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https://doi.org/10.1590/2317-4889202320220069

BJGEO Brazilian Journal of Geology

Deformational sequence of inversion in the Paramirim Aulacogen, northern region of the intracontinental sector of the Araçuaí Orogen

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Abstract

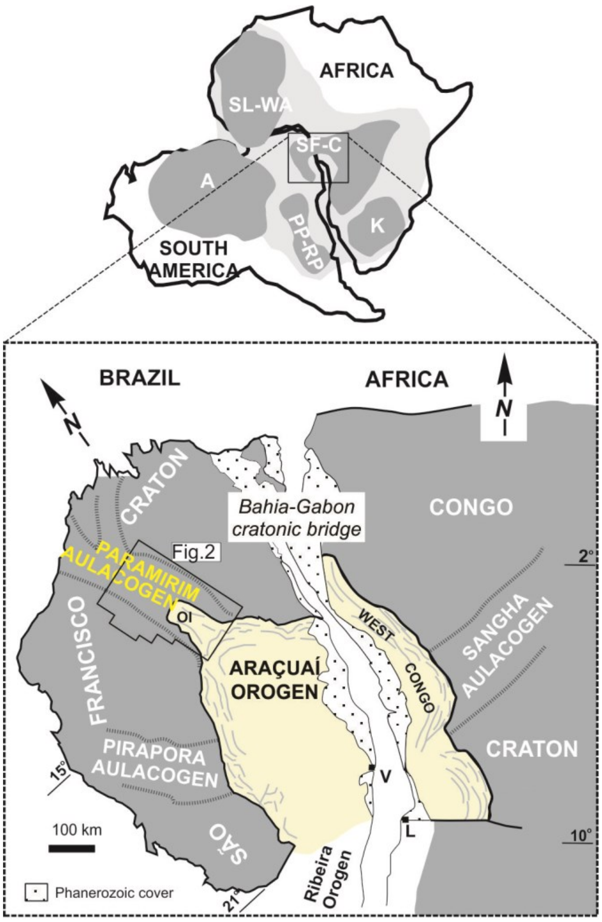
The Paramirim Aulacogen was filled by the Espinhaço and São Francisco supergroups in the period from 1.75 to 0.69 Ga, and suffered partial inversion during the Ediacaran. In the northern sector of the intracontinental domain of the Araçuaí-WestCongo Orogen, six compressive deformational phases were interpreted and associated with the frontal inversion of the Paramirim Aulacogen. Three structural domains were identified: Jacaraci Fold-Thrust Belt, Caetité Nappe, and Transpressive Domain. The nucleation of deformational structures is related to a maximum stress field with general WSW-ENE orientation. The first deformational phase (D_1), found in the Jacaraci Fold-Thrust Belt and the Transpressional Domain, is related to the evolution of the Rio Pardo Salient. A dextral transpressional system nucleated the Caetité Nappe. This system also juxtaposed amphibolite facies rocks over lower temperature facies, as well as Statherian over Tonian rocks. Furthermore, this system was responsible for deformation in the transpressional domains and late deformation in the Jacaraci Fold-Thrust Belt. The region presents a variety of structures and is, therefore, an excellent natural laboratory for studying positive inversion in aulacogens.

KEYWORDS: aulacogen; orogen; tectonic inversion; craton; deformational phases.

INTRODUCTION

The Paramirim Aulacogen (Fig. 1) is one of the aborted arms of a superimposed rift system of Statherian-Cryogenian age, developed in the São Francisco-Congo paleocontinent (Brito-Neves *et al.* 1999, Campos-Neto 2000, Alkmim and Martins-Neto 2001, Cruz 2004, Cruz and Alkmim 2006, 2017). Filling of the aulacogen occurred between 1.75 and 0.69 Ga (Danderfer-Filho *et al.* 2015, Santana 2016), distributed in the Espinhaço and São Francisco supergroups. This aulacogen was a precursor basin of the Araçuaí-West Congo Orogen. Surrounded by the São Francisco-Congo Craton, this confined orogenic incision displays concavity facing south. The pre- and post-collisional magmatic components date from ca. 650 to 490 Ma (Pedrosa-Soares and Alkmim 2011, Pedrosa-Soares *et al.* 2020, Caxito *et al.* 2022).

Inverted aulacogens are recognized worldwide (Vicat *et al.* 1989, Schröder 1981, Alvarez and Maurin 1991, Hamilton 1988, Bartholomew *et al.* 1993, Varga 1993, Molzer and Eerslev 1995, Knott *et al.* 1995, Turner and Williams 2004, Kadima *et al.* 2011, Fossen *et al.* 2017, Nepomuceno *et al.* 2021, Cibambula *et al.* 2022). These basins constitute critical zones of weakness



OI: Araçuaí-West Congo Intracontinental Orogen.
Source: modified from Pedrosa-Soares *et al.* (2007).

Figure 1. The Araçuaí-West Congo Orogen and the adjacent São Francisco-Congo craton in the context of West Gondwana.

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in the continental domains, both because the thick volume of sediments and association with the reactivation of successive pre-existing structures (Sengör *et al.* 1978). In the collisional domains in which the aulacogens are located in the foreland region, they are connected and arranged at high angles to the former continental margin. Deformation tends to channel to the interior, generating complex tectonic arrangements.

The northern region of the intracontinental sector of the Araçuaí Orogen coincides with the zone of maximum Ediacaran inversion of the Paramirim Aulacogen. This NNW-oriented mega feature is limited to the north by the Queimada Nova shear zone (Cruz 2004) at 13°S. In this sector, the thick-skinned deformation juxtaposed Archean and Statherian rocks on the Tonian units (Bitencourt *et al.* 2019) of the Santo Onofre Group. Two fold-thrust belts with thick-skinned deformation were identified (Danderfer-Filho 1990, 2000, Cruz 2004, Cruz and Alkmim 2006, Cruz *et al.* 2012a): the northern Serra do Espinhaço, to the west, whose western limit is the Santo Onofre Shear Zone; and the Chapada Diamantina, to the east, whose eastern limit is the João Correia-Barra do Mendes Shear Zone.

This study aimed to present the deformational structures associated with the tectonic inversion (*Sensu* Glennie and Boegner 1981, Cooper and Williams 1989) of the Paramirim Aulacogen and present an evolutionary model for part of the Serra do Espinhaço Fold-Thrust Belt, north of the intracontinental sector of the Araçuaí Orogen.

GEOLOGICAL CONTEXT

The basement of the Paramirim Aulacogen (Fig. 2) comprises the rocks of the southern portion of the Gavião Paleoplate (Cruz *et al.* 2016), consisting mainly of metagranitoids of tonalitic-granodioritic composition with amphibolitic enclaves. Paleo and Mesoarchean ages are dominant. Neoarchean metagranitoids, metavolcano-sedimentary sequences of Mesoarchean ages, including Greenstone Belts, Neoarchean, Rhyacian, and Orosirian, intruded by Siderian-Rhyacian-Orosirian granitoids are also known (Cordani *et al.* 1985, 1992, Martin *et al.* 1991, Marinho 1991, Nutman and Cordani 1993, Cunha *et al.* 2012, Santos-Pinto *et al.* 1998, 2012, Bastos-Leal *et al.* 1998, 2000, Rosa *et al.* 2000, Peucat *et al.* 2002, Cruz *et al.* 2012b, 2016, Medeiros *et al.* 2017, Leal *et al.* 2018, Barbosa *et al.* 2020). Locally, granulitic orthogneisses are present (Arcanjo *et al.* 2005, Santos 2018, Guimarães 2019). Anorogenic, felsic, alkaline, and plutonic magmatism are represented by the Lagoa Real Intrusive Suite (Arcanjo *et al.* 2005) aged around 1.75 Ga (Turpin *et al.* 1988, Cordani *et al.* 1992, Lobato *et al.* 2015).

In the intracontinental sector of the Araçuaí Orogen, the Espinhaço and São Francisco supergroups fill the Paramirim Aulacogen. These units outcrop in the fold and thrust belts of the northern Serra do Espinhaço, to the west, and Chapada Diamantina, to the east. The Espinhaço Supergroup has a thickness of more than 5,000 m (Guimarães *et al.* 2012) and comprises predominantly siliciclastic rocks (metarenites, metapelites, and metaconglomerates) with subordinate acidic, alkaline, and anorogenic metavolcanic rocks. The age of deposition of the rocks of this supergroup is estimated between 1.75 and 0.9 Ga (Danderfer-Filho *et al.* 2015, Guadagnin *et al.* 2015).

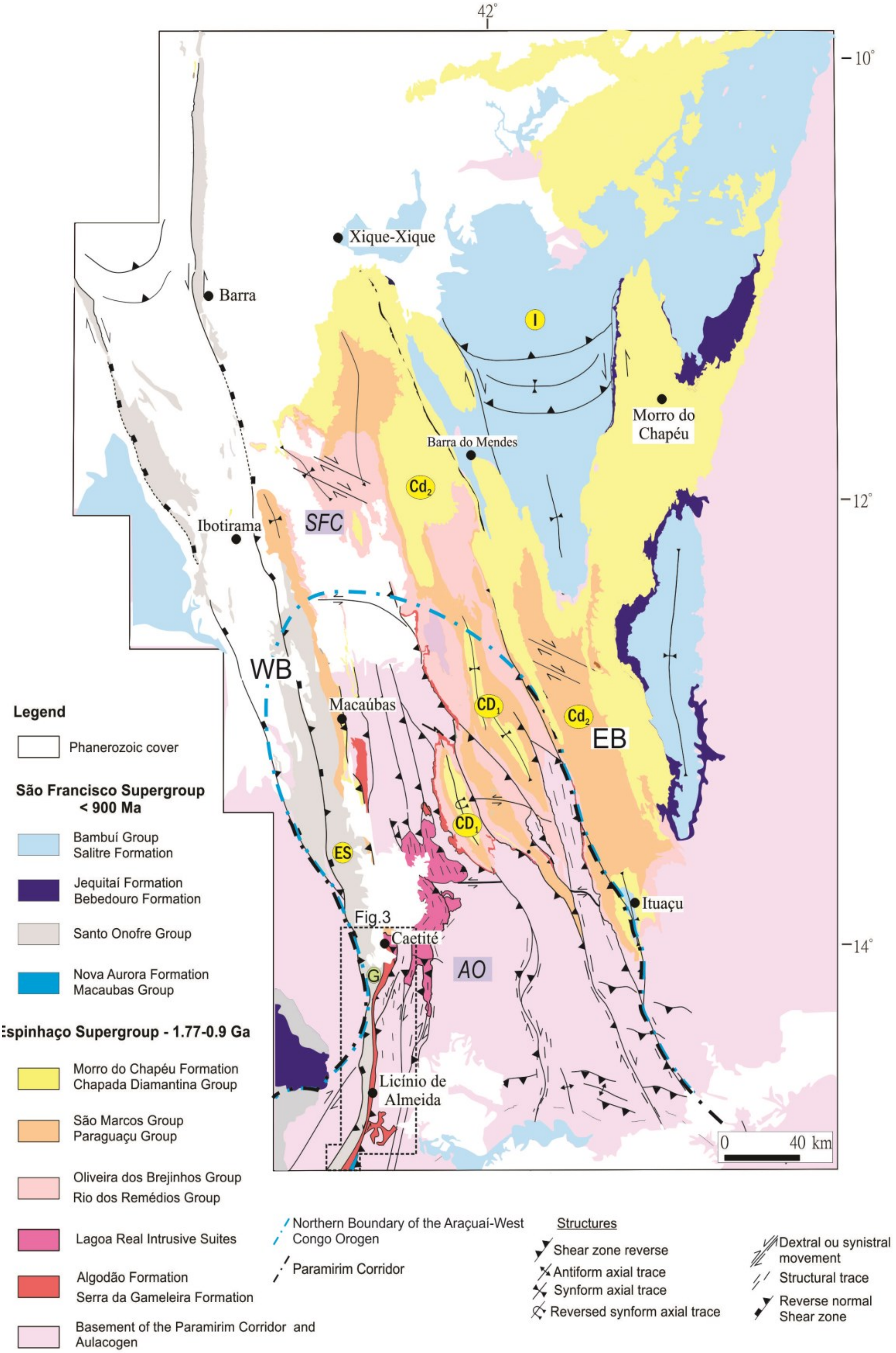
The São Francisco Supergroup comprises:

i. in the northern Serra do Espinhaço Fold-Thrust Belt, the Santo Onofre Group (2,040 meters thick; Guimarães *et al.* 2012), and with the Fazendinha, Serra da Vereda, Serra da Garapa formations, and Boqueirão, separated by very well-exposed depositional contacts north of Caetité. To the south of this town, the contact between the units of this group is defined by a dextral transpressional shear zone. Generally, it consists of feldspathic metarenites, lithic metarkoses, and metaquartzarenites, stratified and massive, with matrix-sustained oligomictic metaconglomerates (Guimarães *et al.* 2008);
ii. in the Chapada Diamantina Fold-Thrust Belt, the Bebedouro and Salitre formations. The Bebedouro Formation consists mainly of massive and stratified clast- and matrix-supported polymictic diamictites, pelites, arkoses, lithic subarkoses, graywackes, and quartz sandstones with subordinated carbonates, which were deposited into a glacial-marine environment (Guimarães *et al.* 2012). According to these authors, the Salitre Formation mainly comprises carbonates with calcarenites, dolarenites, and subordinated columnar stromatolites. Santana (2016) obtained an U-Pb age (zircon, LA-ICP MS) of 669 ± 14 Ma for a felsic metavolcanic rock intercalated with carbonates of this formation.

Dark-gray to greenish diorites and gabbros/diabases (Arcanjo *et al.* 2005, Menezes *et al.* 2012 and cited references) intrude the units of the Espinhaço Supergroup producing sills and dikes. According to these authors, these are tholeiitic rocks from a continental intraplate environment with substantial crustal contamination. Two crystallization age groups were obtained in zircon from these mafic rocks: the oldest group, located in the Eastern Basin, yielded ages of 1,514 ± 22 Ma (Babinski *et al.* 1999, TIMS), 1,496 ± 3.2 Ma, 1,492 ± 16 Ma (Guimarães *et al.* 2008, Loureiro *et al.* 2009), and 1,507 ± 7 Ma (Silveira *et al.* 2013). In turn, the youngest group, with representatives in both Western and Eastern basins, produced ages at 854 ± 23 Ma (Danderfer-Filho *et al.* 2009, SHRIMP, zircon) and 934 ± 14 Ma (Loureiro *et al.* 2009, LA-ICPMS, zircon), respectively.

The positive inversion (*Sensu* Gillcrist *et al.* 1987) of the Paramirim Aulacogen occurred in the Ediacaran (Cruz and Alkmim 2006), and two main structural domains can be identified (Danderfer-Filho 1990, 2000, Lagoeiro 1990, Cruz and Alkmim 2006, Cruz *et al.* 2007a, 2007b, 2007c, 2012a):

i. the domain of thin-skinned deformation, which nucleates a varied set of structures in the Espinhaço and São Francisco Supergroup rocks, described by Danderfer-Filho (1990, 2000), Lagoeiro (1990);
ii. the domain of thick-skinned deformation (Cruz and Alkmim 2006), with the formation of the Rio Pardo Salient (Cruz and Alkmim 2006, Peixoto *et al.* 2018), which is truncated by reverse to transpressional dextral shear zones that are anchored in the basement older than 1.75 Ga and that truncate the Espinhaço and San Francisco supergroups. In the northern Espinhaço Fold-Thrust Belt structures



AO: Araçuaí Orogen; SFC: São Francisco Craton; WB: Western Basin; EB: Eastern Basin; ES: Northern Espinhaço Fold-Thrust Belt; CD: Chapada Diamantina Fold-Thrust Belt; CD$_1$: thick-skinned deformation; Cd$_2$: thin-skinned deformation. Note the location of Fig. 3.

Source: modified from Cruz and Alkmim (2017).

Figure 2. Simplified geological map of the Paramirim Aulacogen.

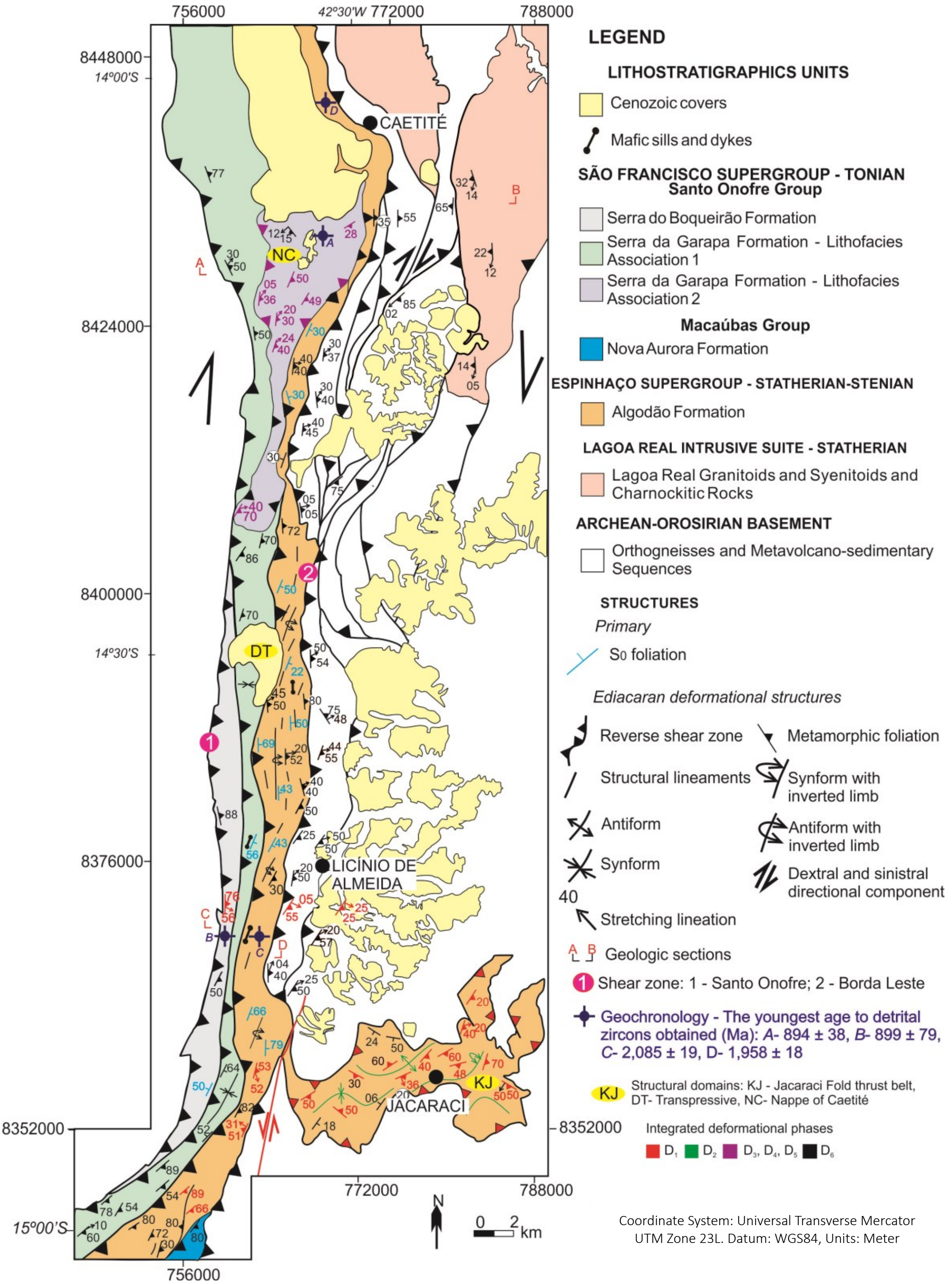
located north of Caetité were described by Danderfer-Filho (2000) and Guimarães (2019), and those located south of that town will be described in this study.

Typical shear zones that reactivate these structures are related to the collapse of the Araçuaí-West Congo Orogen (Cruz *et al*. 2015).

GEOLOGY OF THE SOUTHERN SECTOR OF THE NORTHERN SERRA DO ESPINHAÇO FOLD BELT

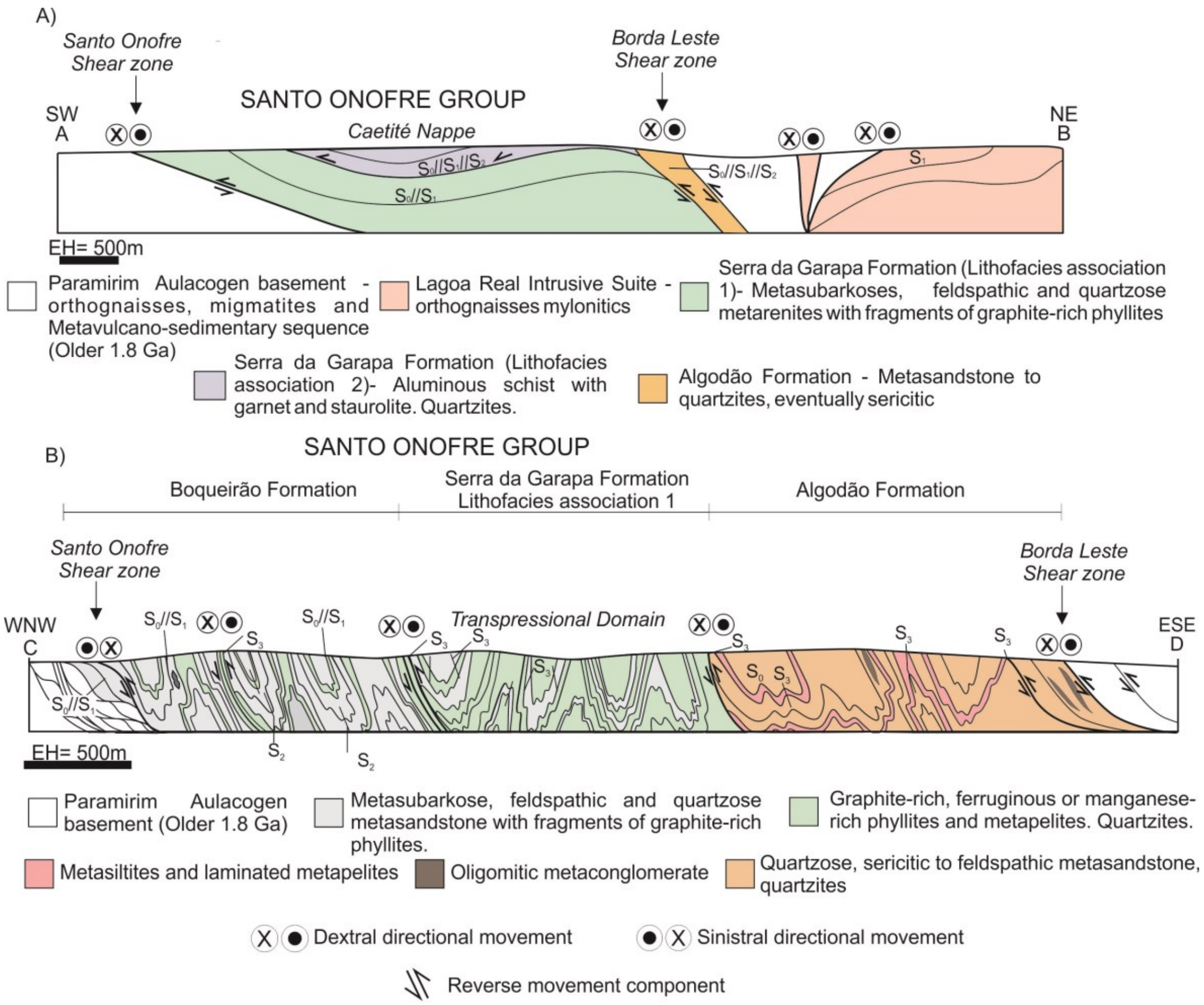
Lithological units

Studies carried out by Bitencourt *et al*. (2019) allowed us to identify (Figs. 3 and 4):



Source: modified from Bitencourt *et al*. (2019).

Figure 3. Geological map of the study area. Integrated deformational phases: vide Table 1.



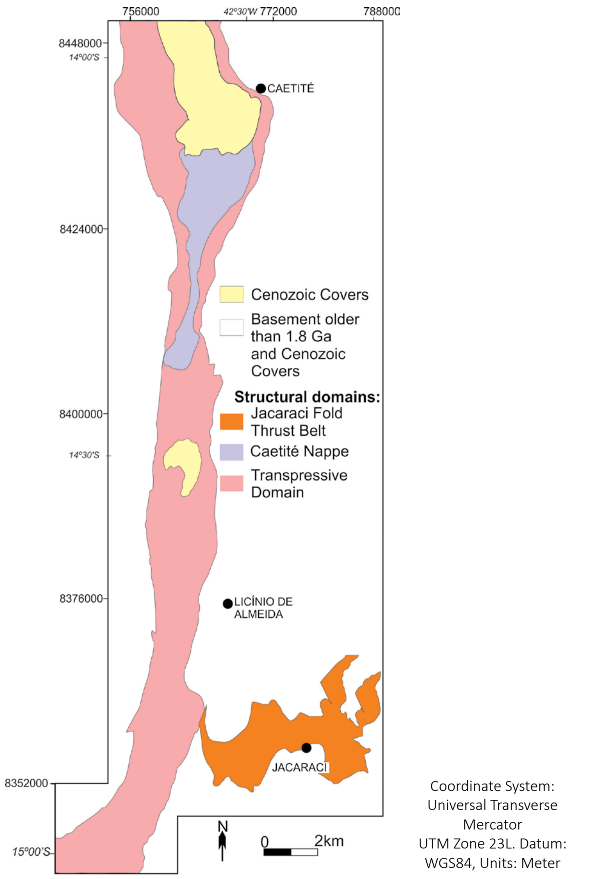
Source: modified from Bitencourt *et al.* (2019).

Figure 4. Geological sections of the study area. The location of the sections is indicated in Fig. 3.

- basement older than 1.75 Ga, comprising: (i) Mesoarchean rocks of the Santa Izabel Magmatic Suite, with tonalitic, granodioritic, quartz-monzodioritic, quartz-dioritic, and dioritic composition with crystallization ages between 3,091 ± 24 and 3,136 ± 8 Ma (LA-ICPMS, zircon, Medeiros *et al.* 2017). These rocks have been migmatized to varying degrees and have amphibolitic and metaultramafic enclaves; (ii) Leandrinho metavolcano-sedimentary sequence that intercalates aluminous schists (metapelite), metagraywackes, acid metatuffs, and metalapillites. The crystallization age of acid metatuffs is 2,550 ± 2 Ma (Vitoria *et al.* 2022); (iii) Guanambi-Urandi monzosyenitic batholith, with syenites and monzonites with subordinate granitic and mafic rocks (Rosa *et al.* 2000, Teixeira 2000). The crystallization ages range from 2,041 ± 2 Ma - 2,054 -6/+8 Ma (zircon, isotope dilution, Rosa *et al.* 2000);
- Undeterminated age metavolcano-sedimentary sequence that comprises metarkose, metagraywacke, quartzite, aluminum and manganese schists, graphite-rich phyllites, felsic and mafic schists (metavolcanic rocks), itabirite, marble (some of which are manganese rich), and a carbonate-silicate rock (Cruz *et al.* 2009, Borges *et al.* 2015);
- Algodão Formation (Espinhaço Supergroup) consists of alternating quartz to feldspathic metasandstones, sericitic metasandstones, oligomictic metaconglomerates, metasandstones and quartzites, laminated metapelites, metarhythmites and metasiltites, and quartzites. The youngest age is 1,958 ± 18 Ma (Bitencourt *et al.* 2019). North of Caetité, Danderfer-Filho *et al.* (2015) dated metavolcanic rocks of the Algodão Formation crystallized at 1,775 ± 26 Ma (U-Pb, LA-ICPMS, zircon).
- Lagoa Real intrusive suite, with metasyenites and metasienogranites, mylonitized to varying degrees, with crystallization age of ca. 1.7 Ga (Turpin *et al.* 1988, Cordani *et al.* 1992, Lobato *et al.* 2015).
- Santo Onofre Group (São Francisco Supergroup), with Serra da Guarapa and Boqueirão formations. The Serra da Garapa Formation was subdivided into two lithofacies associations. The first is composed predominantly of quartzites, hematite-rich, graphite-rich, or manganese-rich metapelites and phyllites. The second lithofacies association comprises staurolite-garnet-quartz-biotite aluminous schist and quartzites. The Boqueirão Formation predominate metasubarkoses, lithic metasandstones, and metasiltites besides oligomictic metamicroconglomerates. The youngest ages obtained are 894 ± 38 and 899 ± 79 Ma, respectively (Bitencourt *et al.* 2019).

Structural framework

From south to north, three structural domains were identified: Jacaraci Fold-Thrust Belt, Caetité Nappe, and Transpressional Domain (Fig. 5). The connection between Jacaraci Fold-Thrust Belt and the Transpressional Domain is made by a sinistral transcurrent shear zone (Fig. 3).



Source: modified from Bitencourt *et al.* (2019).

Figure 5. Map of the structural domains in the southern sector of the Northern Espinhaço Fold-Thrust Belt.

Jacaraci Fold-Thrust Belt

In this compartment, the Algodão Formation predominates (Figs. 3 and 6), with medium- to large-sized parallel and cross stratifications. The attitudes of the primary bedding planes (S_0) have strong data dispersion (Fig. 7A). Along the basal contact of the Espinhaço Supergroup rocks with the Aulacogen basement, the oldest deformational structures in the area and associated with basal detachment are found, which are the $S_0//S_1$ schistosity (Fig. 7B) and the stretching lineation (L_{x1}) (Fig. 8A). Both structures also show strong dispersion (Figs. 7B and 7C). Internally to the $S_0//S_1$ schistosity, isocline and intrafolial folds can be found, as well as symmetrical and asymmetrical boudins. Although dispersed, the stretching lineation mainly occupies the SW and SE quadrants. S/C structures suggest, in general, top to NW movement. Moving upward, away from the basal detachment, deformation gradually decreases and the primary bedding (S_0) predominates again. In this case, faults and reverse and thrust shear zones are observed less frequently.

Caetité Nappe

This structure was mapped southwest of the town of Caetité (Figs. 3, 5 and 9), where the rocks of lithofacies association 2 of the Serra da Garapa Formation outcrop. The $S_0//S_1$ foliation is observed in intrafolial isoclinal folds, being transposed by the $S_0//S_1//S_2$ foliation (Fig. 8B). Both structures comprise a compositional banding and schistosity. In the compositional banding of the $S_0//S_1//S_2$ foliation, there is an alternation of aluminous schists, with varying proportions of quartz, muscovite, garnet, staurolite, chlorite, pyrite, hematite and graphite,

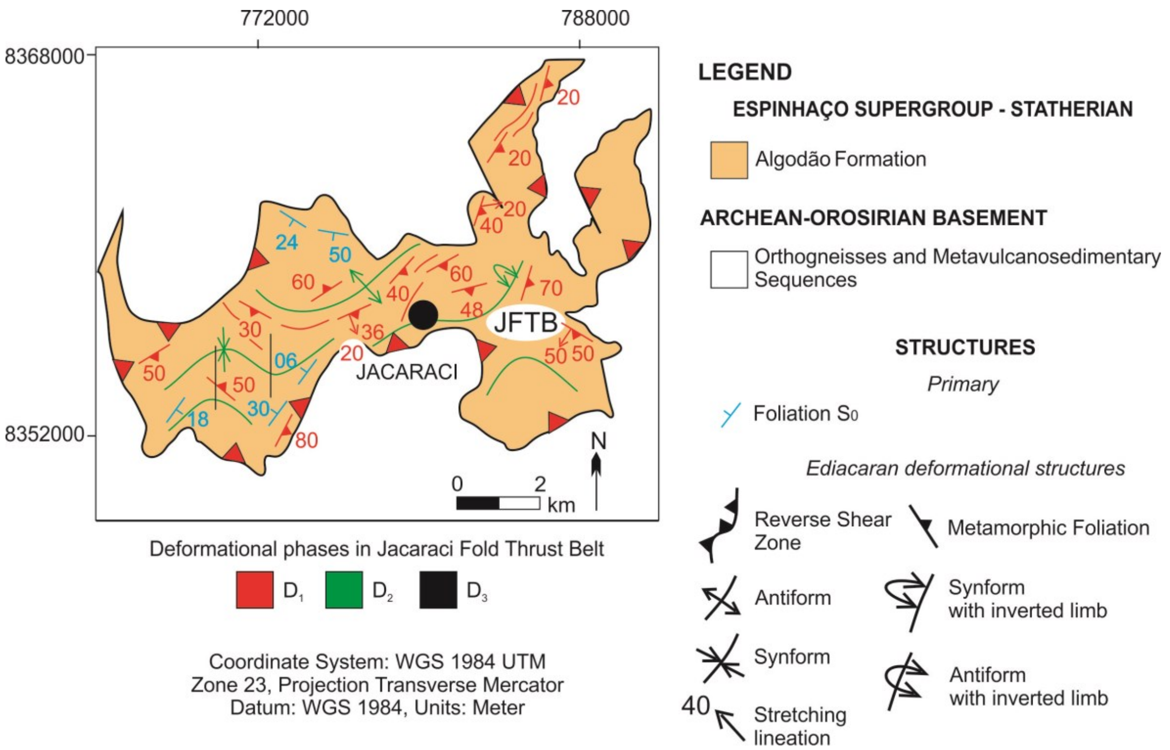


Figure 6. Geological Map of the Jacaraci Fold-Thrust Belt (JFTB). The location of the figure in the study area is shown in Fig. 5.

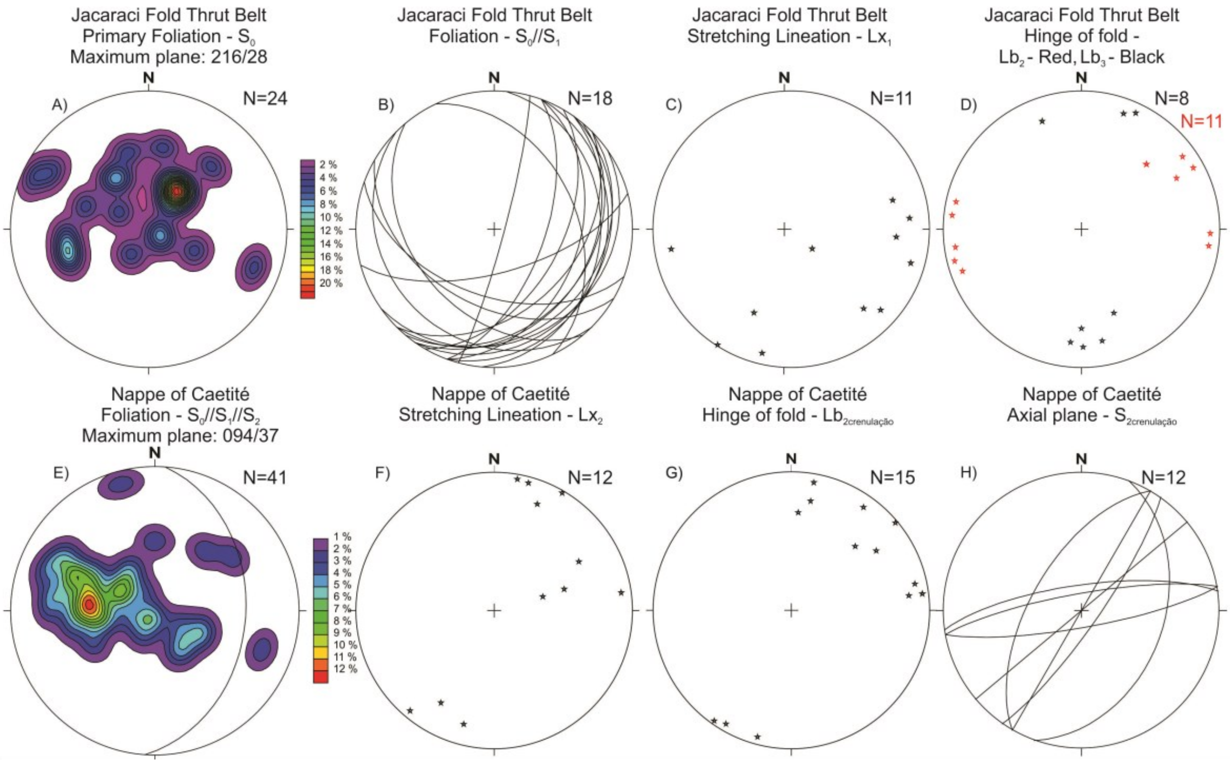


Figure 7. Stereograms of the structures of the Jacaraci Fold-Thrust Belt (A–D) and Caetité Nappe (E–H) domains. Lower Hemisphere, equal area diagram. Values calculated for 1% of the area. N: number of measurements.

and quartzites. The schistosity is marked by the muscovite orientation. In Fig. 7E, the S_0//S_1//S_2 foliation shows strong dispersion. Associated with the S_0//S_1//S_2 foliation occur the following microstructures:

i. granoblastic, sometimes polygonal, porphyroclastic and core-mantle, all associated with quartz. New polygonal grains are observed around quartz porphyroclasts;
ii. porphyroblastic, poikiloblastic, helicitic, and pressure shadow, associated with garnet and staurolite$_1$;
iii. lepidoblastic, by the preferential orientation of muscovite;
iv. decussate, by the radial arrangement of staurolite$_2$ grains;
v. nematoblastic, associated with elongated quartz grains.

The stretching lineation (L_{x2}) (Fig. 8C) is marked by the preferential orientation of quartz. This structure is paralleled with a muscovite-oriented mineral lineation (L_{m2}). The general orientation of these structures is NE (Fig. 7F). Both lineations are paralleled with crenulation fold hinges (L_{b2}) (Figs. 7G and 8D). The axial plane foliation of the crenulation folds has strong dispersion in the diagram of Fig. 7H.

An interference fold pattern and superimposed fold (type III of Ramsay and Huber 1987) is interpreted for the northern sector of Caetité Nappe (Fig. 9). The oldest folds (F_3) are open to smooth and harmonic (*Sensu* Ramsay and Huber 1987). The second folding phase's structures are horizontal normal (*Sensu* Fleuty 1964), open, and disharmonious (*Sensu* Ramsay and Huber 1987). These structures are truncated by dextral transpressional shear zones (Fig. 7F) that structure the contacts of the Serra da Garapa Formation with the Algodão Formation and of this formation with the basement of the Paramirim Aulacogen.

Transpressive Domain

In this domain are outcrop units of the Algodão Formation, the Santo Onofre Group (Serra da Garapa and Boqueirão Formations), and the Macaúbas Group (Nova Aurora Formation) (Figs. 3 and 5), in addition to the basement rocks of the Paramirim Aulacogen and the Lagoa Real intrusive suite. Plane-parallel and crossed primary bedding are observed in metarenites of the Algodão Formation, especially in outcrops further away from the shear zones that structure the contacts of these units. The distribution of these primary structures has a maximum plane at 097°/50° (Fig. 10A). WNW dips are also observed. Predominantly south of the 14°30' parallel (Fig. 5), an S_0//S_1 schistosity can be observed, which is positioned parallel to the compositional banding. The microstructures associated with this foliation are:

i. granoblastic, predominantly polygonal, in addition to porphyroclastic, core-mantle, mylonitic, pressure shadow, ribbons, σ-type mantled porphyroclast, all related to quartz grains;
ii. lepidoblastic, by the preferential orientation of muscovite. The S_0//S_1 schistosity, in general, is oriented along NS to NE-SW, with dips between 30° and 78° to E (Fig. 10B).

In siliciclastic rocks, metamorphic paragenesis, when present, is mainly made up by quartz, muscovite, and chlorite.

The stretching lineation (L_{x1}) is marked by the preferential orientation of quartz and clasts in metaconglomerates and occupies the SE quadrants mainly and the NW quadrants subordinately (Fig. 10C). S/C/C' structures suggest structural top to NW, and intrafolial isoclinal folds (F_1) are present. A mineral lineation L_{m1} is positioned parallel to the

Figure 8. General aspect of deformational structures in (A) Jacaraci Fold-Thrust Belt and (B–F) Caetité Nappe. (A) S_0//S_1 foliation at the base (23L, 774833/8357443); (B) intrafolial isoclinal folds (23L, 767211/8432119); (C) stretching lineation (L_{x2}) (23L, 765694/8432518); (D) crenulation folds (23L, 767211/8432119); (E) Regional folds with general NW-SE orientation (23L, 763339/8427068; (F) dextral transpressional shear zone that structures the western contact of the Serra da Garapa Formation with the Boqueirão Formation (23L, 762790/8427234).

stretching lineation L_{x1}, revealed by the orientation of phyllosilicates. Compressional and frontal overlapping duplexes and fans are found in the western contact between the Boqueirão Formation (Santo Onofre Group) and the basement rocks of the Paramirim Aulacogen in the Santo Onofre Shear Zone (Figs. 5 and 11A). The distributions of the S_0//S_1 foliation and the L_{x1} stretching lineation in Figs. 10B and 10C diagrams suggest that these structures are folded (F_2) with a NE-SW hinge.

Primary bedding S_0 and metamorphic foliation S_1 are folded by the second generation of these structures (F_3) (Figs. 11B-11D). This generation's folds with asymmetrical, disharmonious, acylindrical, open, and closed envelopes predominate (*Sensu* Ramsay and Huber 1987), from normal-horizontal, predominant, to reclined fold (*Sensu* Fleuty 1964). The general vergence is to the west, and the reclined folds are located in the vicinity of dextral transpressional shear zones that limit the units of the Santo Onofre Group (Fig. 5). Parasitic in S, Z, M, or W and chevron folds are part of the framework. Especially in phyllites and metapelites, the folds develop axial plane foliation (S_3), spaced, and

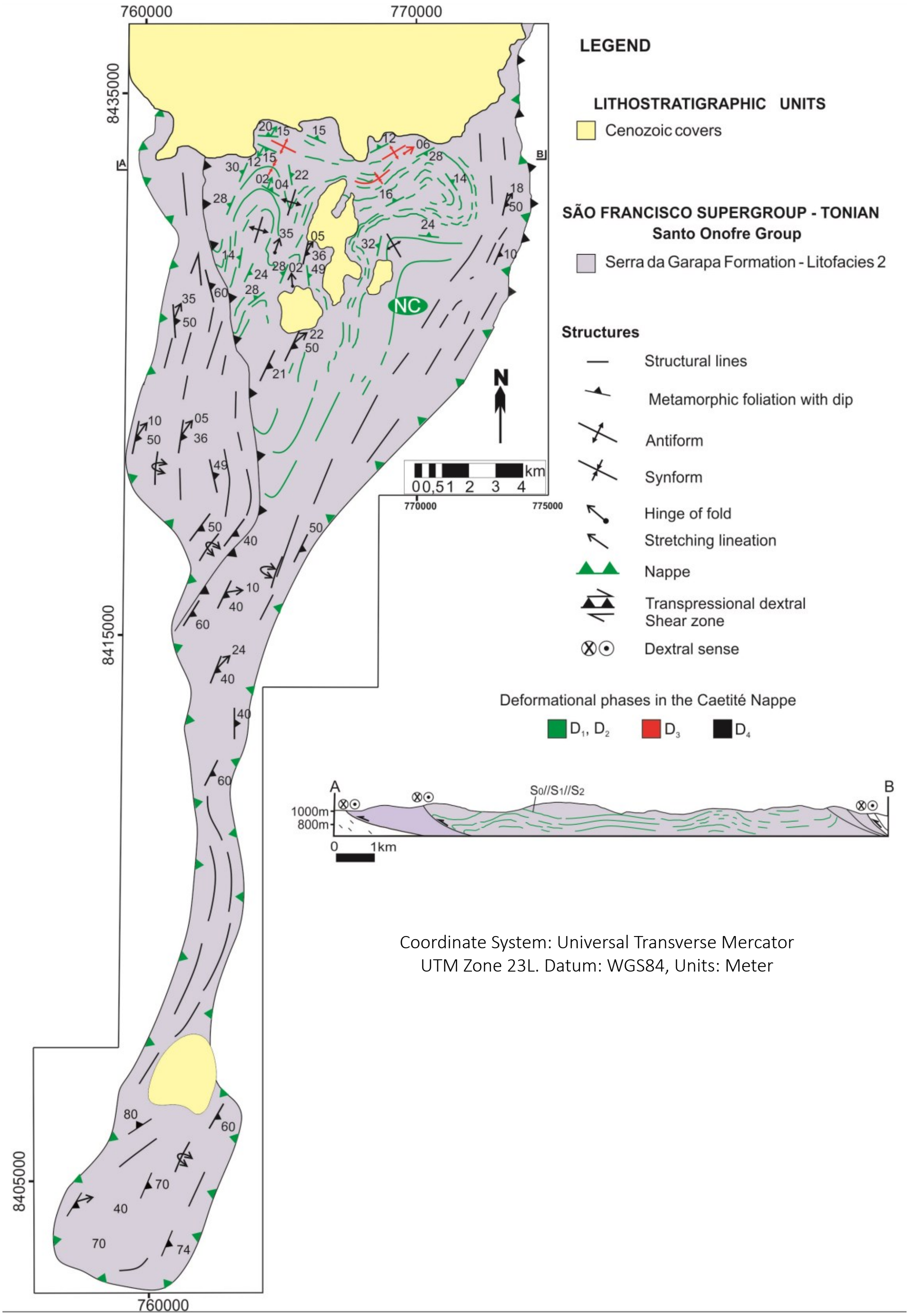
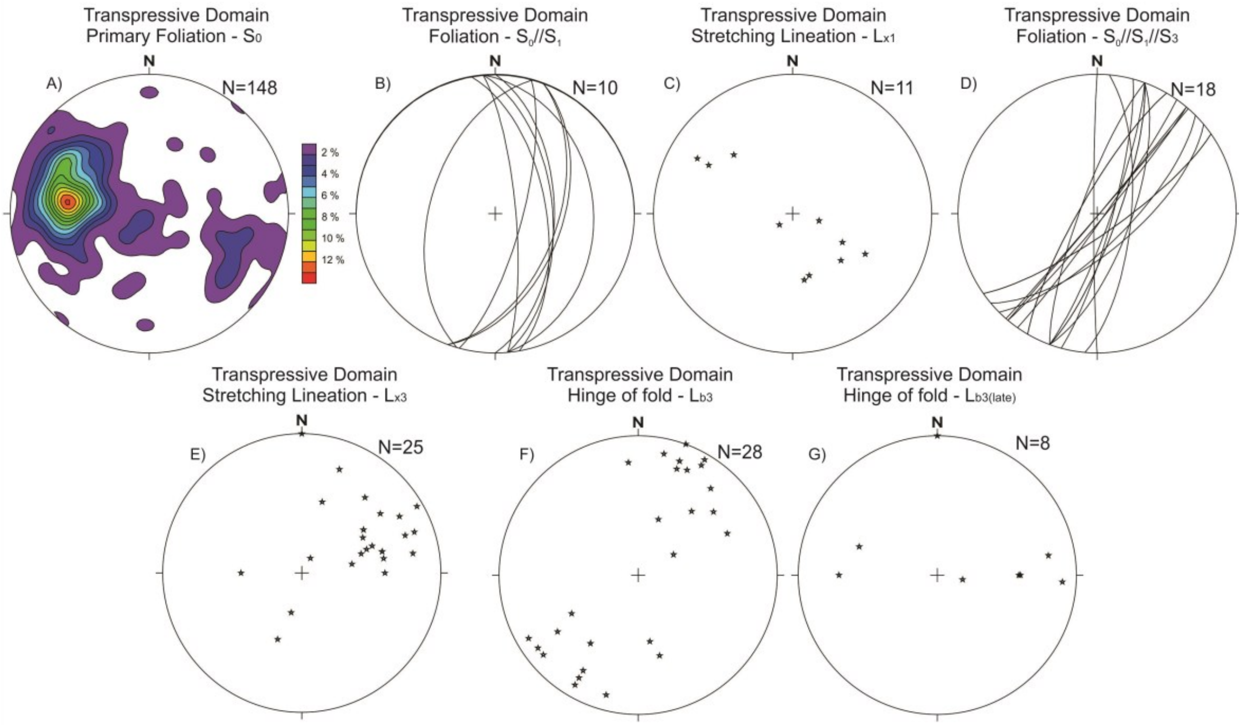


Figure 9. (A) Geological map and (B) geological section of Caetité Nappe (NC).

discontinuous (*Sensu* Passchier and Trouw 2005), with a NE-SW trend.

The reverse-dextral shear zones (Fig. 11E) have a general orientation NNE-SSW with inflection to NS and are mainly located in the contacts between the units of the Santo Onofre Group with the Algodão Formation, as well as in the contact of the rocks of this Formation with the basement rocks of the Paramirim Aulacogen (Fig. 5). The schistosity $S_0//S_1//S_2//S_4$ is found in these structures. The stretching lineation (L_{x4}) is marked by the preferential orientation of quartz, being medium to high rake and preferentially positioned in the NE-SW direction. A positive flower structure associated with a dextral transcurrent shear zone oriented according to NNE-SSW was interpreted E-SE of the town of Caetité and involves



N: number of measurements.

Figure 10. Stereograms of the structures of the transpressional domain. Lower Hemisphere, equal area diagram. Values calculated for 1% of the area.

the basement units of the Aulacogen, the Lagoa Real Intrusive Suite, the Algodão Formation, and the Santo Onofre Group (Fig. 6). The kinematic indicators are S/C structures (Fig. 11F).

Related to these shear zones, a set of folds, less penetrative, asymmetrical in Z with a hinge of medium to a high angle of dip (Fig. 10G), later rotated the F_2 folds. This asymmetry can be observed on a map (Fig. 5).

The later structures of these domains are normal shear zones and negative flower structures described by Cruz *et al.* (2015) and interpreted as related to the orogenetic collapse of this sector of the Intracontinental Orogen.

DISCUSSION: DEFORMATIONAL EVOLUTION

The structural framework of the studied area is complex and each structural domain individualized in this study presents a distinct deformational history, but with the following structural relationships:

i. the Jacaraci Fold-Thrust Belt has deformational structures whose kinematic indicators suggest mass transport generically to the NW;
ii. the similarity of the structural framework and the vergence of this belt with what was defined for the western sector of the Rio Pardo Salient by Cruz and Alkmim (2006);
iii. the oldest structures verified in the Transpressional Domain, specifically the $S_0//S_1$ foliation and the first-generation folds, have similar geometry and vergence to those found in the Jacaraci Fold-Thrust Belt, defined in this study, and in the Rio Pardo Salient;
iv. the structures of the Rio Pardo Salient are the oldest structures related to the inversion of the Paramirim Aulacogen and that are regionally truncated by a dextral transpressional system related to the frontal to transpressional inversion phase of the Paramirim Aulacogen (Cruz and Alkmim 2006). These structures have geometric and kinematic similarities, as well as physical continuity with the transpressional domain defined in this study;
v. the structures of Caetité Nappe, and their interference features, are associated with the late regional transpressional system with the inversion of the Paramirim Aulacogen (Phase Dp de Cruz and Alkmim 2006), which truncates the structures of the Rio Pardo Salient.

From the identified structural relationships and their regional relationships, a total of six compressive deformation phases (D_1, D_2, D_3, D_4, D_5, and D_6) were interpreted for the study area. The correlations between the three structural domains defined in this study are shown in Table 1. These deformations were developed under a maximum regional stress field oriented according to WSW-ENE, which reactivated and inverted the extensional structures related to the long evolution of the Paramirim Aulacogen and the precursor basins of the Araçuaí-West Congo Orogen (Fig. 12A).

The first phase of compressional deformation (D_1) (Fig. 12B) was responsible for the formation of the Jacaraci Fold-Thrust Belt and the oldest structures (Foliation $S_0//S_1$) described in the Transpressional Domain. These structures were folded by the D_2 phase (Fig. 12C). D_1 and D_2 deformational phases are correlated with the D_a generation of Cruz and Alkmim (2006). They are associated with the development of the Rio Pardo Salient, whose nucleation, under the WSW-ENE stress field, is related to the counterclockwise rotation of the São Francisco-Congo Plate and the interaction between the Araçuaí Orogen

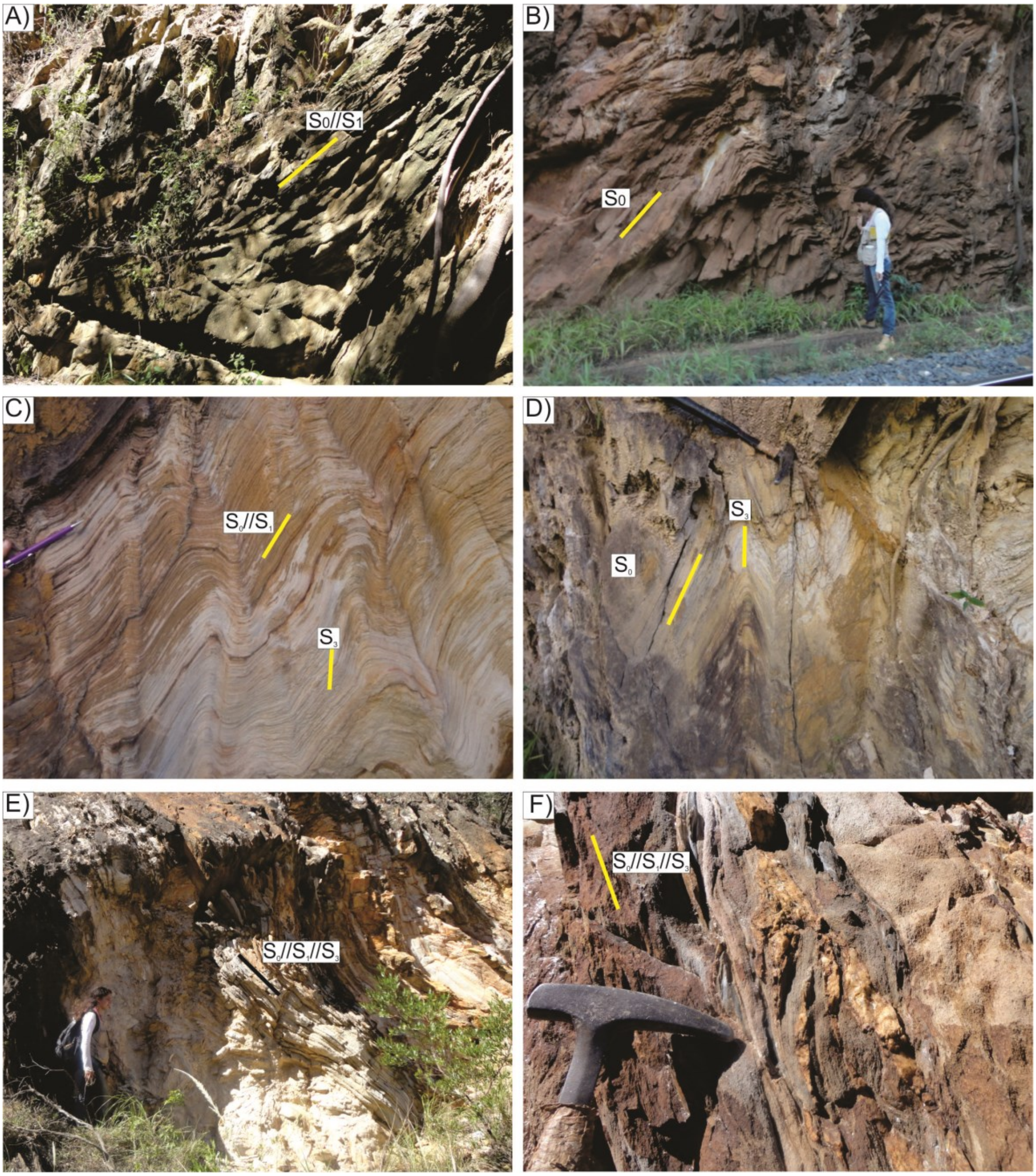


Figure 11. General aspect of the deformational structures of the transpressional domain. (A) Duplex in the contact of the Boqueirão Formation with the basement of the Paramirim Aulacogen (23L, 758665/8370897) in the Santo Onofre shear zone; (B) folds in the Algodão formation (23L, 761245/8368125); (C and D) folds in lithofacies association 1 of Serra da Garapa (23L, 760032/8369363); (E) shear zone at the contact between the Boqueirão and Serra da Garapa formations (23L, 759258/8368589); (F) detail of the movement indicator (S/C structure) of the shear zone of (E).

and the Paramirim Aulacogen. In the Rio Pardo Salient, tectonic transport varies from SE to NW in its western region, from N to S in its central region, and from SW to NE in its eastern region (Cruz and Alkmim 2006). The deformational structures D_1 and D_2 of this study are positioned in the western sector of this salient and reflect the structural top to the NW.

Despite being interpreted as related to a fold-thrust belt, considering the geometry of the structures present in the Jacaraci region, a hypothesis that still needs to be tested is that this belt is a klippe associated with a nappe structure with movement directed to the NW. This nappe would have been amalgamated to the Transpressional Domain through a sinistral shear zone (Fig. 5).

The third, fourth, and fifth deformational phases (D_3, D_4, and D_5) (Fig. 12D) are related to the evolution of Caetité Nappe. In the third phase, the nucleation of foliation $S_0//S_1$ was observed in isoclinal folds intrafolial to foliation $S_0//S_1//S_2$.

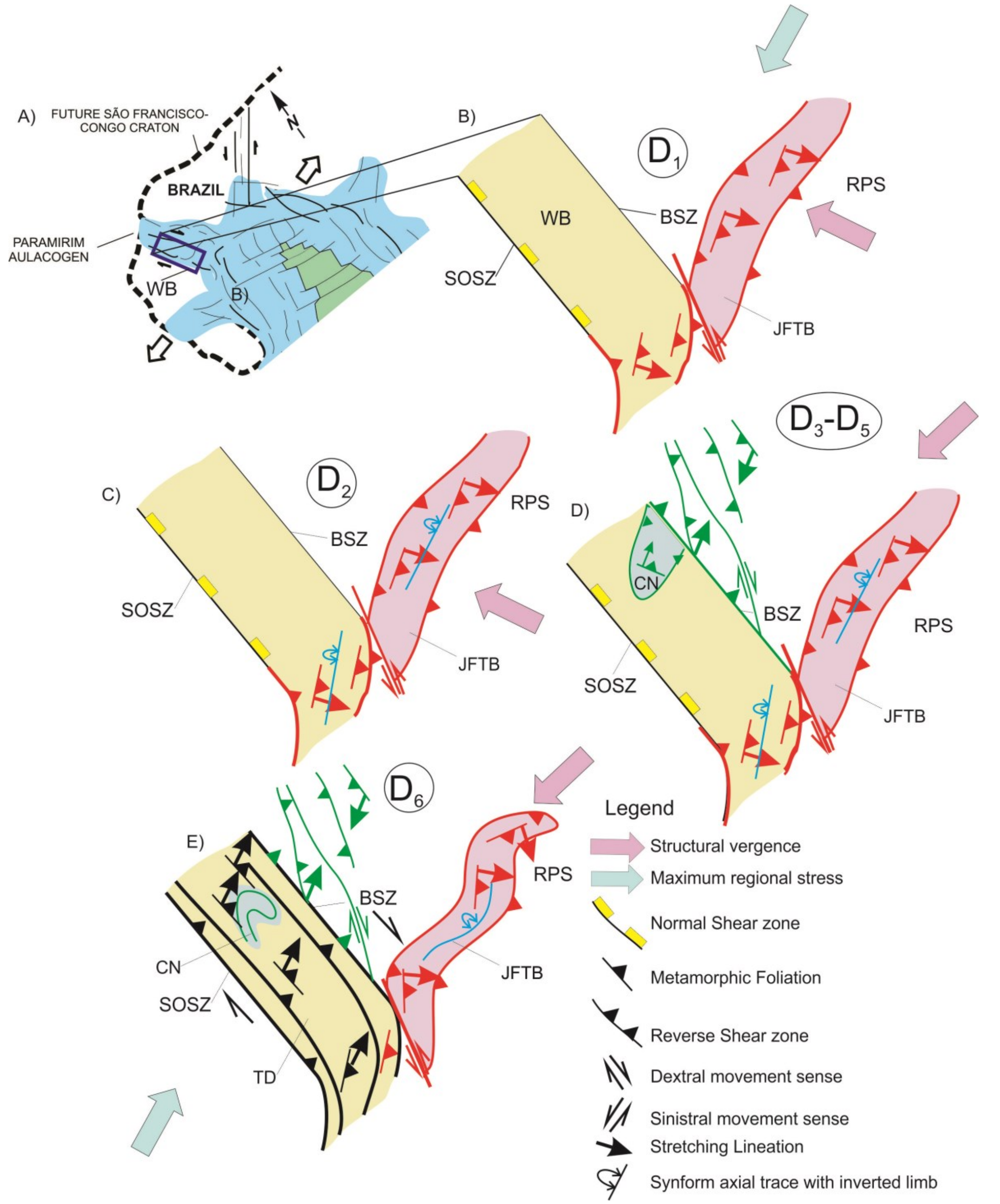
In the fourth deformation phase (D_4), there was the development of locally hierarchical foliation in the nappe as $S_0//S_1//S_2$, as well as stretching lineation (L_{x2}), intrafolial isoclinal

Table 1. Integration of regional deformational structures and deformation phases interpreted for the study area. See text for discussion.

Integrated Deformation Phase/ Structural Domain	Jacaraci Fold-Thrust Belt	Caetité Nappe	Transpressional Domain
D_1	Phase D_1: Schistosity and metamorphic compositional banding ($S_0//S_1$), mineral stretching lineation (L_{x1}); shear zones. Structural top toward NW. Tangential deformation.	–	Phase D_1: Foliation $S_0//S_1$ according to NE-SW, stretching lineation (L_{x1}) with general dip for SE; duplex and compressional imbricated fans. Intrafolial isoclinal folds (F_1). Tangential deformation. Presence of chlorite.
D_2	Phase D_2: F_2 folds with NE-SW trend. Tangential deformation.	–	Phase D_2: F_2 folds with NE-SW trend. Tangential deformation.
D_3	–	Phase D_1: Schistosity and metamorphic banding $S_0//S_1$, intrafolial isoclinal folds (F_1).	–
D_4	–	Phase D_2: Schistosity and metamorphic banding ($S_0//S_1//S_2$), stretching lineation (Lx_2), intrafolial isoclinal folds (F_2) and boudins. Presence of staurolite and garnet in lithofacies association 2 of the Serra da Garapa Formation. Beginning of development of dextral transpressional and positive-flowered shear zones.	–
D_5	–	Phase D_3: F_3 folds with general NW-SE orientation.	–
D_6	Phase D_3: F_3 folds with N-S trend	Phase D_4: F_4 folds with NW-SE trend; fold interference feature (type III, *sensu* Ramsay and Huber 1987). Dextral transpressional shear zones, foliation (Borges *et al.* 2015), stretching lineation (Lx_4), and positive flower structure remains active and reaches its apex.	Phase D_3: F_3 folds with NS to NE-SW trend, axial plane foliation (S_3), reverse to dextral transpressional shear zones, foliation, locally mylonitic, ($S_0//S_1//S_3$), stretching lineation (Lx_3). Development of positive flower and pop-up structures (Borges *et al.* 2015). Late ($F_{3\,late}$): Z- asymmetric folds which high-angle hinge. Presence of chlorite.
D_7	–	–	Phase D_4: Extensional shear zones described by Cruz *et al.* (2015).

folds (F_2) and boudins. The vergence interpreted for this phase is toward SW. A relevant aspect is the presence of paragenesis with garnet and staurolite in lithofacies 2 rocks of the Serra da Garapa Formation, suggesting metamorphic conditions of amphibolite facies, with temperatures between 550 and 650°C and pressures between 250 and 750 MPa (Bucher and Grapes 2011). The metamorphic contrast between the rocks of lithofacies associations 1 and 2, as well as lithofacies association 2 of this formation with the Algodão Formation, in which sedimentary structures are still preserved, suggests that a high-angle structure associated with a transpressional system was responsible for stratigraphic inversions:

i. by the juxtaposition of aluminous schists with garnet and staurolite and quartzites from the Serra da Garapa Formation (lithofacies association 2) over graphitic phyllites with chlorite and metarenites from the lithofacies association 1 of this formation, of greenschist facies metamorphism;
ii. by thrusting the Algodão Formation, of Statherian age, over the rocks of these Tonian units;



D: Deformational phase; Shear Zones: SOSZ: Santo Onofre; BSZ: Borda Leste; JFTB: Jacaraci Fold-Thrust Belt; RPS: Rio Pardo Salient. Dimensionless model.
Figure 12. (A) Western Basin (WB) tectonic context at Paramirim Aulacogen. (B–E) Proposed schematic deformation model for the inversion of Paramirim Aulacogen in the southern sector of the Western Basin (WB). The maximum regional tension is maintained in all phases.

iii. by thrusting the rocks of the Lagoa Real Intrusive Suite over the rocks of the Algodão Formation;
iv. for the riding of this Estaterian suite by the basement of the Paramirim Aulacogen.

The nucleation of dextral transpressional system is related to the frontal to transpressional deformation of the Paramirim Aulacogen described by Cruz and Alkmim (2006). This deformation reactivates and inverts the extensional structures of the basin evolution phase and leads to the juxtaposition of rocks of higher metamorphic grade, of amphibolite facies (Bitencourt 2014), of lithofacies association 2 of the Serra da Garapa Formation on rocks of lithofacies association 1 of this formation, of greenschist facies. The nucleation of the high-angle structure responsible for stratigraphic inversions and for juxtaposing rocks of higher metamorphic grade on rocks of lower metamorphic grade is possibly related to reactivations of extensional structures of the aulacogen or structures older than 1.8 Ga from its basement. The importance of the structural inheritance of the basement of sedimentary basins in controlling the geometries of nucleated structures during their inversion has been demonstrated by several works (Carrera and Munoz 2013, Deng *et al.* 2017, Nepomuceno *et al.* 2021, among others).

In Caetité Nappe, the foliation $S_0//S_1//S_2$ was folded (F_3 fold) during the fifth deformational phase (D_5). The sixth and last deformational phase (D_6) (Fig. 12E) was observed in all three individualized compartments (Table 1), being responsible for the development of:

i. dextral transpressional reverse shear zones that structure the contacts between the units of the Santo Onfre Group with the Algodão Formation, as well as those units with the basement of the Paramirim Aulacogen, in this case inverting and reactivating the Santo Onofre and Borda Leste shear zones, located at west and east, respectively (Fig. 5);
ii. F_3 folds with a general NS trend, null general vergence to WSW observed in the Jacaraci Fold-Thrust Belt, in the Transpressional Domain and in the Caetité Nappe;
iii. F_4 folds with general NW-SE trend and fold interference structure (type III, *sensu* Ramsay and Huber 1987) in Caetité Nappe;
iv. F_3 folds, axial plane foliation (S_3), reverse to dextral transpressional shear zones, foliation $S_0//S_1//S_3$, mineral stretching lineation (L_{x3}), as well as positive flower and pop-up structures (Borges *et al.* 2015) in the Transpressional Domain.

Later, there was the development of asymmetrical Z-folds with high-angle hinges, which reflect the dextral component of the regional transpression. The deformational phases D_3 to D_6 are correlated with the D_p phase of Cruz and Alkmim (2006) and with the D_{n-1} and D_n phases of Borges *et al.* (2015), which were nucleated under thick-skinned deformation conditions.

The last deformational phase is reported in the literature by Cruz *et al.* (2015) and described by those authors in the transpressional domain of this study. This phase nucleated extensional shear zones associated with the orogenetic collapse of the northern sector of the Araçuaí Intracontinental Orogen.

CONCLUSION

Three structural domains were identified in the study area: Jacaraci Fold-Thrust Belt, Caetité Nappe, and Transpressional Domain. The deformational evolution of these domains is complex, comprising six compressional and progressive phases. These phases are related to a maximum stress field, of Ediacaran age, with general orientation of WSW-ENE and are associated with structuring the Araçuaí-West Congo Orogen. The first phase (D_1), found in the Jacaraci Fold-Thrust Belt and the Transpressional Domain, is related to the evolution of the Rio Pardo Salient. The dextral transpressional system was responsible for the nucleation of the Caetité Nappe, for the deformations in the transpressional domains, with the development of a positive flower structure, and in the Jacaraci Fold-Thrust Belt, as well as for larger-scale structures. Regionally, this system is related to the frontal inversion of the Paramirim Aulacogen. At Caetité Nappe, there was a juxtaposition of:

i. rocks metamorphosed into amphibolite facies over lower temperature rocks;
ii. basement rocks older than 1.8 Ga over the Statherian rocks of the Lagoa Real Intrusive Suite;
iii. Lagoa Real Intrusive Suite and Algodão Formation (Espinhaço Supergroup) over Tonian rocks of the Santo Onofre Group (San Francisco Supergroup).

ACKNOWLEDGMENTS

This study was supported by the CAPES (Finance Code 001). The authors thank the FAPESB for the scholarship granted for Caroline Novais Bitencourt and the CNPq for the research fellowship grant provided to Simone Cerqueira Pereira Cruz (grant no. 306502/2018-6 and 309050/2021-9). The authors also thank the anonymous reviewers and editor of the article for their contributions to the improvement of this study.

ARTICLE INFORMATION

Manuscript ID: 20220069. Received on: 13 SEPT 2022. Approved on: 24 JAN 2023.

How to cite: Bitencourt C.N., Cruz S.C.P. (2023). Deformational sequence of inversion in the Paramirim Aulacogen, northern region of the intracontinental sector of the Araçuaí Orogen. *Brazilian Journal of Geology*, **53**(2):e20220069. https://doi.org/10.1590/2317-4889202320220069

C.N.B.: Conceptualization, Methodology, Investigation, Resources, Writing — Review & Editing. S.C.P.C.: Supervision, Conceptualization, Methodology, Investigation, Resources, Writing — Review & Editing.

Competing interests: the authors declare no competing interests.

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