenda Alvorada e Amparo do São Francisco, com idades variando entre 615 ± 6 Ma e 643±72 Ma (Santos, 2017; Brito Neves e Cordani, 1973, respectivamente). Esses corpos graníticos registram o fechamento da bacia precursora da Faixa Sergipana durante a colisão entre a Paleoplaca do São Francisco e o Superterreno Alagoas.

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CAPÍTULO 2 – Artigo 1

Artigo 1: Accretion tectonics in Western Gondwana highlighted by the aeromagnetic signature of the Sergipano Belt, NE Brazil (aceito sem correções e publicado na *Tectonophysics*)

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Accretion tectonics in Western Gondwana highlighted by the aeromagnetic signature of the Sergipano Belt, NE Brazil

Gabriela M. Almeida *, Reinhardt A. Fuck, Darby P.D. de Lima, Elton L. Dantas

Instituto de Geociências, Universidade de Brasília, Campus Universitário Darcy Ribeiro, 70910-900 Brasília, DF, Brazil

A R T I C L E I N F O

Keywords:
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Suture zone
Brasiliano Orogeny
Geodynamic evolution
Gondwana reconstruction
Borborema Province

A B S T R A C T

Identification of suture zones in Precambrian orogens can be a major problem due to later reworking and/or erosion. Interpretation of aerogeophysical data is a useful tool to the understanding of the structure and evolution of old fold belts. In this study, we use aeromagnetic data to identify domain boundaries in the Sergipano Belt (SB), a Neoproterozoic orogen developed on the northern border of the São Francisco Craton (SFC), NE Brazil. The SB was formed due to convergence between the SFC and the Pernambuco-Alagoas Superterrane during the Brasiliano Orogeny, culminating in the assembly of West Gondwana. Total Magnetic Intensity (TMI) and tilt derivative maps provided the delimitation of magnetic domains corresponding to main lithological units of the Sergipano Belt and its basement and the definition of first to fourth order lineaments. Matched filter and Euler deconvolution results allowed to observe the magnetic behavior of both domains and lineaments in depth. The data suggest that the Marancó and Poço Redondo domains are two distinct lithotectonic units and that the Jirau do Ponciano dome, extreme NE of the Sergipano Belt, is likely a structural window of the São Francisco paleoplate reworked basement. Interpretation of these results combined with existent geological data allowed to highlight at least two possible terrane boundaries in the northern margin of the São Francisco Craton, represented by the São Miguel do Aleixo and Belo Monte-Jeremoabo shear zones, and the definition of the High-Intensity Magnetic Zone, which comprises a ca. 10 km wide and 140 km long corridor of mafic and ultramafic rocks, and represents the main suture zone within the SB. The data imply that the Sergipano Belt evolved as an accretionary orogen during West Gondwana assembly.

Accretion tectonics in Western Gondwana highlighted by the aeromagnetic signature of the Sergipano Belt, NE Brazil

Gabriela M. Almeida[1]*, Reinhardt A. Fuck[1], Darby P. D. de Lima[1], Elton L. Dantas[1]

[1]Instituto de Geociências, Universidade de Brasília, Campus Universitário Darcy Ribeiro, 70910-900, Brasília, DF, Brasil

*corresponding author: geol.gmalmeida@gmail.com

Abstract

Identification of suture zones in Precambrian orogens can be a major problem due to later reworking and/or erosion. Interpretation of aerogeophysical data is a useful tool to the understanding of the structure and evolution of old fold belts. In this study, we use aeromagnetic data to identify domain boundaries in the Sergipano Belt (SB), a Neoproterozoic orogen developed on the northern border of the São Francisco Craton (SFC), NE Brazil. The SB was formed due to convergence between the SFC and the Pernambuco-Alagoas Superterrane during the Brasiliano Orogeny, culminating in the assembly of West Gondwana. Total Magnetic Intensity (TMI) and tilt derivative maps provided the delimitation of magnetic domains corresponding to main lithological units of the Sergipano Belt and its basement and the definition of first to fourth order lineaments. Matched filter and Euler deconvolution results allowed to observe the magnetic behavior of both domains and lineaments in depth. The data suggest that the Marancó and Poço Redondo domains are two distinct lithotectonic units and that the Jirau do Ponciano dome, extreme NE of the Sergipano Belt, is likely a structural window of the São Francisco paleoplate reworked basement. Interpretation of these results combined with existent geological data allowed to highlight at least two possible terrane boundaries in the northern margin of the São Francisco Craton, represented by the São Miguel do Aleixo and Belo Monte-Jeremoabo shear zones, and the definition of the High-Intensity Magnetic Zone, which comprises a ca. 10 km wide and 140 km long corridor of mafic and ultramafic rocks, and represents the main suture zone within the SB. The data imply that the Sergipano Belt evolved as an accretionary orogen during West Gondwana assembly.

Keywords: Sergipano Belt; suture zone; Brasiliano Orogeny; geodynamic evolution; Gondwana reconstruction; Borborema Province

1. Introduction

The understanding of the tectonic evolution of Precambrian terranes is a tricky issue due to their geological complexities and obliteration of large parts of their structures, be it because of erosion or superimposition of younger tectonic events. This difficulty resides in the reconstruction of the evolutive process that generated these terranes, as well as in the precise location of suture zones between different blocks. Magnetic, as well as gravity, data have been recently used with success for better understanding and delimitation of geological terranes (e.g. Catalán et al., 2012; Chernicoff et al., 2014; Rajaram and Anand, 2014; Abedi and Oskooi, 2015; Oskooi and Abedi, 2015; Abedi and Bahroudi, 2016; Sampaio et al., 2017; Abedi et al., 2018; Benhenni et al., 2019; Souza et al., 2019; Sehsah et al., 2019; Nasri et al., 2020).

In this paper, we use airborne magnetic data to characterize the Sergipano Belt (SB), NE Brazil, and its adjacent basement. This belt resulted from continental blocks that collided during West Gondwana amalgamation at the end of the Neoproterozoic. The collision generated a 1000 km long continental orogen on the northern margin of the São

Francisco Craton (Fig. 1) composed of the Rio Preto, Riacho do Pontal and Sergipano belts (Caxito et al., 2016 and references therein), in South America, extending through NW Africa, in the Oubanguides Orogen, on the northern margin of the Congo Craton (Trompette, 1997).

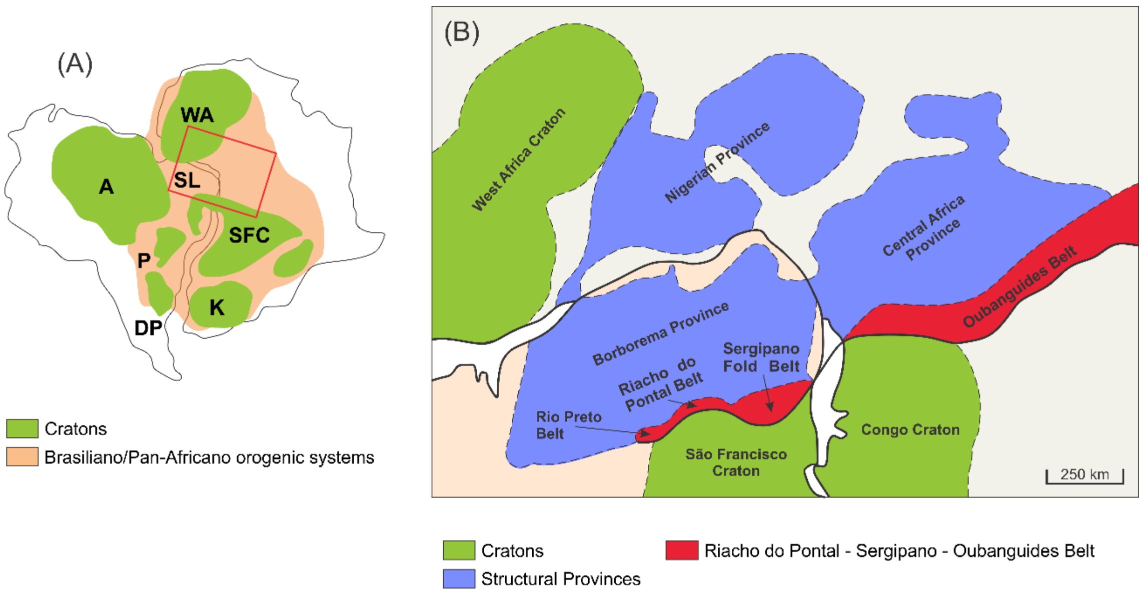

Figure 1: (A) Cratons and Brasiliano/Pan-African orogenic systems of West Gondwana (South America and Africa) and the geotectonic framework of the Brazilian territory, modified from Heilbron et al. (2017); A: Amazonian Craton; WA: West African Craton; SL: São Luís Craton; P: Paranapanema Craton; SFC: São Francisco-Congo Craton; K: Kalahari Craton: DP: Rio de La Plata Craton. (B) A closer view of the rectangle area in Figure 1A, highlighting the transcontinental orogen comprising the Rio Preto, Riacho do Pontal, Sergipano and Oubanguides orogens on the boundary between the São Francisco and Congo cratons (South) and the Borborema and Central Africa provinces (modified from Brito Neves et al., 2001).

The São Francisco Craton (SFC) is, perhaps, the most studied Precambrian terrane of South America and is a key for understanding the evolution of the Gondwana supercontinent. It was first defined by Almeida (1977) and comprises mostly Archean TTG-gneisses, granitoids, and greenstone belts, together with Paleoproterozoic plutons and supracrustal successions (Heilbron et al., 2017). The history of knowledge about the SFC, its limits, and marginal belts is extensively summarized in Heilbron et al. (2017) and references therein. In this paper, we focus on the northern limit of SFC, more precisely in the Sergipano Belt, for which the exact position of a suture is still object of extensive debate.

For D'el-Rey Silva (1992), the paleosuture lies along the southern border of the Pernambuco-Alagoas superterrane (PEAL). West of the Tucano Basin the suture would coincide with the Macururé Shear Zone. On the other hand, Oliveira et al. (2010) believe that the suture lies along the São Miguel do Aleixo Shear Zone. Through gravity and aeromagnetic data, Oliveira and Medeiros (2018), at first view, support the Oliveira et al. (2010) proposal, defining the north São Francisco Craton limit along the São Miguel do Aleixo Shear Zone.

Available magnetic data allowed us to delimit magnetic domains and lineaments for the area as well as their extent in depth. For this, tilt derivative, Matched Filter, and Euler Deconvolution were applied to the total magnetic intensity (TMI) map. The results lead us to interpret the main paleosuture and at least two possible terrane boundaries in the Sergipano Belt, leading to key information to a better understanding of the structure of the belt and its role in the amalgamation of Gondwana.

2. Geological setting

2.1. Summary

The Sergipano Belt is an ESE-WNW trending orogen located in the southern Borborema Province, formed during the Brasiliano Orogeny due to oblique collision between the São Francisco Craton and the Pernambuco-Alagoas Superterrane. Despite the different interpretations, it is agreed that this orogen was formed by the closure of a passive margin basin (D'el-Rey Silva, 1992, 1995; Oliveira et al., 2010, 2014; Neves et al., 2016).

The Sergipano Belt is usually divided into six lithostratigraphic domains, from south to north: Estância, Vaza Barris, Macururé, Marancó, Poço Redondo, and Canindé (Fig. 2). Regional shear zones divide these domains: Itaporanga, São Miguel do Aleixo, Belo Monte-Jeremoabo, Poço Redondo and Macururé, respectively (Davison and Santos, 1989; Silva Filho and Torres, 2001; Sousa et al., 2019). The Rio Coruripe domain was suggested by Silva Filho and Torres (2001) and has recently been defined as a distinct unit (Neves et al., 2016; Mendes and Brito, 2017), a proposal used in the present work (Fig. 2).

The Estância, Vaza Barris, Macururé and Rio Coruripe domains are composed mainly of metasedimentary rocks, which metamorphic grade varies from anchimetamorphism (Estância) to greenschist (Vaza Barris and Macururé) to amphibolite facies (Macururé), reaching granulitization stages (Rio Coruripe). The Macururé Domain presents multiple Neoproterozoic igneous intrusions. The Marancó, Poço Redondo and Canindé domains display more diverse rock associations, such as granitic rocks, metavolcanosedimentary sequences, migmatites, and mafic and ultramafic rocks) and are interpreted as allochthonous blocks, accreted during the Neoproterozoic (Oliveira et al., 2010).

The igneous intrusions present in the Sergipano Belt record the tectonic events associated with the SFC-PEAL collision. The Cariris Velhos event (Brito Neves et al., 1995, Santos et al., 2010 and references therein) is represented by the Serra Negra augen-gneiss, a 951.8±1.5 Ma old leucogranitic body that intrudes the Marancó and Poço Redondo domains (Carvalho, 2005). The Brasiliano event (Cordani et al. 1973, Almeida et al. 1973; Brito Neves et al., 2014 and references therein) is represented by a variety of

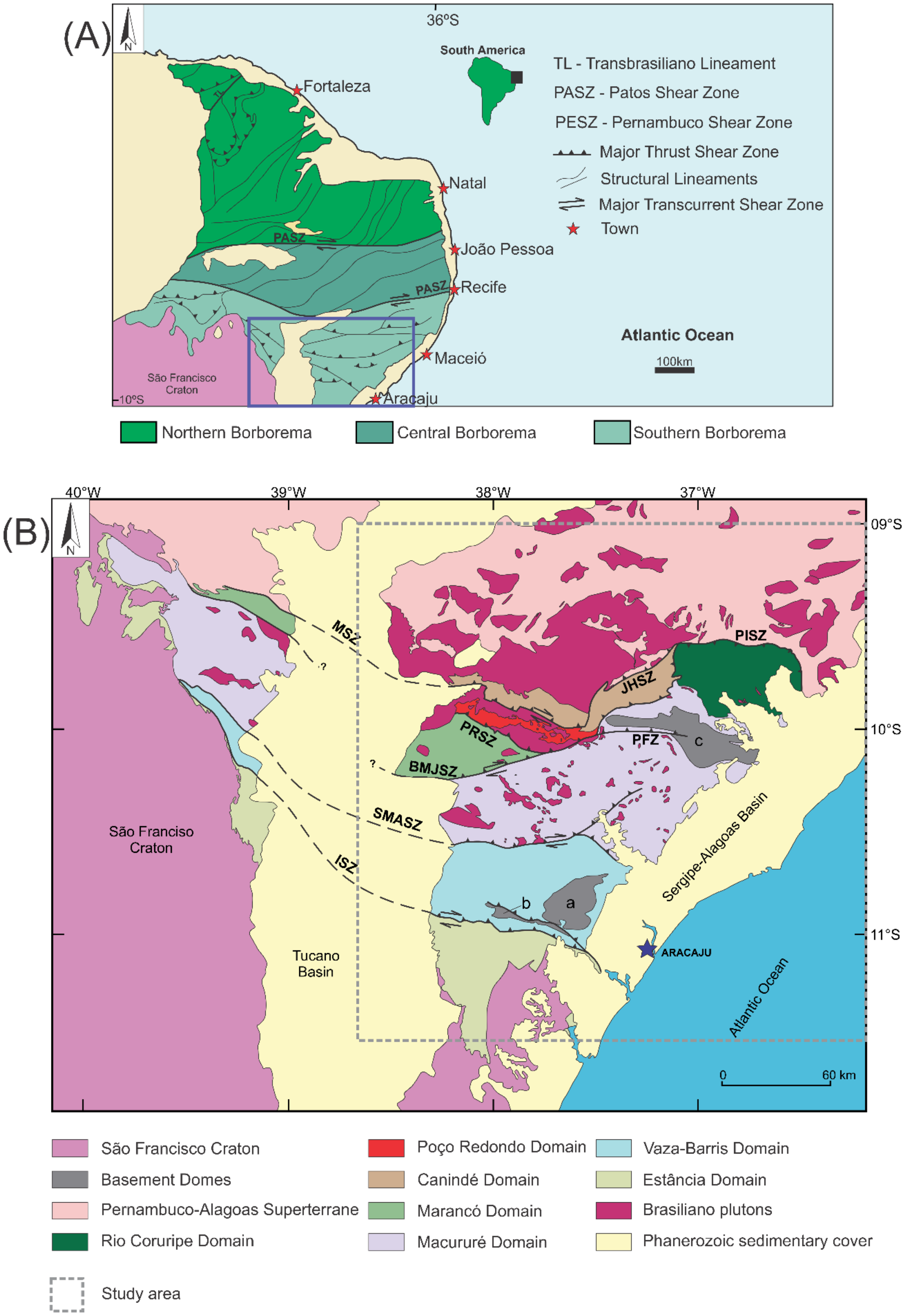

Figure 2: (a) Schematic map of the Borborema Province showing the three sub-provinces with emphasis on the Sergipano Fold Belt (modified from Brito Neves et al., 2000); (b) Geological map of the Sergipano Fold Belt modified from Pinho Neto (2018). Basement domes: a – Itabaiana;

b – Simão Dias, c – Jirau do Ponciano. Shear zones: ISZ – Itaporanga; SMASZ – São Miguel do Aleixo; BMJSZ – Belo Monte-Jeremoabo; PFSZ – Porto da Folha; PRSZ – Poço Redondo; MSZ – Macururé; JHSZ – Jacaré dos Homens, PISZ – Palmeira dos Índios.

intrusions in the Poço Redondo, Marancó, Canindé and, especially, in the Macururé domains. Conceição et al. (2016) divide these intrusions according to their composition and crystallization age: mafic-ultramafic rocks (626 to 620 Ma), leucogranites (626 Ma), granodiorites (625 to 618 Ma) and shoshonitic rocks (616 to 608 Ma and 588 Ma).

Three basement domes stand out in the Sergipano Belt (D’el-Rey Silva, 1992, 1999). The Itabaiana and Simão Dias domes are composed of Archean gneissic-migmatitic rocks and occur in the southeastern portion of the orogen. They constitute the basement of the sedimentary rocks deposited in the Vaza Barris precursor basin (D’el-Rey Silva, 1992, 1995, 1999; Del-Rey Silva and McClay, 1995). The Jirau do Ponciano dome is located in the northeastern portion of the orogen and comprises a core of Archean tonalitic orthogneisses to granodiorites surrounded by the metavolcanosedimentary rocks of the Nicolau-Campo Grande Complex (Lima et al., 2018).

2.2. Previous geotectonic models

The first studies of the Sergipano Belt (Humphrey and Allard, 1967) characterized this orogen in terms of a geosyncline. Brito Neves et al. (1977) and Silva Filho et al. (1978) were pioneers to interpret the Sergipano Belt in the light of plate tectonics. The former assumed that this orogen was formed by oblique collision between the São Francisco Craton and the Pernambuco-Alagoas Superterrane, called a massif at that time. Campos Neto and Brito Neves (1987) interpreted the orogen as a series of major tangential thrust nappes produced during the collision. Jardim de Sá et al. (1986) also recorded low angle thrusting between the fold belt and the São Francisco Craton (Davison and Santos, 1989).

Davison and Santos (1989) stated that the Sergipano Belt was the result of a NE-SW to NNE-SSW-directed continental shortening between the São Francisco Craton and the Pernambuco-Alagoas Superterrane during the Brasiliano Orogeny. For these authors, the belt is a collage of six distinct terranes bounded by sub-vertical regional shear zones continuous from one to the other side of the Tucano basin. Such interpretation suggests shear zones with large sub-horizontal displacements that eventually juxtaposed allochthonous terranes representing distinct crustal levels. All models before Davison and Santos (1989) considered the buildup of the belt after deformation of a single contiguous basin.

D'el-Rey Silva (1992) resumed the idea of lithostratigraphic continuity between the domains across a precursor basin. For the author, the Sergipano Belt fits the model of a classic orogen resulting from the closure of a narrow ocean (Canindé Sea), where the sedimentary rocks of the Estância, Vaza Barris and Macururé domains would represent a single wedge of continental to marine proximal, intermediate, and distal sedimentation, respectively. The corresponding sediments would have been deposited in an asymmetric basin, which evolved to a passive margin at the northern edge of the São Francisco paleoplate, subsequently subducted under the southern edge of the Pernambuco-Alagoas Superterrane. In this model, the suture zone would be located along the Macururé Shear Zone, the westernmost segment of the long fault stretching along the southern border of PEAL (Fig. 2).

According to the most recent model (Oliveira et al., 2010), the Sergipano Belt records the closure of an ocean in a complete Wilson cycle. These authors suggest that the Macururé Domain rocks were deposited on the southern margin of the Pernambuco-

Alagoas Superterrane, while the Estância and Vaza Barris rocks were deposited on the northern margin of the São Francisco paleoplate. Based on several detrital zircon U-Pb ages, these authors argue that the uppermost formation of sandstones on top of the cratonic Estância domain is the record of a former foreland basin. In their model, the São Miguel do Aleixo Shear Zone would be the most probable suture zone between the two colliding blocks. Based on regional scale gravity and magnetic data, Oliveira and Medeiros (2018) support such a model, suggesting the São Miguel do Aleixo Shear Zone as the suture zone.

Recently, based on new detrital zircon ages for the Rio Coruripe domain and reinterpretation of the data presented by Oliveira (2008) and Dias et al. (2015), Neves et al. (2016) consider impracticable the existence of an ocean in the Sergipano Belt. Differently of the previous models, Neves et al. (2016) propose a model based on a continuous continental crust basement. According to them, the Sergipano Belt derives from basin inversion after a large scale intraplate lithospheric extension in a pre-existent continent.

3. Materials and methods

Geophysical data used in this paper are from aerial surveys of Projeto Geofísico do Estado de Sergipe (1102) and Projeto Geofísico Paulo Afonso-Teotônio Vilela (1104) undertaken by the Brazilian Geological Survey (CPRM). These projects embrace the eastern portion of the Sergipano Belt (eastward of the Tucano Basin, Fig. 2), comprising an area between 9°S and 11°30’S and 36°W and 38°45’W (Study area in fig. 2). Both projects were acquired with N-S flight lines spacing 500 m and E-W control lines spacing 10 km, with 100 m average height flight. Data processing and analysis were accomplished using Geosoft Oasis Montaj^{TM} v9.3 software.

Database integration before data processing is an important procedure for uniformization and standardization of magnetic characteristics. Grid knit function was applied as the suture method between the two surveys, in order to correct any errors and eliminate background noise, mainly at the edges of the magnetic data junction. Both projects have the same specifications, datum (WGS84) and are in the same UTM zone, which facilitated the procedure.

3.1. Processing and enhancement techniques

Data processing and enhancement techniques are essential for magnetic characterization and geological interpretation. The basis for processing and data interpretation was the micronivelated total magnetic intensity (TMI, total magnetic field reduced from International Geomagnetic Reference Field - IGRF). Reduction to the pole (RTP, Baranov, 1957; Baranov and Naudy, 1964) and differential reduction to the pole (dRTP, Cooper and Cowan, 2005) were processed but the results were not satisfactory due to the algorithm instability at low latitudes.

3.1.1. Tilt derivative

The tilt derivative (Miller and Singh, 1994) represents the application of the arctangent function of the vertical derivative $\left(\frac{\partial m}{\partial z}\right)$ and the total horizontal gradient amplitude. This enhancement technique is useful in the detection of linear trends that can be related to subsurface geological structures.

3.1.2. Matched filter

This filter proposed initially by Spector and Parker (1979) aims at the separation of anomalies by depth. This technique is used in the Fourier domain, in which the potential spectrum is observed and adjusted by several linear tendencies that represent the anomalies groups for distinct depths.

3.1.3. Euler deconvolution

Euler deconvolution is applied as a quantitative tool in the investigation of the anomalous source depths. This tool is also a support in the solution for problems in magnetic and gravimetric data interpretation (Reid et al., 1990, 2014).

The application of Eq. (1) to the potential datum infers that the field relative to this datum obeys the Euler homogeneity relationship.

$$(x - x_0)\frac{\partial P}{\partial x} + (y - y_0)\frac{\partial P}{\partial y} + (z - z_0)\frac{\partial P}{\partial z} = \eta P \quad (1)$$

For magnetic data, a magnetic anomaly (P, P = (x, y, z)) produced by a tridimensional point source located in (x_0, y_0, z_0) coordinates satisfy the 3D Euler homogeneous equation, also called standard Euler deconvolution. The structural index (η) represents the change in the potential field due to the distance in meters (Reid et al., 1990; Barbosa and Silva, 2005). For each chosen structural index, the standard Euler deconvolution estimates the coordinates and depth of the anomalous source (Barbosa and Silva, 2005). Each index is represented by uncertainties according to the position and depth expressed in percentage (Geosoft, 2015). This research used the structural indexes zero, 0.5, and 1.0.

4. Results

The basis for all interpretations was the TMI, tilt derivative maps (Fig. 3), Matched Filter, and Euler deconvolution techniques. The qualitative analysis allowed the separation of magnetic domains, identification of main lineaments directions at different depths, location of Euler solutions, and correlation of magnetic structures with the structural framework of the Sergipano Belt and adjacent areas.

4.1. Magnetic domains

The interpretation of magnetic domains follows the premise that the crustal framework is related directly with the magnetic contrast between the different domains. For the sake of simplification, our interpretation is based on the combination of TMI and tilt derivative maps, considering that only induced magnetization is present in the area. As magnetic boundaries reflect rocks and their structures in-depth, these limits are not coincident with those at the surface. Therefore, the units here described are called magnetic domains. The Sergipano Belt and its surroundings comprise eleven magnetic domains (A to K, Fig. 4) summarized in Table 1.

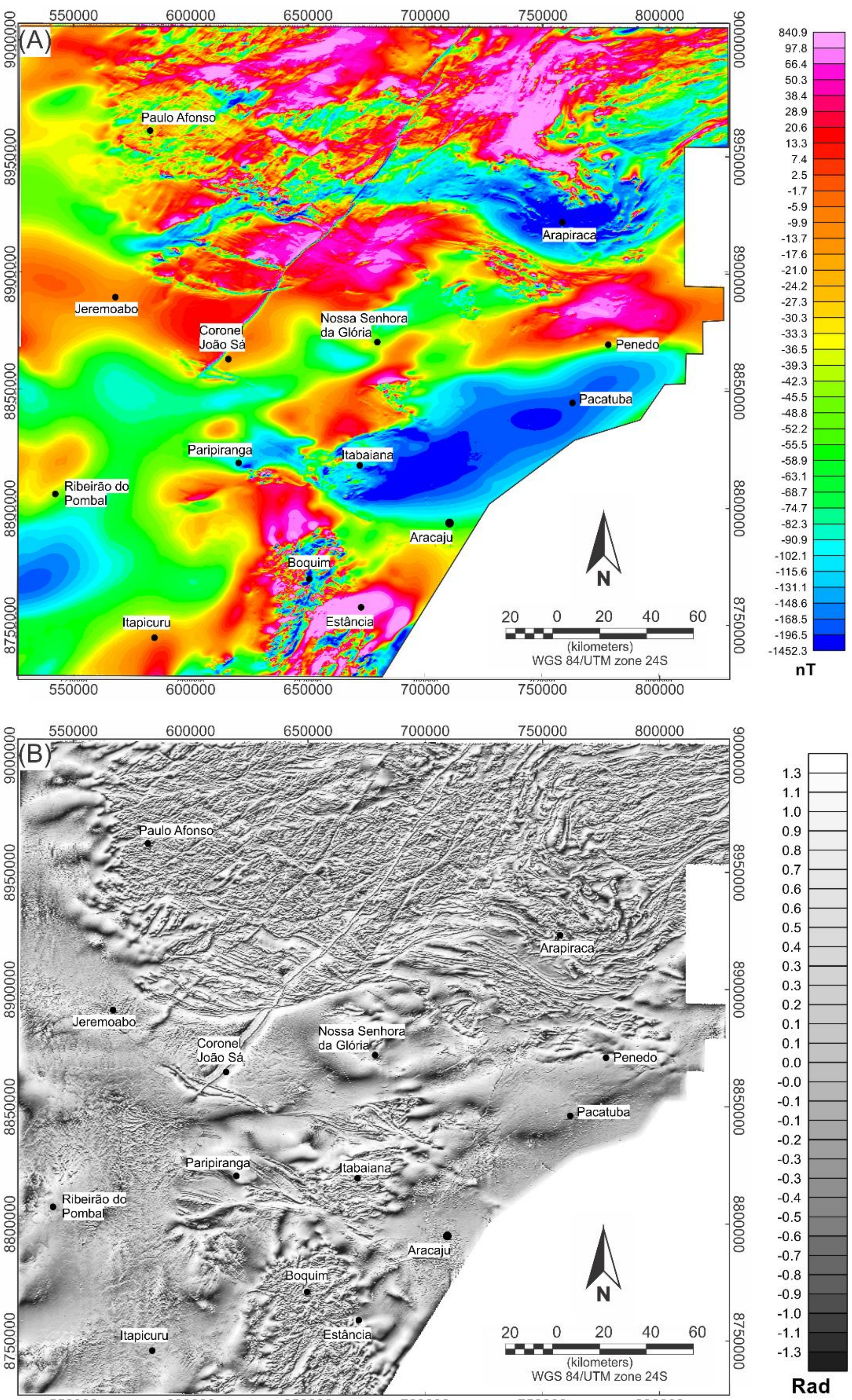

Figure 3: (A) Total Magnetic Intensity (TMI) and (B) tilt derivative maps of the study area.

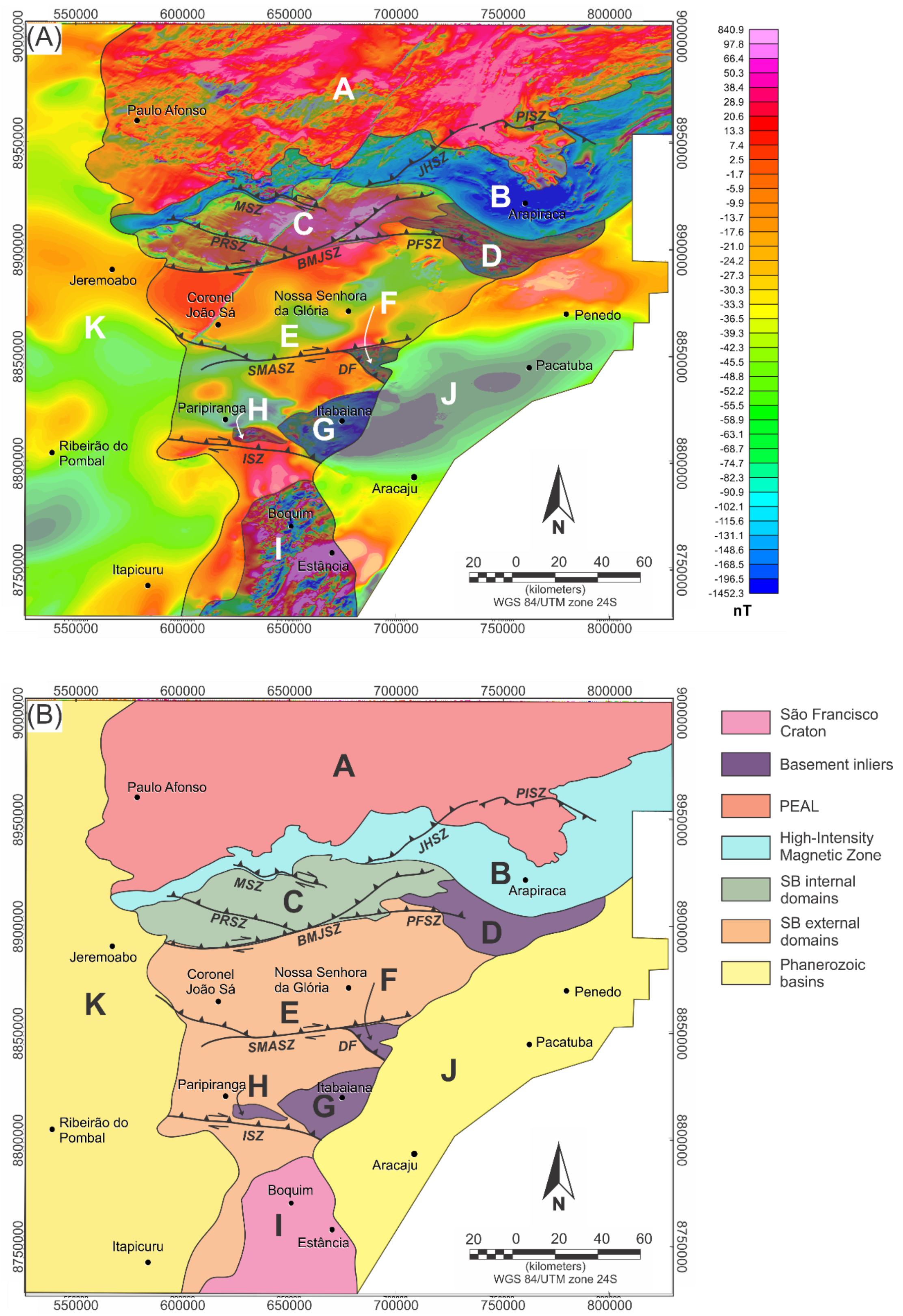

Figure 4: Magnetic domains interpretation (using TMI and tilt derivative maps) and main Sergipano Belt shear zones. (B) Magnetic domains without TMI map. Shear Zones: DF: Dores Fault; BMJSZ: Belo Monte-Jeremoabo Shear Zone; PFSZ: Porto da Folha Shear Zone; PRSZ:

Poço Redondo Shear Zone; MSZ: Macururé Shear Zone; JHSZ: Jacaré dos Homens Shear Zone; PISZ: Palmeira dos Índios Shear Zone.

4.2. Matched filter

The radial potential spectrum allows us to obtain depth values from distinct sources in different crustal levels. Five main depth levels for the top of magnetic sources are estimated: 0.18 km, 0.47 km, 1.50 km, 5.83 km, and 8.88 km (Fig. 5).

4.3. Magnetic lineaments

Magnetic lineaments show the main directions of geological structures in the subsurface, such as faults, dykes, and lithologic boundaries, which are essential features to identify shear zones. The magnetic lineaments map and its interpretation were made using the tilt derivative map (Fig 3B).

The areas correspondent to the Phanerozoic basins were isolated and only the lineaments related to the Sergipano Belt and its basement (SFC, PEAL, and basement domes) are interpreted (Fig. 6). Lineaments are also analyzed in different depths using the matched filter data (Fig. 7) to observe the behavior of these structures in depth. Four main orders of lineaments are described and summarized in Table 2.

Table 1: Major characteristics of magnetic domains on the TMI and tilt derivative maps.

Domain	Units	Magnetic field (nT)	Characteristics
A	PEAL	-39.3 to 840.9	Rough magnetic relief, crosscut by several magnetic lineaments with three main directions: NNE-SSW, ESE-WNW, and NE-SW.
B	High-Intensity Magnetic Zone (HIMZ)	-1452.3 to -74.7	Region dominated by high negative magnetic values located between PEAL and SB. Presents rough magnetic relief and comprises parts of Rio Coruripe and Canindé domains.
C	SB internal domains	-1452.3 to -74.7	Rough magnetic relief, characterized by ESE-WNW lineaments crosscut by NNE-SSW lineaments. Corresponds to Marancó, Poço Redondo, and part of Canindé domains, which are separated by shear zones recorded in TMI map with negative magnetic signatures between -1452.3 and 74.7 nT. Represents the internal zone (D'el-Rey Silva, 1992) or the allochthonous domains (Oliveira et al. 2010) of the belt.
D	Jirau do Ponciano dome (JPD)	-74.7 to 38.4	Basement inlier with rough magnetic relief and ESE-WNW trend.

E	SB external domain	-102.1 to 28.9	Smooth magnetic relief. Crosscut by two sets of E-W lineaments correspondent to SMAZS and ISZ, limiting the Macururé, Vaza-Barris, and Estância metasedimentary domains. It represents the cratonic and external zones (D'el-Rey Silva, 1992) or autochthonous domains (Oliveira et al., 2010) of the belt.
F	-	-36.5 to -90.9	Rough magnetic relief. Probably corresponds to an unexposed reworked basement inlier covered by supracrustal rocks of the Macururé Domain and Sergipe-Alagoas Basin.
G	Itabaiana Dome (ID)	-1452.3 to -82.3	Basement inlier with rough magnetic relief.
H	Simão Dias Dome (SDD)	-36.5 to 38.5	Southernmost basement inlier with rough magnetic relief.
I	SFC	-1452.3 to 840.9	Rough relief, crosscut by two main sets of lineaments: NNE-SSW and ESE-WNW.
J	Sergipe-Alagoas Basin	-1452.3 to 840.9 nT	Smooth magnetic relief.
K	Tucano Basin	-196.5 to 13.3	Smooth magnetic relief.

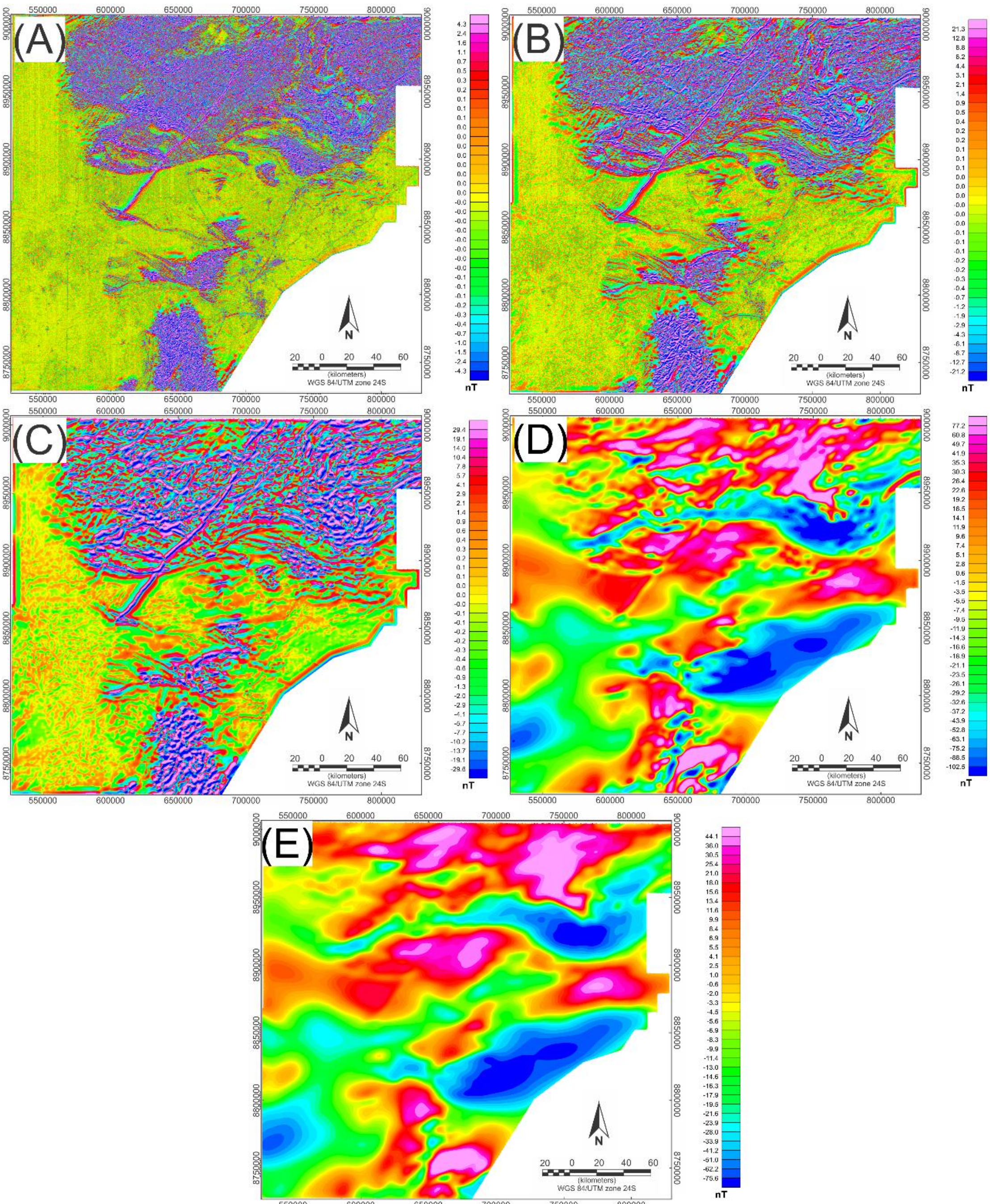

Figure 5: Matched filter results applied to TMI map. Different source depths with top at: (A) 0.18 km; (B) 0.47 km; (C) 1.50 km; (D) 5.83 km; (E) 8.88 km.

Table 2: Summary of main lineament directions

Lineament order	**Main trend**	**Mean direction**	**Description**
First	E-W to NE-SW	N82E	Delimits magnetic domains (dark green lines in Fig. 6), appears expressively at 1.5 km depth, and can be observed until 8.88 km depth in the matched filter maps. Can reach lengths of 95.28 km.
Second	NNE-SSW	N55E	Abundant within the PEAL and CSF domains (red and light green lines in Fig. 6, respectively). They are more expressive in shallower depths, becoming sparse at 5.83 km and disappearing at 8.88 km depth. They are approximately 28.78 km long; a set of these lineaments extends from PEAL to the São Miguel do Aleixo Shear Zone, reaching a length of approximately 190 km.
Third	ESE-WNW	N75W	SB main trend (purple and yellow lines in Fig. 6). They are approximately 16 km long, eventually reaching up to 85.5 km. This lineament set is abundant until 0.47 km depth (Fig. 7), becoming sparse at 1.50 km. At 5.83 km depth, they can only be observed in the western

			portion of PEAL, vanishing at 8.88 km. They are also present in SFC (dark blue lines in Fig. 6).
	NE-SW	N73E	Restricted to the NE portion of PEAL, reaching up to 58 km. This set of lineaments is expressive until 0.47 km depth, sparse at 1.50 km, and vanishes at 8.88 km depth.
Fourth	-	-	Restricted to the external domain of the Sergipano Belt, where they are represented by regional folds (yellow lines, Fig, 6), associated with ESE-WNW lineaments, which play the role of axial planes. These lineaments have lengths of approximately 11.84 km and their main direction varies according to the axial plane of the folds.

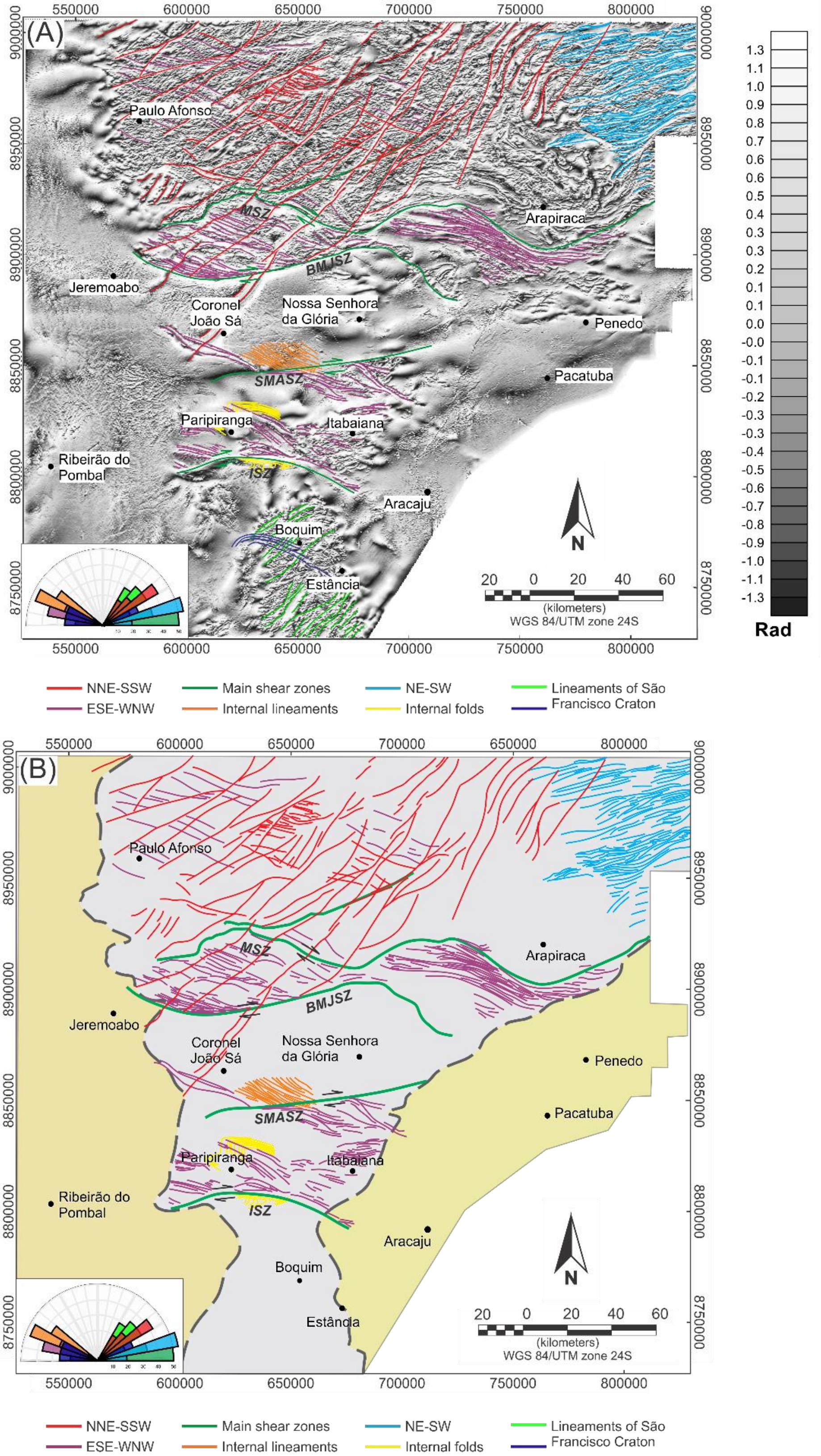

Figure 6: (A) Extraction of magnetic lineaments in the tilt derivative map. (B) Map of main lineaments. Shear zones: MSZ (Macururé), BMJSZ (Belo Monte-Jeremoabo), SMASZ (São Miguel do Aleixo) and ISZ (Itaporanga).

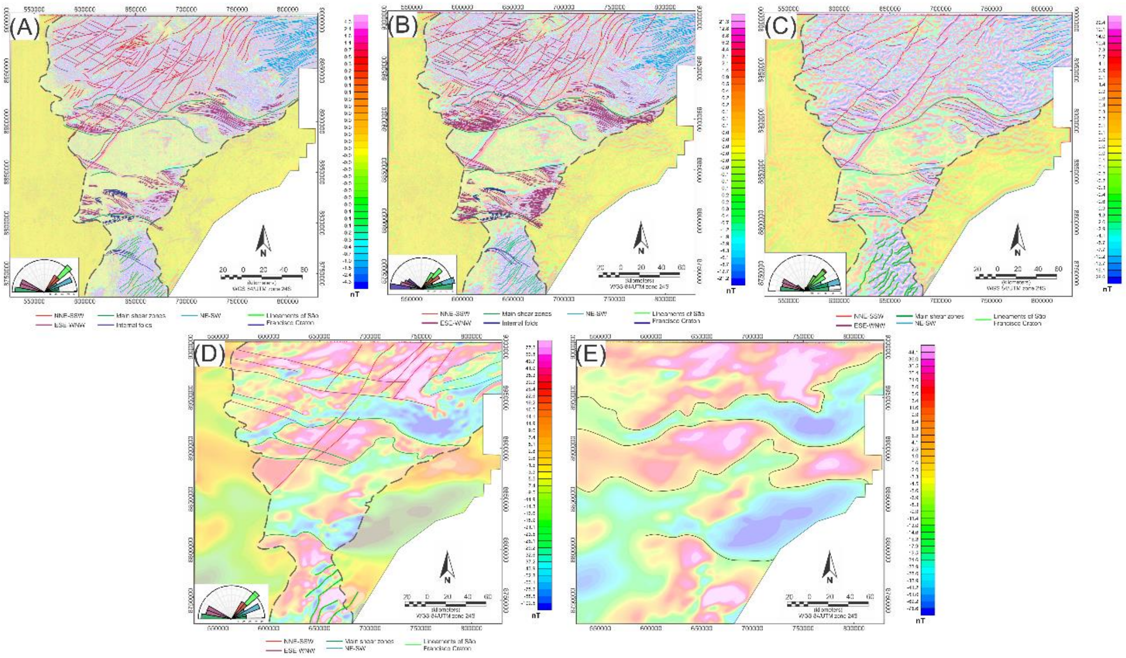

Figure 7: Magnetic lineaments interpreted in Matched filter for depths of: (A) 0.18 km; (B) 0.47 km; (C) 1.50 km; (D) 5.83 km; (E) 8.88 km.

4.4. Euler deconvolution

Data obtained by Euler deconvolution are used to reinforce the geological interpretation. A 1500 m wide window was applied, with structural indexes (SI) 0, 0.5, and 1. The structural index 1 is the best fit to characterize the structures in depth (Fig. 8). Individualized Euler solutions for SI 1 are shown in Fig 9.

Most depths found are around 400 m, as shown in Fig 9. Depths up to 500 m highlight the regional main lineaments trends. The dominance of shallow sources in Euler solutions follows the behavior of the regional TMI map, which presents several magnetic features associated with high-frequency anomalies.

Results obtained by Euler deconvolution display good correlation with the magnetic lineaments, especially when compared to matched filter results. There is a good correlation between the depths in the two methods, implying good consistency of the data.

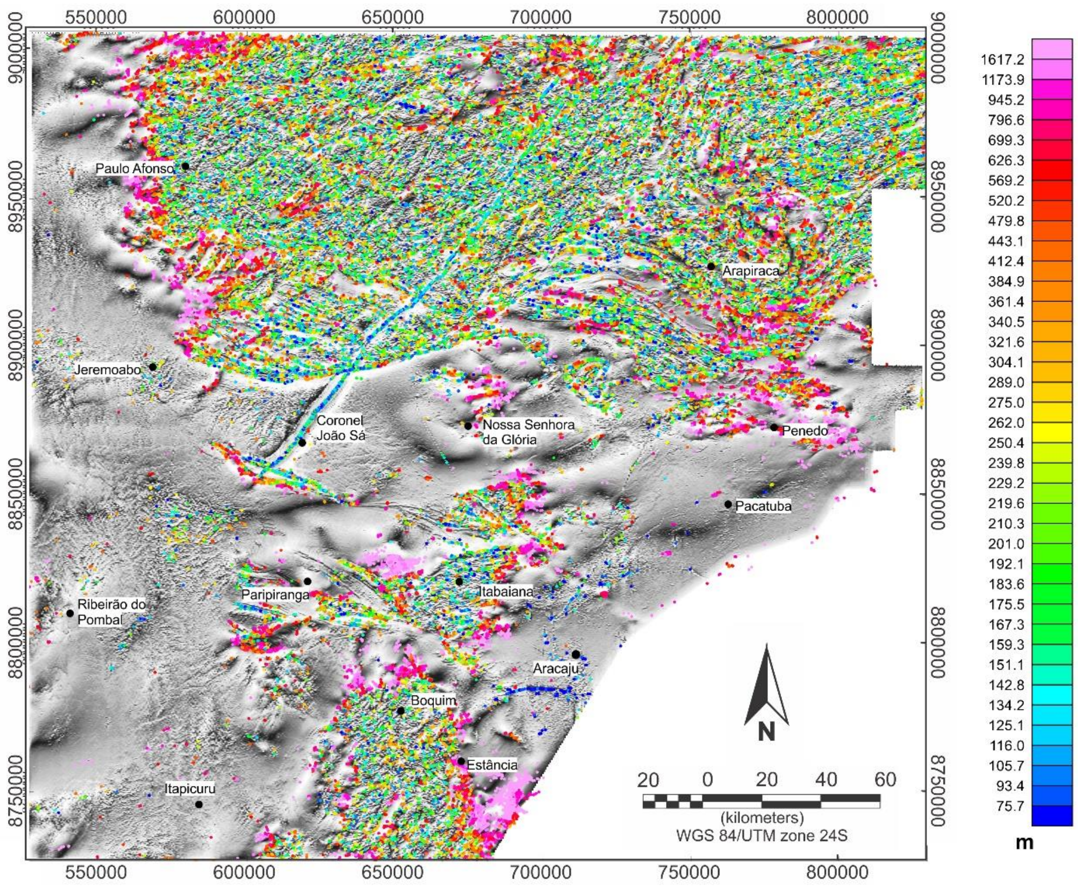

Figure 8: Euler solutions obtained with SI 1.

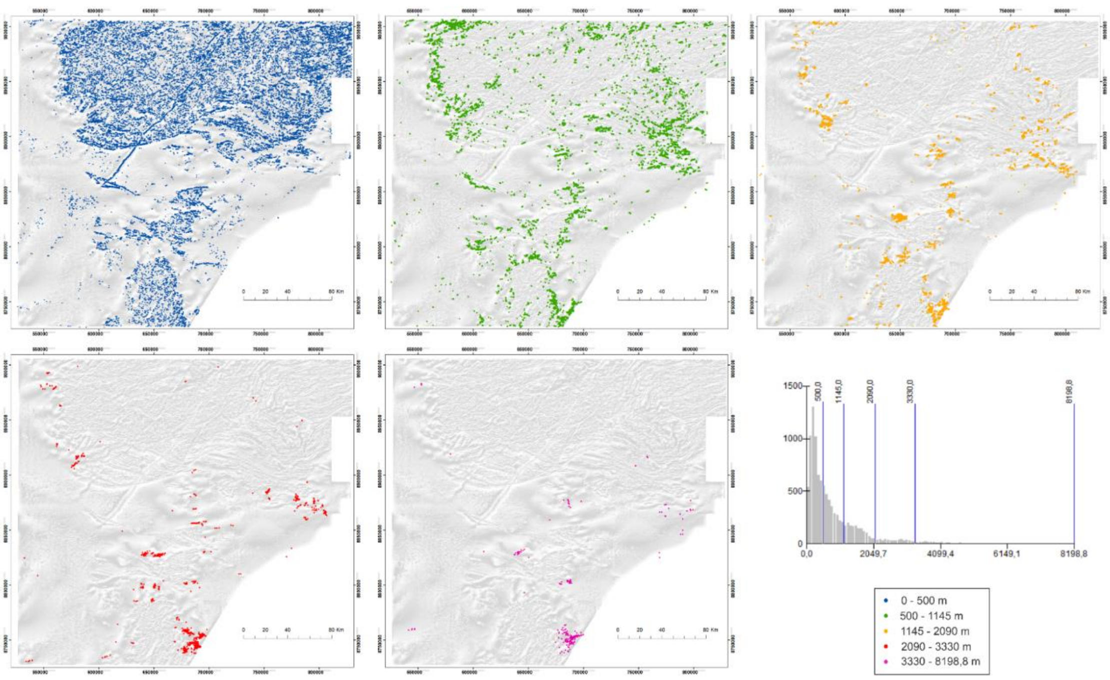

Figure 9: Individualized Euler solutions in different depth intervals for SI 1.

5. Discussions

The results show different magnetic signatures for the supracrustal rocks and the crystalline basement. At 8.88 km depth (as shown in Fig. 7E), five Precambrian regions can be individualized, from south to north: SFC, Sergipano Belt external domain, Sergipano Belt internal domain, HIMZ, and PEAL. Magnetic data emphasize that the Sergipano Belt internal and external domains are geologically distinct (Fig. 4). This heterogeneity had already been observed, leading to the suggestion of dividing the Sergipano Belt in two, Sergipano and Alagoano belts, separated by the Belo Monte-Jeremoabo Shear Zone (Silva Filho and Torres, 2001; Silva Filho et al., 2002). Carvalho (2005) and Oliveira et al. (2010, 2017) corroborate this proposition, stating that the Poço Redondo and Marancó domains had their formation associated to an Andean-type continental arc developed at the PEAL southern margin during the Cariris Velhos Event and later on were accreted to the external domain of the Sergipano Belt during the Brasiliano Orogeny.

5.1. HIMZ – The main suture

The HMIZ stands out in relation to the surrounding domains in every depth found by the matched filter map (Fig. 7). It points to a geological structure with deep roots, separating the northward Pernambuco-Alagoas superterrane from the southward Sergipano Belt. The Arapiraca Complex (Mendes and Brito, 2017) underlies most of the HMIZ area. This complex is part of the Rio Coruripe Domain and is formed of gneissic to migmatitic, locally granulitic, metasedimentary rocks with lenses and layers of metamafic rocks, marble, calc-silicate rocks, banded iron formation, and metamafic-ultramafic complexes. The Arapiraca Complex displays a large wavelength magnetic signature (around 50 km) and about 300 nT amplitude. According to Mendes and Brito

(2017), this anomaly is superimposed by a positive Bouguer anomaly. Curie depth estimative (Dutra et al., 2018) and magnetic and gravimetric modeling by Dutra et al. (2019) show that this domain has deep crustal roots up to 22 km, standing out between the Sergipano Belt and PEAL signatures as an important terrane boundary. Although several authors consider the Rio Coruripe domain as a northern extension of the Macururé Domain (Oliveira et al., 2010, 2015, 2017; Lima et al., 2018, 2019), data shown by Neves et al. (2016), Mendes and Brito (2017) and our own, demonstrate that it is, in fact, a distinct unit.

HMIZ extends eastwards with minor expression in areas where the Cabrobó and Belém do São Francisco complexes, lithostratigraphic units of PEAL, are exposed, and westward in areas of the Araticum Complex exposures and several Neoproterozoic igneous intrusions. The Araticum Complex is part of the Canindé domain and comprises a polydeformed metavolcanosedimentary sequence metamorphosed under amphibolite facies conditions, composed of mica schists, biotite gneisses, metawackes, metamafic and metaultramafic rocks, iron formations, marble, quartzite, and calc-silicate rocks.

The Neoproterozoic intrusions associated with the HIMZ correspond to the Serra do Catu Suite. They intruded the limit between the Canindé Domain and PEAL, and are of shoshonitic to ultrapotassic late- to post-tectonic nature, similar to post-collisional granites, with geochemical signature related to orogenic zones, including continental arc and subduction processes (Brito et al., 2009, Gentil, 2013). West of the Tucano Basin, the extension of the suture zone coincides with the Macururé Shear Zone, as already stated by D’el-Rey Silva (1992) and agrees with the SFC-PEAL limit proposed by Melo et al. (2019).

The Canindé Domain has inspired several interpretations over the years: ophiolitic complex (Silva Filho, 1976), island arc lithotypes (Jardim de Sá et al., 1986; Silva Filho, 1998), intracontinental magmatism (Oliveira and Tarney, 1990), orogenic intracontinental environment (Bezerra, 1992) and rift environment (Nascimento, 2005, Liz et al., 2018). For Oliveira et al. (2010), the Canindé Domain formed initially as a rift installed on an extended crust, around 715 Ma ago, that may have evolved to an ocean basin, and later accreted to the Poço Redondo and Marancó domains around 630 Ma ago (Oliveira et al., 2010). This last hypothesis correlates the last magmatic phases of the Canindé Domain with the Monte Orebe Complex in the Riacho do Pontal Belt to the west. The Monte Orebe Complex is characterized by a sequence of mafic metavolcanics interlayered with metapelagic sedimentary rocks. The geochemical signature of the complex is tholeiitic of the T-MORB type. It was dated at 819±120 Ma (Sm-Nd, Caxito et al., 2016, 2017) and is considered as representing the suture of the Riacho do Pontal Belt. Thus, the Canindé Domain could represent the suture zone between SFC and PEAL and, therefore, the entire HIMZ can be considered as the suture zone in the eastern portion of the Sergipano Belt.

Pereira and Fuck (2005) and Rocha et al. (2019), using gravimetric and seismic tomography data, respectively, place the limit of the São Francisco paleoplate farther north of the HIMZ, near the Pernambuco Lineament. According to Rocha et al. (2019), this is the paleoplate boundary in mantle depths. Aeromagnetic data have a shallower resolution, reaching maximum depth at the Curie surface, which for the southern Borborema Province is slightly below the Mohorovic discontinuity, indicating the presence of a hydrous, serpentinized mantle, typical of subduction zones (Correa et al., 2016). Combination of these data leads us to infer that the crustal limit of the São Francisco paleoplate is defined by HIMZ and its subducted crust under the PEAL and its mantle limit at depth are near the Pernambuco Shear Zone.

If the HIMZ is the most likely suture zone between SFC and PEAL, it leads to imply that the Jirau do Ponciano Dome can be a reworked SFC basement window, corresponding to the northern portion of the São Francisco paleoplate. Recent geochronology studies shed more light upon the origin of the dome and confirm the statement above. Spalletta and Oliveira (2017) found 2.04-2.07 Ga ages (LA-SF-ICPMS on zircon) for the Jirau do Ponciano core orthogneisses crystallization. Lima et al. (2019) studied the Nicolau-Campo Grande Complex, i.e. the metavolcanosedimentary unit that surrounds the Jirau do Ponciano gneissic-migmatitic core, and found crystallization ages (LA-ICP-MS in zircon) of 2054±20 Ma in andesitic basalt, 2061±8.6 Ma in metarhyodacite and 2055 Ma in rhyodacite. Detrital zircon grains display prominent peaks of 2779, 2850, 3066, and 3324 Ma are found in hornblende-biotite paragneiss of this unit.

Sm-Nd model ages from the Jirau do Ponciano Dome (Lima et al., 2019) are similar to those found by Oliveira et al. (2015) in Simão Dias Dome gneisses and migmatites (3.00-3.03 Ga) and in biotite gneiss and granulite of the Itabaiana Dome (2.13-3.54 Ga). Ages obtained by Lima et al. (2019) also agree with the age of 2729 Ma obtained by Santiago et al. (2018) for gneisses and migmatites of the Itabaiana Dome. All these data, together with aeromagnetic data of this paper suggest the Jirau do Ponciano as a strong candidate for a window of the São Francisco paleoplate.

5.2. Magnetic lineaments and Sergipano Belt probably terrane boundaries

The presence of magnetic lineaments is notable in the Sergipano Belt and its basement, corresponding largely to shear zones and zones of weakness. The first order lineaments are geologically correspondent to the main shear zones in the Sergipano Belt and divide not only geological but also magnetic domains. They can be interpreted as zones of stress accommodation during the collision. Inside these domains, third and fourth-order lineaments can be observed.

Third-order NE-SW lineaments are restricted to the eastern portion of PEAL and represent the regional structuration of main shear zones in this area, such as the Palmares, Maravilha, Ribeirão, Limitão, Rio da Chata, Itaíba and Cajueiro shear zones (Silva Filho et al., 2016 and references therein). Third-order ESE-WNW lineaments are largely present in all magnetic domains and represent the Sergipano Belt main trend in response to the oblique collision between SFC and PEAL. NNE-SSW (second-order) lineaments crosscut all other sets of lineaments, dislocating them, suggesting that they most likely are late structures, such as dykes or fractures (Mendes and Brito, 2017) associated with the lithospheric stretching related to Pangea breakup in the Cretaceous, according to crustal stretching observed in magnetotelluric imaging (Santos et al., 2014).

The first order (NE-SW) and third-order (ESE-WNW) lineaments form a set of S-shaped sigmoid structures, mostly in the internal domain of SB, representing the main kinematic of the CSF-PEAL collision, and evidencing compression and NW-SE-trending lateral scape. These sigmoids can be associated with the accretionary processes that occurred in the assembly of the Sergipano Belt.

The Itaporanga shear zone (ISZ) is an extensive first order linear feature trending E-W to NE-SW (Fig. 5). This feature is visible until 1.50 km depth (Fig 7C), suggesting that, although regional, this shear zone is contained in the same crustal block as a shallow fault. The São Miguel do Aleixo Shear Zone (SMASZ) is also a linear E-W feature with similar behavior to the ISZ in the present data. However, Dutra et al. (2019) show that its signature ranges between 15 to 20 km in magnetic and gravimetric modeling. The authors also show that Vaza Barris and Macururé have crustal depths of 5 km and 15 km, respectively. The SMASZ is, therefore, an important domain boundary of two different crustal level blocks and was taken as the northern limit of SFC (Oliveira et al., 2010); Oliveira and Medeiros, 2018). This is emphasized when the Vaza Barris and Macururé domains are compared: despite both being formed of metasedimentary rocks with an apparent discrete transition, the existence of multiple Brasiliano igneous bodies in the Macururé Domain, including mafic bodies near the Dores Fault (Pereira et al., 2020), and the absence of those in the Vaza Barris Domain, suggests a strong difference of the crustal level in which they were formed.

As mentioned above, the Belo Monte-Jeremoabo shear zone (BMJSZ) is a major terrane boundary that separates the so called Alagoano and Sergipano belts (Silva Filho and Torres, 2001; Silva Filho et al., 2002). This is corroborated by magnetotelluric imaging of the southern Borborema Province provided by Santos et al. (2014), which shows contrasting resistivity pattern in the Macururé domain when compared to the patterns of the internal domains of the Sergipano Belt and of the Pernambuco-Alagoas Superterrane. Although they all show a high resistivity signature, implying in a more sialic crust, the regions corresponding to the BMJSZ and north Canindé Domain (HIMZ) have contrasting low resistivity signature, comprising regions richer in Fe-Mg rocks.

In the internal domain, the shear zones display signatures that stand out as narrow high magnetic zones (Fig. 4), highlighting the distinction between the Poço Redondo and Marancó domains, as well as the Canindé domain. Carvalho (2005) considered Poço Redondo and Marancó as a single geological domain due to lack of expressive shear zones between them in LANDSAT-ETM satellite images and in the field, proposition that was corroborated by Oliveira et al. (2010, 2015). However, the limit between them is well established by a magnetic low in the TMI map (Figs. 4, 6) and in different depth levels extracted by the matched filter (Figs. 5, 7). Therefore, Poço Redondo and Marancó are distinct domains, separated by a regional shear zone, labeled Poço Redondo (Sousa et al., 2019).

5.3. Tectonic implications

Magnetic data interpretation integrated with existent geological and geophysical data provides clues to understand the evolution of the Sergipano orogen. Distinctive magnetic features suggest that the lithotectonic associations in the area correlate with different fault-bounded terranes that underwent subsequent amalgamation. These features include: (i) contrasting magnetic signature between terranes, with more magnetic rocks present in the, here defined, HMIZ; (ii) contrasting magnetic relief, with smoother relief belonging to metasedimentary rocks of the external domain; and (iii) magnetic lineaments with at least three main directions, highlighting superposition of structural events.

Such characteristics are distinctive of accretionary orogens growth (Cawood et al. 2009, 2013), largely documented in Gondwana, especially at its margins, such as the Australides and Tasmanides orogenic belts (Vaughan et al., 2005 and references therein). Despite that, identification of terrane evolution in several portions of Gondwana remains a difficult task due to the obliteration of many structures and rock units during reworking events.

Data presented here supported by Curie depth estimative (Dutra et al., 2018), magnetic and gravimetric modeling (Dutra et al., 2019) and MT imaging (Santos et al. 2014) show that the Sergipano belt main places of terrane collage, marked by the HIMZ and other possible tectonic boundaries represented by the Belo Monte-Jeremoabo, São Miguel do Aleixo and possibly Poço Redondo shear zones, imply that the Sergipano belt evolved as an accretionary orogen.

The geometry of structures in the Sergipano Belt is consistent with those reported for classic accretionary orogens, such as the North American Cordillera and the Southern Appalachians (Pfiffner, 2017 and references therein), and involved initial thrust structures associated with terrane assembly followed by transcurrent movement as shown by the deformational phases proposed by Oliveira et al. (2010) for the structural evolution of this orogen.

The airborne magnetic data are not coherent with a geodynamic model involving deposition in two passive margins (Oliveira et al., 2010), pointing instead to probable deposition in a single passive margin that subducted beneath PEAL. This is evidenced by the extension of the São Francisco Paleoplate beneath the Macururé Domain in the magnetic data, contrasting with the deposition of Macururé sedimentary units on the southern margin of PEAL proposed by the authors. Geochronological detrital zircon U-Pb and Sm-Nd data reported by Oliveira et al. (2010, 2015), on the other hand, are not in agreement with the interpretation that the Sergipano Belt evolved by basin inversion, with sediments sourced only in the São Francisco Craton (D'el-Rey Silva, 1992, 1995), since Oliveira et al. (2010, 2015) show that the Borborema Province is the main source area of the metasedimentary units.

A better fit for the Sergipano Belt evolution is a model that resembles the one proposed by Davison and Santos (1989). The authors stated that the Sergipano Belt was formed through the collage of distinct lithostratigraphic domains. Main shear zones that divide these domains would be thrust zones that juxtaposed geological units of different crustal levels. This is corroborated by Santos et al. (2014), Dutra et al. (2019) and our data. In this hypothesis, the SFC limit is represented by de SMASZ as proposed by Oliveira et al. (2010) and Oliveira and Medeiros (2018). The Macururé Domain is an allochthonous terrane accreted to the São Francisco paleoplate margin and the final suture is represented by the collision of the Marancó-Poço Redondo arc (Oliveira et al., 2010) and the closure of an ocean that is represented by the HIMZ.

Collage of distinct terranes is a characteristic feature of accretionary processes and, in fact, some authors propose the evolution of the Borborema Province as a progressive accretion of exotic terranes during the Neoproterozoic since the 1990s and early 2000s (Santos, 1996; Santos et al., 2000; Brito Neves et al., 2000). This proposal has been reinforced by recent studies in the Northern and Transversal domains of the province such as those of Ferreira et al. (2020) and Santos et al. (2017, 2018, 2019), respectively. Thus, evidence points to an accretionary origin for the Sergipano Belt and highlights the importance of accretion tectonics in the evolution of the Borborema Province and the amalgamation of Western Gondwana.

6. Conclusions

Heterogeneity in the magnetic signature allows the dividing of the Sergipano Belt in two main geophysical domains: external and internal. The external domain is characterized by low magnetic frequency and smooth magnetic relief, comprising anchimetamorphic and greenschist facies metasedimentary rocks of the Estância, Vaza Barris, and Macururé geological domains. The internal domain is characterized by high frequency and rough magnetic relief. It encompasses amphibolite facies metavolcanic and metaigneous rocks (Marancó and Canindé domains) and migmatites (Poço Redondo Domain). The geophysical limit between the external and internal units is the Belo Monte-Jeremoabo Shear Zone. The data also permit identifying magnetic domains corresponding to the São Francisco Craton, Pernambuco-Alagoas Superterrane and reworked crystalline basement domes, and the Phanerozoic Sergipe-Alagoas and Tucano basins. An unexposed body of probably reworked basement was characterized across the interface between the Macururé Domain and the Sergipe-Alagoas sedimentary cover.

The TMI map outlines a ca. 10 km wide and 100 km long E-W strip of high magnetic signature, here introduced as the High-Intensity Magnetic Zone (HIMZ), that embraces part of the Canindé and Rio Coruripe domains and is the most likely region of main suture zone of the SFC-PEAL collision. This implies that the Jirau do Ponciano is probably the northernmost outcropping portion of the reworked São Francisco paleoplate, upon which were deposited and consolidated the rocks of the Estância, Vaza Barris and Macururé domains. Two other important terrane boundaries are identified: the São Miguel do Aleixo shear zone, representing the northern limit of São Francisco Craton and the Belo Monte-Jeremoabo shear zone, separating the Macururé Domain from the Marancó-Poço Redondo Tonian arc. These results point to the accretion of ribbon continents in the northern São Francisco margin before the final collision, supporting the hypothesis that the Sergipano Belt evolved as an accretionary orogen during the assembly of West Gondwana.

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CAPÍTULO 3 – Artigo 2

Artigo 2: Oblique collision and accretionary processes in the South Borborema Province: Insights from structural geology and geophysical data (submetido para a *Tectonophysics*)

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Oblique collision and accretionary processes in the South Borborema Province: Insights from structural geology and geophysical data

Gabriela M. Almeida[1]*, Reinhardt A. Fuck[1], Elton L. Dantas[1], Sanmy S. Lima[2]

[1]Instituto de Geociências, Universidade de Brasília, Campus Universitário Darcy Ribeiro, 70910-900, Brasília, DF, Brasil

[2]Programa de Pós-graduação em Geociências, Universidade Federal de Pernambuco. Avenida da Arquitetura, S/N, 50740-550, Recife, PE, Brasil

*corresponding author: geol.gmalmeida@gmail.com

Abstract

During orogenesis, the forming structures vary according to several factors such as the nature of rocks, geological environment, P-T conditions, and type of collision. Deformational styles play a significant role in this process. While thin-skinned tectonics comprise only supracrustal deformation, in thick-skinned tectonics both supracrustal rocks and basement are deformed reaching Moho depths. Both styles may coexist in a single orogenic system and the recognition of different sectors may help to unravel the nature of the orogen. In this paper, we apply the definition of tectonic styles on the São Miguel do Aleixo Shear Zone, a major transpressive shear zone in the Sergipano Belt, NE Brazil. It separates domains with different structural and metamorphic grades and provides evidence to understanding the tectonic implications of this structure and its role in the evolution of the orogen. We suggest that the São Miguel do Aleixo Shear Zone is a major crustal boundary formed during oblique collision with and a possible transitional region between areas with dominant thin-skinned and thick-skinned tectonics. The presence of both structural styles together with metamorphic grade and geological

environment lead to suggest that accretionary processes had a key role in the evolution of the Sergipano Belt.

Keywords: Western Gondwana, Sergipano Belt, progressive metamorphism, thin-skinned tectonics, thick-skinned tectonics, Brasiliano Orogeny

1. Introduction

During orogenesis, the crust and its sedimentary cover are subjected to horizontal contraction in convergent settings leading to deformation in a variety of styles (Coward, 1983; Pfiffner, 2006, 2017). Two fundamental deformational styles are common: thin- and thick-skinned tectonics, introduced in the literature by Rodgers (1949). In the first, deformation occurs in the supracrustal package only, and a series of thrust and faults are formed through decollement surfaces of weaker rock layers such as salt or shales. In turn, in thick-skinned tectonics, there is the involvement of the basement leading to major thrust zones that can reach Moho depths. Pfiffner (2006, 2017) proposed the term basement-involved thin-skinned tectonics to refer to deformation in which the upper portions of the basement participate, generally by reactivation of normal faults, without reaching deeper crustal levels.

Major shear zones play a vital role in unraveling the history of an orogen since they may preserve key structures that are indicative of the kinematics and stress field during the orogeny. The understanding of these elements upholds evidence of the acting deformational styles during orogenesis since different types of orogens generate distinct deformational patterns (Pfiffner, 2006, 2017 and references therein). Furthermore, geophysical data, such as magnetometry, gravimetry, and especially seismic data, help us to constrain the geometry and depths of different orogen zones (e.g., Speranza and

Chiappini, Scrocca et al., 2005; 2002; Abedi and Oskooi, 2015; Oskooi and Abedi, 2015; Japas et al., 2016; Carboni et al., 2019) and are a useful tool in structural analyses of orogens.

The Sergipano Belt, NE Brazil (Fig 1), is a key area for the understanding of West Gondwana. The belt has been studied by several authors since the late 1960s (Humphrey and Allard, 1967; Brito Neves, 1975; Silva Filho, 1976; Davison and Santos, 1989; D'el-Rey Silva, 1992, 1995, among others), but the history of its geodynamic evolution has been limited by incomplete knowledge such as lack of detailed structural and deformations analyses.

The São Miguel do Aleixo Shear Zone (SMASZ) is an ESE-WNW trending zone that separates two distinct geological domains – Macururé and Vaza Barris, north and south respectively (Fig 1B) – and its role in the evolution of the Sergipano Belt is still uncertain. While some authors consider it as a major limit between two crustal continuous geological units (D'el-Rey Silva, 1992, 1995) others consider it as a suture zone between two distinct terranes (Davison and Santos, 1989; Oliveira et al., 2010).

This paper presents new structural and magnetic data to describe the deformation and metamorphism style along the SMASZ and discusses its relationship to the tectonics of the Sergipano Belt and West Gondwana assembly. Our results suggest that the SMASZ is a major crustal limit between a domain with dominant thin-skinned and another with probable thick-skinned tectonics. The difference of tectonic styles within this orogen supports an accretionary evolution model for the Sergipano Belt.

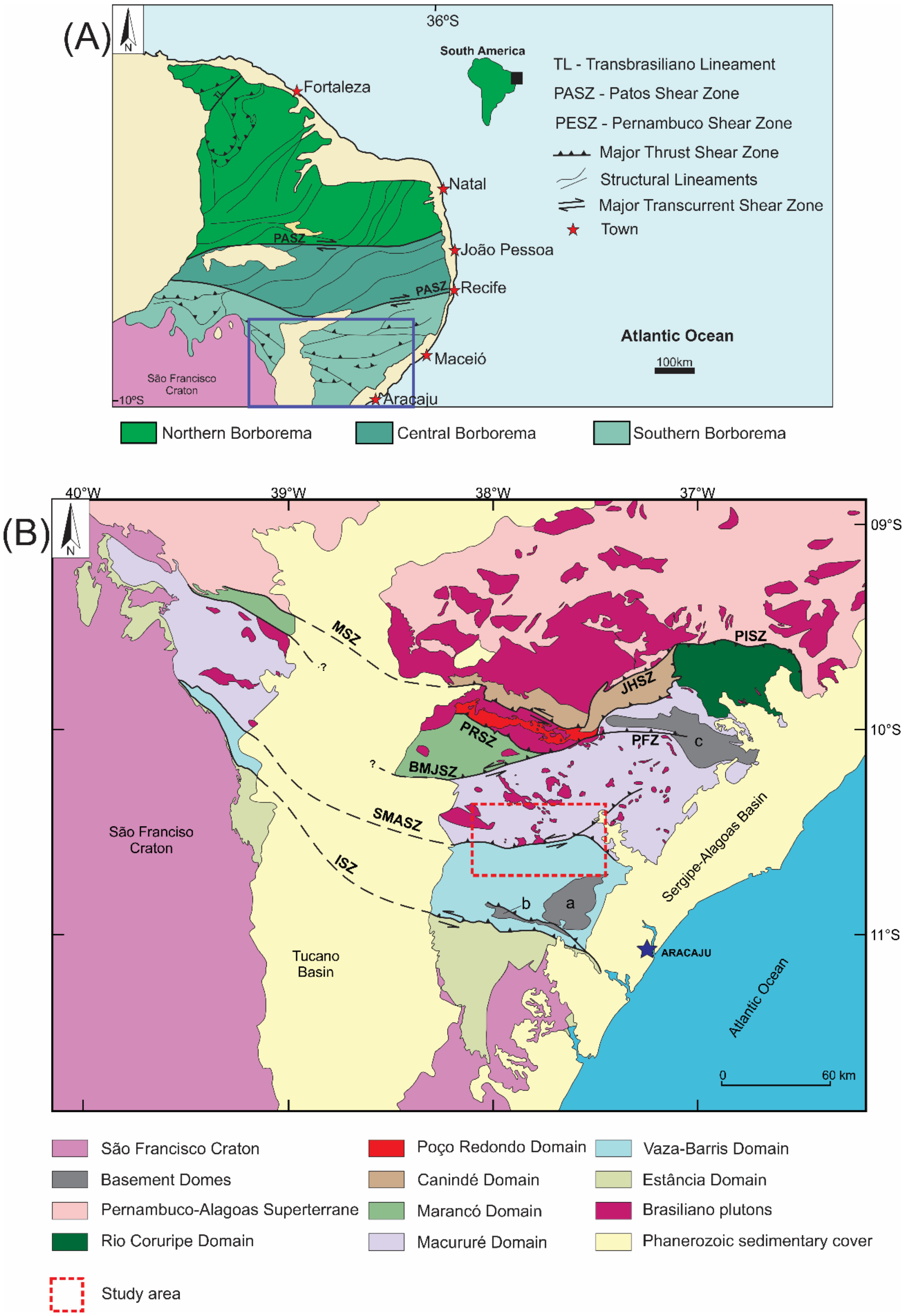

Figure 1: (a) Schematic map of the Borborema Province showing the three sub-provinces with emphasis on the Sergipano Fold Belt (modified from Brito Neves et al., 2000); (b) Geological map of the Sergipano Fold Belt (Almeida et al., 2021). Basement domes: a – Itabaiana; b – Simão

Dias, c – Jirau do Ponciano. Shear zones: ISZ – Itaporanga; SMASZ – São Miguel do Aleixo; BMJSZ – Belo Monte-Jeremoabo; PFSZ – Porto da Folha; PRSZ – Poço Redondo; MSZ – Macururé; JHSZ – Jacaré dos Homens, PISZ – Palmeira dos Índios.

2. Geological setting

The Sergipano Belt is an ESE-WNW trending orogen located in the southern Borborema Province (Fig. 1A), formed during the Brasiliano Orogeny due to oblique collision between the São Francisco Paleoplate and the Pernambuco-Alagoas Superterrane. Despite the different interpretations, it is agreed that the orogen resulted from the closure of a passive margin basin (D'el-Rey Silva, 1992, 1995; Oliveira et al., 2010, 2014; Neves et al., 2016).

The Sergipano Belt is divided into six lithostratigraphic domains, from south to north: Estância, Vaza Barris, Macururé, Marancó, Poço Redondo, and Canindé (Fig. 1B). Regional shear zones divide these domains: Itaporanga, São Miguel do Aleixo, Belo Monte-Jeremoabo, Poço Redondo and Macururé, respectively (Davison and Santos, 1989; Silva Filho and Torres, 2002; Sousa et al., 2019). The Rio Coruripe domain was suggested by Silva Filho and Torres (2002) and has recently been defined as a distinct unit (Neves et al., 2016; Mendes and Brito, 2017), a proposal used in the present work (Fig. 1B).

The Estância, Vaza Barris, Macururé and Rio Coruripe domains are composed mainly of metasedimentary rocks, the metamorphic grade of which varies from anchimetamorphism (Estância) to greenschist (Vaza Barris and Macururé) to amphibolite facies (Macururé), reaching granulitization stages (Rio Coruripe). The Macururé Domain presents multiple Neoproterozoic igneous intrusions. The Marancó, Poço Redondo and Canindé domains display more diverse rock associations, such as granitic rocks, metavolcanosedimentary sequences, migmatites, and mafic and ultramafic rocks) and are interpreted as allochthonous blocks, accreted during the Neoproterozoic (Oliveira et al., 2010).

There are a few geodynamic models proposed for the Sergipano Belt, in which the regional shear zones play a leading role, the meaning of which may vary according to different authors. It is agreed in all proposed models that the Sergipano Belt is an area of shortening that presents major NW-SE to WNW-ESE trending folds, verging southwards toward the São Francisco Craton (Davison and Santos, 1989; D'el-Rey Silva, 1992; Oliveira et al., 2010), but the nature of this shortening is interpreted differently. For Davison and Santos (1989), the Sergipano Belt is a collage of six distinct domains with distinct lithological, metamorphic, and magmatic characteristics, bounded by major E-W to WNW-ESE sub-vertical shear zones. This interpretation suggests shear zones with large sub-horizontal displacements that eventually juxtaposed allochthonous terranes representing different crustal levels.

D'el-Rey Silva (1992) proposed a lithostratigraphic continuity between the domains across a precursor basin. For the author, the Sergipano Belt fits the model of a classic basin inversion resulting from the closure of a narrow ocean (Canindé Sea), where the sedimentary rocks of the Estância, Vaza Barris and Macururé domains would represent a single wedge of continental to proximal, intermediate, and distal marine sedimentation, respectively. In this model, the main shear zones are a place of high strain accommodation dividing continuous domains and the Macururé shear zone represents the suture zone of the São Francisco paleoplate and PEAL collision.

For Oliveira et al. (2010), the orogen records a complete Wilson cycle, suggesting that the Macururé Domain rocks were deposited on the southern margin of the PEAL, while the Estância and Vaza Barris rocks were deposited on the northern margin of the

São Francisco paleoplate. In this model, the São Miguel do Aleixo Shear Zone is suggested as the suture zone of the collision, proposition that is also supported by Oliveira and Medeiros (2018).

Recently Almeida et al. (2021), using airborne magnetic data, suggested that the Sergipano Belt may have evolved as an accretionary orogen. The suggestion is supported by the behavior of the main shear zones and domains at different depths, integrated with extensive literature data (see Almeida et al., 2021 and references therein). For the authors, there are two possible terrane boundaries, represented by the Belo Monte-Jeremoabo and São Miguel do Aleixo shear zones, and the main suture of the São Francisco-PEAL collision is represented by the Macururé shear zone and a series of highly magnetic rocks along the Canindé and Rio Coruripe domains. Recent data by Passos et al. (2021) corroborate this proposition. These authors propose an arc-back-arc environment for the Canindé Domain developed at ca. 740 Ma, whereas the Poço Redondo Domain could be an exotic terrane or a fragment of PEAL.

In this paper, we present a detailed study of the structure of the São Miguel do Aleixo Shear Zone (Fig. 2) to better understand the limit between the Vaza Barris and Macururé domains and its role in the evolution of the Sergipano Belt through structural and metamorphic analysis supported by airborne magnetic and radiometric data.

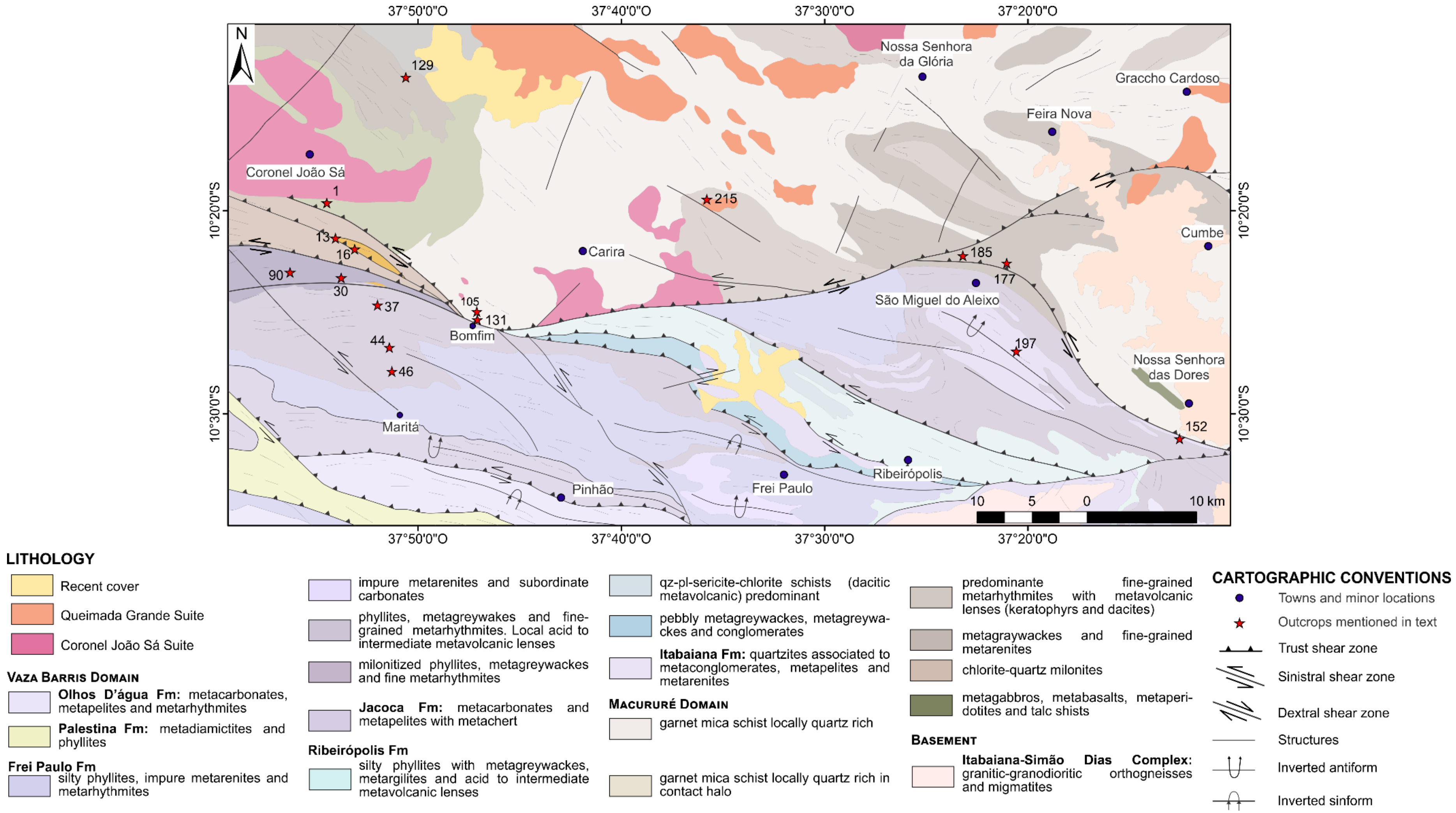

Figure 2: Geological map of the study area.

3. Aerogeophysical data

Magnetic and gammaspectrometric data used in this paper are from aerial surveys of Projeto Geofísico do Estado de Sergipe (1102) and Projeto Geofísico Paulo Afonso-Teotônio Vilela (1104) undertaken by the Brazilian Geological Survey (CPRM). These projects embrace the eastern portion of the Sergipano Belt (eastward of the Tucano Basin, Fig. 2), comprising the area between 9°S and 11°30'S and 36°W and 38°45'W (Study area in fig. 2). Both projects were acquired with N-S flight lines spacing 500 m and E-W control lines spacing 10 km, with 100 m average height flight. Data processing and analysis were accomplished using Geosoft Oasis Montaj™ v9.3 software.

Database integration before data processing is an important procedure for the uniformization and standardization of magnetic characteristics. The grid knit function was applied as the suture method between the two surveys, to correct any errors and eliminate background noise, mainly at the edges of the magnetic data junction. Both projects have the same specifications, datum (WGS84), and are in the same UTM zone, which facilitated the procedure.

Total magnetic intensity (TMI) is the basis for magnetic processing and data interpretation. Reduction to the pole (RTP, Baranov, 1957; Baranov and Naudy, 1964) and differential reduction to the pole (dRTP, Cooper and Cowan, 2005) were processed but the results were not satisfactory due to the algorithm instability at low latitudes. The K, eTh, and eU channels images (not shown) were performed to compose the RGB ternary image used for the interpretation of surface geological structures.

For the analysis of magnetic data, we used the TMI and tilt derivative. The tilt derivative (Miller and Singh, 1994) is useful to highlight linear structures such as shear zones, faults and lineaments, and geologic bodies (e.g., dykes). These products allow to individualize the main magnetic structures of the study area and correlate them with geological features.

3.1. Magnetometry

Detailed magnetic characterization of the Sergipano Belt was made by Almeida et al. (2021), dividing the orogen into magnetic domains as well as classifying the major magnetic lineaments. In this paper, TMI (Fig. 3A) and tilt derivative (Fig. 4A) were used to locally interpret the main magnetic lineaments and correlate them with structural field data.

The TMI shows a region dominated by a smooth magnetic relief crosscut by an E-W lineament (São Miguel do Aleixo Shear Zone), separating the metasedimentary rocks of the Macururé domain to the north from the Vaza Barris domain to the south (Fig. 3B). Two rough regions are seen and correspond to the Sergipano Belt basement, as detailed in Almeida et al. (2021). In addition to the magnetic lineaments described by Almeida et al. (2021), a set of ENE-WSW fourth-order lineaments was found in the study area (Fig. 4B).

In tilt derivative, the lineaments have a strong correlation with the structural framework of the area (Figs. 4B, C). Both domains show several ESE-WNW lineaments corresponding to the main foliation direction seen in the field, representing the main trend of the Sergipano Belt. In the Macururé Domain, there is a set of NNE-WSW (red lines in Fig. 4B) to the west of the study area, which corresponds to a drainage pattern notched in regional fractures. Another set of lineaments present in the Macururé domain trends ENE-WNW and is observed in the field as faults or fractures (Fig. 4B).

The Vaza Barris Domain displays a set of regional folds exposed in the SW portion of the study area, in which the ESE-WNW lineaments play the role of axial plane.

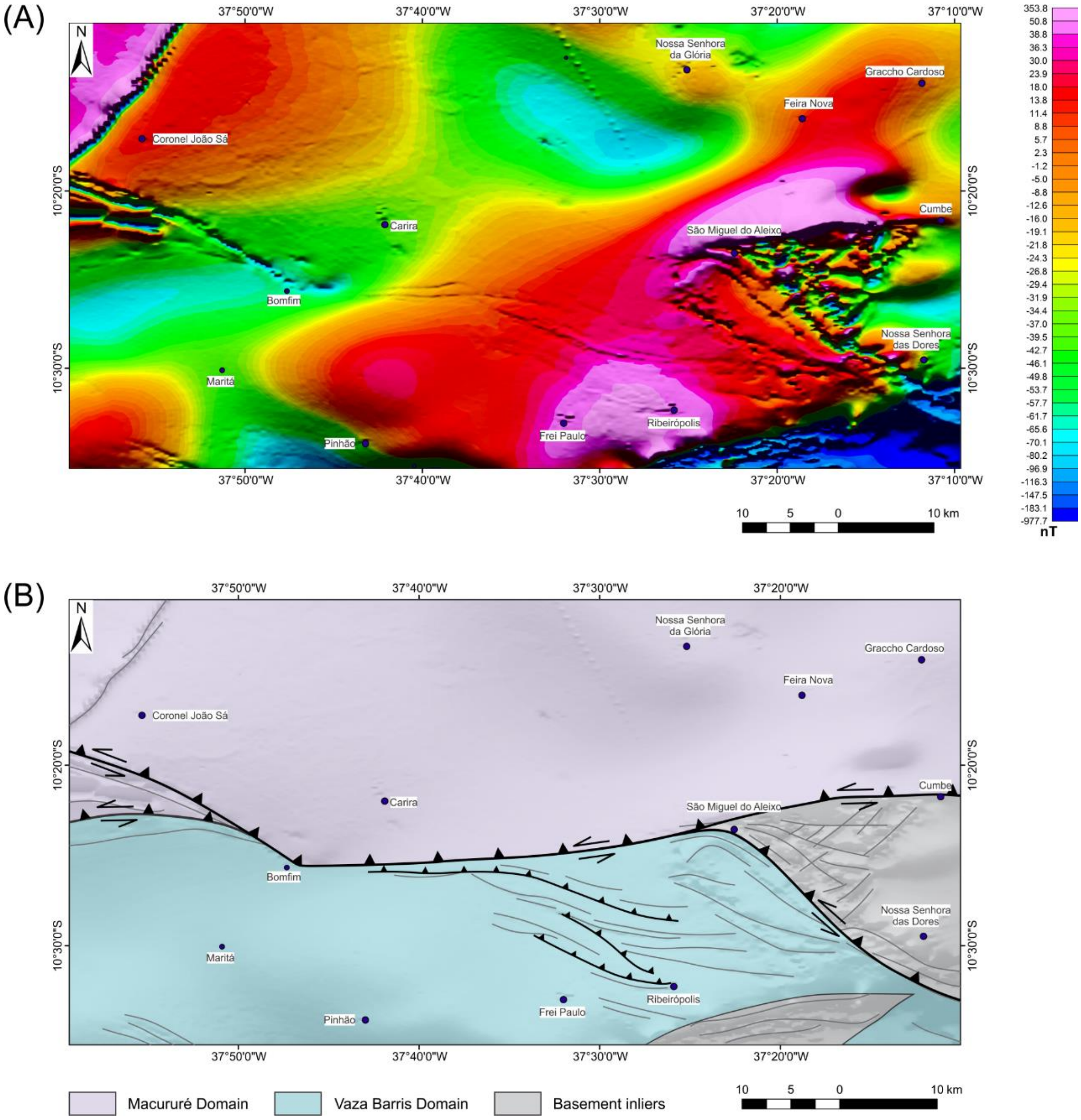

Figure 3: (A) TMI of study area; (B) Composition showing Magnetic domains and main structures of the study area.

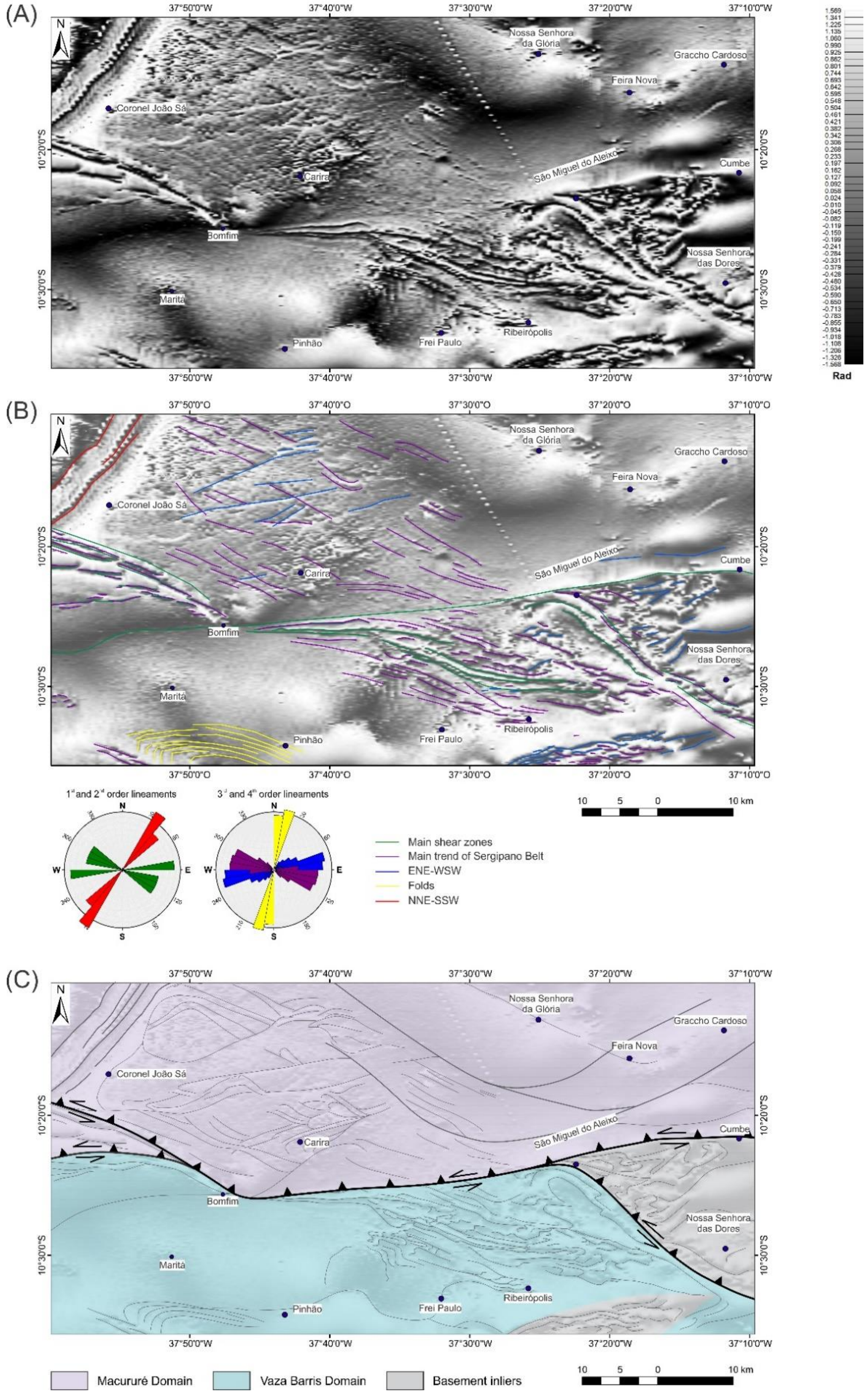

Figure 4: (A) Tilt derivative map; (B) Main lineaments in the tilt derivative map; (C) Interpreted structures observed in the tilt derivative map.

These folds are tight to isoclinal and their limbs trend NNE-SSW to N-S. ESE-WNW trending magnetic lineaments are not prominent in this domain. The regions representative of basement inliers are characterized by a rough relief in the tilt derivative image (Fig. 4B), showing two sets of lineaments with ESE-WNW and ENE-WSW directions.

The SMASZ is an outstanding feature both in TMI and tilt derivative maps. It has a main ENE-WSW to E-W direction and branching to ESE-WNW on its tips and accommodating shears. These branches draw a sinistral sigmoid pattern that is observed in the ternary RGB image (see below, Fig. 5A) and in the geological map (Fig. 2).

3.2. Gammaspectrometry

The gammaspectrometric data defined strong contrasts based on the distribution of radio elements in the geological units of the studied area. The K, eTh, and eU channels (not shown) were used to obtain general information of the study area and to compose the ternary image (RGB), which allowed the qualitative evaluation of the three variables (Fig. 5A).

The interpretation of the ternary image allowed the individualization of surface geological structures, mostly folds. The composite image RBG + tilt derivative displays a good correlation (Fig. 5B) implying that the structures extend from the surface to crustal depths.

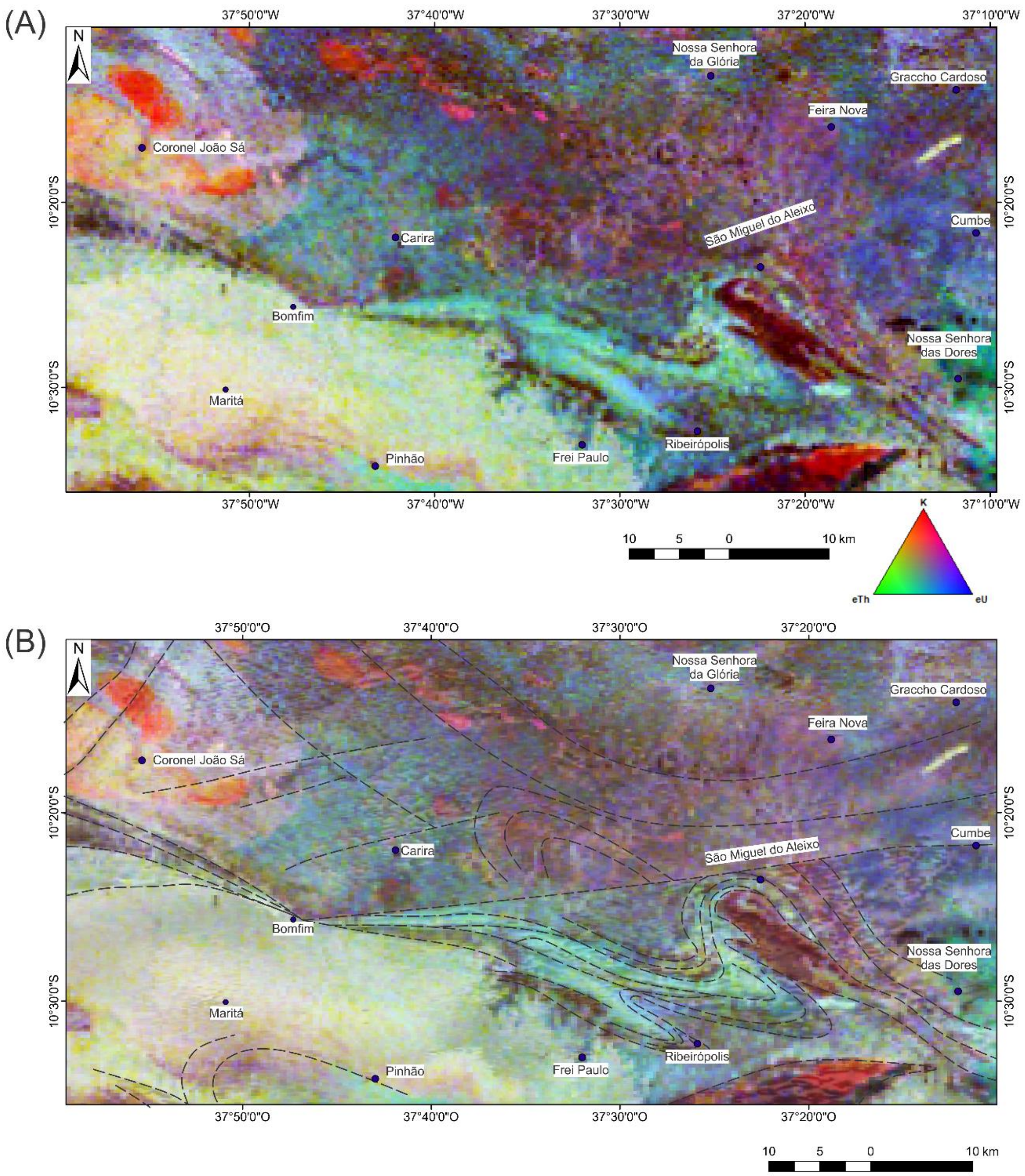

Figure 5: (A) RGB (K-Th-U) ternary image of the study area; (B) Interpreted RGB + tilt derivative composite image.

4. Structural analysis

The geological map and cross-section (Fig. 6) show that the overall structure of the study area comprises an ESE-WNW sinistral transpressional south verging shear zone

(SMASZ) with a positive flower structure/horsetail termination in the western portion. The fabric elements in both Vaza Barris and Macururé domains characterize transpressional deformation recorded in the evolution of a distinctive composite foliation.

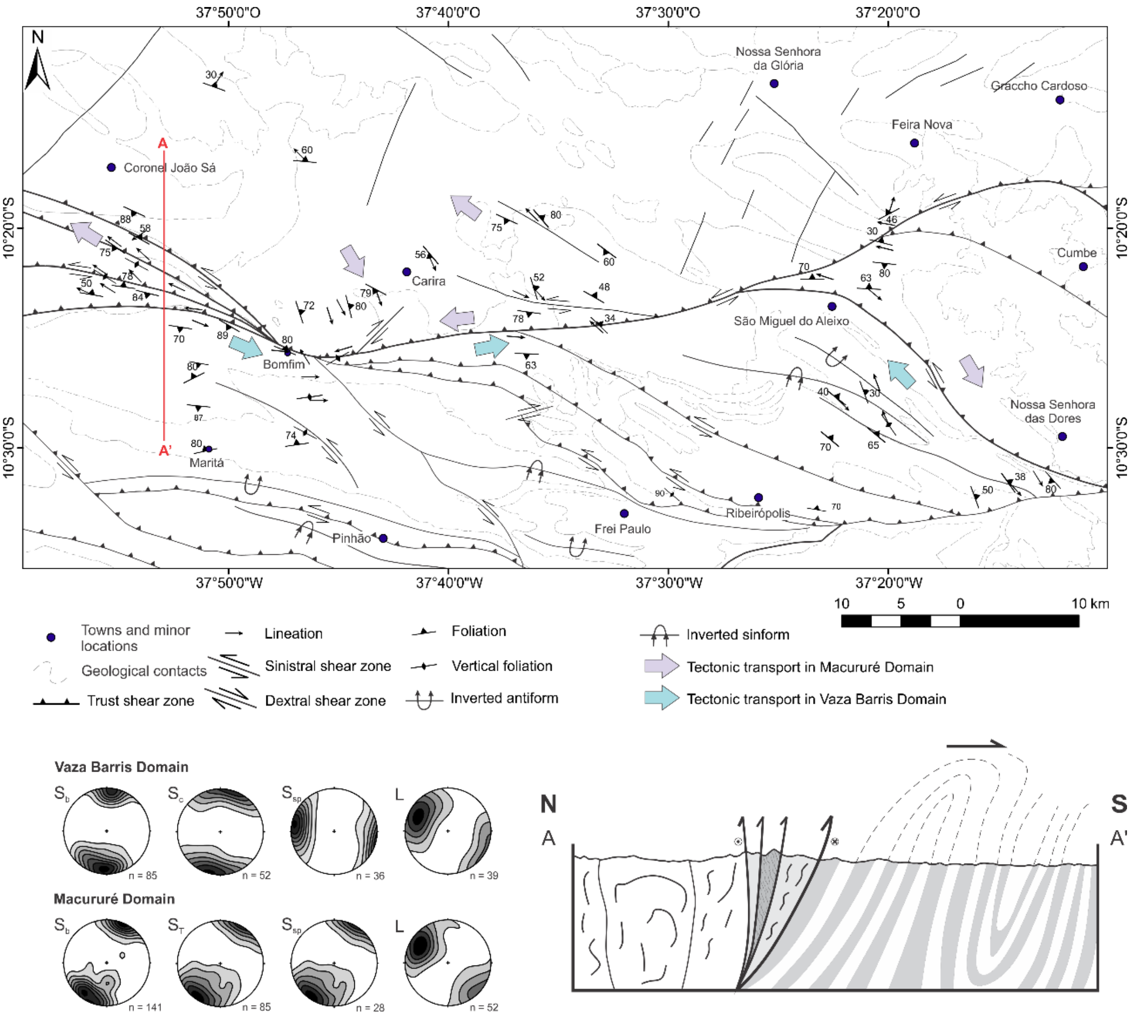

Figure 6: Structural map and cross-section.

Southwards of the shear zone, the Vaza Barris Domain is dominated by brittle to brittle-ductile structures with a series of contractional strike-slip duplex and associated large scale drag folds. In this domain, phyllites and metarhythmites still preserve the original bedding (S_b; Fig. 7A). This foliation dips preferentially 67° to 86°. In microscale, S_b is characterized by the intercalation of millimeter to centimeter-thick psamite and pelite layers (Fig. 7B). An incipient slaty cleavage (S_c) may be associated with S_b (Fig. 7C). S_c has higher dips than S_b, mostly 74° to 90°. Both S_b and S_c foliation have higher dips near SMASZ and dip direction alternates northwards and southwards. Orthogonal to this composite foliation a spaced cleavage (S_{sp}) is observed that dips mainly 75° to 90° eastwards or westwards. Folds have SSW vergence and vary from interlayered decimetric tight folds (Fig. 7D) to metric open folds, in which S_c coincides with their axial planes, hinges plunge preferentially 10° to 35° NNW to NW. Lineation in this domain occurs parallel to the SMASZ direction and plunges 10° to 30° eastwards. Quartzites are intensely recrystallized and mylonitized, showing dextral shear sense (Fig. 7E). These indicators are concordant with the orientation of SSW verging asymmetrical recumbent folds (Fig 7F).

In the Macururé Domain, fine-grained quartz schists with garnet and ilmenite are found around the Coronel João Sá batholith (Fig. 8A). Garnet schists with centimetric micas dominate in the central area (Fig 8B). Fine-grained metarhythmites, metagraywackes and metarenites are present in the São Miguel do Aleixo and Feira Nova areas (Fig. 8C). A few granitic injections and volcanic layers subparallel to the main foliation are also observed in the field. The structures are similar to those in the Vaza Barris Domain, but in a dominant ductile deformation regime. S_b dips mostly 70° to 88°, northwards and southwards, and is less prominent than in the Vaza Barris Domain. S_b is frequently transposed by schistosity (S_s) with dips dominant between 70° and 90° and may form S-C foliation observed in thin section (Fig. 8D). Northwards, S_s becomes crenulated (S_{cr}, Fig. 8E), evolving to crenulation cleavage (S_{cc}, Fig. 8F), especially near the Coronel João Sá batholith. This transposition foliation (S_T) dips in average 70° to 90° both NE and SW. S_{sp} foliation is also observed and dips 70° to 90° NW or SE. Open and tight metric do centimetric folds with SSW vergence are also observed in this domain and behave as in the Vaza Barris Domain. Lineation plunges mostly 6° to 35° in two directions: mainly parallel to the SMASZ, westwards, and secondary NE-SW direction.

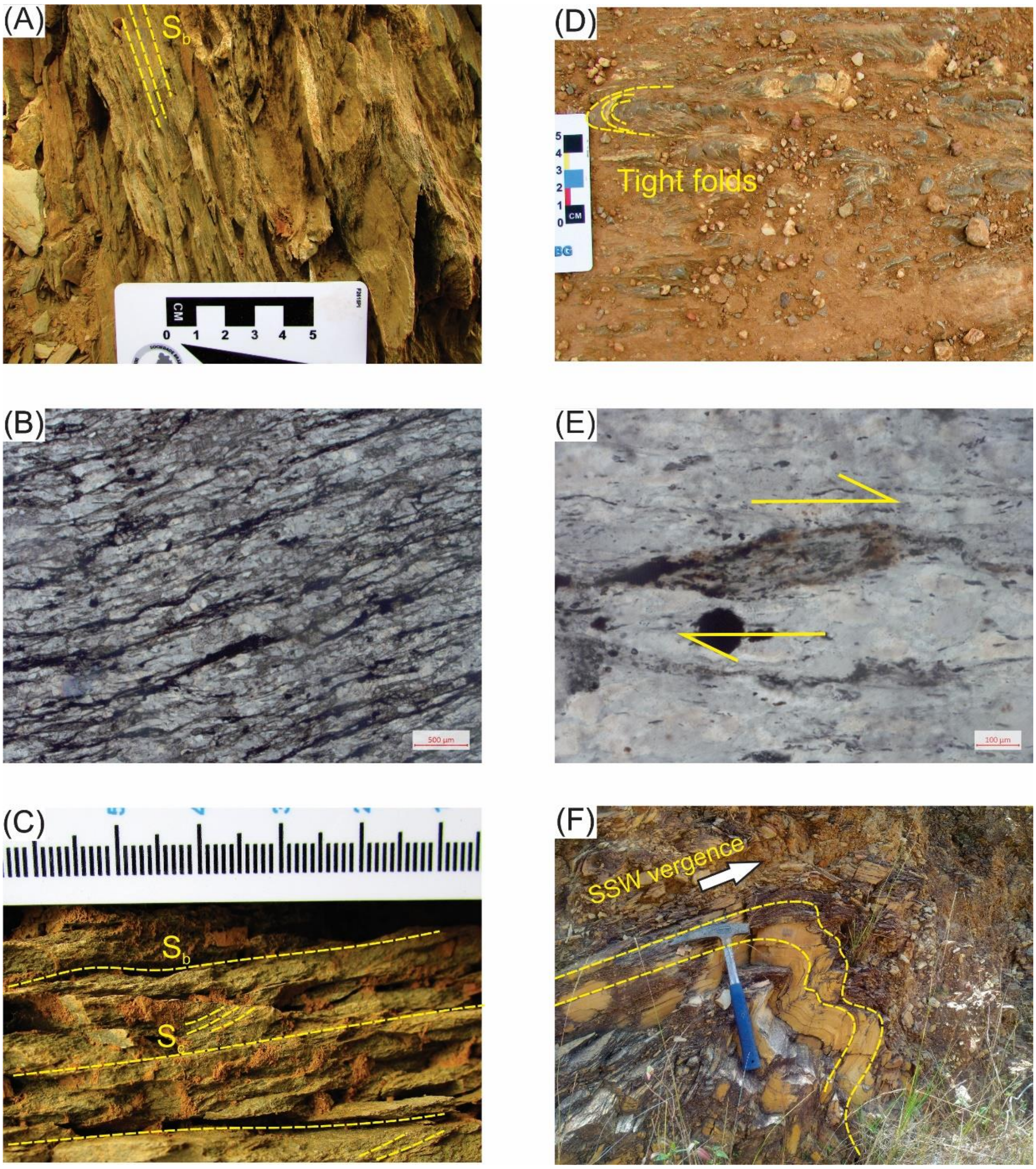

Figure 7: (A) Phyllite with preserved original bedding (S_b; outcrop 46); (B) original bedding in microscale (outcrop 90); (C) S_b and associated S_c (outcrop 37); (D) interlayered decimetric tight folds (outcrop 43); (E) dextral kinematic indicator in quartzite (outcrop 197); (F) asymmetrical recumbent fold (outcrop 197).

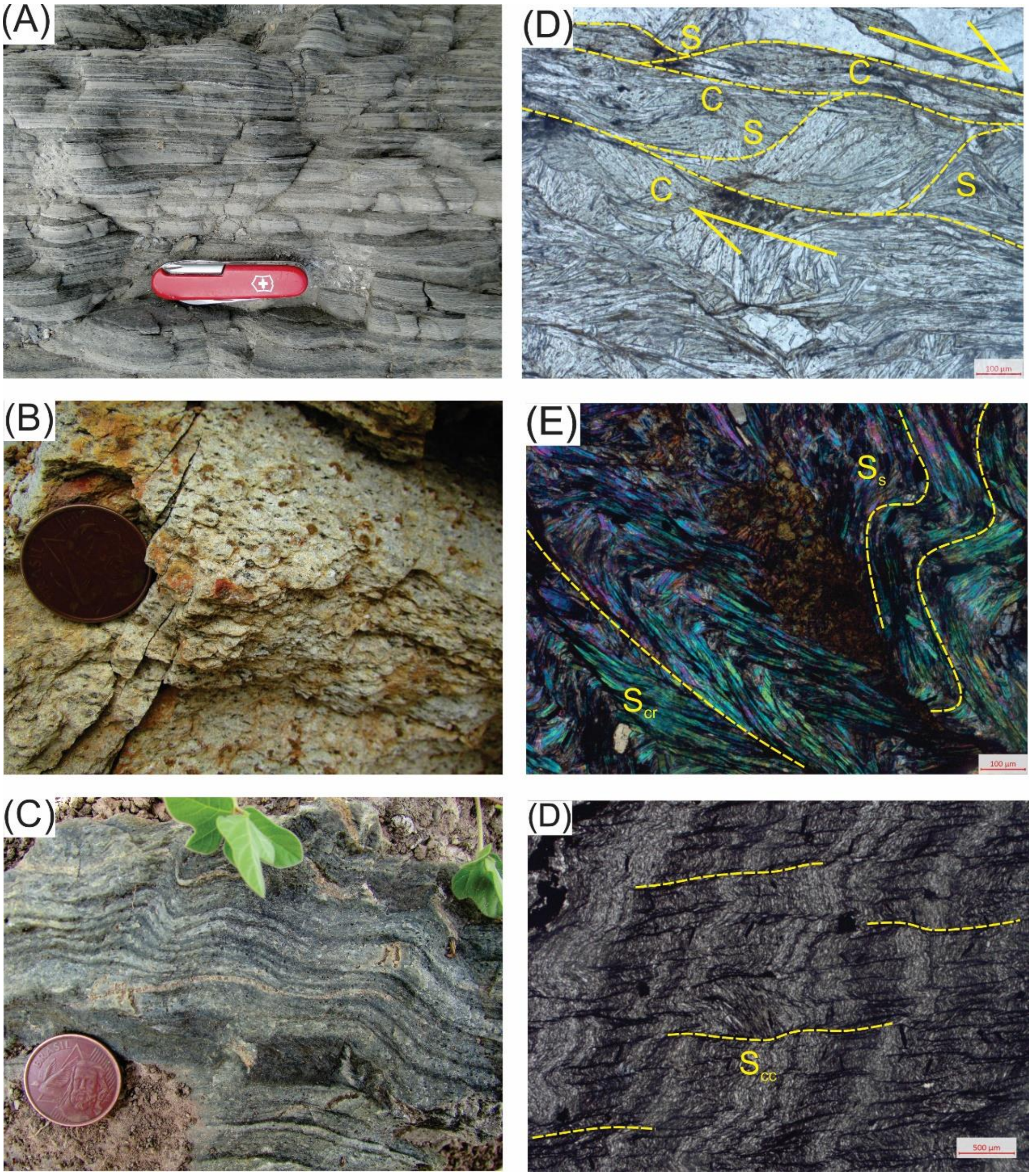

Figure 8: (A) fine-grained quartz schist with garnet and ilmenite (outcrop 1); (B) garnet mica schist (outcrop 105); (C) banded metarenite (outcrop 185); (D) S-C foliation (outcrop 131); (E) Crenulation of S_s foliation (outcrop 30); (F) S_s foliation completely transposed to S_{cc} (outcrop 129).

The transition between domains is heterogeneous. Between São Miguel do Aleixo and Feira Nova, the transition is gradual and discrete. However, in the Coronel João Sá-Marita profile, the transition is marked by swarms of quartz veins parallel to the shear zone as well as mylonites and ultramylonites. Mylonites and ultramylonites outcrops stand out as aligned ridges. Mylonites have the characteristic S-C foliation dipping mostly 75° to 90° NE and 68° to 80º NE, for S and C foliations, respectively. These rocks display sinistral kinematic indicators and are composed of quartz with muscovite and chlorite as accessories, quartz showing recrystallized rim by subgrain rotation (Fig. 9A). Ultramylonites may exhibit alternate dark and light layers (Fig 9B) and in thin section are characterized by recrystallized quartz ribbons with recrystallized rim evidencing grain boundary migration.

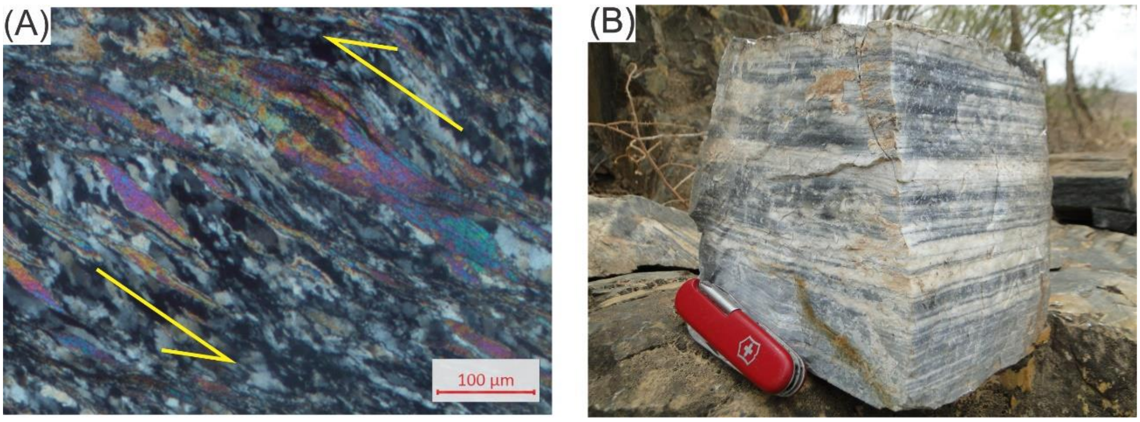

Figure 9: (A) quartz-mylonite in thin section with sinistral mica-fish (outcrop 16); (B) ultramylonite (outcrop 13).

5. Metamorphism

The transpressive deformation in the area occurred under metamorphic greenschist facies conditions. The distribution of the mineral assemblages characterizes a classical Barrovian metamorphic zoning with lower grade mineral assemblages in the Vaza Barris Domain and higher grade in the Macururé Domain.

The general mineral assembly in the Vaza Barris Domain is qz + ms ± cal ± chl ± ilm, indicative of metamorphism in the chlorite zone. Macururé Domain rocks display three main mineral paragenesis: (i) qz + ms + chl + bt ± ilm ± cc; (ii) qz + ms + bt + chl + grt + ilm and (iii) qz + ms + chl + ilm ± grt. Paragenesis (i) and (ii) indicate medium to high greenschist facies, biotite, and garnet zones respectively, while paragenesis (iii) seems to represent a retrometamorphic assemblage.

Overall, muscovite and chlorite define the main foliation in the phyllites and schists (Fig. 10A). In the Macururé schists biotite, when present, is characterized by disperse lamellae deflecting the S_b foliation and defining the S_T foliation (Fig 10B). Garnet is characterized by type σ or ϕ porphyroblasts (mantled or not) slightly deflecting the main foliation (Fig. 10C). Aggregates of chlorite and quartz seem to be garnet pseudomorphs formed during a retrogressive phase.

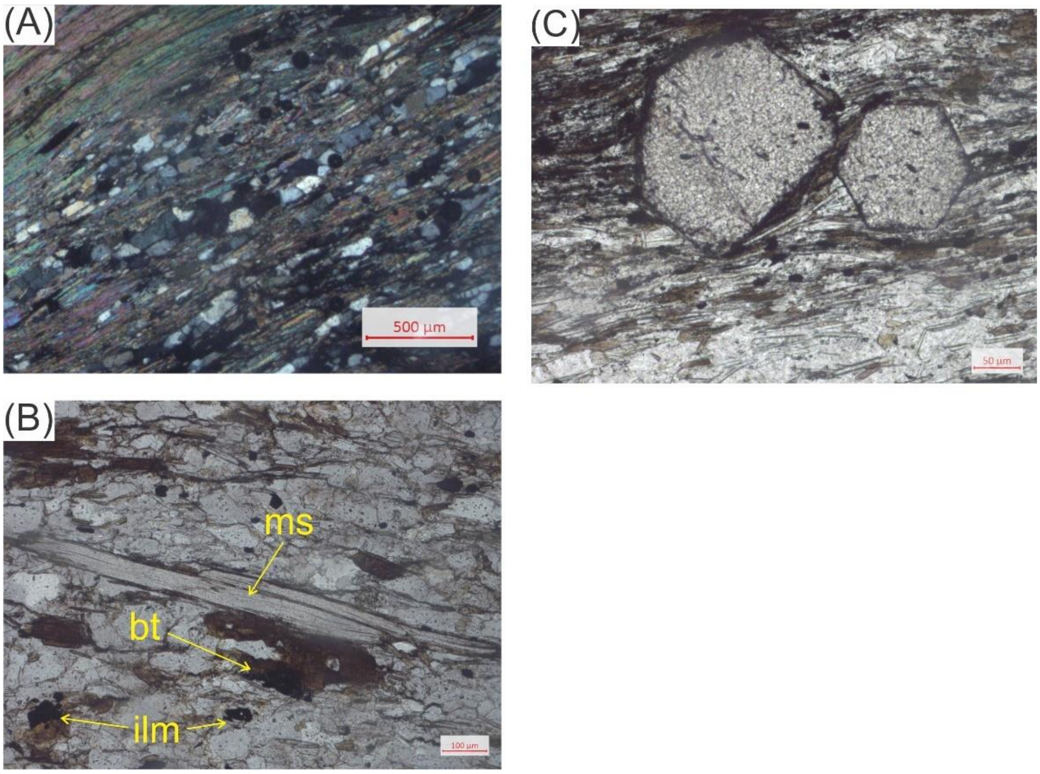

Figure 10: (A) muscovite and chlorite defining the foliation (outcrop 152); (B) biotite lamellae associated with muscovite (outcrop 1); (C) Garnet porphyroblasts deflecting the main foliation (outcrop 1).

6. Geothermometry

Due to the low metamorphism, it was not possible to perform a suitable and stable geobarometry analysis in the area. For the average temperature (AvT) calculation, the chlorite composition of five samples (GMA-001, GMA-011, GMA-051, GMA-177 and GMA-191) and the biotite-garnet pair of two samples (GMA-001 and GMA-177) were used. All samples analyzed belong to the Macururé Domain; Vaza Barris samples are very fine-grained, which hampered their polishing, therefore precluding to perform adequate analyses.

6.1. Analytical procedures

Polished thin sections of the selected samples were submitted to wavelength dispersive spectroscopy (WDS) quantitative analyses at the Laboratório de Microssonda (LABSON) from Universidade de Brasília (UnB), using a JEOL JXA-8230 electron microprobe analyzer. Analyses were performed under the following operating conditions: a column accelerating voltage of 15 kV, a current of 10 nA, an analysis time of 10 s. The standards used for instrument calibration were andradite (Ca and Fe), microcline (Si, Al, and K), olivine (Mg), albite (Na), pyrophanite (Ti and Mn), vanadinite (V and Cl), nickel oxide (Ni), chromium trioxide (Cr), and celestine (Sr). All thin sections selected for electron microprobe analyses were previously carbon coated. The data were treated using the softwares Qmin (Silva et al., 2021). Table 1 presents the most representative mineral chemistry data.

The chlorite spreadsheet was first calculated by WinCcac software (Yavuz et al., 2015) and then plotted in the Temperature vs. Si diagram of De Caritat et al. (1993). For the biotite-garnet pair calculation only garnet rim compositions were used due to chemical zoning. Conventional thermometry??. According to Thomas and Rana (2019), the temperatures obtained by the Thompson (1976), Holdaway and Lee (1977), Ferry and Spear (1978), and Perchuk and Lavrente'va (1983) models were taken into consideration.

6.2. Results

The obtained temperature values are concordant with the field metamorphic zoning of the study area. Bellow there is a brief description of the samples according to the metamorphic assemblage, followed by detailed description of the index mineral compositions.

Table 1: Major element compositions of representative mineral assemblages from analyzed samples.

Sample	GMA-001			GMA-011	GMA-051	GMA-177			GMA-191
mineral	chl	grt	bt	chl	chl	chl	grt	bt	chl
SiO_2	24.30	36.93	35.19	24.70	25.10	25.18	35.31	31.521	24.23
FeO	24.90	20.87	18.17	25.44	26.96	28.12	20.94	17.85	21.52
MgO	14.84	31.03	20.01	14.89	12.96	13.08	27.58	23.39	27.04
CaO	0.01	2.69	10.09	0	0.05	0.03	1.04	11.42	13.69
Al_2O_3	22.21	1.64	0.04	22.31	20.70	19.24	6.82	0	0.029
Na_2O	0	0.01	0.09	0.04	0.07	0.02	0.05	0.07	0
K_2O	0.04	0.00	8.03	0.02	0.05	0.06	0.00	5.80	0.00

TiO_2	0	0.26	1.21	0.16	0.22	0	0.17	0.67	0
P_2O_5	0.06	0.00	0	0	0	0.03	0.04	0	0.06
MnO	0.10	6.74	0.02	0.16	0.15	0.20	7.68	0.11	0.15
Cr_2O_3	0	0	0.06	0	0.04	0	0.02	0.03	0.05
V_2O_3	0	0.01	0.05	0.02	0.03	0.05	0	0	0.01
NiO	0	0.01	0	0.05	0.02	0.04	0.0	0.07	0.06
Cl	0.03	0	0.29	0.00	0.02	0.02	0	0.25	0.05
F	0	0	0	0	0	0.06	0	0.01	0
Total	86.49	100.19	93.25	87.74	86.37	86.12	99.65	91.17	86.91

Sample GMA-011 is a mica schist representative of the chlorite zone, with qz + fsp + chl + cc + ilm assemblage. In thin section, this rock displays zonal mylonitic foliation defined by muscovite and chlorite interlayered with quartz aggregates. Feldspar porphyroclasts are also observed, as well as poikiloblastic calcite engulfing quartz and feldspar; ilmenite occurs as accessory. Sample GMA-051 is a quartz-mica schist of the biotite zone, with a similar assemblage to sample GMA-011, adding biotite. Muscovite, chlorite and biotite define an anastomosed, locally mylonitic, foliation. Calcite, feldspar porphyroclasts and ilmenite are also present.

Samples GMA-001 and GMA-177 characterize the garnet zone. GMA-001 is a very fine schist with qz + ms + bt + chl + grt + ilm assemblage. It has a parallel spaced foliation (S_b) defined by muscovite and chlorite, deflected by biotite layers that define the

S_T foliation. Garnet porphyroblasts are clean without inclusions and measure between 70 and 295 μm, slightly deflecting the main foliation with small or no pressure shadows. Ilmenite occurs as accessory. GMA-177 sample is a garnet schist with qz + ms + chl+ bt + grt + fsp + ilm assemblage. In thin section, this rock has porphyrolepidoblastic texture defined by alternance of ribbon-quartz and mica layers with garnet porphyroblasts and bt + chl +qz/fsp aggregates. Garnet porphyroblasts have opaque (ilmenite?) inclusions and are 583 to 1600 μm large; as in sample GMA-001 they slightly deflect the main foliation.

Sample 191, in turn, has ms + qz + chl + opq + matrix assemblage. It is a very fine-grained schist with two well marked foliations: S_b delimited by the alignment of matrix micas, and a S_{cr} foliation that crenulates and deflects S_b. Chlorite, quartz and muscovite form aggregates that resemble garnet pseudomorphs. If so, they were formed in a retrometamorphic event possibly through the reaction garnet + biotite + ilmenite + H_2O = chlorite + muscovite + titanite + quartz.

According to Hey (1954), the general chlorite composition of the analyzed samples plots in the ripidolite field (Fig. 11). MgO amounts vary between 11.68% and 15.49%; sample GMA-177 shows lower values (11.68%-13.39%) while higher amounts are observed in sample GMA-001 (13.33%-15.49%). Samples GMA-001, GMA-011 and GMA-051 display low FeO, ranging from 24.59% to 26.33%; higher amounts (26.15%-28.46%) are found in sample GMA-191. Sample GMA-177 shows a wide range, between 23.63% and 30.72%, with most values between 26.15% and 30.72%; the other samples display values in the 24.6% to 25.93% interval. Regarding Al_2O_3 content, sample GMA-177 shows the lower values, from 17.87% to 19.57%, whereas higher values were obtained in sample GMA-001 (21.73% to 22.83%). The other samples have intermediate to high values between 19.22% and 22.52%.

The chlorite spreadsheet was first calculated by WinCcac software (Yavuz et al., 2015) and then plotted in the Temperature vs. Si diagram of De Caritat et al. (1993) (Fig. 12). The temperatures found show a progressive trend. Sample GMA-177 shows lower temperatures (289 °C to 342 °C) and the higher temperatures are found in sample GMA-191, ranging from 376 °C to 439 ºC.

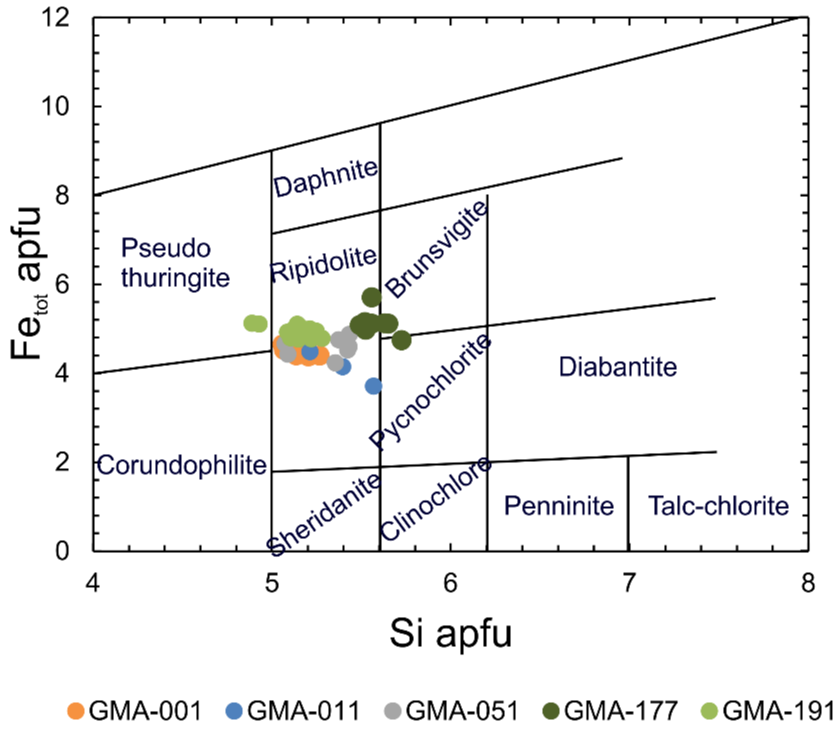

Figure 11: chlorite classification diagram by Hey (1954).

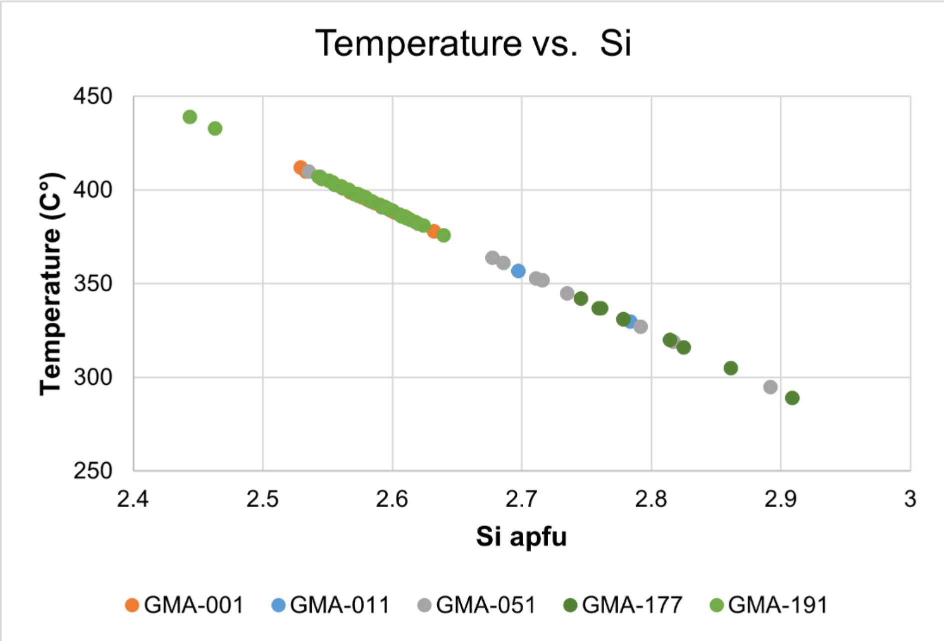

Figure 12: Chlorite temperature vs. Si diagram (De Caritat et al., 1993).

Biotite lamellae show a homogeneous composition, all samples have similar values of FeO and Al_2O_3, varying from 17.31% to 26.78% and from 15.55% to 18.24%, respectively, while showing different values of MgO. The first cluster (samples GMA-001 and GMA-177) displays enrichment in this oxide relative to the second one (samples GMA-051 and GMA-185), with ratios of MgO varying from 9.25% to 11.42% compared to 7.28% to 8.11% in the second cluster. The amount of TiO_2 is homogeneous in cluster 2 ranging from 1.14% to 2.46% and shows a wide variation in cluster 1, ranging from 0.40% to 7.09%.

Two different textural types of garnet were identified: (i) inclusion-rich garnet porphyroblasts (583 to 1600 µm) and (ii) inclusion-free or poor small grains (70 to 295 µm). In both types, the dominant end member is almandine, but they show different compositions, and the general formula of type I garnet is $Alm_{57.17\text{-}75.8}Prp_{3.4\text{-}22.15}Grs_{10.23\text{-}21.33}Sps_{3.33\text{-}17.84}$ and of type II is $Alm_{76.49\text{-}63.69}Prp_{9.93\text{-}14.12}Grs_{3.15\text{-}6.59}Sps_{6.62\text{-}17.57}$. The chemical profile shares some similarities in both types (Fig 13); however, in type I garnets (sample GMA-177, outcrop 177), the almandine content shows a near flat pattern, while type II garnet (sample GMA-001, outcrop 1) records a more conspicuous chemical zoning. Sample GMA-001 shows a flattened pattern for both Prp and Grs; in the sample GMA-177, the Prp pattern is flat while there is an enrichment of Grs in the core. In both samples, there is a rim-ward increase of spessartine and an opposite pattern for almandine. The temperatures obtained by conventional thermometry through the garnet-biotite pair of samples GMA-001 and GMA-177 are displayed in table 2.

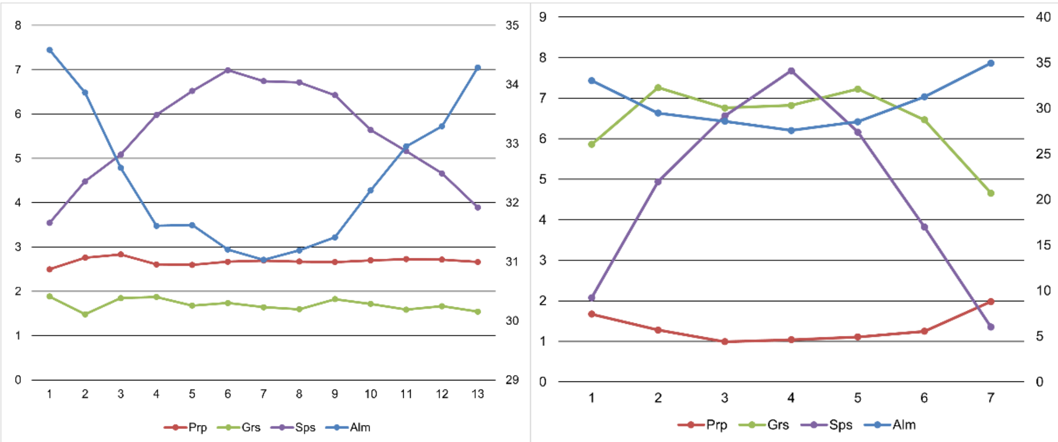

Figure 13: Chemical profiles of type I (left) and type II (right) garnet.

Table 2: Temperatures found by calculations based on biotite-garnet models. FS78: Ferry and Spear (1978); PL83: Perchuk and Lavrente'va (1983); T76: Thompson, 1976; HL77: Holdaway and Lee (1977).

Sample	Ref. P (kbar)	Temperatures (°C)			
		FS78	**PL83**	**T76**	**HL77**
GMA-001	5	538	560	564	551
GMA-177	5	411	482	459	458

7. Discussions

7.1. Structure and deformation of the São Miguel do Aleixo Shear Zone

In an oblique convergence the relative motion between the two blocks contains a thrusting (compressional) and a strike-slip (transcurrent) component (Plujjm and Marshak 2004), leading to a tranpressive deformation event (Sanderson and Marchini, 1984; Dewey et al., 1998). In the Sergipano Belt, this tectonic process is well represented in the deformational history of SMASZ.

Strain distribution is heterogenous between the domains due to distinct rheology and metamorphic grades. Phyllites and carbonatic metarhythmites with ductile-brittle deformation dominate in the Vaza Barris Domain. In contrast, the Macururé domain is mainly composed of metapelites deformed under ductile regime with subordinate metarhythmites, metarenites and metagraywackes. This feature is clearly recorded in the structural map (Fig. 6), in which a series of duplexes are present in the Vaza Barris domain, which are absent in the Macururé domain, indicating obliteration of the thrusts due to a more pervasive ductile regime in this domain.

The contractional stacked duplexes are rhombohedral and sigmoidal stepovers, corroborating the sinistral shear sense of SMASZ. They are interpreted as subsidiary stacked thrust sheets (Cunningham and Mann, 2007 and references therein) formed by the partitioning of deformation due to competence difference of layers in response to the compressional regime.

In the Vaza Barris Domain, the sedimentary bedding (S_b) is the dominant foliation with a discrete slaty cleavage (S_c), whereas in the Macururé Domain, there is a composite foliation $S_T = S_b \rightarrow S_c \rightarrow S_s \rightarrow S_{cr} \rightarrow S_{cc}$, with transposition increasing northwards. A later foliation (S_{sp}) is present in both domains and is interpreted as formed due to the N-S compressional component of the transpressional deformation. Fold hinges coincide with E-W-trending lineation. In the RGB + tilt composite map (FIGX), megascopic sinistral drag folds are observed in the Vaza Barris Domain, indicating the transcurrent component direction. A set of ENE-WSW magnetic lineaments is also observed in the magnetic data that could represent a later brittle stage of the deformation.

In the westernmost portion of the area, the shear zone terminates as a horsetail splay that forms a sinistral positive flower structure (Cunningham and Mann, 2007). This structure is composed of an utramylonite core bounded by mylonite. The ultramylonites are intensely silicified and associated with a swarm of quartz veins parallel to the shear zone. These features suggest the participation of SiO_2-rich fluid in the transpression process, which may have contributed to the Macururé domain overthrusting the Vaza Barris domain. In thin section, quartz-mylonites quartz ribbons display recrystallization by subgrain rotation, indicative of medium to high temperatures and strain rate, while ultramylonites quartz ribbons are intensely recrystallized by grain boundary migration.

Regarding the metamorphic grade, there is a shift from the chlorite zone (Vaza Barris) to the biotite and garnet zone (Macururé), indicating progressive Barrovian-type metamorphism. Progression of metamorphism is also seen in the gradual temperature increase measured by chlorite thermometry (Fig. 14). Two garnet generations were identified, corroborating thermometry estimates. Type I garnet indicates a metamorphic peak between 323 °C and 420 °C (medium- to high-T greenschist facies). Type II garnet indicates temperatures ranging from 538 °C to 564 °C, suggesting metamorphism at the greenschist-amphibolite facies transition.

The zoning of both garnet generations exhibits a classic progressive metamorphic pattern (Fig. 13). Metamorphism in the amphibolite – greenschist transition indicated by type II garnet is explained by the contact metamorphism due to the Coronel João Sá intrusion, as demonstrated by Guedes (2019), who found metamorphic halos in the staurolite zone around granitic bodies within the Barrovian garnet zone of the study area.

These features point to distinct depositional environments and crustal levels between the Vaza Barris and Macururé domains juxtaposed due to the São Francisco–PEAL collision, as already stated by Davison and Santos (1989). The presence of igneous intrusions in the Macururé Domain also supports this hypothesis.

7.2. Composite deformational style

Thin-skinned and thick-skinned structural styles may coexist in orogens. Geometry and interaction between separate portions of an orogenic system are useful tools to help understanding the nature of its formation. In the Sergipano Belt, the Vaza Barris domain, interpreted as a foreland basin (Oliveira et al., 2010), represents a fold-and-thrust belt. Thin-skinned deformational style dominates in this domain. As the transpression took place, the foreland basin was compressed generating stacked thrust sheets, represented by the rhombohedral and sigmoidal duplexes observed in the structural map (Fig. 6). Less competent layers, such as phyllites, acted as site of decollement thrust faults. D'el-Rey Silva (1995) stated that the gneiss-migmatitic basement of the Itabaiana and Simão Dias domes were deformed concomitantly to the supracrustal rocks, indicating the ductile involvement of the basement during the contractional evolution of the Sergipano Belt.

Basement involvement in deformation is not an absolute indicative of thick-skinned deformation. Pfiffner (2006, 2017) proposed the term basement-involved thin-skinned tectonics to describe a contractional style where thrust faults run parallel to the basement-cover contact a few kilometers beneath this contact and thus delimiting relatively thin basement slices. In contrast, thick-skinned tectonic style implies the involvement of thrust faults that cut across the upper crust and possibly the lower crust.

According to D'el-Rey Silva (1995), the Itabaiana Dome area was probably a deep depocentre associated with a roll-over syncline-anticline pair, which explains the thick quartzite layer around it. During transpression, these faults were reactivated as transpressive zones that squeezed the ductile top of the basement along with the ESE-WNW trend of the belt (D'el-Rey Silva 1992, 1995). The author also states that the quartzite pile slided between two lubricant-like layers. The Simão Dias Dome, in turn, probably evolved as a series of basement slices bounded by listric extensional faults that inverted in the SF-PEAL collision (D'el-Rey Silva, 1995). This evolution agrees with basement-involved thin-skinned tectonics, in which reactivation of extensional faults in transpressive faults leads to the uplift of higher basement portions without reaching deeper crustal levels.

In the Macururé Domain, ductile deformation dominates, and duplex structures are not observed. These features may be obliterated due to pervasive folding of a crust thermally weakened by magmatic activity or regional burial metamorphism (Pfiffner, 2006, 2017). Burial and heating of this area also lead to the interaction of the metapelites with magmatic activity, represented by a series of intrusions in this domain (Oliveira et al., 2014; Conceição et al., 2016; Lisboa et al., 2019; Pereira et al., 2020; among others).

Magnetic, gravimetric, and seismic data (Dutra et al. 2019; Fianco, 2019) show that the Vaza Barris-Macururé limit is well defined in depths that reach up to 15 km into the crust. Fianco (2019) also shows that the São Francisco Craton crust extends under almost all the Macururé domain. Moreover, Oliveira et al. (2014) state that the Macururé domain displays a structure analogous to the ductile channel flow model proposed for the High Himalaya, implying a probable dominant thick-skinned tectonic style.

Thus, we suggest that the SMASZ is an important crustal fault transitioning between thin-skinned and thick-skinned dominant areas, thrusting metapelites of a deeper crustal level side by side with the foreland fold-and-thrust-belt of the Vaza Barris domain. Figure 14 shows a schematic profile for the area.

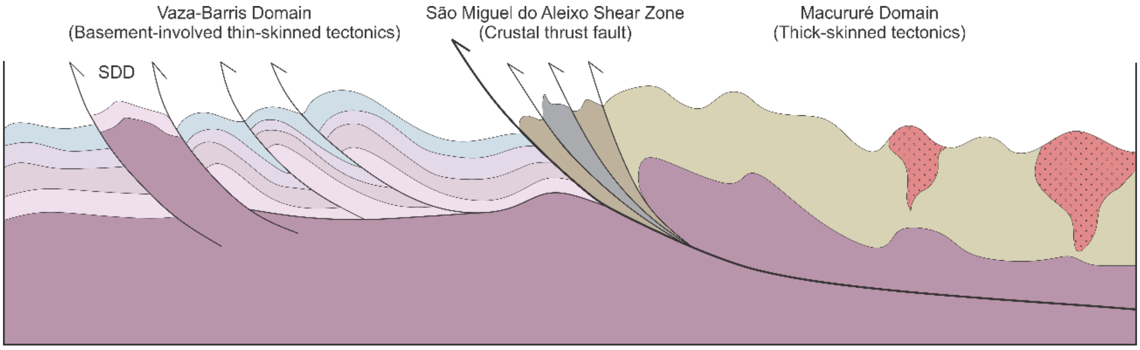

Figure 14: Schematic hypothetical profile for the study area. SDD: Simão Dias Dome.

The Sergipano belt is an orogen with a composite style of deformation. In the Vaza-Barris domain, dominates basement-involved thin-skinned tectonics, while in the Macururé domain, the structures indicate a possible thick-skinned tectonics style. Classic collisional orogens, in general, consist of a central zone flanked by foreland fold-and-thrust belts (Hatcher, 1989; Pfiffner, 2006). This model does not fit well in the Sergipano Belt since there is a thick-skinned system between the foreland and the central zone of the orogen. On the other hand, in accretionary orogens, a series of belts of different styles of deformation are juxtaposed.

In the Tasmanides (Gray et al. 2006 and references therein), there are three accreted fold belts, each one with a different tectonic style of deformation. According to Gray and Foster (1998) and Gray et al. (2006), faulting in accretionary orogenic systems consists of a combination of thin and thick-skinned belts. For the authors, the thin-skinned thrust systems consist of either detachment-related folds and thrust belts within passive margin and foreland environment or chevron-folded turbidites developed within former submarine fans overlying back-arc basins, while thick-skinned tectonics consist of major thrust faults that root into the seismic reflection Moho with no apparent common décollement and involved former arc, forearc, submarine fan, and accretionary complex elements.

The depositional environment of the Vaza Barris and Macururé domains also supports the interpretation of different tectonic styles. The Vaza Barris domain is interpreted as a passive margin basin (Del-Rey Silva, 1992, 1995) and as a passive margin overlain by a foreland basin (Oliveira et al., 2017). Both suggested settings are coherent with the evolution of a thin-skinned tectonic style. The Macururé domain is interpreted as a passive margin of the São Francisco Paleoplate (Del-Rey Silva, 1992, 1995), which is discarded due to the provenance ages of its metasedimentary units (Oliveira et al. 2010), or as the southern passive margin of PEAL (Oliveira et al., 2010). However, recent data (Passos et al., 2021) imply the existence of subduction in the Canindé domain at ca. 740 Ma. This fact implies that at least part of the Macururé domain was deposited in a syn-orogenic basin, either as a forearc, submarine fan, or an accretionary complex, supporting the idea of thick-skinned dominant tectonics for this domain.

Recent papers show that accretionary processes may have an important role in the formation of the Sergipano Belt and other areas of the Borborema Province (Santos et al., 2018, 2019, 2020, 2021a, 2021b, 2021c; Santos and Santos, 2019; Almeida et al., 2021; Silva Filho et al., 2021). Regarding these and the data presented in this paper, it is possible to infer that the accretionary hypothesis for the formation of the Sergipano Belt seems to represent more accurately its evolution. However, more investigation is necessary, especially using reflection seismic aiming to better understand the structure of the deeper crust of the Sergipano Belt.

8. Conclusions

The Vaza Barris and Macururé domains are two distinct units that were juxtaposed by the São Miguel do Aleixo shear zone, a major crustal thrust zone. This shear zone was formed as a response to transpressional stress due to the oblique convergence between the São Francisco Paleoplate and the Pernambuco-Alagoas Superterrane during the Brasiliano Orogeny. The Vaza Barris domain is a foreland fold-and thrust-belt with a dominant thin-skinned structural style. Stacked rhombohedral and sigmoidal thrust duplexes dominate this region. Another transpressional feature present is a positive flower structure in the westernmost portion of the study area that comprises a ultramylonite zone bounded by mylonites. The Macururé domain was deformed under a ductile regime with probable dominant thick-skinned style. The structuration of these domains supports the hypotheses that accretionary processes played an important role in the Sergipano Belt evolution.

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CAPÍTULO 4 – Considerações finais

Ainda há muito a ser estudado para um melhor entendimento da Faixa Sergipana. Nesta tese mostramos que nenhum dos modelos atuais, inversão de margem passiva ou ciclo de Wilson completo, se encaixa nesse orógeno, sendo um modelo acrescionário mais verossímil para a região. Apesar de bem embasados, os dados de magnetometria interpretados no capítulo 2 desta tese ainda precisam ser confirmados com trabalhos de campo sistemáticos em áreas estratégicas, sobretudo nos domínios Marancó, Poço Redondo e Rio Coruripe, que ainda carecem de dados.

Ficou claro que a Zona de Cisalhamento São Miguel do Aleixo é um importante limite crustal e que os domínios Vaza Barris e Macururé são distintos e foram depositados e deformados em ambientes e níveis crustais distintos. Os indicadores cinemáticos da região permitem inferir que durante a colisão oblíqua entre a Paleoplaca do São Francisco e o Superterreno Pernambuco-Alagoas a componente cisalhante teve papel muito mais expressivo que a componente compressional e que toda a Faixa Sergipana provavelmente atuou como zona de acomodação de escape lateral. As interpretações do arcabouço estrutural dos domínios Vaza Barris e Macururé serão mais completas por meio de estudos de reflexão e refração sísmica profunda para que seja conhecida a geometria das estruturas em subsuperfície. Além disso, dados isotópicos para estudo de proveniência são ferramentas que irão ajudar o entendimento dos ambientes deposicionais desses domínios e auxiliar na reconstrução de um modelo geodinâmico mais fiel para esse orógeno.