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Papers

Lineament Patterns and Structural, Tectonic, and Neotectonic Control in the Relief of the Pancas Region (Espírito Santo, Southeast Brazil)

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Geological structures
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Abstract
The main objective of this research is to investigate the lithostructural, tectonic, and neotectonic control on the relief of the Pancas region (Espírito Santo, Southeastern Brazil). The methodology was organized into computer and field analyses. In a computer, lineament and structural trend maps were generated from the manual extraction technique using editing tools of ArcGIS 10.3.1™ software (ESRI, 2012) over a Digital Elevation Model (DEM) with different artificial illumination (scale 1:110.000) and orientation rosettes were generated. The geological and geomorphological maps were organized/elaborated with ArcGIS from the Geographic Information System (GIS). The cartographic bases were configured in the UTM projection system, and DATUM SIRGAS 2000, zone 24S, and later analyzed and compared with the data of the orientations of the dedicated lineaments, with the orientation of the studied outcrop failures and with the existing literature. The results presented NW-SE/NNW-SSE and NE-SW/NNE-SSW orientations, with the predominance of NNW-SSE and NW-SE orientations identified in the analysis of the lineaments and structural trends, similar to the orientations of the geological faults and neotectonic faults present in the studied area, reflecting the regional structuring of the area, presenting the same orientations as the Colatina Belt. The secondary orientations of the Araçuaí Orogen (NE-SW), the identification of morphotectonic features, the presence of abrupt topographic differences (topographic profiles), and the identification of tectonic regions (base surface map) and tectonic blocks (scanning profile) demonstrate the tectonic control in the relief of the Pancas-ES region, achieving the objective of this research.

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INTRODUCTION

The present research studies the relationship between lineaments, geological structures, tectonics, and neotectonic faults in the Pancas region (Espírito Santo, Southeastern Brazil), which is of fundamental importance for understanding the evolution of the relief in the region.

The area is characterized by relief patterns with strong structural and tectonic control. In addition, it is important to mention the existence of neotectonic faults at the site, suggesting conditioning these faults in the mentioned features (BRICALLI, 2011). It also presents a high density of faults/fractures and is inserted in the most important geotectonic feature of the state of Espírito Santo (BRICALLI, 2011) of NNW-SSE orientation, with brittle characteristics associated with compressive and tensile efforts, being considered an area with the presence of tectonic reactivations (NOVAIS et al., 2004).

The analysis of lineaments has been a useful tool for research in areas that may indicate locations of occurrence of important geological structures, thus proving the structural and/or tectonic influence on the evolution of the relief. This occurs because the lineaments reflect the main regional lines of weakness (BRICALLI; MELLO, 2013) and their importance for neotectonic analyses.

The relief controlled by structural discontinuities can corroborate the inference of a neotectonic action in a region with evident signs of recent tectonic reactivation, which plays a key role in the geomorphological delineation of the current relief (OLIVEIRA et al., 2018).

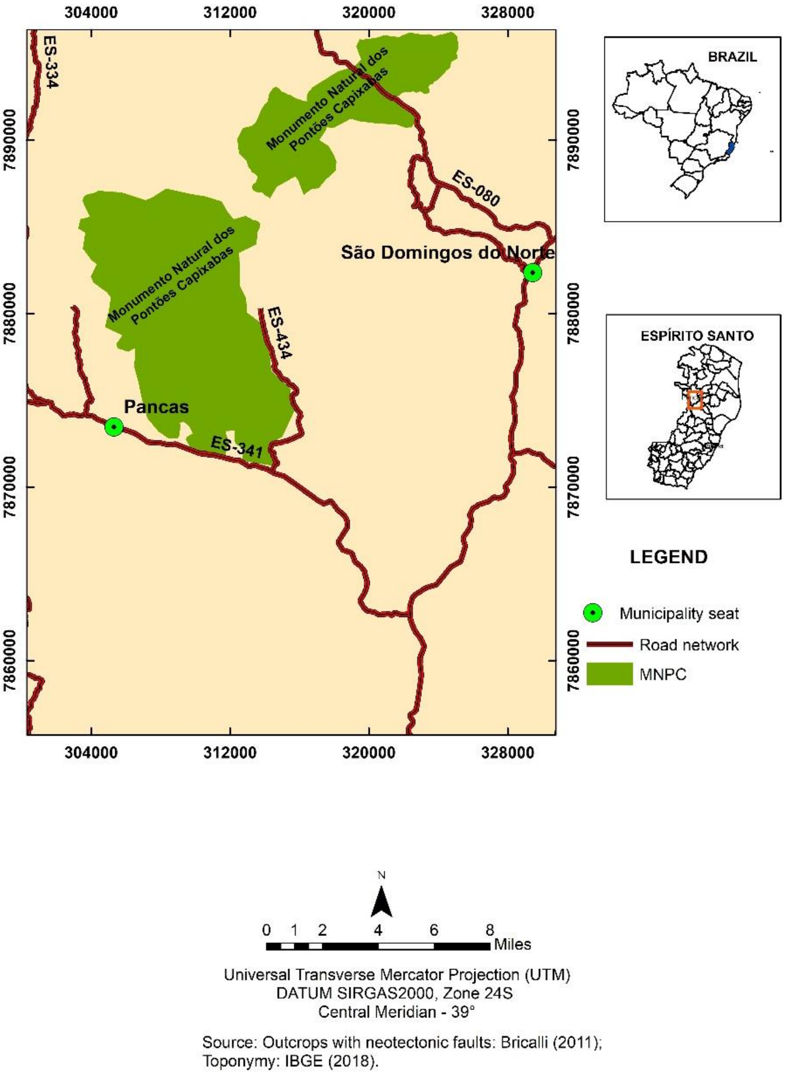
Given the above, the main objective of this research was to investigate the lithostructural, tectonic, and neotectonic control on the relief of the Pancas region, the state of Espírito Santo. The specific objectives were: i) To identify lineament patterns in the Pancas region, according to the manual extraction methodology; ii) Relate lineament patterns, geological structures, the orientation of the structures of the Araçuaí Orogen, orientation of the Colatina Belt, and neotectonic fault orientations to the relief of rock dome (sugarloaf).

STUDY AREA

Location and Access

The studied area comprises the region of Pancas, northwest of the state of Espírito Santo, covering 1,375.29 km², located between latitudes 19°00'49.15"S – 19°24'10.62"S and longitudes 40°36'47.57"W – 40°54'58.39"W. Access from Vitória takes the BR-101 North and, from the Municipality of João Neiva, takes the BR-259 towards Colatina and the ES-341 towards Pancas. The area features a relief in the shape of a rock dome (sugarloaf), whose scenic beauty gave rise to the Monumento Natural dos Pontões Capixabas, category of Conservation Unit (UC) with full pretection, created in 2002 (Figure 1).

Figure 1- Location map of the studied area

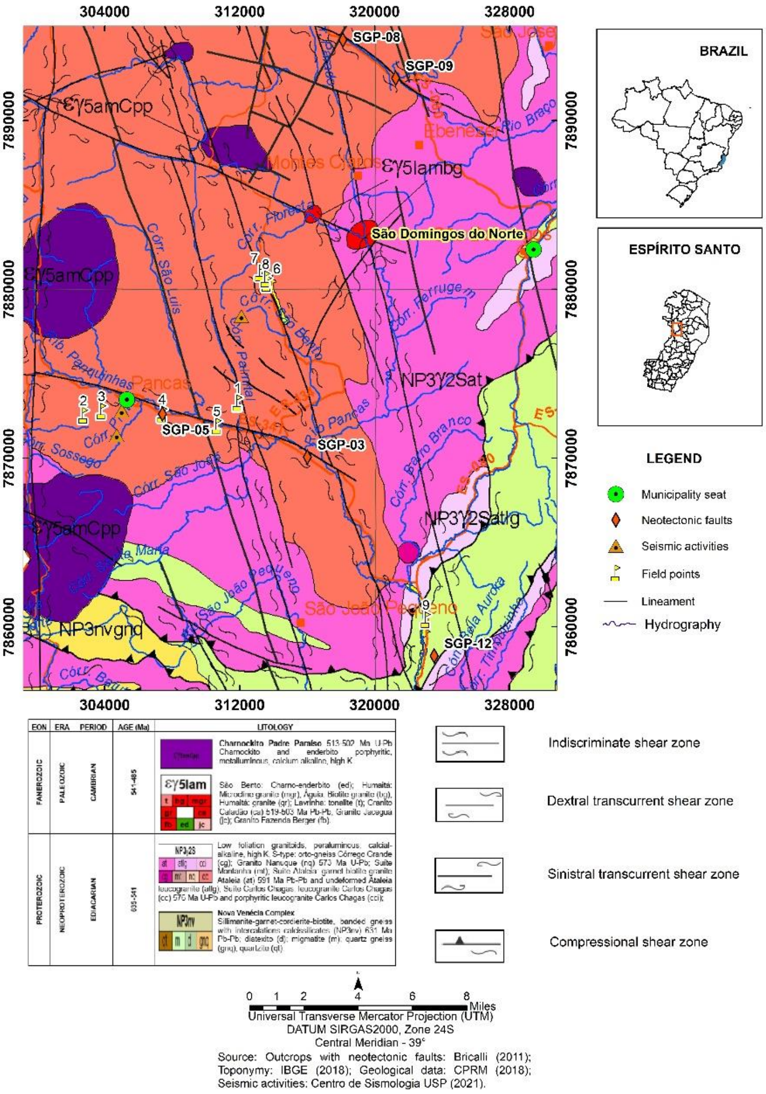


Source: The authors (2022).

Local Geology

The area presents diversified lithology, belonging to the following geological units: i) Nova Venécia Complex (Neoproterozoic) composed of sillimanite-garnet-cordierite-biotite banded with calc-silicate intercalations (NP3nv), quartz gneisses (gnq); ii) Nanuque granite (nq) (Neoproterozoic); Ataleia Suite: garnet-biotite, Ataleia granite (at) and undeformed Ataleia leucogranite (atlg) and the Carlos Chagas Suite composed of leucogranite; iii) Padre Paraíso Charnockite (Paleozoic) composed of porphyritic, metaluminous, high-K calc-alkaline Charnockite and enderbite distributed in portions in the area covered by the Carlos Chagas Suite (CPRM, 2018) – figure 2.

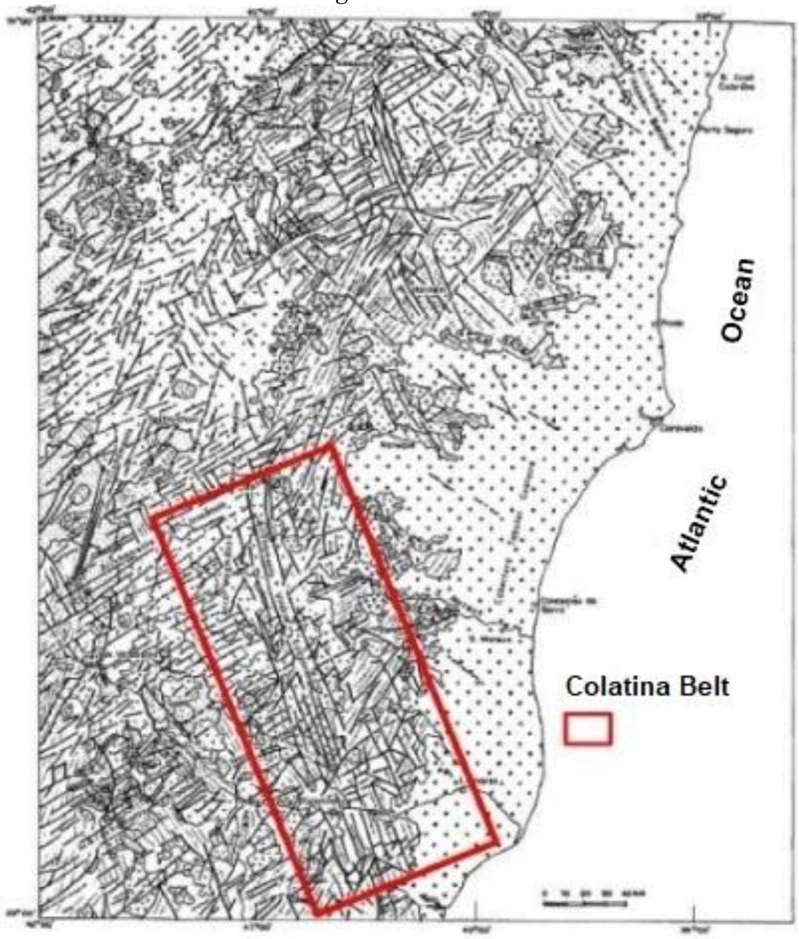
Figure 2 - Geological map of the studied area



Source: The authors (2022).

Geological structures with predominantly NW-SE to NNW-SSE orientations (CPRM, 2018) are present in the area: i) Indiscriminate shear zone; ii) Sinistral transcurrent shear zone; iii) Dextral transcurrent shear zone; iv) compressional shear zone; and v) Failures/fractures. The area is inserted in the Precambrian Basement Compartment, corresponding to the Araçuaí Orogen mobile belt (HEILBRON et al., 2004) and presents an important tectonic-structural feature, the Colatina Belt (NNW-SSE) - (NOVAIS et al., 2004; NOVAIS, 2005) - figure 3.

Figure 3 - Colatina belt



Source: Adapted from Silva et al. (1987).

Seismic Activity

The seismic activities recorded in the studied area in 2021 may be influenced by the extensive shear zones and faults/fractures with a predominance of NNW-SSE and NW-SE direction, Colatina Belt (NNW-SSE), high density of fractures/faults and lineaments (BRICALLI, 2011), in addition to neotectonic activities.

Local Geomorphology

The area is inserted in two morphostructural domains (GATTO et al., 1983; MENDES et al., 1987), which are: 1) Massive Plutonic Domain (Domínio Maciços Plutônicos); and 2) Remobilized Folding Range Domain (Domínio Faixa de Dobramentos Remobilizados).

The Bloco Montanhoso Central geomorphological unit has a mountainous aspect and altitudes around 500m and 700m, reaching up to more than 1,000m in the mountains and influence of structural control, preferably in the NW-SE and NE-SW directions (MENDES et al., 1987).

The Depressão Marginal Geomorphological Unit corresponds to the dissected and depressed sectors, presenting structural control, indicating structural interferences of the geotectonic cycles (MENDES et al., 1987).

The Patamares Escalonados do Sul Capixaba geomorphological unit presents staggered levels of dissection, forming terraces, suggesting tilted blocks, as a result of epigenetic impulses related to the action of geotectonic cycles and Wealdenian Reactivation (MENDES et al., 1987).

MATERIALS AND METHODS

The research was divided into 2 (two) key stages: i) computer analysis and; ii) field analysis.

Computer Analyses

In the computer analyses, the lineaments were decoded in ArcMap™ ArcGIS 10.3.1™ (ESRI, 2012) over a digital elevation model (DEM) with

30m spatial resolution (Topodata) - Valeriano (2002).

Artificial illumination techniques and 45º solar altitude were applied on the MDE, using the "Hillshade" tool, and the "Z-factor" was established with the value 0.00000934 (BRICALLI, 2011) from the average between the values of the latitudes that cover the state of Espírito Santo. Then, the lineaments were decalcified according to the manual extraction methodology (BRICALLI, 2011), taking into account their characteristics (LIU, 1984).

Lineament direction values were calculated using *AzimuthFinder®* 1.1 software (QUEIROZ et al., 2014). Then the Calculate Geometry tool is applied to calculate the lengths of the lineaments extracted in the unit meter.

The azimuths of the lineaments and length were represented according to Allmendinger et al. (2013) using the Oriana *software* (version 3.2.1, demo license, 2022) from Kovach Computing Services and made into rosette diagrams.

The lineament density map pointed out the regions with higher and lower concentrations of lineaments. For this, the *Lineament Density tool of ArcToolBox* of ArcGIS was used, with cell size 30 and area unit km/km². Subsequently, the structural trends of the area were recalculated on the lineament density.

The lineament map on digital orthophotos (GEOBASES, 2021), at scales 1:25.000 and 1:10.000, as well as the azimuth calculation, the lineament length calculation, the lineament density and the decal of the structural trends, were prepared in the same way as the lineament map on the DEM, except for the artificial illuminations, since these are aerial photographs.

The map of faults and structures was generated in ArcGIS software, based on the geological map of CPRM (2018), scale 1:400.000 from the vectorization of geological structures in the area.

The hypsometric map was prepared through the DEM, presenting five (5) altitude class intervals (77m to 188m; 188m to 300m; 300m to 442m; 442m to 596m, and 596m to 901m).

For the elaboration of the map of base surfaces (BS), the altimetric information of the studied area and extraction of the drainage network were obtained from the DEM and determined the drainage hierarchy as proposed by Strahler (1952). After these steps, using the *Stream Order* tool of ArcGIS, the hierarchy of rivers was determined. The second-order segments (STRAHLER, 1952) were selected and converted to points. The altitude value of each point was obtained from the (DEM) and, finally, the data was interpolated using the "INVERSE OF DISTANCE WEIGHTED (IDW) " method, in power 2, with a search radius of 2.5 km and considering the 15 closest points, resulting in the base surface map (SALVADOR; PIMENTEL, 2009).

The 02 (two) scanning profiles were prepared in NW-SE (profile A-B) and NE-SW (profile C-D) orientations, according to the methodology proposed by Meis et al. (1982), on the IBGE (1979) cartographic base on the São Gabriel da Palha (SE.24-Y-C-III) topographic chart, scale 1:100.000. The altimetric point values were extracted and transferred to Excel® *software* in table form, and a scatter plot was generated. Using the *Windows Paint®* editing program, the blocks were drawn on the scatter plot.

A transect in E-W orientation was drawn in ArcGIS for the geological-geomorphological profile. The lithology classification was performed manually from the beginning and end of the lithological boundaries (CPRM, 2018) and inserted into the prepared topographic profile, thus allowing 2D topographic representation.

The neotectonic analyses were performed from the existing neotectonic data in the state of Espírito Santo (BRICALLI, 2011), paying attention, especially, to the orientation of the faults, the types of faults (normal, reverse, sinistral, or dextral), affected stratigraphic unit and identification of the neotectonic events pointed out.

Field Analyses

The field points were recorded with GPS, a digital camera, drone imaging, notes, and drawings in a field notebook. The recording of geological and geomorphological features was performed through *in situ* analysis of the lithotypes, geological structures, and geomorphological features present, as well as a comparison with pre-existing geological and geomorphological mapping (CPRM, 2018; MENDES *et al*., 1987).

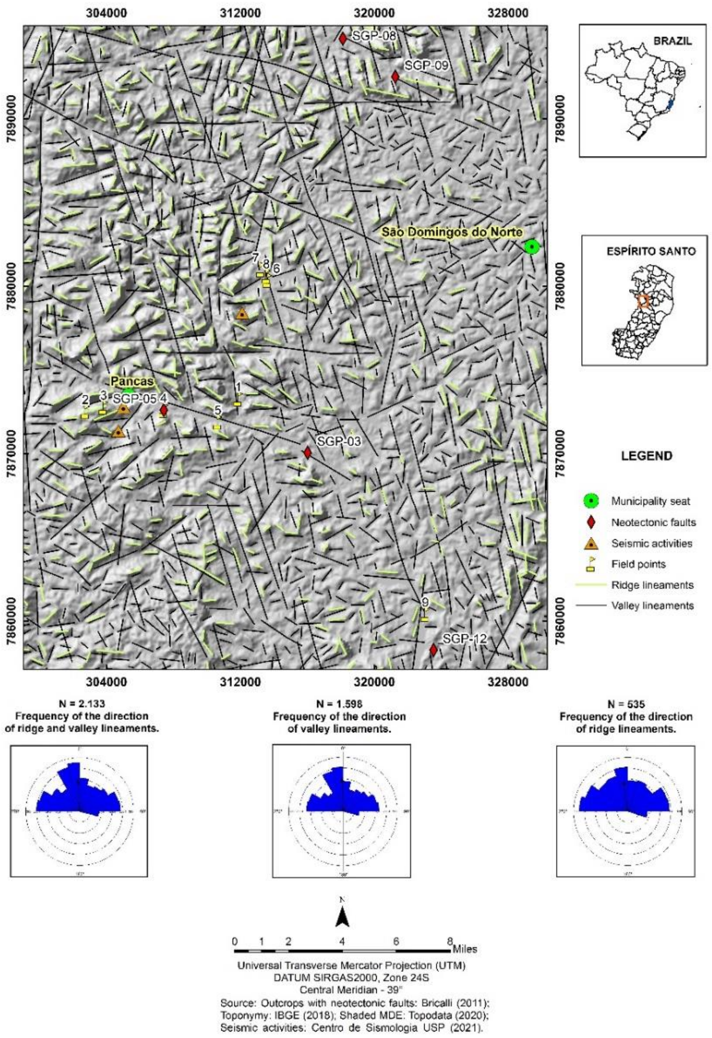
The macroscopic analysis identified the lithotypes using a geological hammer and a magnifying glass (10mmx20mm). The geological structures (faults and fractures) were measured using a compass of the Brunton model. The morphologies were interpreted from the classification of the tops, slopes, and valleys morphologies present in the area.

RESULTS AND DISCUSSIONS

In the study area, 2133 lineaments were traced, 1598 valley lineaments, and 535 aligned crest lineaments (Figure 4).

The rosette charts demonstrate the predominance of the NNW-SSE and NW-SE lineaments, followed by the NNE-SSW and NE-SW orientations and the N-S orientation. The E-W orientations are not very representative. The NNW-SSE and NW-SE orientations reflect the regional structures (lineaments of the state of Espírito Santo) identified by Bricalli (2011).

Figure 4 - Lineament map



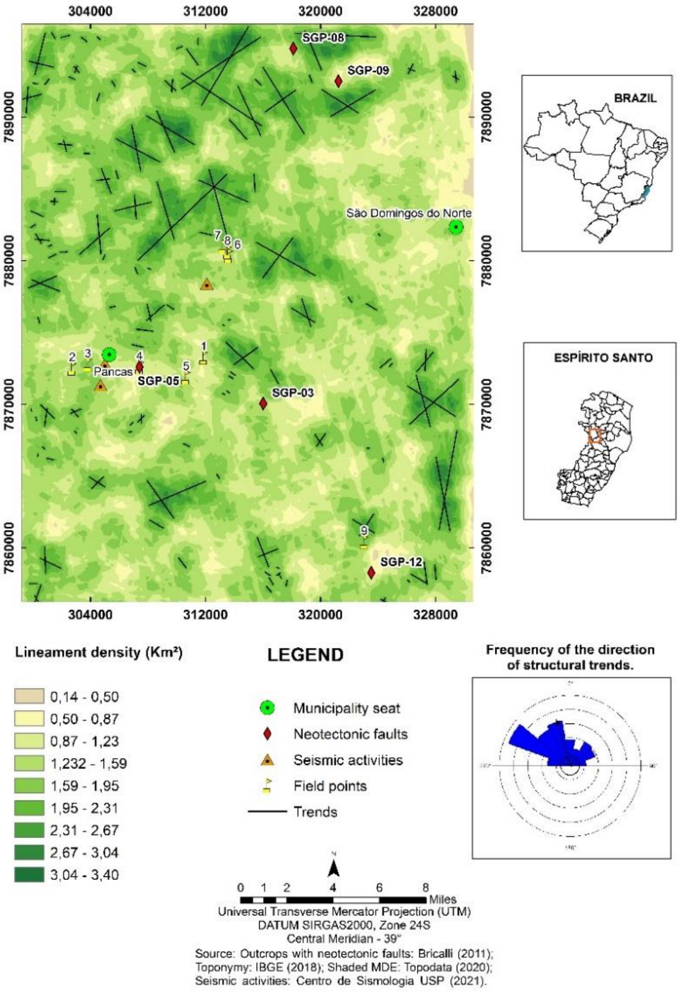
Source: The authors (2022).

The NNW-SSE and NW-SE orientations of the lineaments reflect the orientation of the Colatina Belt and coincide with the predominant orientations of the structural trends map (Figure 5). The NNW-SSE to NW-SE orientations of the lineaments also coincides with the orientation of an NNW-SSE dextral fault of points SGP-08 and SGP-09, as well as an NNW-SSE dextral fault of point SGP-12 (BRICALLI, 2011).

The NNE-SSW and NE-SW direction lineaments reflect the orientation of the Araçuaí Orogen (NE-SW) - (MACHADO FILHO et al., 1983; PEDROSA SOARES; WIEDEMANN-LEONARDOS, 2000). These orientations also reflect the regional structures identified by Bricalli (2011). They also reflect the orientations of the ENE-WNW dextral fault of points SGP-08 and SGP-09 and the normal NE-SW and NNE-SSW dextral faults of point SGP-12 (BRICALLI, 2011).

The lineament density and structural trend map showed a total of 167 lineaments traced across the studied area (Figure 5).

Figure 5 - Lineament density map and structural trends



Source: The authors (2022).

The largest class intervals, between 1.95 km² and 3.4 km², are concentrated in the northern portion of the Plutonic Massifs Domain and small areas distributed in the center and south of this Domain. In the southeast portion, in the Faixa de Dobramentos Remobilizados Domain, there are also areas with a concentration of these class intervals. The class intervals between 0.87 Km² to 1.95 Km² are uniformly distributed throughout the studied area.

The rosette chart of structural trends showed a predominance of NNW-SSE and NW-SE lineaments, followed by NE-SW orientations. The N-S and E-W orientations are less expressive than those mentioned. The orientations also reflect regional structures identified by Bricalli (2011).

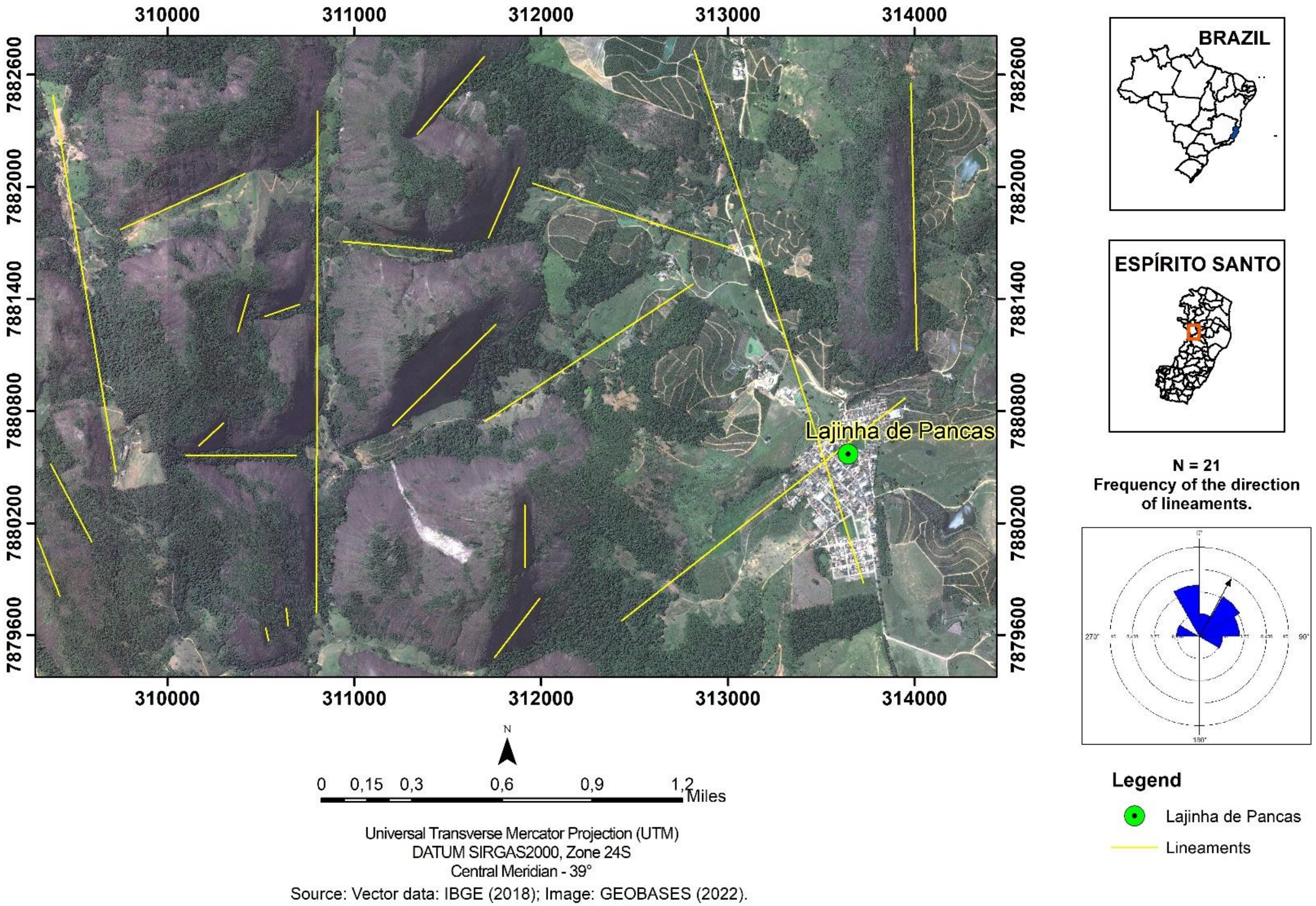
The NNW-SSE and NW-SE orientations of the lineaments reflect the orientation of the Colatina Belt and coincide with the orientations of the structural trends. The NNW-SSE to NW-SE orientations of the lineaments also coincides with the orientation of a dextral NNW-SSE fault of point SGP-12 and a dextral NNW-SSE fault points SGP-08 and SGP-09 (BRICALLI, 2011).

The NNW-SSE and NW-SE orientations of the lineaments reflect the orientation of the Colatina Belt and coincide with the orientations of the structural trends. The NNW-SSE to NW-SE orientations of the lineaments also coincides with the orientation of a dextral NNW-SSE fault of point SGP-12 and a dextral NNW-SSE fault points SGP-08 and SGP-09 (BRICALLI, 2011).

The lineament map on digital orthophoto, scale 1:25.000 (GEOBASES, 2021) showed 21 lineaments traced around the District of Lajinha de Pancas-ES. The rosette chart showed a predominance of the NNW-SSE direction, followed by the NE-SW orientation and the WNW-ESE and ENE-WSW orientations (Figure 6).

The predominant orientation (NNW-SSE) of the lineaments reflects the orientation of the Colatina Belt. The NNW-SSE to NW-SE orientations of the lineaments also coincides with the orientation of an NNW-SSE dextral fault of point SGP-12, NNW-SSE dextral fault of points SGP-08 and SGP-09 (BRICALLI, 2011), these points close to the delimited area.

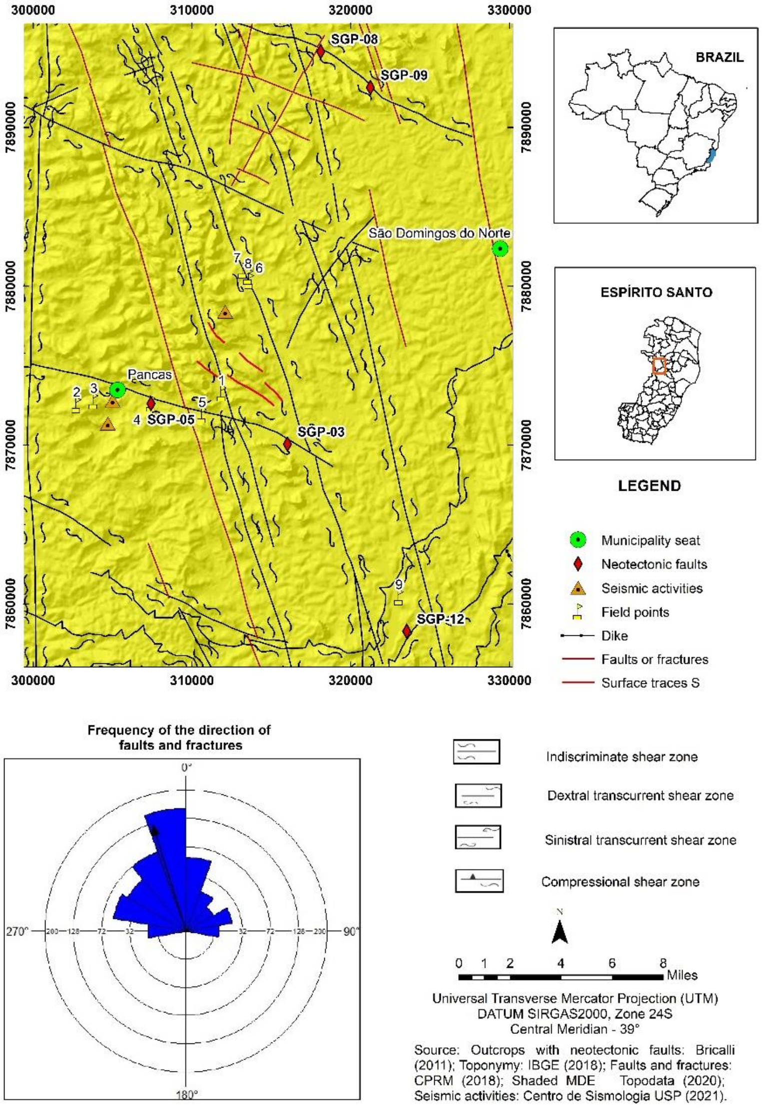
Figure 6 - Lineament map in digital orthophoto - Scale 1:25.000



Source: The authors (2022).

The rosette chart of the existing fault and fracture map in the studied area showed the predominance of lineaments in the NNW-SSE and NW-SE directions, followed by the NNE-SSW and NE-SW and the WNW-ESE and ENE-WSW directions. These guidelines reflect the regional structures identified by Bricalli (2011). The NNE-SSW and NE-SW direction lineaments reflect the orientation of the Araçuaí Orogen (Figure 7).

Figure 7 - Fault and fracture map



Source: The Authors (2022).

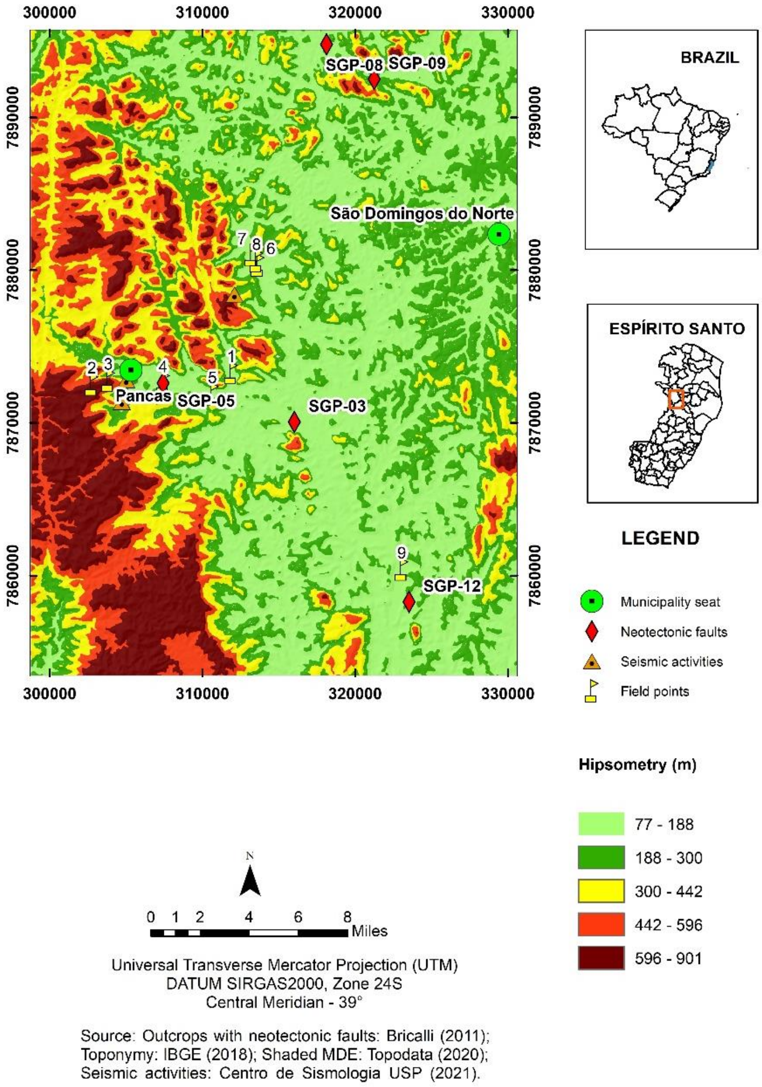
They also reflect the orientations of the WNW-ESE and ENE-WSW dextral faults of points SGP-03 and SGP-05, normal and sinister faults NE-SW and NNE-SSW dextral faults of point SGP-12 (BRICALLI, 2011). The NNW-SSE to NW-SE orientations of the lineaments reflect the orientation of the Colatina Belt and coincide with the orientations of the NNW-SSE dextral fault of point SGP-12 and the normal NW-SE faults of points SGP-08 and SGP -09 (BRICALLI, 2011).

The hypsometric map was prepared with 5 (five) intervals of altitude classes (77m to 188m; 188m to 300m; 300m to 442m; 442m to 596m, and 596m to 901m), representing the altimetric variation of the relief in the Domains of Plutônicos Massifs and Faixa de Dobramentos Remobilizados that comprise the studied area, with the highest altitudes (300m to 901m) covering its western portion (Figure 8).

In the Plutônicos Massifs Domain, in the southern portion, the class intervals between 442m and 901m predominate, and in the northern portion, the class interval from 300m to 442m. The Bloco Montanhoso Central Geomorphological Unit presents fragments of plateaus with flat tops, associations of hills, strong structural control, and occurrence of pontoons and dissection in humps (MENDES et al., 1987).

The class intervals from 188m to 300m are distributed in the Faixa de Dobramentos Remobilizados Domain, standing out east of the studied area and in small areas in the Plutônicos Massifs Domain. The Faixa de Dobramentos Remobilizados Domain is characterized by the formation of plateaus, notched main rivers, tabular and hilly interfluves, hills, dissected plateaus interspersed with deep V-shaped valleys, interfluves with convex tops and hills interspersed with more resistant cores in the form of pontoons and ridges separated by flat-bottomed and filled valleys (MENDES et al., 1987).

Figure 8 - Hypsometric map



Source: The Authors (2022).

The hypsometric map shows relief with more elongated hills in the southwestern portion, with fractures in the NE-SW orientation, and isolated hills in the northwestern portion, separated by well-marked fractures, especially in the NNW-SSE and NW-SE orientation. In the eastern portion of the area, the relief is quite dissected, with deep structural furrows, scarps, ridges, and pontoons, oriented predominantly in the NNW-SSE direction, followed by the NNE-SSW orientation, unlike the western portion of the area.

The orientations of fractures in the NNW-SSE and NW-SE orientations on the hypsometric map (Figure 8) reflect the dominant orientations also on the lineament maps, the structural trends map, and the geological fault map present in the area (BRICALLI, 2011), and reflects the same orientation as the Colatina Belt. Moreover, this dominant orientation coincides with mapped neotectonic fault orientations in and near the area.

Given the above, it can be seen that the altitudes of the area, as well as the relief, show strong structural and tectonic control.

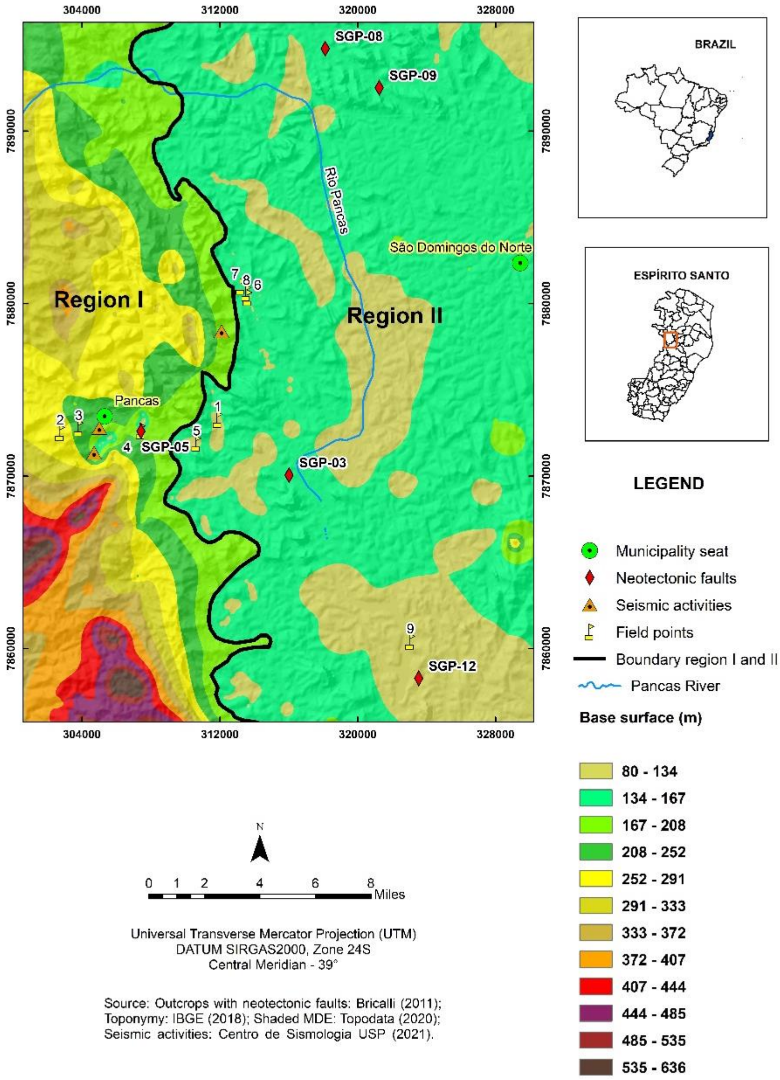
The base area map presents twelve (12) isobase classes: 1) 80m to 134m; 2) 134m to 167m; 3) 167m to 208m; 4) 208m to 252m; 5) 252m to 291m; 6) 291m to 333m; 7) 333m to 372m; 8) 372m to 407m; 9) 407m to 444m; 10) 444m to 485m; 11) 485m to 535m and; 12) 535m to 636m, thus allowing the identification of sharp relief contrasts (Figure 9).

From the analysis of the isobase classes, 02 (two) regions were delimited: i) Region I (167m to 636m) and; ii) Region II (80m to 167m).

In region I, the geological Units Suíte Carlos Chagas, Charnockito Padre Paraíso, Suíte Ataleia, and the Nova Venécia Complex predominate, presenting faults/fractures, S surface traces and shear zones of NNW-SSE, NW-SE and WNW-ESE orientations (CPRM, 2018).

In region II, the geological Units Suíte Carlos Chagas, Granito Águia, Suíte Ataleia, and the Nova Venécia Complex predominate, presenting faults/fractures and shear zones of NNW-SSE, WNW-ESE, and NNE-SSW orientations, (CPRM, 2018). The NNE-SSW orientation reflects the orientation of the Araçuaí Orogen (NE-SW) (MACHADO FILHO et al., 1983; PEDROSA SOARES; WIEDEMANN-LEONARDOS, 2000).

Figure 9 - Base Surface Map



Source: The authors (2022).

It also reflects the NNE-SSW dextral fault orientation of point SGP-12 (BRICALLI, 2011). The NNW-SSE orientation reflects the orientation of the Colatina Belt and the NNW-SSE dextral fault of point SGP-12.

Region I presents concentrated isobase lines, especially in the southwestern portion of the area, evidencing the existence of rugged areas coinciding with the highest altitudes in the area (Figure 8), with morphologies of the Plutônicos Massifs Domain, with mountainous and sugarloaf-shaped relief, standing out in the landscape, about Region II. The sharp deviations in the directions of the isobase lines in this region may reveal tectonic shifts or abrupt lithological changes (Figures 8 and 9). The compression of the isobase lines indicates faults, as seen on the geologic map (CPRM, 2018) and the lineament map (Figure 3).

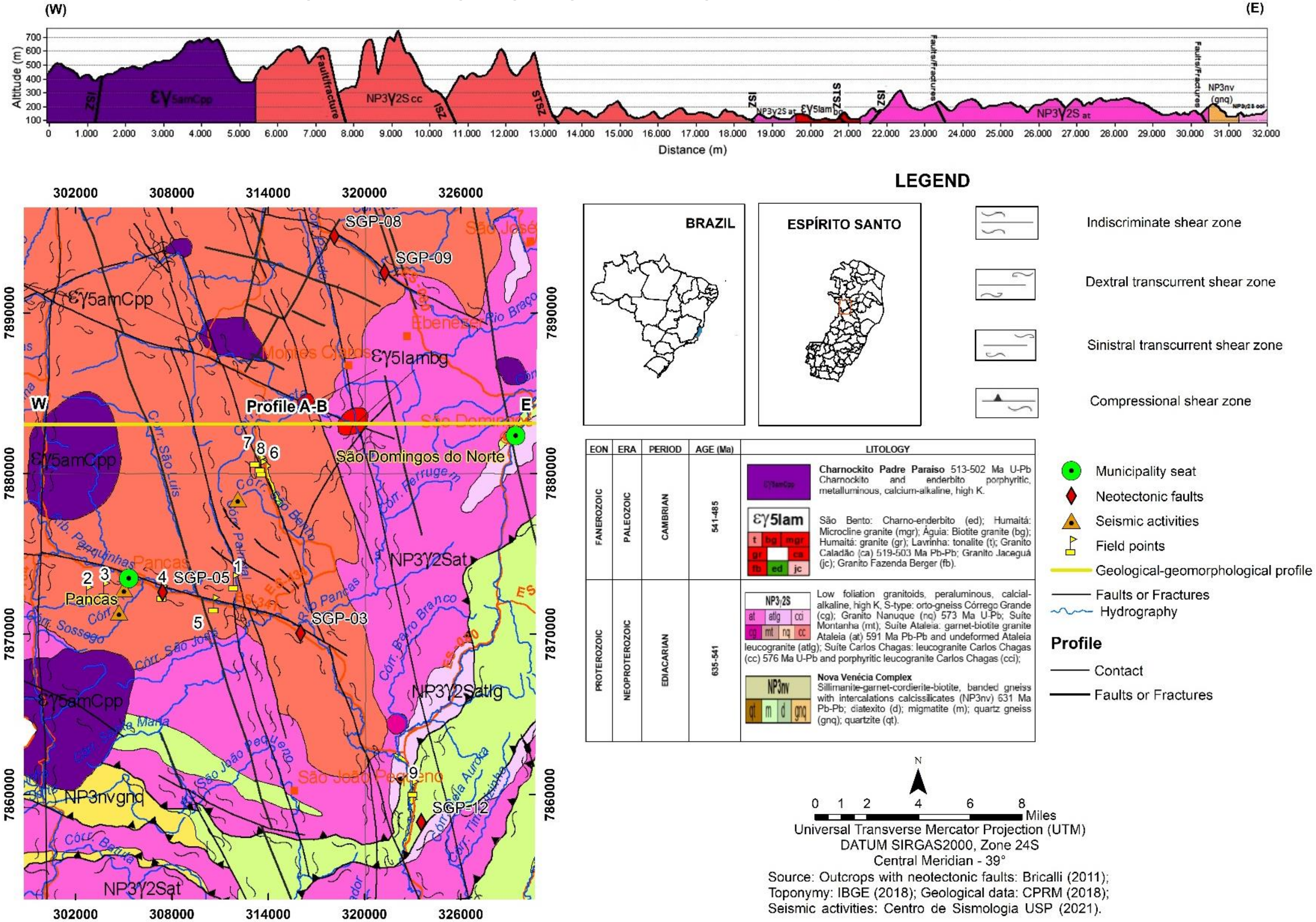
Region II presents isobase lines more spaced concerning Region I, coinciding with the lowest altitudes in the area, with a predominance of morphologies of the Remobilized Fold Belt Domain, denoting a strong dissection of the relief, with isolated and nucleated hills, with dominance for the hills in rock dome morphology (Figure 9).

The geological-geomorphological profile AB (E-W orientation) (Figure 10, presents a considerable topographic and altimetric diversity. The highest altitudes are present in the western portion of the profile (500m to 700m) present in the Charnockito, Padre Paraíso, and Suíte Carlos Chagas geological units (CPRM, 2018).

In the geological unit Suíte Carlos Chagas, in its highest part, the relief is observed in the form of pontoons, delimited by the geological structures Indiscriminate shear zone, Sinistral transcurrent shear zone, faults/fractures (CPRM, 2018) and by the Colatina Belt (Figures 1, 2, and 10), as well as observed in the field (Figure 11). This area of the profile can be interpreted as a horst.

In the central area of the profile, a relief with much lower altitudes is observed about the western portion of the profile, in addition to a very dissected relief encompassing the units Suíte Carlos Chagas, Suíte Ataleia, and Granito Águia (CPRM, 2018).

Figure 10 – A-B geological-geomorphological profile (E-W orientation).



Source: The authors (2022).

Figure 11 – Pancas-ES

Source: Photography by Lincoln Duques de Barros (2022).

This dissected relief in the profile begins abruptly, to the west of the profile, still in the Carlos Chagas Suite Unit (CPRM, 2018), and the beginning of this dissected area also coincides with the geological structure Sinistral transcurrent shear zone (CPRM, 2018). This area finalizes to the east of the profile, where the Ataleia Suite geological Unit begins (CPRM, 2018). Moreover, this lower and more dissected area coincides with another geological structure, the Indiscriminate shear zone.

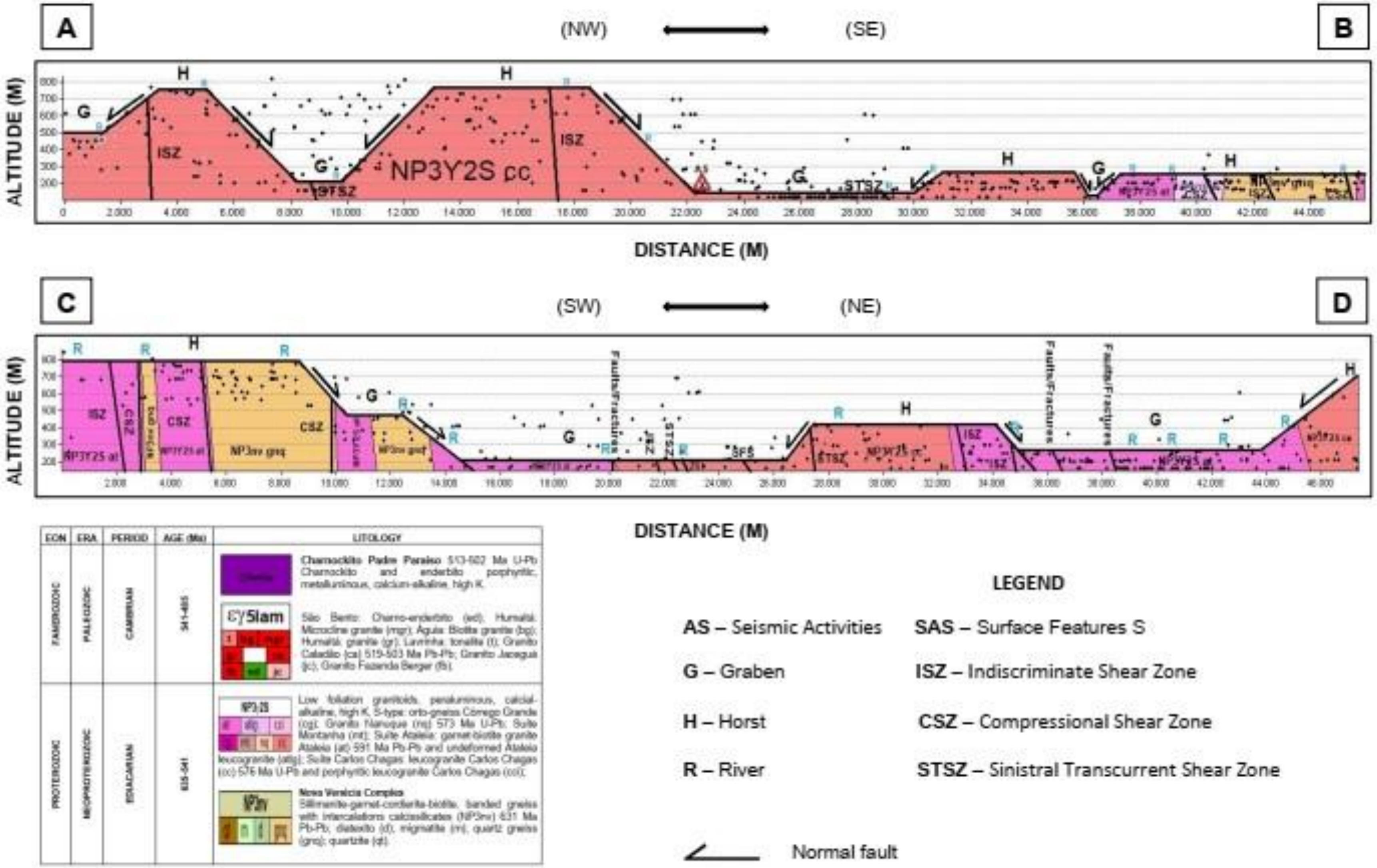
Thus, considering that lower altitudes are observed in this central portion than in the western portion and that geological faults delimit this area, it is characterized as a graben. This altimetric change coincides with the lithological boundary between the Carlos Chagas and Ataleia Suite Units (CPRM, 2018).

Where the Ataleia Suite geological unit begins, we have an increase in altitude, also coinciding with a geological fault. This portion is considered a horst. In the extreme eastern portion of the profile, the altitudes decrease again - still in the Suíte Ataleia geological unit - followed by the Nova Venécia Complex and Suíte Carlos Chagas units (CPRM, 2018), and may characterize a graben for the altitudes of the Suíte Ataleia Unit (CPRM, 2018).

In the studied area, two (2) scan profiles were prepared: A-B in the NW-SE orientation; and C-D in the NE-SW orientation, covering the geological units Suíte Carlos Chagas Suite, Suíte Ataleia, and Nova Venécia Complex (CPRM, 2018) and the geomorphological units Bloco Montanhoso Central and Patamares Escalonados do Sul Capixaba. (MENDES et al., 1987) – figure 12.

The elaboration of the A-B scan profile allowed the delimitation of eight tectonic blocks, six located in the geological Unit Suíte Carlos Chagas (CPRM, 2018) and Geomorphological Units Bloco Montanhoso Central and Patamares Escalonados do Sul Capixaba (MENDES et al., 1987). Two of these blocks are located in the geological units Suíte Ataleia and Complexo Nova Venécia (CPRM, 2018) and Geomorphological Unit Patamares Escalonados do Sul Capixaba (MENDES et al., 1987).

Figure 12 – AB (NW-SE) and CD (NE-SW) scan profiles



Source: The authors (2022).

The CD scan profile allowed the delimitation of six tectonic blocks, three of which are located in the Geological Units Suíte Ataleia and Suíte Carlos Chagas Complex (CPRM, 2018) and Geomorphological Units Bloco Montanhoso Central and Patamares Escalonados do Sul Capixaba (MENDES et al., 1987) and three in the geological Units Suite Carlos Chagas, Suite Ataleia and Complexo Nova Venécia (CPRM, 2018) and Geomorphological Unit Patamares Escalonados do Sul Capixaba (MENDES et al., 1987).

The presence of hemi-grabens, horst, and grabens morphologies that correspond to morphotectonic features formed by normal faults can be observed in the scanned profiles (SUMMERFIELD, 1987). In addition, the faults demarcated in the scanned profiles coincide with the faults mapped by CPRM (2018).

Along the scanned profiles, the Geomorphological Unit Patamares Escalonados do Sul Capixaba (MENDES et al., 1987) largely corresponds to a graben, which was expected, due to its altitude being lower than the altitudes of the relief of the Bloco Montanhoso Central geomorphological Unit, also presenting geological structures, demonstrating that the rocks of this Unit present neotectonic faults (BRICALLI, 2011), thus the graben could have been originated by neotectonic faults (Figure 12).

Field Analyses

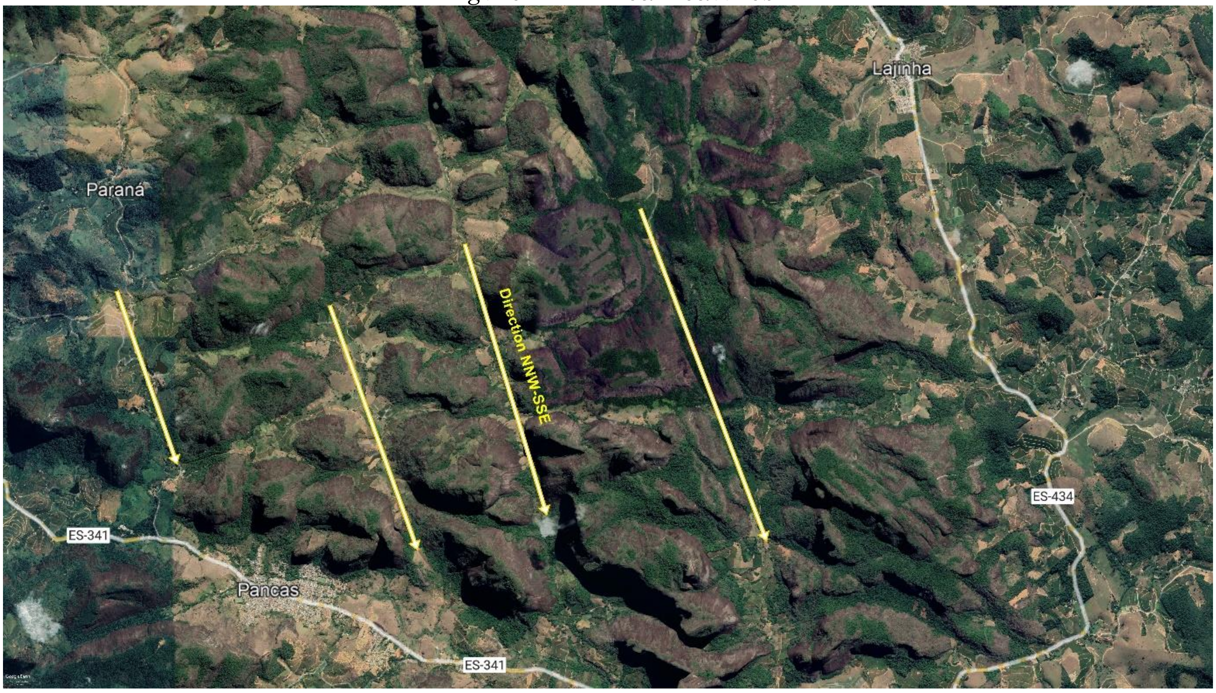
In the field analyses, we sought to identify, especially, geological structures, morphotectonic features, outcrops with neotectonic faults studied by Bricalli (2011), and present geomorphological features. The areas with records of recent seismic activity, in which there was material damage (Figure 13), were also analyzed and are related to the high density of fracturing/faults that is the Colatina Belt and that crosses the region, as well as to the movement of the local faults that need to be further studied.

Figure 13 - Damage to the residence

Source: Photography by Thayana Wanderley Caus (2022).

The linear features, valleys, and recesses are well-highlighted, occupying large areas. These features, zones of weakness, and fractured areas that are located between the hills are parallel to each other and are also observed in intrusive magmatic rocks. (Figure 14).

Figure 14 - Linear features



Source: Image adapted from Google Earth (2022).

FINAL CONSIDERATIONS

The characterization of the main orientations of the lineaments and structural trends showed that the predominant orientations are NW-SE/NNW-SSE and, secondarily, NE-SW/NNE-SSW.

The predominant orientations NNW-SSSE and NW-SE are similar to the predominance of these same orientations in the geological faults present in the area and mapped by CPRM (2018), as well as in the neotectonic faults present in the Neotectonic regime of Dextral Transcurrence E-W, identified by Bricalli (2011).

In addition, these orientations also reflect the regional structure of the area, presenting the same orientations as the Colatina Belt (an important structural feature of the state of Espírito Santo), NNW-SSE.

The second predominant NE-SW orientations, present in the analysis of lineaments and structural trends, regionally reflect the orientation of the Araçuaí Orogen (TUPINAMBÁ et al., 2013) and the neotectonic faults present in the NW-SE Distension Neotectonic regime or sinistral Transcurrence E-W, identified by Bricalli (2011).

The presence of abrupt topographic differences (topographic profiles) and the identification of tectonic regions (base surface map) and tectonic blocks (scanned profiles) demonstrate the tectonic control in the relief of the Pancas region (Espírito Santo, southeastern Brazil), reaching the objective of this research.

Analyzing the main orientations of lineaments and structural trends in the area (NW-SE/NNW-SSE) and, secondarily, NE-SW/NNE-SSW, we can classify them in the neotectonic regimes recognized for the state of Espírito Santo: i) E-W sinistral transcurrence, attributed to a neogenic age; ii) E-W dextral transition, considered of Pleistocene to Holocene age; and iii) NW-SE distention, of Holocene age (BRICALLI, 2011), also recognized in other studies in southeastern Brazil (MELLO et al., 1999; FERRARI, 2001; RICCOMINI et al., 2004; SILVA, 2006).

The NNW-SSE and NW-SE orientations of lineaments and structural trend orientations are predominant in the region. This fact can be explained by the fact that these orientations (NNW-SSE and NW-SE) reflect the lithostructural control of the Colatina Belt in the state of Espírito Santo but also reflect the predominance of the NW-SE and NNW-SSE orientations of the neotectonic faults, dominant in the state of Espírito Santo and corresponding to the E-W Dextral Transcurrence tectonic event, as attested by Bricalli (2011).

Additionally, the area also has a history of earthquakes, some of which occurred recently, with low-magnitude earthquakes, but with a direct effect on the local population.

Therefore, it is observed that the relief of the region of the Pancas (ES) is conditioned by tectonics and neotectonics.

Carrying out the fieldwork proved to be an important step in identifying the relationship between the orientation of the main relief features (rock dome or rock dome) in the area with the lineaments and geological faults identified in cartographic bases and their relationship with the neotectonic faults present in the area and adjacent to the area.

The integration of mapping data with data analyzed in the field allowed the recognition of an important correlation between lineaments, Araçuaí Orogen, Colatina Belt, lithologies, and neotectonic events described in the literature for the state of Espírito Santo (MIRANDA, 2007; 2009; RIBEIRO, 2010; BRICALLI, 2011), showing that, in addition to the evident lithostructural control, the relief is conditioned by neotectonic stress regimes.

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