STRATIGRAPHIC AND STRUCTURAL RELATIONSHIPS THROUGH GEOLOGICAL AND GAMMAESPECTROMETRY ANALYSIS IN THE INTERFACE BETWEEN THE SÃO FRANCISCO CRATON AND THE ARAÇUAÍ OROGEN (SANTA RITA ANTICLINE, MINAS GERAIS, BRAZIL)

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Received on October 10, 2019; accepted on January 22, 2020

Abstract: Geological mapping (1:25.000 scale), supported by gammaespectrometric analysis, was conducted in the Santa Rita Anticline region, a regional structure located in the contact between the Araçuaí Orogen external belt and the São Francisco Craton. The work aimed to detail the region's structural and stratigraphic relationships between the rocks of Espinhaço and São Francisco supergroups, which contact is not characterized by a thrust front, as it is in a large part of the Espinhaço Meridional Range (EMR). Five units from Espinhaço were mapped: Galho do Miguel Formation and Conselheiro Mata Group, represented by the Santa Rita, Córrego dos Borges, Córrego Bandeira and Córrego Pereira formations. By its turn, three units from the São Francisco Supergroup were mapped: undivided Macaúbas Group and Bambuí Group, represented by the Serra de Santa Helena and Lagoa do Jacaré formations. Restricted to the Espinhaço units, the Santa Rita Anticline consists in a structure with a south dipping axis and inflections that form saddle structures. The analysis of the gammaespectrometric responses provided clues that were confirmed in the field, highlighting an angular unconformity between the Córrego Pereira Formation and the Macaúbas Group and the local presence of isoclinal folds in Serra de Santa Helena rocks, promoting relevant questions regarding possible intermediary deformational events between the Statherian and Tonian tafrogenesis. The study contributes by raising questions about the evolution of the Araçuaí Belt in its contact with the São Francisco Craton and possible implications imposed by the Paramirim Aulacogen.

Keywords: Aerogeophysics, Litho-structural framework, Fold belt and craton transition, Espinhaço Meridional Range

INTRODUCTION

The Espinhaço Range is an expressive geomorphological landmark that covers more than 1200km in a north-south general trend through the Brazilian states of Minas Gerais and Bahia, being called Espinhaço Meridional Range (EMR), southwards of the 17°00' S parallel (Knauer, 2007). The evolutionary history of the São Francisco Craton (SFC) is intrinsically related to the deposition of the rocks that sustain the EMR (Espinhaço Supergroup). The individualization of the cratonic area took place from the Paleo to Neoproterozoic, with the establishment of its limits, deposition of the São Francisco Supergroup rocks and formation of the namesake basin (Alkmin & Martins-Neto, 2001; Alkmin, 2004; Reis, 2011).

At the studied area, the main regional morpho-strucural relationships comprise the SFC and the Araçuaí Belt, formed by rocks from the Espinhaço Supergroup and considered to be the external metamorphic domain of the Araçuaí-West Congo Orogen (AWCO; (Alkmin et al., 2007). The EMR's regional structuration is marked by a series of west-verging thrust faults, in the direction of the SFC (Rolim, 1992), product of accretionary events in the Ediacaran (Alkmin & Martins-Neto, 2001).

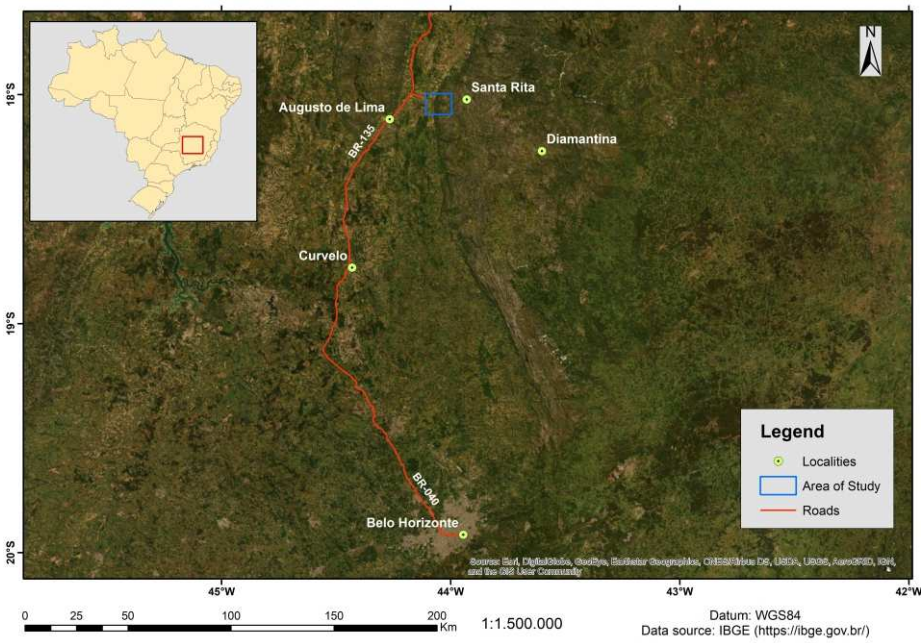

Figure 1 – Location of the studied area in the central portion of Minas Gerais State, Brazil, featuring some important localities and main access routes. Cartographic data source: IBGE, 2019. .

doi:10.18285/geonomos.v27i1.21853

In this sense the studied area is peculiar, since its structural configuration in the transition between the Araçuaí Orogen and the SFC is characterized by a regional anticlinal structure that involves mainly the Espinhaço Supergroup, covered in its west limb by the Macaúbas Group, both dipping to west with no evidence of tectonic inversion.

We propose to nominate this structure Santa Rita Anticline since it is near Santa Rita village, which also inspired Pflug (1968) to designate the namesake formation, part of the Conselheiro Mata Group (Espinhaço Supergroup) proposed by Dossin et al. (1984). The studied area (Figure 1) is located in the municipality of Augusto de Lima, approximately 265 km north of Belo Horizonte, in the Minas Gerais State.

REGIONAL GEOLOGY

The two main rock units (Figure 2) occur regionally, being them the Espinhaço Supergroup and the São Francisco Supergroup – Macaúbas and Bambuí groups - (Knauer et al., 2014a), deposited over an Archean basement (Machado et al., 1989; Dussin & Dussin, 1995).

The Espinhaço Supergroup (Schöll & Fogaça, 1979), comprised by the formations proposed by Pflug (1968) is seen as a result of the induced sedimentation due to the opening of a continental rift around 1,7 Ga (Almeida-Abreu, 1995; Dussin & Dussin, 1995).

The Galho do Miguel Formation is composed mainly by pure quartzites, usually showing cross bedding and broad granulometric variation, with phyllitic intercalations in the upper and bottom limits (Pflug, 1965). This unit sedimentation is commonly seen as related to an eolian environment, being the phyllitic facies an indicator of the system's "drowning" (Dossin et al., 1990; Martins-Neto, 1998).

The Conselheiro Mata Group (Dossin et al., 1984) outcrops are mainly located at the west portion of the EMR, with thicknesses that reach more than 800 m (Lopes-Silva, 2008). This unit comprises the following formations, from bottom to top, according to Dossin et al. (1984): Santa Rita, Córrego dos Borges, Córrego Bandeira, Córrego Pereira and Rio Pardo Grande. In a general way the observed lithologies are intercalations of phyllites with quartzites, commonly fine grained and micaceous, with a variety of sedimentary structures as low angle cross beddings, flaser laminations, ripple marks and others (Lopes-Silva, 2008).

The Conselheiro Mata Group considered a succession of coastal marine sequences, somewhat platformal, from the Espinhaço passive margin (Almeida-Abreu, 1995; Martins-Neto 1998).

Overlaying the Espinhaço Supergroup in a usually discordant way it is the São Francisco Supergroup (Pflug & Renger, 1973), covering a large area in the namesake basin. In the studied area, the São Francisco Supergroup can be divided into two main lithostratigraphic units: Macaúbas Group and Bambuí Group, both dating from the Neoproterozoic (Reis, 2011).

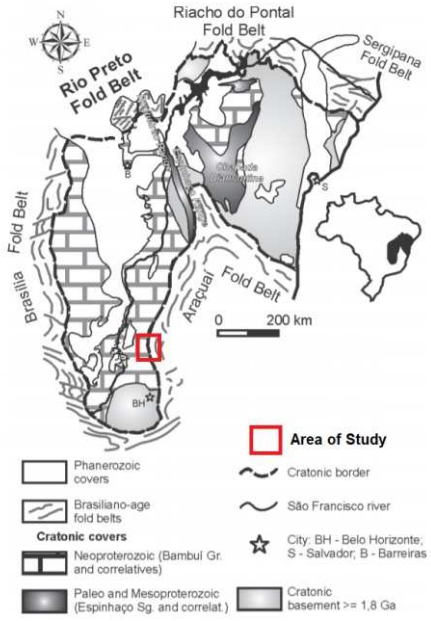

Figure 2 – Geological and geotectonic contextualization from the main elements of the São Francisco Craton, featuring the studied are in red. Source: Modified from Caxito et al., 2012.

The Macaúbas Group (Schöll, 1973) is formed basically by metadiamictites with lateral and vertical gradation of quartzites and metapelites that are understood as being a record of a glaciation (Karfunkel & Hoppe, 1988; Uhlein, 1991). U/Pb detrital zircon dating pointed to maximum depositional ages between 800-700Ma, providing ground for some authors to argue that the Macaúbas Group is related to the Sturtian global glaciation event (Uhlein et al., 2007).

Showing great representativeness in the São Francisco Basin, the Bambuí Group can be characterized in general as a pelitic-carbonatic platform succession that passes in its top to tempestitic deposits and sand-clay successions also marine (Dardenne, 1978). In its eastern portion, the Bambuí Group comprises the following formations, from bottom to top: Sete Lagoas, Serra de Santa Helena, Lagoa do Jacaré, Serra da Saudade and Três Marias, occurring a vast predominance of marine platformal facies in the region (Uhlein, 2017).

The geotectonic context that controlled the sedimentation of the São Francisco Group is connected initially with the Tonian tafrogenesis (Reis, 2011; Zalan & Romeiro-Silva, 2007). This extensional tectonic event was responsible by the opening of the Macaúbas rift, which led to the formation of the Macaúbas Basin and its evolution to a context formed by two passive margins that probably hosted all units seen today in the Araçuaí and West Congo belts (Alkmin et al., 2007). Therefore, the Macaúbas Group would be the glacial record of this rifting event (Alkmin et al., 2007). Posteriorly, in the Cryogenian, a new pulse of stretching formed a broad epicontinental sea where began the deposition of the Bambuí Group (Pedrosa-Soares & Alkmin, 2011).

The sedimentation of the Bambuí Group follows until the end of the Brasiliano Cycle (Uhlein, 2017), with the collisions responsible for Gondwana's amalgamation (Alkmin, 2004).

MATERIAL AND METHODS

Basic geological mapping aided by geophysical analysis consist in the main methodological bases of this work. Regarding the geophysical data, the information was obtained by the Aerogeophysical Survey of Minas Gerais – 2008/2009 Program; Area 10 – sponsored by the Companhia de Desenvolvimento Econômico de Minas Gerais (CODEMIG) and the Brazilian Geological Survey (CPRM). Amongst the products presented in the survey, the gammaespectrometric responses were considered the most relevant bearing in mind the proposed objectives, highlighting the ternary image composition (RGB).

The spectrometer model used was a Radion Solutions RS-500 and the following are the basics acquisition information regarding the survey carried by CODEMIG (2010): Direction of flight lines: N-S; Flight lines spacing: 0,5 km; Direction of control lines: E-W; control lines spacing: 10 km; interval between consecutive measures of the spectrometer: 1s; mean flight height: 100 m; approximated flight speed: 270km/h

GEOLOGY AND GAMMAESPECTROMETRIC RESPONSES OF THE SANTA RITA ANTICLINE AND REGION

The geological mapping (Figure 3), in a 1:25.000 scale, shows the local relations between the Espinhaço Supergroup and the São Francisco Supergroup.

Even though the rocks found in the studied area undoubtedly suffered low grade metamorphism, the abundance and scale of well-preserved sedimentary structures and textures are distinguished characteristics.

ESPINHAÇO SUPERGROUP

Galho do Miguel Formation

The outcrops of Galho do Miguel Formation is usually associated with slopes in a high gradient, abundant outcrops and drainages incised in the direction of the main fracture systems (Figures 3, 4). Galho do Miguel Formation top contact is characterized by a disconformity with the Santa Rita Formation.

The lithology is basically composed by white quartzites, occasionally pinkish, with medium to coarse granulation and high textural maturity. Other than those pure quartzites also occur quartzites with higher mica content, developing a persistent and well-marked foliation (Figure 5A). Asymmetric ripple marks are usually found (Figure 5B), indicating distinct paleocurrents. Also, there are tangential cross beddings with centimetric to metric dimensions (Figure 5C, 5D). Parallel to the bedding planes, sometimes occur millimetric to centimetric black-gray levels (Figure 6) with presence of manganese oxide, suggesting the percolation of some fluid.

CONSELHEIRO MATA GROUP

Santa Rita Formation

Santa Rita Formation (Figure 3) presents thicknesses that reaches 225 m, being discordant with Galho do Miguel Formation at its base and in gradational contact with Córrego dos Borges Formation at its top. This unit shows a remarkable geomorphological difference within the Santa Rita Anticlinal limbs. In contrast, in the west limb it is noticeable a relevant narrowing of the unit in map, coincident with a morphology formed by small elevations spreaded in inclined mid slope context, with rising altitudes to the west.

The Santa Rita Formation base is mainly composed by gray metasiltstones, with variations of pinkish shades (Figure 7), fine granulation and variable content in sand grains. In general, materialized by micaceous plans, a penetrative foliation is well marked.

The Santa Rita Formation shows a clear coarsening upward style, characterized by the occurrence of friable micaceous quartzites, with white-grayish color and parallel centimetric bedding strata and incipient foliation. Asymmetric ripple marks occur concentrated in the unit's upper portions while symmetric ripple marks are usually related to the unit's base.

Peculiar sedimentary structure observed in the Santa Rita Formation are synaeresis cracks, characterized by irregular elongated forms in plant view (Figure 8), with variable size but rarely bigger than 10 cm, presenting themselves with no apparent ordering and sometimes forming four sided polygons (Figure 8D). Synaerasis cracks are typical structures of sub-aqueous environment formed by water loss from the sediment pores due to the reorganization of originally highly porous clay particles, by flocculation or volume change in the clay minerals induced by salinity alterations (Collinson et al., 2006).

Córrego dos Borges Formation

The Córrego dos Borges Formation is concentrated in the central and south portions (Figure 3). Gradational contact is observed at its base, with Santa Rita Formation, and at the top with Córrego Bandeira Formation. In the southeastern portion the contact with the Córrego Pereira Formation is marked by a paraconformity, and in the central portion, the contact with the Macaúbas Group consist in a disconformity with no significative attitude change in between the units. Córrego dos Borges Formation thickness reaches until 140 m.

The unit is composed by dark to light gray quartzites (Figure 9), with medium to fine granulation, locally coarse. Centimetric to millimetric foliated metapelitic levels intercalations are common.

Regarding sedimentary structures (Figure 10A, 10B, 10C) are most common.

In the top of the Santa Rita Formation and the base of the Córrego dos Borges Formation a structure that suggests fluid actuation in the area is present and occurs amidst the intercalation between the quartzites strata.These structures are rounded shaped with 1 to 6 cm diameter (Figure 11A), similar to bubbles, and invariably present themselves with the same color of the light color strata and “moving” in direction of the dark color strata (Figure 11A). When isolated inside the dark strata they tend to

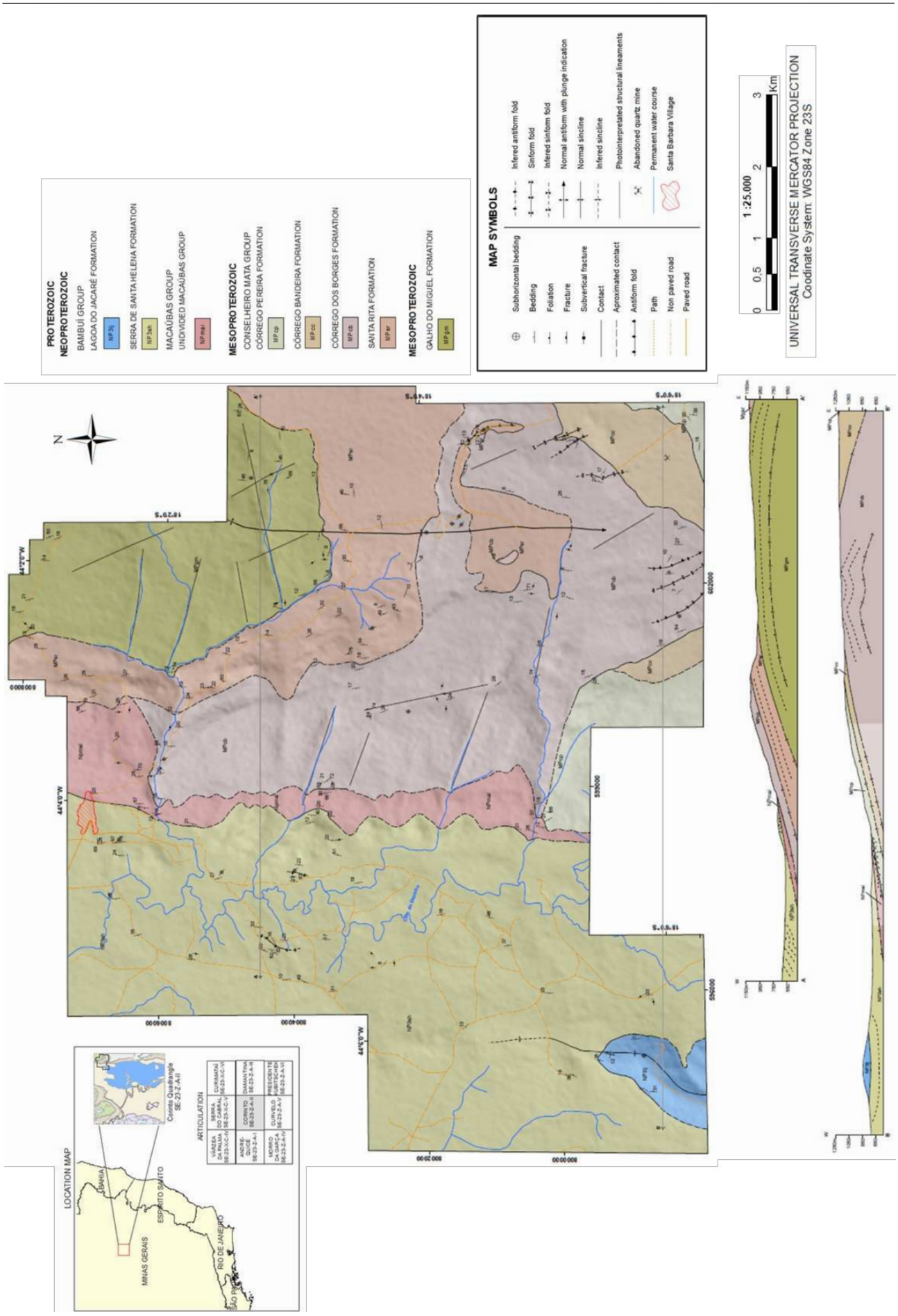

Figure 3 – Schematic geological map in 1:25.000 scale of the Santa Rita Anticline area, Augusto de Lima district (MG, Brazil).

Figure 4 – Galho do Miguel Formation. (A) E-W fracture family connected by an oblique family. (B) Drainage incised in the main fracture family direction (E-W).

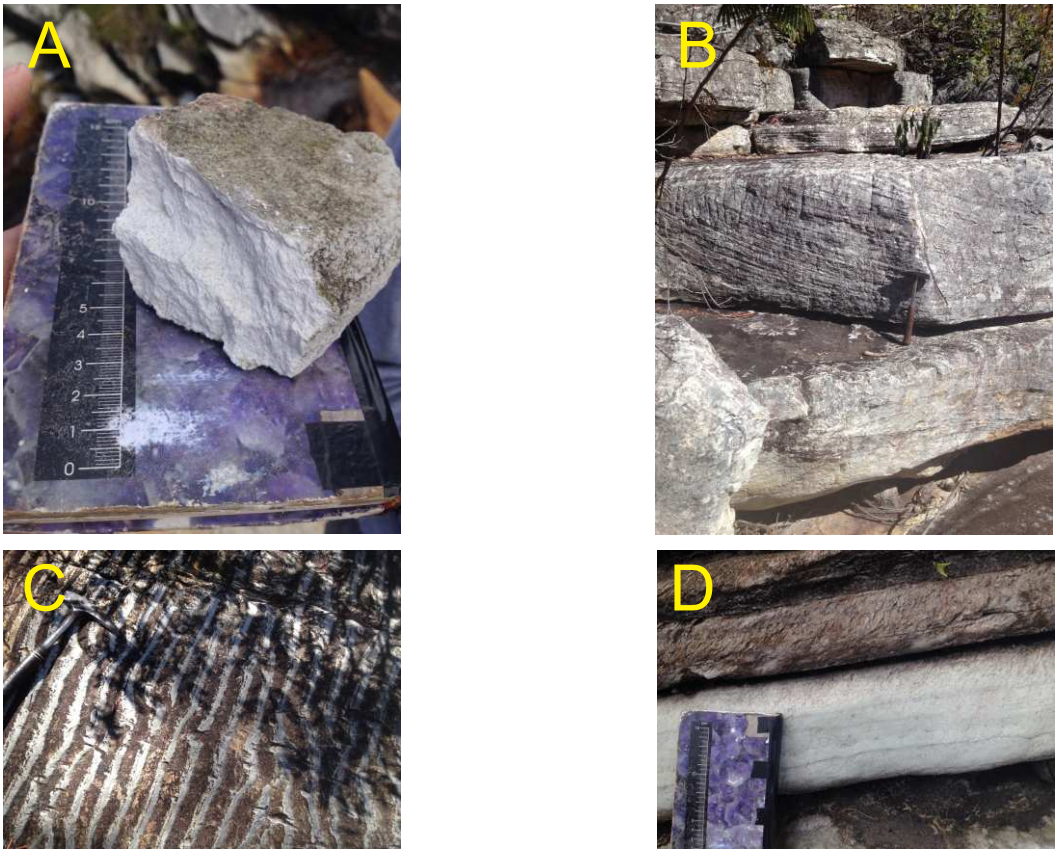

Figure 5 – Quartzites from Galho do Miguel Formation. (A) Micaceous foliated quartzite. (B) Tangential cross beddings. (C) Asymmetric ripple marks. (D) Plan-parallel decametric strata.

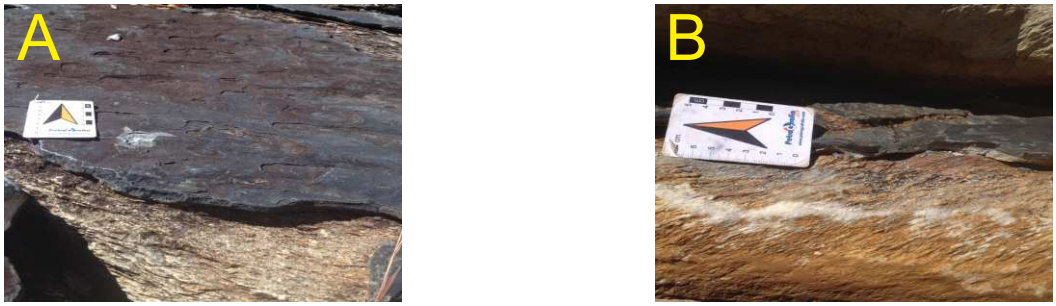

Figure 6 – (A,B) Manganese oxide levels in the quartzites from Galho do Miguel Formation.

have almost perfect circular dimensions. In some places the strata show significative disturbance, with several waves where the bubbles can be observed detaching from the lighter strata in direction of the darker ones (Figure 11A, 11B). In petrographic sections there is a fine opaque line in the boarder of the bubbles and bubbles and host rock are petrographically similar . (Figure 11C).

Córrego Bandeira Formation

At the south of the Santa Rita Anticline, the Córrego Bandeira Formation (Figure 3) is characterized by fine quartzites, very friable and weathered, with white to gray color. These rocks have medium to fine granulation, showing planar beddings intercalated with micaceous laminations.

The lower and upper contacts are gradational, in the normal sequence of the Conselheiro Mata Group. Having approximately 85 m of thickness in the east limb, the unit starts to gradually narrow in map view towards west, until it is no longer mapped between the Córrego dos Borges and Pereira formations. The Conselheiro Mata Group is consensually seen as a product of a series of transgressions and regressions, and so it is expected that in a basin complex architecture a retrograding stratum eventually can seize to be deposited in a maximum transgression context.

Córrego Pereira Formation

The Córrego Pereira Formation (Figure 3) is formed by pure quartzites of fine granulation and usually friable, although some portions show higher recrystallization conditions. An incipient foliation due the mica content is locally seen.

The unit upper contact is characterized by an angular unconformity with the Macaúbas Group, feature that suggests possibilities of tectonic interpretations that will be further addressed. The lower contact is graditional with Córrego Bandeira Formation. Additionally, there is a direct contact between the Córrego Pereira and Córrego dos Borges formations, due to the non-deposition of the Córrego Bandeira Formation, as explained in the previous section. This contact is marked by an erosive surface that served as a lower resistance patch to the weathering processes, being today exposed in a pronounced incise valley (Figure 12).

SÃO FRANCISCO SUPERGROUP

Macaúbas Group

Occurring elongated in a north-south trend, the Macaúbas Group (Figure 3) was mapped as undivided. Its lower contact with the Santa Rita and Córrego dos Borges formations is marked by a paraconformity, although an erosive character can be seen in some points (Figure 13). Also, there is a lower contact with the Córrego Pereira Formation, in the form of an angular unconformity. By its turn, the upper contact is in paraconformity with the metasiltstones from the Serra de Santa Helena Formation from the Bambuí Group. The thickness of the unit ranges approximately from 35 to 120 m.

There are different facies representing the Macaúbas Group in the area, occurring interdigitated. Very characteristic are the metaparaconglomerates (Figure 14) and metadiamictites facies (Figure 15), formed by a white silt-sandy matrix with incipient foliation. The clasts are poorly sorted, ranging from granule to cobble, mainly composed by quartz and quartzite and with a single occurrence observed of ferruginous quartzite in metadiamictite. Specially in the metadiamictites (Figures 15A,B) angular clasts (Figure 15C) are common.

A common characteristic of these rocks is their reddish to pinkish shades (Figure 16), and the predominance of rounded to subrounded quartz grains of medium sand grain size. In general these quartzites are well to moderately recrystallized and locally show planar beddings and asymmetric ripple marks. Additionally, with minor expression there are gray metasiltstones with pronounced foliation.

BAMBUI GROUP

Serra de Santa Helena Formation

The Serra de Santa Helena Formation (Figure 3) is the predominant unit in the cratonic portions of the mapped area. The outcrops are at drainages or road cuts and the unit is mainly cover by a soil coverage expressed in the landscape by subtill slopes.

These rocks are metasiltstones that, when fresh, show light to dark gray color, with alternance between planar beddings and planar laminations.

Lagoa do Jacaré Formation

This unit is restricted to the southwestern portion (Figure 3). Its morphological expression is marked by an elevation that stands out in the flattened landscape of the cratonic context.

This elevation's base is supported by calcareous rocks and structurally represents a syncline, the unit thickness reaches 138 m. The base of the Lagoa do Jacaré Formation is composed by recrystallized gray metacalcilutites, exhibiting sparse subrounded quartz grains (Figure 18).

Above the calcareous level there is a stratum composed by a weathered yellow metapelite, interpreted as an intercalation between two calcareous levels.

STRUCTURAL CHARACTERISTICS

The area structuration is directly associated with the transition context between orogen and craton. Nevertheless, the thrust faults of north-south direction with west vergency that normally mark the EMR-Craton contact do not crop out in the surface.

Instead, what is observed is the folding of the Espinhaço Supergroup in the shape of a great anticline (Santa Rita Anticline; Figure 3), having the EMR scarp as the expression of its west limb.

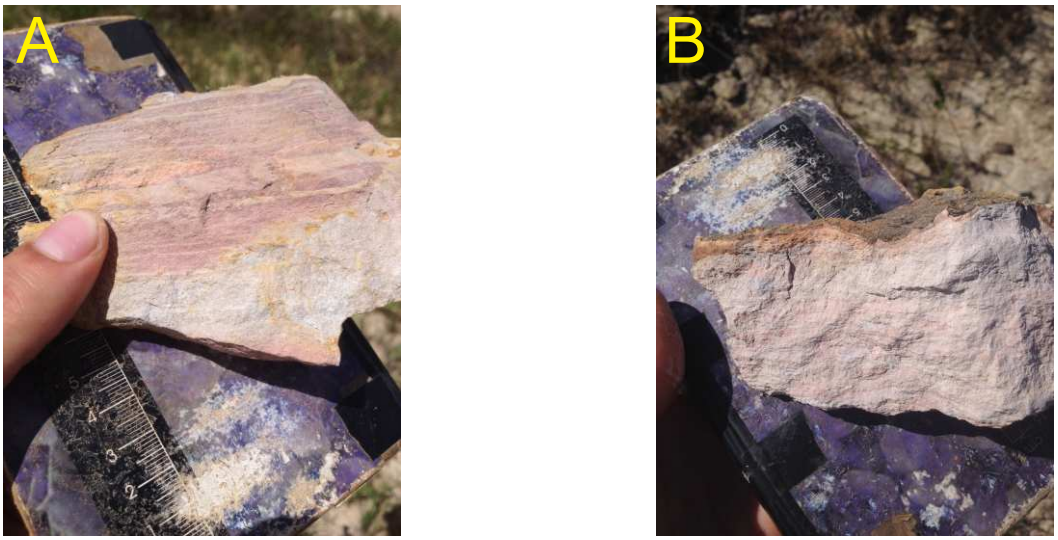

Figure 7 – Laminated metasiltstones from Santa Rita Formation in the studied area, typical of the unit's base.

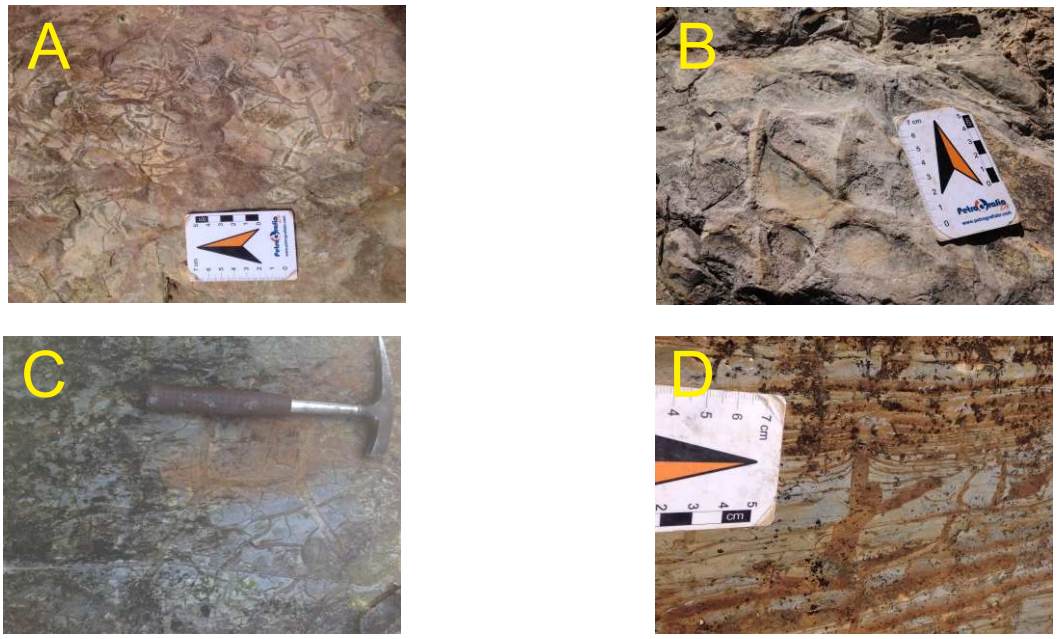

Figure 8 – Synaeresis cracks in different sites of the Santa Rita Formation. (A) Metasiltstone. (B) Four sided polygons formed by the cracks. (C) Micaceous quartzite. (D) Profile view of synaeresis crack, showing that the structure has arched the micaceous quartzite lamination.

Figure 9 – Córrego dos Borges Formation quartzites. (A) Medium to coarse quartzite with lamination. (B) Photomicrograph (2,5x objective, transmitted light, parallel nicols) featuring the intercalation, in the center of the image, of a fine lamination between portions of coarser quartzite.

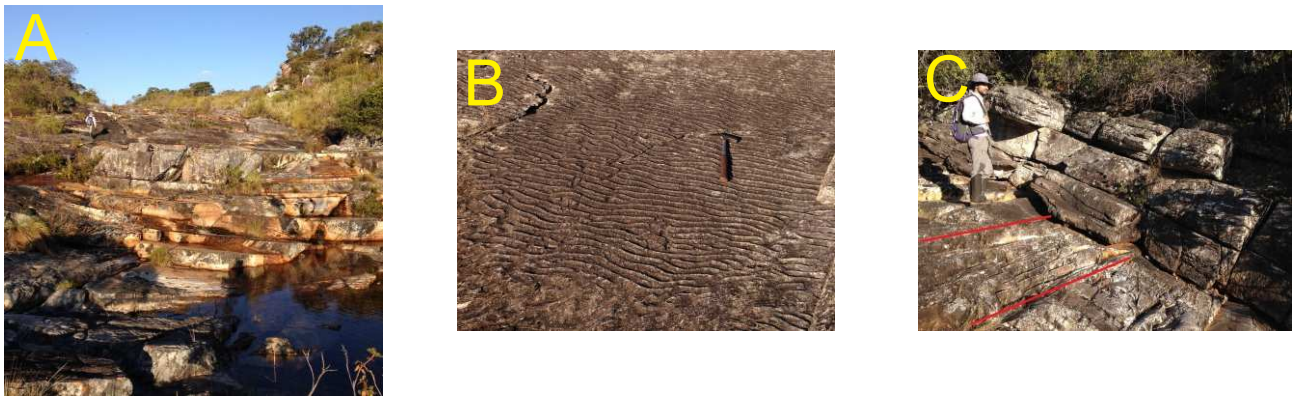

Figure 10 – Sedimentary structures in Córrego dos Borges Formation. (A) Planar beddings. (B) Asymmetric ripple marks. (C) Tangential cross beddings (highlight set in red) truncating the planar beddings.

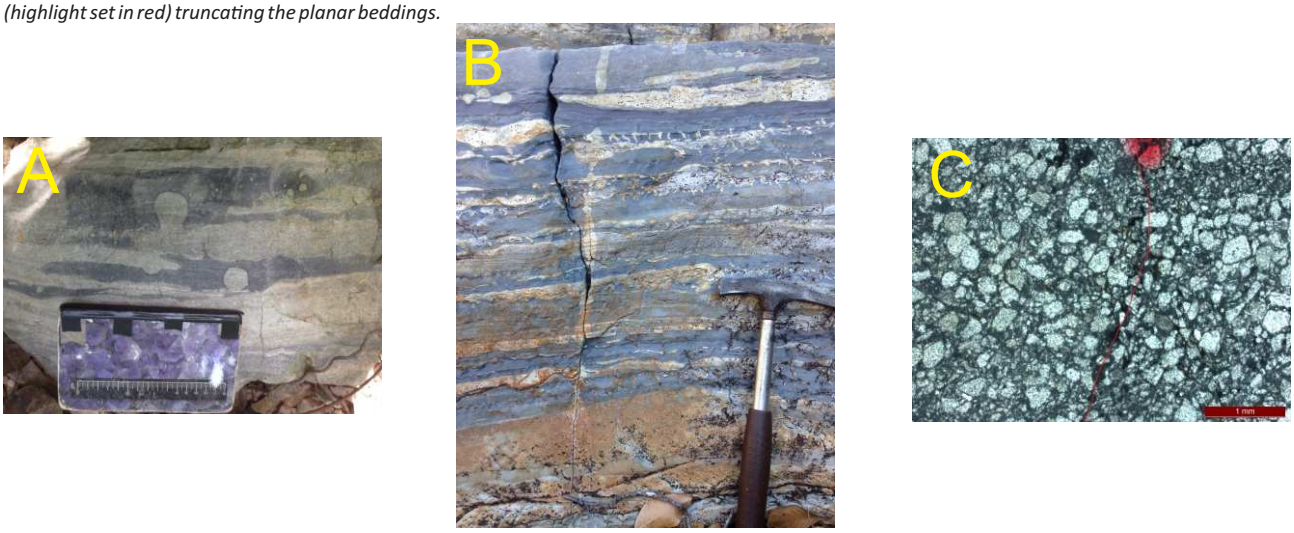

Figure 11 – Bubble shaped structures common to the transition between the base of the Córrego dos Borges Formation and the top of the Santa Rita Formation. (A) Invariably white colored bubbles that seems to detach from the white strata in direction of the dark strata. (B) Profile view showing an upward vertical flux from base to top. (C) Photomicrograph (2,5x objective, transmitted light, parallel nicols) of a bubble found in the Córrego dos Borges Formation, where the red line marks the discrete opaque line that sets the bubble limit (bubble to the left of the line). Bubbles and the host rock are similar petrographically.

Figure 12 – Transition context between Córrego Pereira and Córrego dos Borges formations, marked in the landscape as an incised valley, highlighted by the dashed red line. West limb of Santa Rita Anticline, in the southwest of the mapped area.

Figure 13 – Erosive contact, highlighted in red, between the Macaúbas Group and the Córrego dos Borges Formation (Espinhaço Supergroup) close to the south-center limit of the studied area.

Figure 14 – Metaparaconglomerates of the Macaúbas Group. Both have poorly sorted matrix in the sand fraction, showing quartzite clasts that range from round to angular.

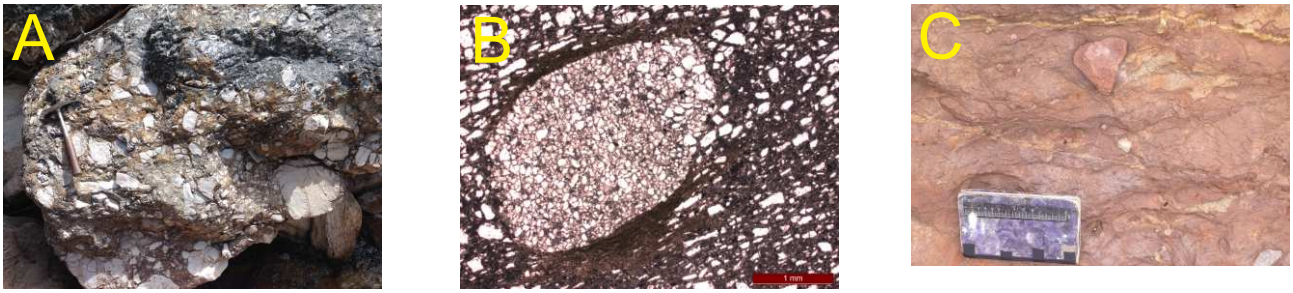

Figure 15 – (A) Macaúbas Group metadimictites in the same outcrop, showing extremely poorly sorted clasts. (B) Photomicrograph (2,5x objective, transmitted light, parallel nicols) from metadiamictite, featuring a quartzite clast amidst a fine matrix. (C) Weathered metadiamictite from Macaúbas Group, highlighting a angular clast.

Figure 16 – Red-pink quartzite with sparse granules from Macaúbas Group.

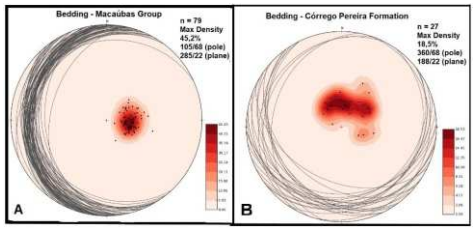

Figure 17 – - Angular unconformity between the Macaúbas Group and the Córrego Pereira Formation (Espinhaço Supergroup).

Figure 18 – Lagoa do Jacaré Formation metacalcilutites.

The São Francisco Supergroup rocks are disposed over this limb, with similar attitude, both to the west. This general configuration is only different in the south-center portion of the area, where the usual paraconformity passes to an angular unconformity between the Espinhaço Supergroup and the Macaúbas Group.

The Santa Rita Anticline is a structure that extrapolates the mapped area limits. Despite that, a representative part of the anticline is within the studied area, affecting the entire eastern portion (Figure 3), coincident with the Espinhaço Supergroup rocks. In this sense, the rocks are folded following the anticline configuration, having the Galho do Miguel Formation as its core, as well as the Conselheiro Mata Group rocks.

The Santa Rita Anticline axis has a north-south direction, plunging to south. The bedding attitudes measured in the Espinhaço Supergroup states the fold geometry with dips to the east, west and south. Such behavior is well observed in the Galho do Miguel Formation outcrop region, in which it is noticeable that fold width is not much inferior to its length, maybe characterizing the Santa Rita Anticline as a braquianticline. In this portion, close to the hinge zone, the measured dips have low angle, with modal maximum in 5 degrees in the Galho do Miguel Formation. In the limbs the dips are around 20 degrees.

Inserted in the Córrego dos Borges Formation there is a sequence of sinforms and antiforms also with north-south axis. Besides that, the main axis of the Santa Rita Anticline presents inflections in its dipping, with a clear south tendency (Figure 19A,B). Therefore, the Santa Rita Anticline geometry consists in a complex form imposed by overlapping folding patterns, with variations in the axis dip generating a "saddle" shape (Figure 19).

Regarding the São Francisco Supergroup rocks, these show a general tendency of having bedding plans dipping west. The Macaúbas Group has a homogeneous attitude, with maximum density of 45,2% in the 285/22 plan. These consistent west dips are contrasting with the attitudes seen in the Córrego Pereira Formation, pointing out the angular unconformity that exists between the Macaúbas Group and the Espinhaço Supergroup in the south-center portion of the mapped area (Figure 17).

Bearing in mind the presented structural characteristics it is noticeable that the São Francisco and the Espinhaço supergroups have more similarities than differences in this aspect.

Despite the presence of the Santa Rita Anticline in the EMR domain, to the east, which is different from the smaller proportion folds that occur in the cratonic domain, to the west, it can be seen that the geometries of the folds in both domains are somewhat similar, being generally more open and with axes approximately with north-south direction and slight west vergency.

The similarity of the foliation attitudes between both supergroups is also clear. Even though the foliation plans in the São Francisco Supergroup represent slightly lower dip angles than the Espinhaço Supergroup both dip approximately to the same direction, *i.e.* east.

GAMMAESPECTROMETRY

The dark shade stripes represent the Córrego dos Borges and Galho do Miguel formations (Figure 21), composed generally by pure quartzites. The dark tone is due to the low concentration of Th, K and U in these rocks, as expected.

By its turn, the Santa Rita Formation is related to a "V" stripe immediately to the south of the Galho do Miguel Formation (Figure 22), having two different

gammaespectrometric responses. It is interesting to observe that it is practically the Santa Rita Anticline axis that marks the division between these responses.

The east limb is marked by greenish shades, sometimes bluish, showing enrichment in Th and U respectively. This area is geomorphologically characterized by flattened surfaces or low gradient convex slopes. In the other hand, in the west limb there is a strong red tone, indicating K concentration. This element is more mobile than the other two and seems to be concentrated in the Santa Rita Anticline west limb, where the landscape is irregular, with occurrence of incised valleys. Besides, it may be favorable to the described context the fact that there is a general inclination from the east to the west limb, where the gradient favors the superficial fluxes in this direction.

Hence, the K may be carried and concentrated in the west limb, bearing in mind yet the presence of a physical barrier presented by the Córrego dos Borges Formation (Figure 21), that reaches relatively higher altitudes. Thus, the ternary image (RGB) showed responses that coincide with the geomorphological compartmentation expressed by the São Francisco Craton and the Espinhaço Range (Figure 20). Both geomorphological compartments showed in Figure 20 coincide with the two mapped supergroups, São Francisco and Espinhaço. For the latter the gammaespectrometric responses allowed clear lithological and structural analysis.

It is noticeable the intercalation of dark shade stripes with red/greenish stripes that form "V" shapes with ends pointing south (Figure 20). This is the structuration of the Santa Rita Anticline as it may be seen in the geological map (Figure 3). The units that comprise the most external portion of the Santa Rita Anticline, i.e. Córrego Bandeira and Córrego Pereira formations, have singularities in their gammaespectrometric responses that seem to be related with structural aspects of the area. The Córrego Bandeira Formation, similarly to the Santa Rita Formation, is characterized in the east limb by greenish shades (Th concentration) and passes to more reddish colors close to the Anticlinal axis (the passage itself is outside the mapped area but the RGB image enables to see the continuity of the structure to the south), indicating K concentration in the west limb (Figure 23).

As previously discussed, this context implicates in an angular unconformity between the Espinhaço Supergroup and the Macaúbas Group. The gammaespectrometric response of the inflection point (Figure 23) indicates high K concentration, and in this area, there is a highly incised valley with west-east direction. Despite de fact that the "V" stripe formed by the Córrego Bandeira Formation in the west limb suggests that the unit follows up north and inflects to the

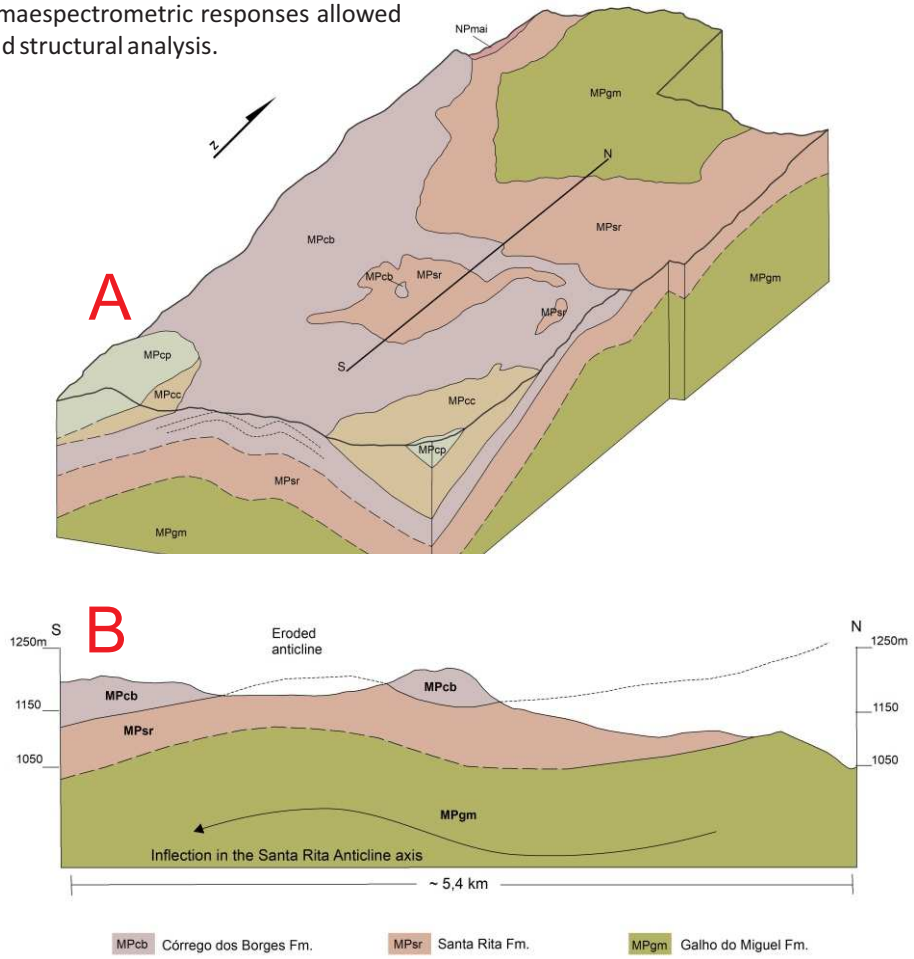

Figure 19 –Santa Rita Anticline geometry. (A) Schematic block diagram of the anticline showing the units that occur as well as the geometry of the structure. The landscape is not represented in the block diagram. The profile presented in Figure 20B is marked by the N-S line in the center of the block. Acronyms: MPgm - Galho do Miguel Formation; MPsr – Santa Rita Formation; MPcb – Córrego dos Borges Formation; Mpcc – Córrego Bandeira Formation; MPcp – Córrego Pereira Formation. (B) Schematic geological profile, out of scale, in north-south direction, showing the inflections in the Santa Rita Anticline dip.

craton, this is not observed in the field. The narrowing of the Córrego Bandeira Formation is morphologically very well-marked in the field.

One peculiar characteristic of the cratonic area in the RGB image is coincident with the topographic elevations formed by metasiltstones of Serra de Santa Helena Formation, that in the image appear as semi-circular blue shade patterns (Figure 24), indicating U concentration, aligned in a north-south trend following the EMR scarp. Uranium is a more static element and its concentration in the elevations could be only relative, i.e. a product of K and Th loss.

DISCUSSION

Sedimentary features and possible implications

The Galho do Miguel Formation presents the typical structures related to eolian environment, like mega cross bedding, are not observed in the unit. Nevertheless, the outcropping quartzites shows significative content in mica, therefore representing a facioligical lateral variation. Typical desertic environments variations showcasing more impure sediments, as the wadi, could be a hypothesis to explain the observed scenario. Another possibility would be a context of fast transgression leading to the drowning of the sediments from the east to the west, implying in the clay enrichment.

About the Santa Rita Formation, the encountered structures like symmetric and asymmetric ripple marks lead to believe in a sub-aqueous depositional context, where changes in the flux regime took place over time.

Another singular feature of Santa Rita Formation is the presence of synaeresis cracks. The specific environmental conditions in which these cracks occur are still not well known, but marginal marine settings could be favorable once this context is more susceptible to salinity variations (Collinson et al., 2006). It is common to mistake these structures for desiccation cracks and sandstone dykes (Collinson et al., 2006) but, for the studied area, the profile depth of the cracks seems too big to be the former and too small to be the latter (Collinson et al., 2006).

Something characteristic of the base to top transition in the Santa Rita Formation is the irregularity of the contacts between the metasiltstones and the micaceous quartzites. The observed geometry indicates an interdigitated depositional context, where paleogeographic differences controlled the sedimentation, making sense with the heterogeneity of modern marine platforms.

Regarding the Córrego Bandeira Formation narrowing and disappearance in the west limb of the Santa Rita Anticline, is here understood as a product of sedimentation changes inside the marine basin filled by the Conselheiro Mata Group. The Córrego Bandeira Formation could be representative of a marine transgression, from east to west, responsible for the advance of fine sediment in the basin. The direct contact between the Córrego dos Borges Formation and the Córrego Pereira Formation could be only due to the non-deposition of the Córrego Bandeira Formation.

A very distinctive characteristic of the Macaúbas Group (Figure 3) is the irregularity of some portions, existing significative enlargements of the unit in the area. A hypothesis to explain this irregular geometry could be different local paleogeography or a structural relationship with the geological units.

Structural aspects

The Santa Rita Anticline marks the transition between the external belt of the Araçuaí Orogen and the São Francisco Craton mostly in the form of a paraconformity, different from the usual thrust fault context observed regionally in the EMR. Besides, other specific feature is also relevant to the structural framework of the area, which is the Pirapora Aulacogen presence.

The Pirapora Aulacogen is a structural low inside the São Francisco Craton, formed from the nucleation of distensive tectonics features in the Precambrian (Alkmin, 2004). The cratonic basement was subject to rifting movements, posteriorly aborted, that originated grabens formed by normal faulting (Alkmin, 2004). These structures served as deposition site for the Araçuaí Orogen precursors basins in the Statherian and Tonian tafrogenesis (Alkmin, 2004).

Hercos et al. (2008) present seismic lines that point out the Espinhaço Supergroup undersurface presence, related to the superficial outcrops represented by the Crabral and Água Fria ranges. Similarly to what is found in the studied area, these ranges comprise big folds in which cores crops out the Espinhaço Supergroup rocks. Therefore, the deformation mechanism responsible for the nucleation of the Santa Rita Anticline could be analogous to the one that act upon the Cabral Range structures.

During the Brasiliano Orogeny, responsible for the Araçuaí Orogen edification, the Pirapora Aulacogen worked as a WNW-ESE corridor that dissipated the tension from the collision that was taking place, and so concentrated most part of the deformation in the craton's interior (Alkmin, 2004). The deformation front advance towards west generated a ledge ("Serra Mineira protrusion") that can be observed today as an inflection with NE-SW direction in the EMR alignment, in which limit the studied area is inserted.

The interaction between the orogen and craton at this point could have provoked the inversion of normal faults in the Aulacogen's interior, reactivating these structures as reverse faults and remobilizing basement blocks (Hercos et al. 2008). In the most oriental portion of the Pirapora Aulacogen the remobilization of a cratonic basement block could have caused the arching of the Espinhaço Supergroup coverage in the form of a great anticline (*i.e.* Santa Rita Anticline), being the faults from which this deformation was nucleated not cropping out.

Still regarding the possible influences of the Brasiliano deformation, immediately in the EMR's contact (Santa Rita Anticline west limb) occurs an alignment of small

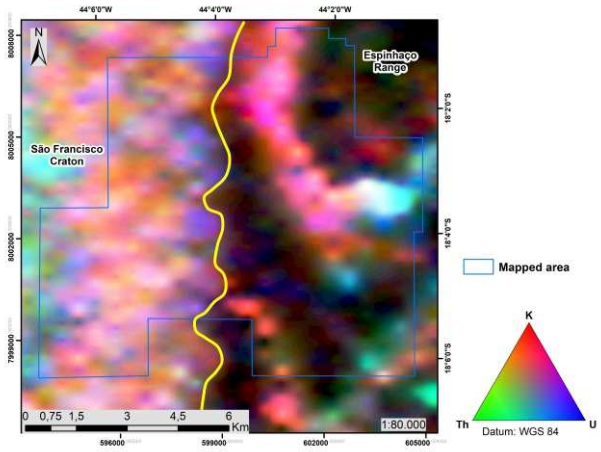

Figure 20 – Transition context between Córrego Pereira and Córrego dos Borges formations, marked in the landscape as an incised valley, highlighted by the dashed red line. RGB image featuring the mapped area (blue polygon) and the contrast between the gammaespectrometric responses of the cratonic area (to the west of the red line in the image's center) and the Espinhaço Range (to the east of the red line). Geophysical data source: CODEMIG, 2010.

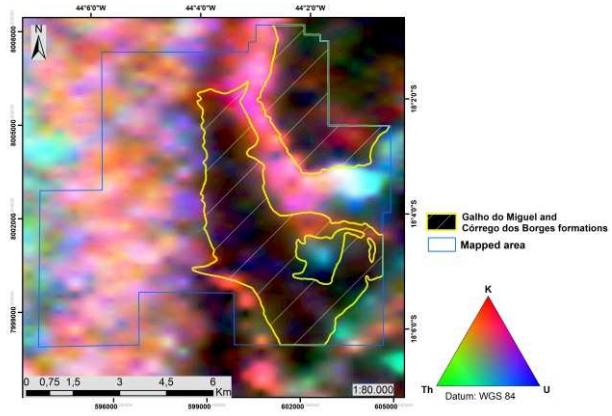

Figure 21 – RGB image of the mapped area highlighting with hatches the Galho do Miguel Formation, at northeast, and the Córrego dos Borges Formation. Both units are basically formed by pure quartzites and have great outcrop exposition in the surface, allowing the clear gammaespectrometric response in dark shades and indicating low concentrations of K, Th and U. Geophysical data source: CODEMIG, 2010.

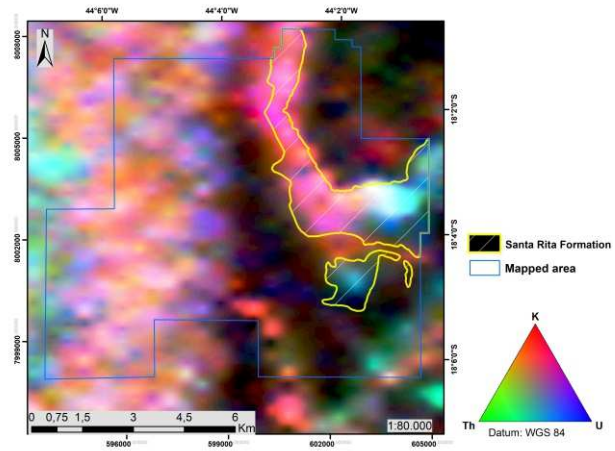

Figure 22 – RGB image highlighting the Santa Rita Formation in hatches. It is noticeable the "V" shape stripe of the main area occupied by this unit, as well as the transition in the geophysical response near to the anticlinal axis. Geophysical data source: CODEMIG, 2010.

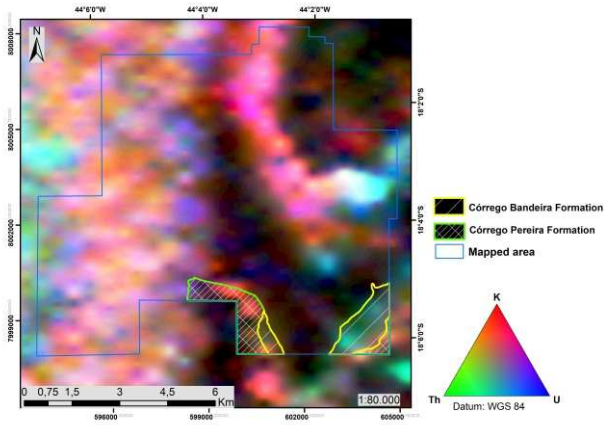

Figure 23 – RGB image highlighting the Córrego Bandeira and Córrego Pereira formations in hatches. It is possible to see the change in the geophysical response in the "V" shaped stripe close to the anticlinal axis, as well as the abrupt inflection towards the craton in the west limb extremity. Geophysical data source: CODEMIG, 2010.

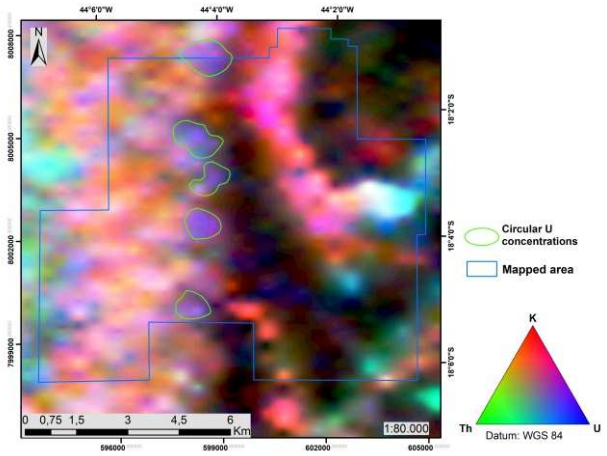

Figure 24 – RGB image highlighting the semi-circular U concentrations coincident with the morphological elevations supported by the Serra de Santa Helena Formation rocks. Geophysical data source: CODEMIG, 2010.

topographic elevations (coincident with the circular U concentrations in Figure 24) formed by the Serra de Santa Helena Formation.

The observed characteristics of the isoclinal folds in these topographic elevations seem to be coherent with the Brasiliano event imposition in a regional scale.

The angular unconformity identified between the Córrego Pereira Formation and the Macaúbas Group indicates that in the moment of deposition, the Espinhaço Supergroup was already folded in some degree.It is possible to build a hypothesis that between the Statherian Tafrogenesis, when the opening of the Espinhaço Basin took place, and the Tonian Tafrogenesis (Macaúbas Basin opening) there should had been some compressive pulse deforming the Espinhaço rocks prior to the Macaúbas Group deposition.

CONCLUSIONS

The Santa Rita Anticline region provides a singular scope

for the establishment of the Araçuaí Orogen external belt in its limit with São Francisco Craton.

The detailed geological mapping of the angular unconformity between the Espinhaço Supergroup and the Macaúbas Group, providing strong evidence to support the idea that some kind of intermediate deformation occurred between the Statherian and Tonian tafrogenesis. Nevertheless, the present data does not allow to understand the magnitude of such event. Facing the lack of regional geological evidence corroborating with an orogenic event, for example, it seems more likely that the scale and magnitude of this intermediate deformation had a more local character.

The non-occurrence of the thrust front with west vergency in the orogen/craton contact as observed in most parts of the EMR is another peculiar point. More substantial hypothesis regarding this matter are yet to be raised in order to properly explain the sudden absence at surface of the main thrust fault. Thought, it seems likely that the nucleation of the Santa Rita Anticline related to the basement's effect, in the Pirapora Aulacogen context as a corridor of deformation from the Brasiliano Event, may be somehow responsible for this scenario where the thrust fault does not crop out.

The gammaespectrometry analysis by the ternary image provided valuable information about the structural and lithological relationships in the area.

The work contributes to the consolidation of the geological understating regarding the EMR and the São Francisco Craton, mainly by presenting data for a still poorly studied specific region, establishing yet the name Santa Rita Anticline.

ACKNOWLEDGMENTS

Acknowledgments to the PETROBRAS Human Resources Formation Program (PRH-PB 238).

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