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Artigo de Pesquisa

Magnetic-Structural and Tectonic Framework in the Genesis Process and Evolution of Relief in the Central portion of the Araucárias Plateau

Arcabouço Magnético-Estrutural e Tectônico no Processo de Gênese e Evolução do Relevo na Porção Central do Planalto das Araucárias

Jacson Gosman Gomes de Lima[1], Marga Eliz Pontelli[2], Andréa Cristina Lima dos Santos Matos[3] e Suze Nei Pereira Guimarães[4]

[1] Instituto Federal de Santa Catarina-IFSC, Departamento de ensino pesquisa e extensão, São Miguel do Oeste, Brasil. jacson.gosman@ifsc.edu.br.
ORCID: https://orcid.org/0000-0003-2228-8896

[2] Universidade Estadual do Oeste do Paraná-UNIOESTE, Núcleo de Estudo Paleoambientais – NEPA, Francisco Beltrão, Brasil. mepontelli@hotmail.com.
ORCID: https://orcid.org/0000-0002-3921-7923

[3] Instituto Nacional de Pesquisas Espaciais – INPE/DIDGE/GEOMA, Grupo de Geomagnetismo, São José dos Campos, Brasil. andrea.matos@inpe.br
ORCID: https://orcid.org/0000-0002-0348-6128

[4] Observatório Nacional - ON/MCTIC, Laboratório de Geotermia, Rio de Janeiro Brasil. sufisica@gmail.com.
ORCID: https://orcid.org/0000-0002-0867-1058

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Abstract: The structural and tectonic influence on the relief of a region can be studied based on subsurface magnetic structures, especially those correlated to the basement (deep structures) and shallow structures linked to geomorphological context, faults/fractures, and drainage network. Aiming to understand the structural and tectonic influence on the relief of the Araucárias Plateau, airborne magnetic geophysical data was processed using Oasis Montaj software (Geosoft TM, 2004) and used to generate magnetic anomaly maps. Interpretations of the vertical derivative applied to the anomalous magnetic field enabled the identification of **49** magnetic lineaments. The characteristics of these lineaments allowed to divide the study area into three distinct geotectonic compartments that are in agreement with the structural blocks of the Paraná basin. The results show that these magnetic lineaments mapped show directional agreement with shallow lineaments and, in many cases, constitute structures that extend from the basement to the surface. It was also possible to observe that the drainage network is adjusted to important mapped magnetic lineaments. This reinforces the importance of these structures in the genesis and evolution of the Araucárias Plateau. The analysis of magnetic lineaments, faults/fractures mapped, and geomorphological lineaments showed **NW-SE** orientations as the most important trend, suggesting that structures with this orientation exert the greatest influence on the relief in the study area.

Keywords: magnetic lineament, shallow lineament, tectonism, relief, Araucárias Plateau.

Resumo: A influência estrutural e tectônica observada no relevo de uma região pode ser estudada a partir de estruturas magnéticas em subsuperfície, especialmente aquelas correlacionáveis ao embasamento (estruturas profundas) e a estruturas superficiais ligadas ao contexto geomorfológico, falhas/fraturas e a rede de drenagem. Com objetivo de compreender a influência estrutural e tectônica no relevo do Planalto das Araucárias, dados geofísicos aeromagnéticos foram processados utilizando o software Oasis Montaj (Geosoft TM, 2004) e utilizados para elaboração de mapas de anomalias magnéticas. A interpretação da derivada vertical aplicada ao campo magnético anômalo possibilitou a identificação de **49** lineamentos magnéticos. As características desses lineamentos permitiram dividir a área de estudo em três compartimentos geotectônicos distintos e concordantes com blocos estruturais da bacia do Paraná. Os resultados mostram que os lineamentos magnéticos mapeados apresentam concordância direcional com lineamentos superficiais e, em muitos, constituem estruturas que se estendem do embasamento à superfície. Também foi possível observar que a rede de drenagem está ajustada a importantes lineamentos magnéticos mapeados, o que reforça a importância dessas estruturas na gênese e evolução do Planalto das Araucárias. A análise dos lineamentos magnéticos, falhas/fraturas mapeadas e dos lineamentos geomorfológicos mostrou orientações **NW-SE** como *trends* mais importantes. O que sugere que as estruturas com essa orientação são as que exerceram maior influência do relevo na área estudada.

Palavras-chave: lineamentos magnéticos, lineamentos superficiais, tectonismo, relevo, Planalto das Araucárias.

1. Introduction

Over the past years, several studies have been developed focusing on the central portion of the Araucárias Plateau, particularly regarding landscape evolution throughout the late Quaternary. These studies reveal important actions concerning chemical weathering processes, which result in deep surface oxide formations (RODRIGUES, 2011; PAISANI et al., 2013; BERTUOL, 2014; DAL-BERTI, 2015; MANFREDINI, 2016; GASPARI, et al., 2020). These processes are responsible for sculpting regional relief, which is controlled by dynamic etchplain action (PAISANI et al, 2013).

Although the influence of processes responsible for the sculpting of the relief in the area is well understood, this does not explain the occurrence of a structural grade between the Serra da Fartura mountain range (border between the Iguaçu and Uruguai river basins) and the Chapecó river channel, an affluent of the Uruguai river.

Morphostructural and morphotectonic studies applied to this area prioritize the analysis of morphometric parameters of the drainage network, and positive and negative lineaments based on radar images. These investigations have allowed the recognition of morphostructural control and neotectonic influence associated with possible reactivations of fault zones in the Paraná basin (PAISANI et al., 2012; LIMA; PONTELLI, 2013; OLIVEIRA, 2014; DAL-BERTI, 2015; MANFREDINI, 2016; FUJITA et al., 2017; LIMA et al., 2019a). However, it is still necessary to further understand the role of deep structures in the genesis and evolution of the local relief.

Thus, the present study sought to contribute to the studies of structural and tectonic influence, particularly regarding subsurface structures, for a better comprehension of regional relief. Here we present an interpretation of the structural framework in the central portion of the Araucárias Plateau based on the processing and analysis of airborne magnetic geophysical data and correlation to geomorphological information.

2. Characteristics of the Study Area

The central portion of the Araucárias Plateau is located in southern Brazil, comprising the state of Paraná, the western part of the state of Santa Catarina, and the northwestern part of the state of Rio Grande do Sul, covering an area of approximately **11,000** km^2 (Figure 1).

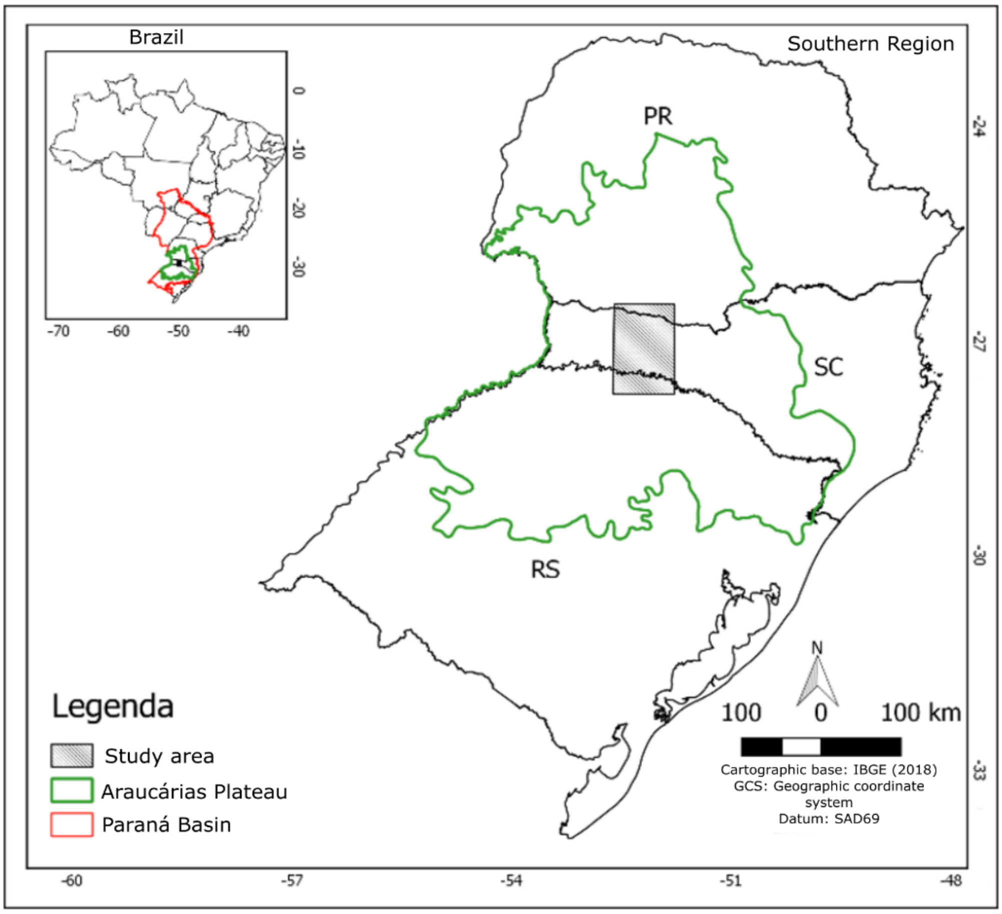

Figure 1. Location of the study area.

Inserted within the Paraná basin, the substrate of the study area is maintained by volcanic rocks from the Serra Geral group. In the portion pertaining to the state of Paraná, this group is composed of basic rocks from the Cordilheira Alta, Paranapanema, Esmeralda, and Chapecó formations; in the state of Santa Catarina, there are rocks from the Campo Êre, Campos Novos, Paranapanema, Chapecó, and Palmas formations; and, lastly, in the state of Rio Grande do Sul, rocks from the Paranapanema and Chapecó formations are found (ARIOLI; LICHT, 2013). The Chapecó and Palmas formations are acidic, while the other lithotypes are basic (WILDNER et al., 2006) (Figure 2).

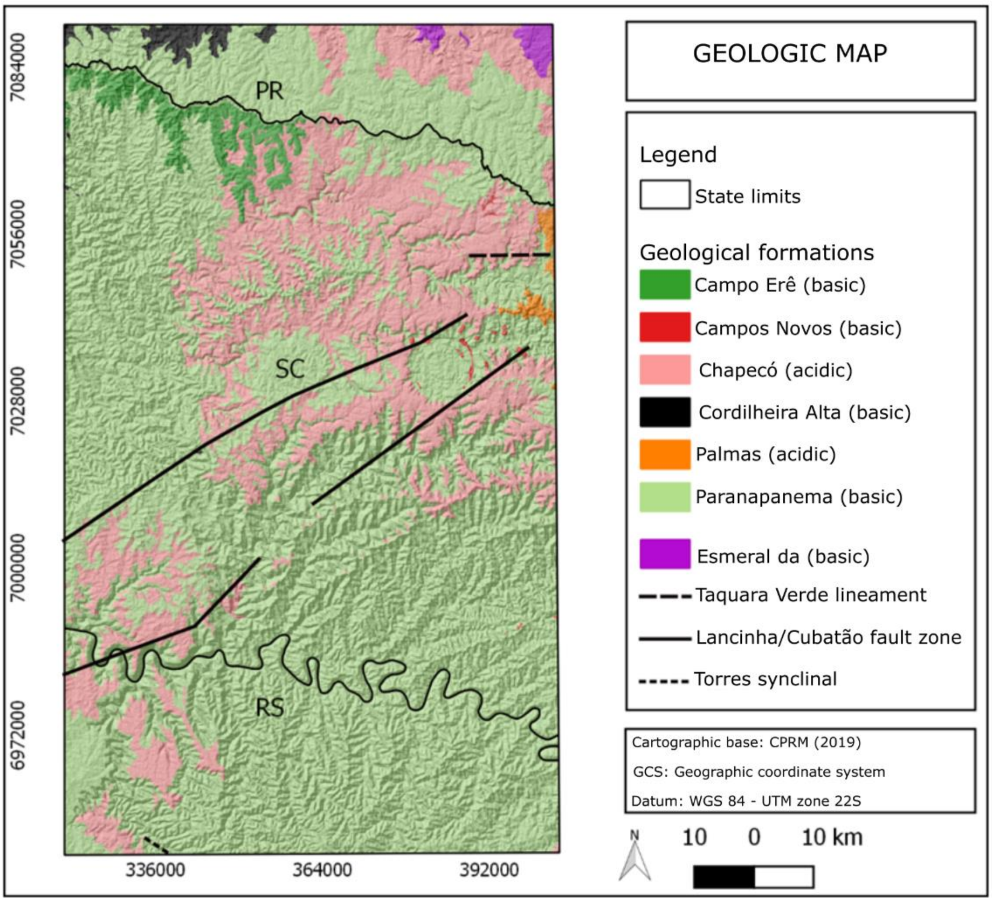

Figure 2. Simplified geology of the study area with the distribution of the main structural lineaments mapped in the region (Adapted from CPRM, 2019b).

Considering outcrops, the rocks of the Serra Geral group are observed as lobed spills alternated by hydro-volcaniclastic breccias, flow and hydro-tuff breccias, with horizontal and vertical fracturing (ARIOLLI; LICHT, 2013; WILDNER et al., 2006). The basic rock outcrops mostly have vertical fracturing, while the acidic ones present horizontal/tabular disjunction (ARIOLLI; LICHT, 2013; NARDY et al., 2002). The structural framework of the Paraná basin is characterized by three main directional trends: **NW-SE**, **NE-SW**, and **E-W**. The Taquara Verde lineament, Lancinha/Cubatão fault zone, and Torres synclinal are of particular relevance in the study area. Tectonic structures oriented respectively as **E-W**, **N50-70E**, and **N50-60W** (ZALÁN et al., 1987).

Regarding physiographic aspects, the central portion of the Araucárias Plateau presents a general westward slope, towards the Paraná River channel, as well as northwards to the Ivaí River, and southwards where it is abruptly interrupted, characterizing the Serra Geral mountain range (ALMEIDA, 1952; PAISANI et al., 2019). A geomorphological analysis shows that relief forms vary between slightly undulated tabular tops to extensive and short levels (structural grades), in addition to residual reliefs (highlands). Valleys are either closed or open, with hillsides that are mostly convex (PAISANI et al., 2019). The drainage network is dense and predominantly dendritic. Parallel, rectangular, and ring-shaped drainage patterns occur in an isolated way.

2. Material and Methods

Given the difficulty to comprehend structural and tectonic influence on a relief, especially in regions where there is a thick layer of weathering and rocks are intensely fractured, as is the case of the present study area, indirect sounding methods such as magnetometry must be used (LIMA, 2020). This method of geophysical investigation yields good results regarding the structural framework, particularly when correlated with other sources of data, such as geomorphological lineaments, geological mapping, and measurements of brittle structures in the field (FERREIRA; ABRAM, 2006; JACQUES, 2013; CASTRO, 2014; CAMACHO; SOUSA, 2017; LIMA, 2020).

The airborne magnetic geophysical data used to elaborate the magnetic anomaly maps presented were acquired from the National Oil and Gas Agency (ANP) and integrate the Rio Iguaçu project (1980). This aerial survey was carried out at a nominal flight altitude of 500 m and acquisition frequency of 1 second, at an interval of 100 meters. Flight lines were spaced 2 km away from each other, following a **N-S** direction, while the control lines were spaced 20 km between each other, following a **E-W** direction.

This data was processed using Oasis Montaj® software, version 8.4. *Geosoft/Seequent*. Airborne magnetic data processing involved, initially, acquisition corrections such as: filtering, levelling, micro levelling, and spike, lag, and positioning corrections. After this stage, magnetic sources were then separated from the geomagnetic field measurements acquired, which included:

- Main Magnetic Field (MMF) – magnetic field generated in the planet's nucleus. Value calculated based on a mathematical model introduced by Gauss in 1830 and made available through the International Geomagnetic Reference Field (IGRF), in which the coefficient used in this calculation is updated every 5 years. This value corresponds to nearly 90% of the magnetometric measurements acquired on the Earth's surface.
- External Magnetic Field (EMF – daily variation) – magnetic field generated from external sources to the planet, basically the Sun, which is monitored on the Earth's surface in a fixed-point during data acquisition.
- Anomalous Magnetic Field (AMF) – magnetic field generated by the presence of magnetic minerals in rocks on the planet's crust, which is encompassed in the objective of the present study.

Therefore, the next step was to generate an AMF grid using the minimum curvature gridding method, with a cell size of 500 m (BRIGGS, 1974) (Figure 3).

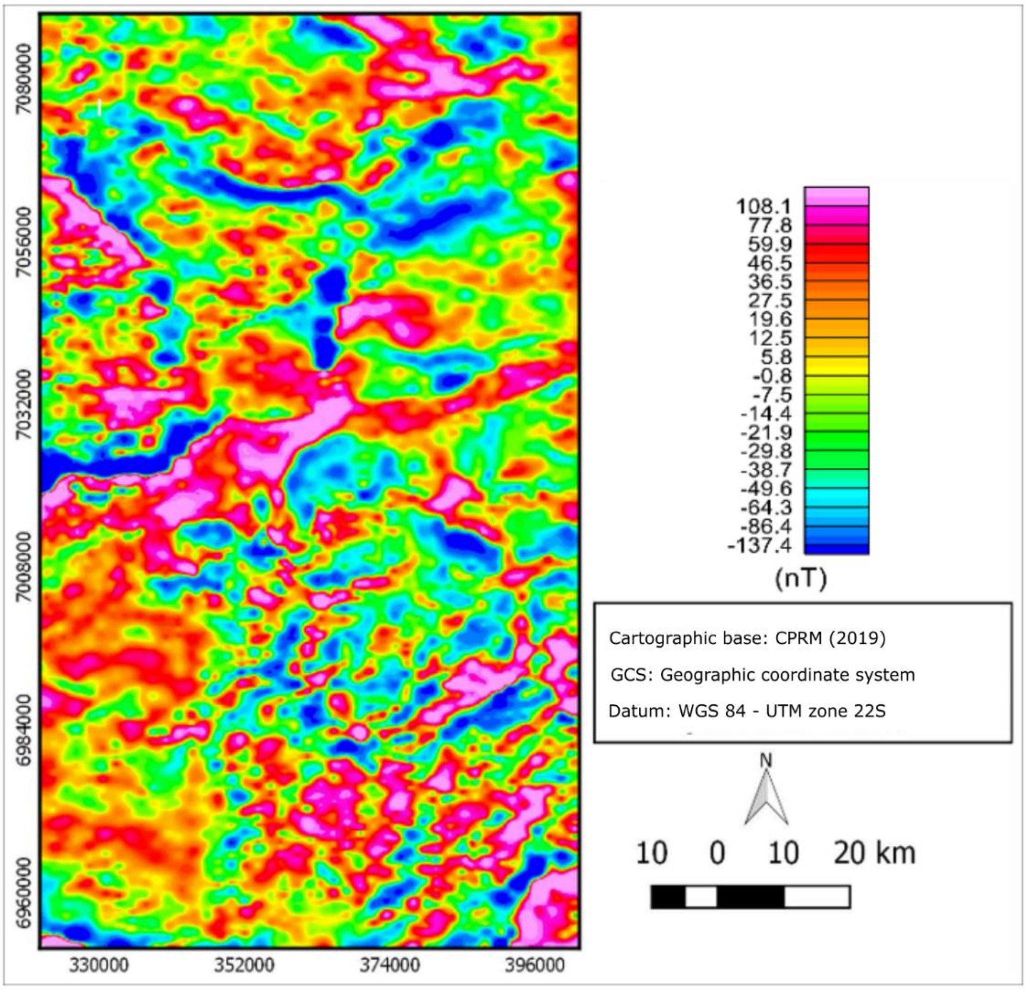

Figure 3. Anomalous magnetic field of the study area.

Interpretive geophysical techniques to enhance magnetic anomalies were then applied for the delimitation of magnetic structures linked to the structural framework, among which are the vertical derivative (VD), horizontal derivative (HD), and analytic signal amplitude (ASA).

The vertical derivative technique (CORDELL; GRAUCH, 1985) enhances the components of shallow sources, eliminating features from deeper components, but maintaining intermediate ones. The shading method was used to better emphasize the magnetic features indicated in the map.

The horizontal derivative technique (CORDELL; GRAUCH, 1985) is characterized by the generation of magnetic anomaly peaks along the margins of thick bodies. Thus, it is also widely used for mapping linear bodies (MILLIGAN; GUNN, 1997).

The analytic signal amplitude technique (NABIGHIAN, 1972; ROEST et al., 1992) is an important tool to locate the limits of bodies that have magnetic contrasts, bringing relevant information about their geometry and applicable to magnetic data from a total anomalous field. The responses of the analytic signal highlight the geometry and location of intrusive geological bodies.

Figure 4 illustrates the results of these techniques: (a) vertical derivative, (b) horizontal derivative, and (c) analytic signal amplitude, applied to the anomalous magnetic field in the study area.

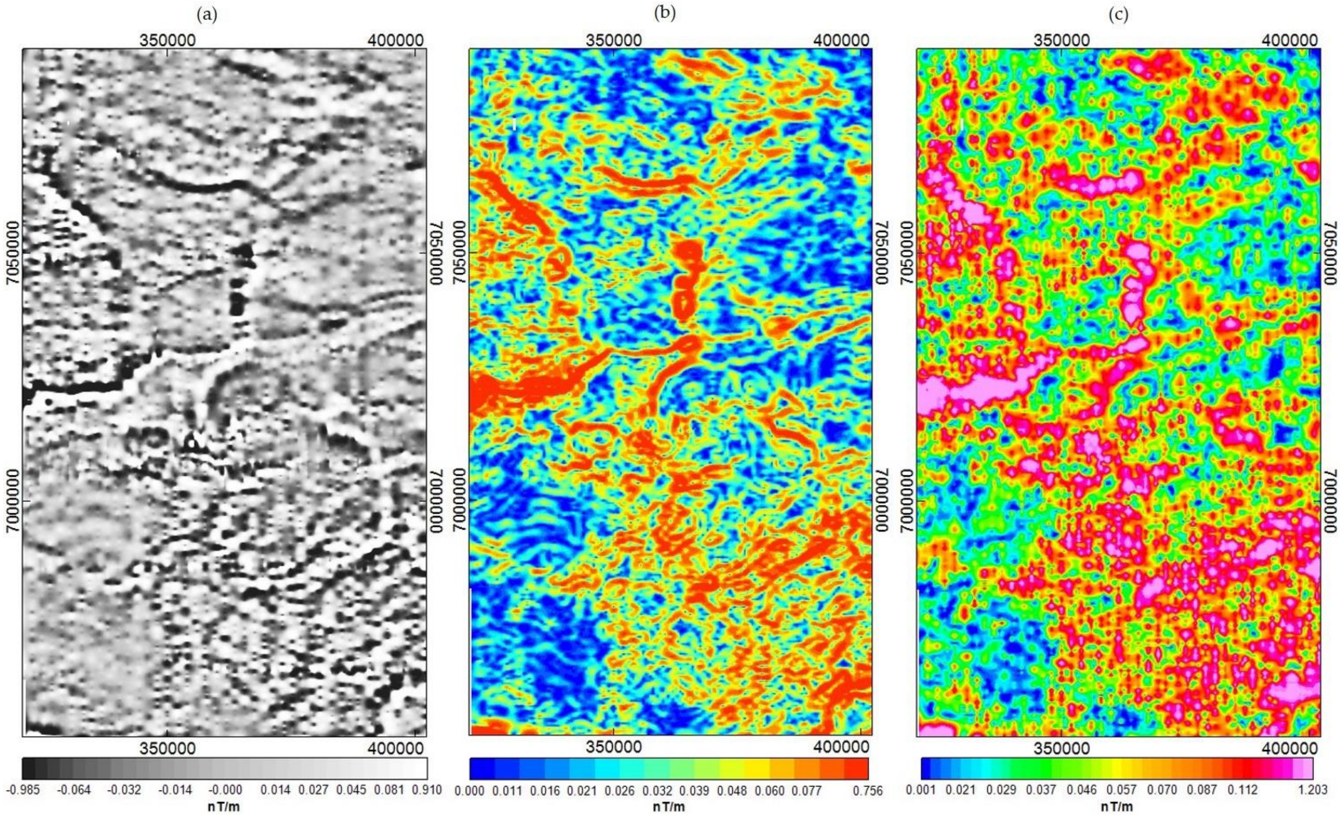

Figure 4. (a) Vertical derivative; (b) Horizontal derivative; and (c) Analytic signal amplitude applied to the anomalous magnetic field in the study area.

3. Results

3.1. Magnetic-Structural Framework of the Study Area

The analysis carried out regarding the AMF map suggests that anomalies with higher magnetic amplitude are distributed across the whole study area and present an elongated shape, mainly oriented as **NE-SW** and **NW-SE**. The most noticeable feature was the magnetic anomaly with a **NE-SW** direction, which allowed to divide the study area initially into two sectors: north and south. The magnetic anomalies of greatest amplitude in the northern sector presented a **NW-SE** main orientation. In turn, the magnetic anomalies of greatest amplitude in the southern sector were more numerous than in the northern sector and the main orientation was **NE-SW** (Figure 5). The differences in magnetic signal amplitude are possibly related to rocky bodies with different magnetic susceptibilities. Thus, the magnetic anomalies of greatest amplitude are indications of the presence of rocky bodies that have higher magnetic susceptibility, such as diabase dikes and sills (GUNN; DENTITH, 1997; SCHÖN, 2004; CAMACHO; SOUSA, 2017).

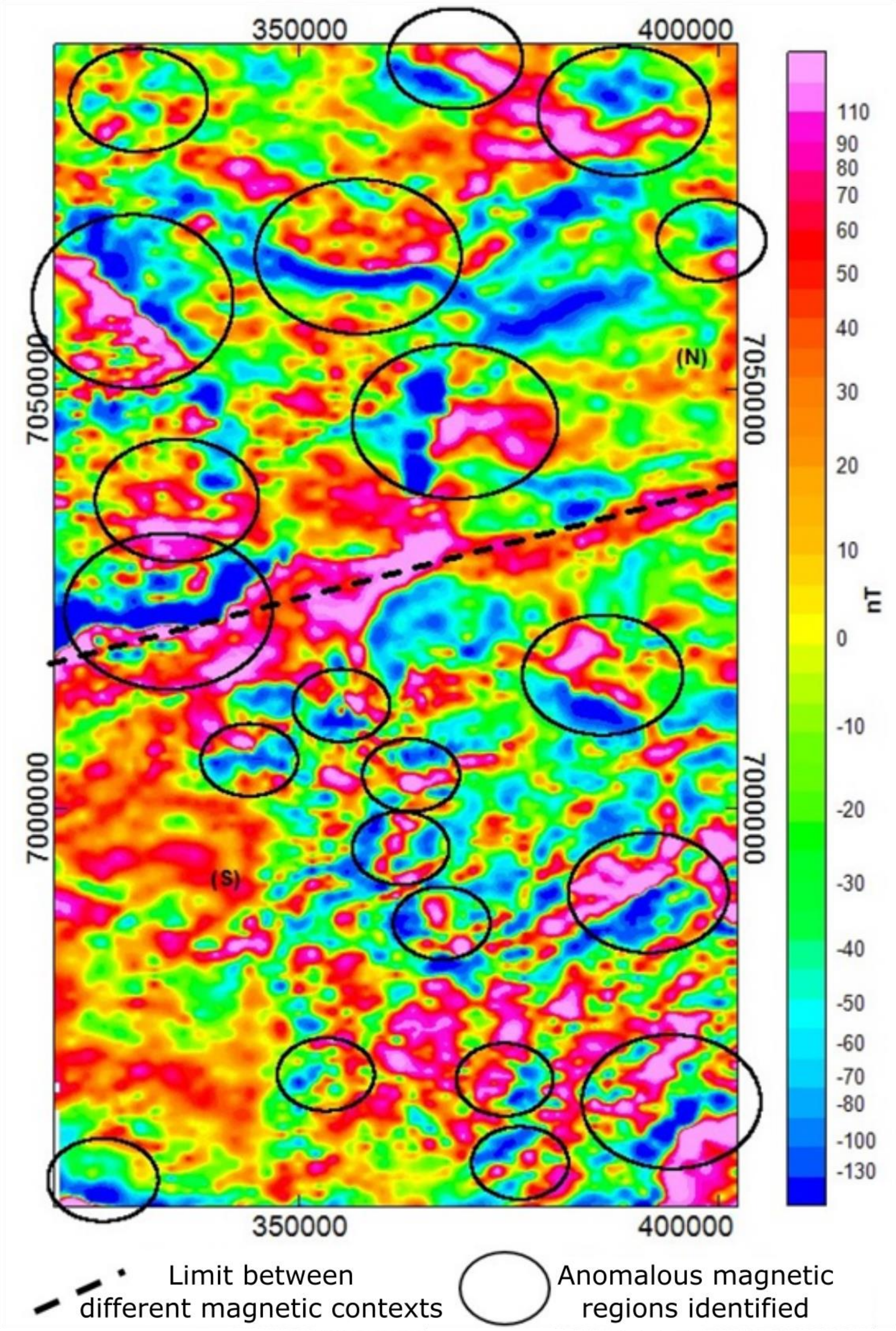

Figure 5. Interpreted anomalous magnetic field.

In general, magnetic susceptibility is greater in basic rocks than in acidic rocks, due to the content of ferrimagnetic minerals in the rocks (SCHÖN, 2004). Thus, magnetic anomalies with greater amplitudes occur in areas where basic volcanic rocks predominantly outcrop, since these are richer in ferrimagnetic minerals than acidic volcanic rocks.

Interpretations of the vertical derivative applied to the AMF enabled the identification of **49** magnetic lineaments, with mean length of 32 km (Figure 6).

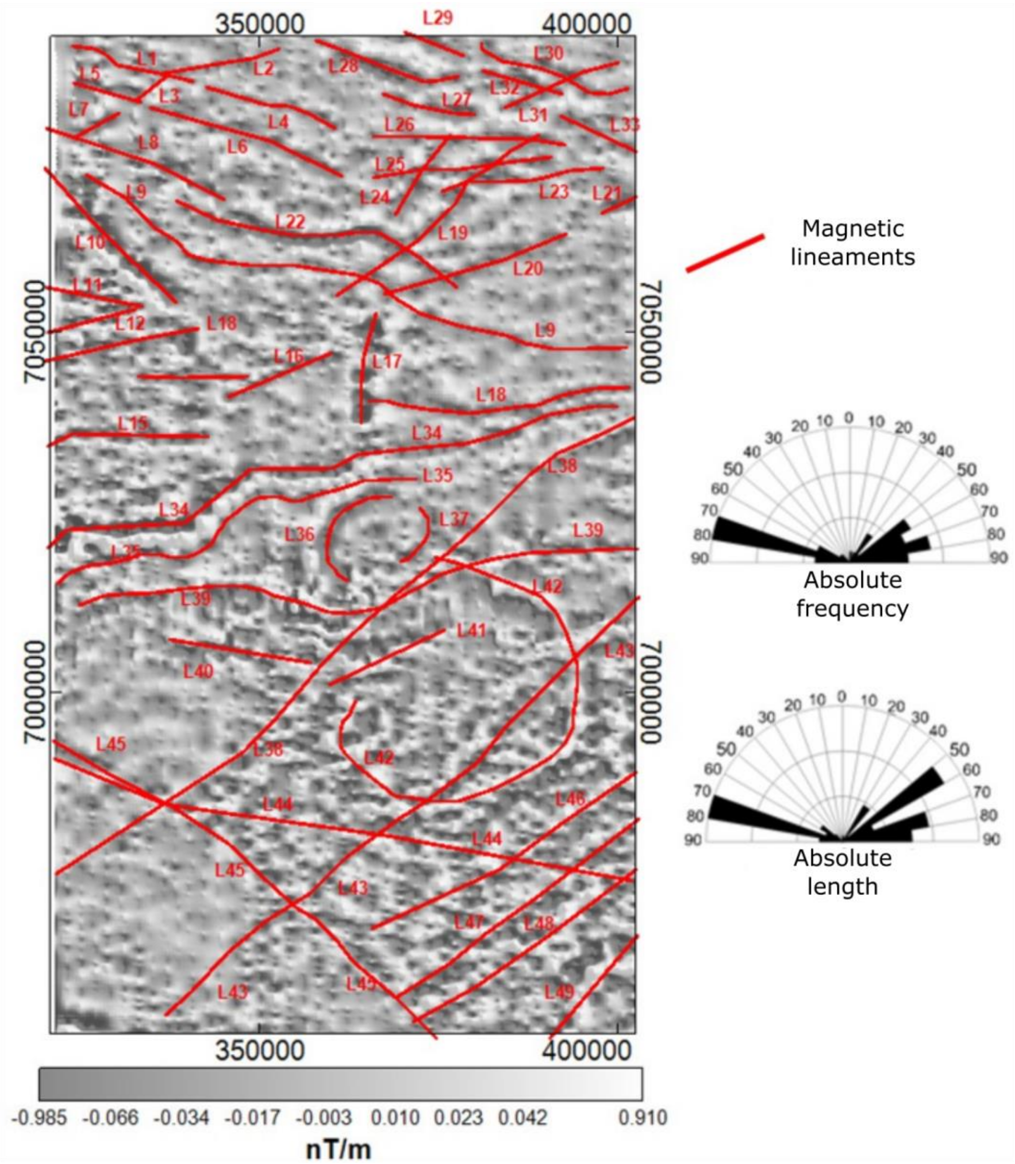

Figure 6. Map of the vertical derivative applied to the anomalous magnetic field interpreted with shading and pseudo-lighting 45°/45°. The magnetic lineaments are numbered (Ln) for identification.

The interpreted vertical derivative map showed that most magnetic lineaments mapped are predominantly oriented as **NW-SE** and **NE-SW**. Some are oriented approximately as **E-W**, and only one presented an approximate **N-S** orientation. Moreover, lineament arcs were observed in the southern sector of the study area. As verified in the AMF map, both magnetic sectors that were characterized are separated by a large lineament (L34), mapped with a **NE-SW** orientation, that occurs approximately across the center of the study area.

The main lineaments observed in the northern magnetic sector of the AMF map present a **NW-SE** orientation, approximately **E-W** and **N-S** (L17)**.** In turn, lineaments with a **NE-SW** orientation and the lineament arcs occur mainly in the southern magnetic sector.

The rosette plot of absolute frequency (Figure 6) shows that 28 lineaments (59%) present **NE** orientation and 21 lineaments (41%) have a **NW** orientation. The trend that concentrates the most lineaments (13) corresponds to a **N70-80W** orientation, composing a modal class. Orientations between **N50-90E** are particularly noteworthy in the **NE** quadrant, which concentrate 23 lineaments.

The most relevant trend in the absolute length graph (Figure 6) is between **N70-80W**. This is due to the higher number of lineaments with this orientation (13) and not necessarily due to their length. In turn, the **N50-60E** trend, which concentrates 6 lineaments, is also highlighted in the absolute length graph, demonstrating that despite the lower number of lineaments, they present the highest mean length. A more detailed analysis reveals that the length of magnetic lineaments oriented between **N70-80W** varies from 9.8 km (L5) to 84.8 km (L44), with a mean value of 29.442 km. On the other hand, the magnetic lineaments oriented between **N50-60E** vary from 56.9 km (L3) to 104.0 km (L38), with a mean value of 52.5 km.

The characteristics of the magnetic lineaments, especially length, orientation, and form, allowed to divide the study area into three different geotectonic compartments: one to the north (I) and two to the south (II and III) (Figure 7).

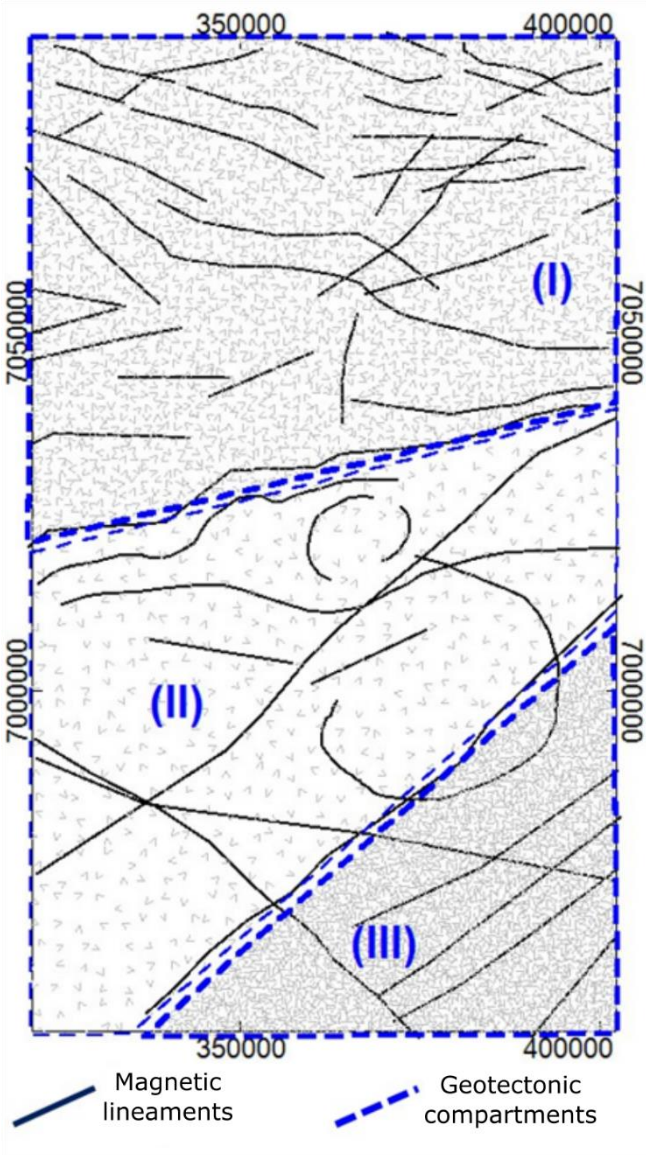

Figure 7. Geotectonic compartments.

Compartment (I) to the north is limited by magnetic lineament L34 and concentrates most lineaments (33). These are mainly oriented following a **NW-SE** direction and have a mean length of 21.2 km. In this compartment there are lineaments (L14; L15; L18; L23; L25; L26) with approximate **E-W** orientation (**N80-90W** and **N80-90**) and one lineament (L17) with approximate **N-S** orientation (**N0-10E**). In the southern sector, the characteristics of the lineaments resulted in the individualization of two geotectonic compartments (II and III).

The first is located between lineaments L34 and L43, and its main characteristic is the presence of lineament arcs (L36; L37; L42). The presence of these almost circular structures sets this compartment apart from the others. Southeastwards from lineament L43, the data suggest another compartment. In this one, the magnetic lineaments occur in a lower number in comparison with those to the north, but their mean lengths are significantly greater (35.5 km) and are mostly oriented towards **NE-SW** (Figure 7).

There are three geotectonic compartments established for the study area in the geologic-structural map of the Paraná basin that are correlated to the magnetic lineament units individualized here. Compartment I, identified in the northern region of the study area, corresponds to the Southeast Platform. Compartment II, located between lineaments L34 and L43, is related to the Três Pinheiros/Matos Costa High, while compartment III which is positioned to the southeast of lineament L43 coincides with the Tangará Low.

The Southeast Platform, Três Pinheiros/Matos Costa High, and Tangará Low are structural blocks limited by fracture zones (lineaments) with **NE-SW** orientation in the basement of the Paraná basin (Figure 8). The **NE-SW** lineaments together with the **NW-SE** ones correspond to ancient weakness lines of the basement that were reactivated and compartmentalized the Paraná basin into a mosaic of grabens and horsts that dip towards the hinterland (FULVARO et al., 1982).

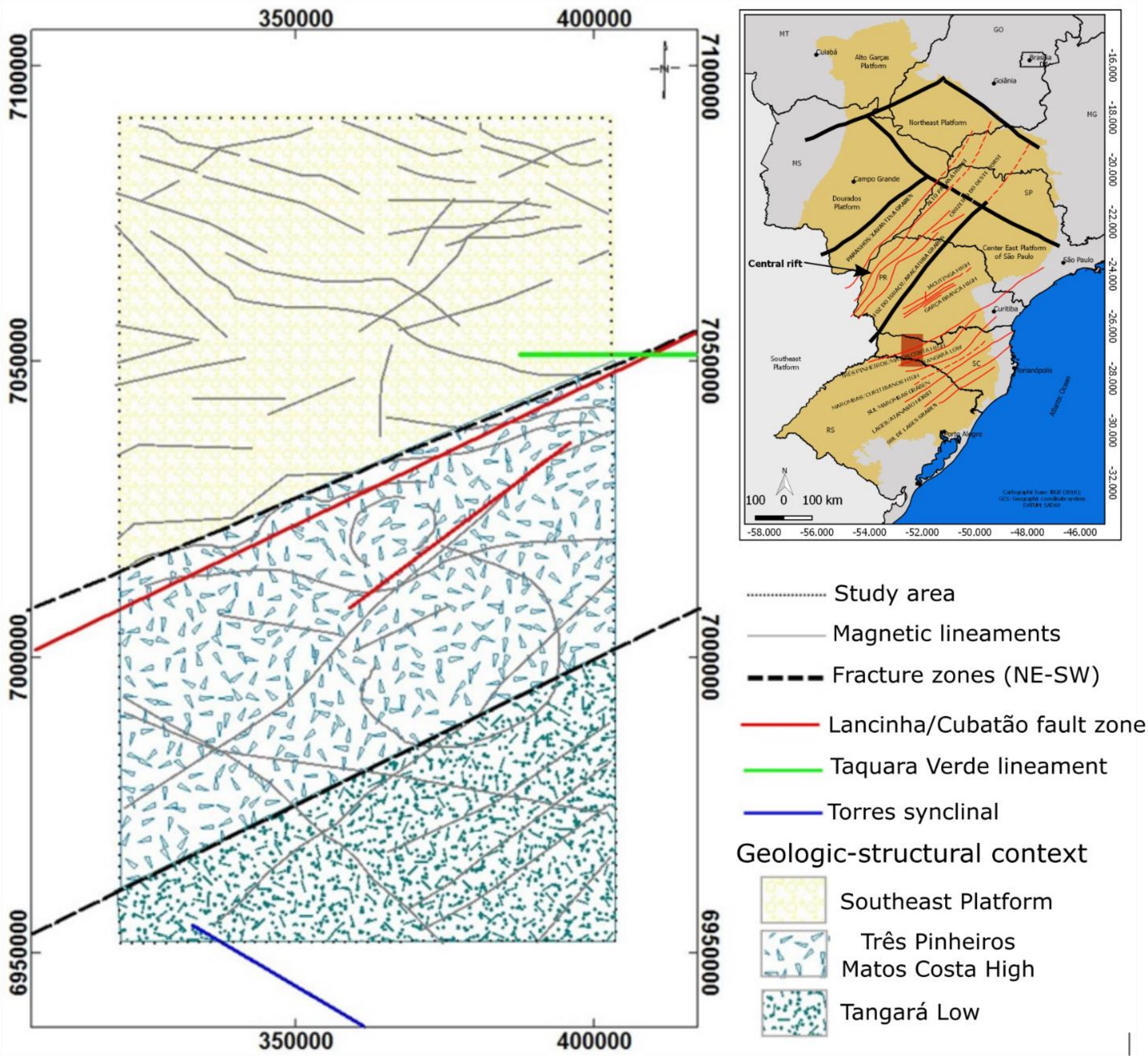

Figure 8. Magnetic lineament map of the study area, showing the relationship between them and the structural blocks of the Paraná basin.

In addition to Fulvaro et al. (1982), there are other authors that mapped the main structures of the Paraná basin (BELLIENI et al., 1986; ZALÁN et al., 1987; SOARES, 1991; ARTUR; SOARES, 2002). Considering these authors, the lineaments mapped showed a good correlation with the magnetic lineaments interpreted in the study area. From the total structures mapped in the Paraná basin, three intersect with the study area, even if only partially: the Taquara Verde lineament, the Lancinha/Cubatão fault zone, and the Torres synclinal (Figure 8). These lineaments are oriented respectively **E-W** (N 80-90 E), **N 50-70E**, and **N50-60W**. In the study area, six lineaments showed a **N80-90E** orientation (L15; L18; L23; L25; L39; L40), 11 were oriented between **N50-70E** (L3; L19; L38; L43; L47; L48; L7; L16; L21; L41; L46), and only one presented **N50-60E** orientation (L45). The direct correlation between the magnetic lineaments and the main structures identified in the basin reinforces what has already been demonstrated in numerous studies: that the main structural orientations of the Paraná basin are **NE-SW**, **NW-SE** and, subordinately, **E-W**.

There was only one lineament in the study area with a **N-S** orientation (L17). As discussed by Soares et al. (2007), this direction is not very common in the Paraná basin, but it should be considered since it is mentioned in a few studies (ZALÁN et al., 1987; ARTUR; SOARES, 2002; JACQUES et al., 2015). In the study by Zalán et al. (1987), for example, the only important structure with a **N–S** direction within the context of the basin is the Assunção Arc. This stress field in the rocks of the Serra Geral Formation has had its age associated with the Eocretaceous (~145-100 Ma) (JACQUES et al., 2015).

None of the publications analyzed suggest the existence of lineament arcs in the Paraná basin, which makes their presence in the area studied unusual. This may be related to the fact that these previous studies were carried out considering a smaller scale, while the present mapping survey was development at a larger scale. The meaning of these structures is unknown, but their position between two structural blocks (Southeast Platform and Tangará Low), suggest the occurrence of tectonic thrusts that led to the Três Pinheiros/Matos Costa High fold. This is a possibility given that the transport direction of the rocky masses that converged and formed the supercontinent Gondwana (~460 Ma), in the sector which today corresponds to the southern region, was **SE-NW** (HASUI, 2010), meaning it was transversal to the structural blocks with **NE-SW** orientation. Thus, they could have pushed the Tangará Low and Três Pinheiros/Matos Costa High towards the Southeast Platform, promoting the fold. Within this context, we suggest that the lineament arcs are ancient structures, generated in the Ordovician (~488 to 443 Ma).

3.2. Relationship between magnetic lineaments (deep structures) and structural surface lineaments

Many of the faults/fractures mapped by the Geological Survey of Brazil (SGB/CPRM) either overlap with the magnetic lineaments characterized in the present study or occur parallel to them. This shows that the magnetic lineaments correspond to tectonic structures that extend from the basement to the surface. The existence of structures that are continuous throughout the different geologic formations in the study area has already been indicated by Descovi Filho (2015). This author demonstrated, for example, that the lineaments with a **NE** direction are connected to the Serra Geral and Guarani aquifers in the state of Santa Catarina. In total, there are 62 faults/fractures mapped in the study area (CPRM, 2019). From these, 55% present a **NW** orientation, while the remaining 45% have a **NE** orientation. The faults/fractures of the first group are mainly concentrated between **N30-60W**, and with the modal class represented by the trends of **N30-40W**. In the second group, the faults/fractures are distributed more heterogeneously, particularly trends **N20-30E** and **N60-70E**. In turn, the magnetic lineaments are mostly oriented to **NE** (59%), while the **NW** orientation corresponds to 41%. The modal class of lineaments is the **N70-80W** trend, but most lineaments are concentrated between **N50-90E** (Figure 9a).

Despite the differences between magnetic lineaments and faults/fractures, the fact that both presented as their modal class **NW** orientations suggests that this is the most important structural direction in the study area. Similar to the faults/fractures, the geomorphological lineaments (LIMA et al., 2019b) are oriented mainly to **NW** (56%) (Figure 9a). These results again suggest that this is the most important structural direction in the study area.

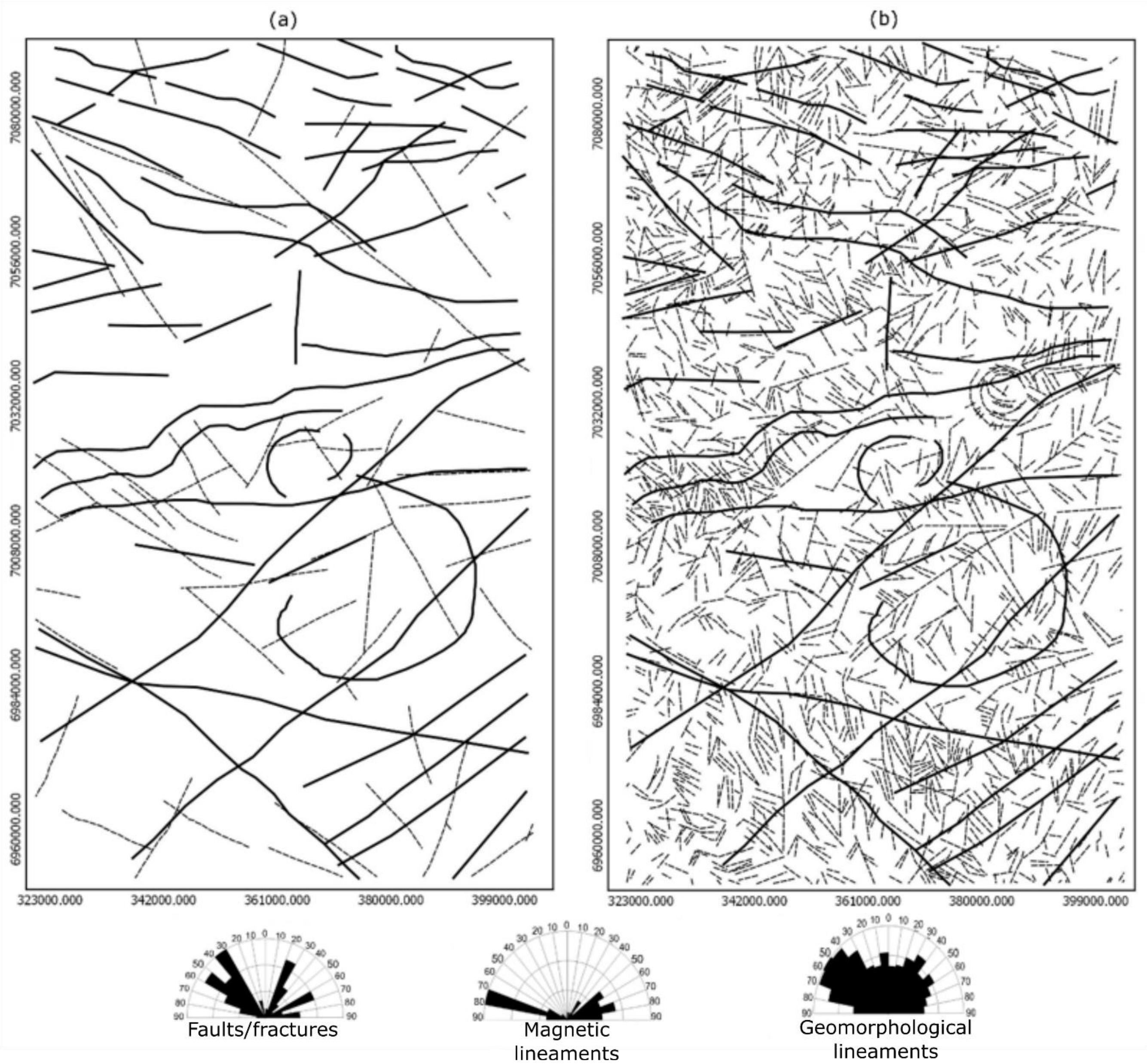

Figure 9. **(a)** Magnetic lineaments with faults/fractures (adapted from CPRM, 2019); **(b)** Magnetic lineaments with geomorphological lineaments.

Based on a visual analysis of Figure 9a and 9B, a directional agreement can be observed between these structures. Many geomorphological lineaments overlap magnetic ones, while others occur parallel to them. In some sectors there is a large concentration of geomorphological lineaments along the magnetic lineaments (Figure 9b), reinforcing the idea that the magnetic lineaments correspond to tectonic structures. This suggests that these structures have an important role in the geomorphology of the study area. Their relevance is even more evident when analyzing the positive (water divider peaks aligned) and negative (rivers that form steep V-shaped valleys) lineaments (geomorphological). This analysis shows that the negative lineaments are mainly oriented to the **NW** (60%), while positive lineaments are 50% to the **NW** and 50% to the **NE**. The fact that most negative lineaments are oriented to the **NW** suggest that the drainage channels are adjusted especially to the magnetic lineaments with **NW-SE** orientation. Drainage adjustment to structures of regional character with a **NW-SE** orientation has been reported in other regions of the Araucárias Plateau (LIMA; PONTELLI, 2013; SORDI et al., 2015; CUNHA et al., 2016; LIMA et al., 2019a).

Comparing the distribution of magnetic lineaments with the distribution of the main rivers in the study area, it is possible to observe that they are adjusted to each other. This adjustment shows that the structural influence may have been fundamental in the organization of the drainage network, directing the main rivers. The correlation between tectonic structures and the drainage network is evident when considering that the main rivers that drain the eastern border of the Paraná basin are related to important tectonic lineaments, which are named after the rivers (BELLIENI et al., 1986). In the study area, the Uruguai river is correlated to a large magnetic lineament (L44), which analogously corresponds to the tectonic lineament of the Uruguai river (Figure 10).

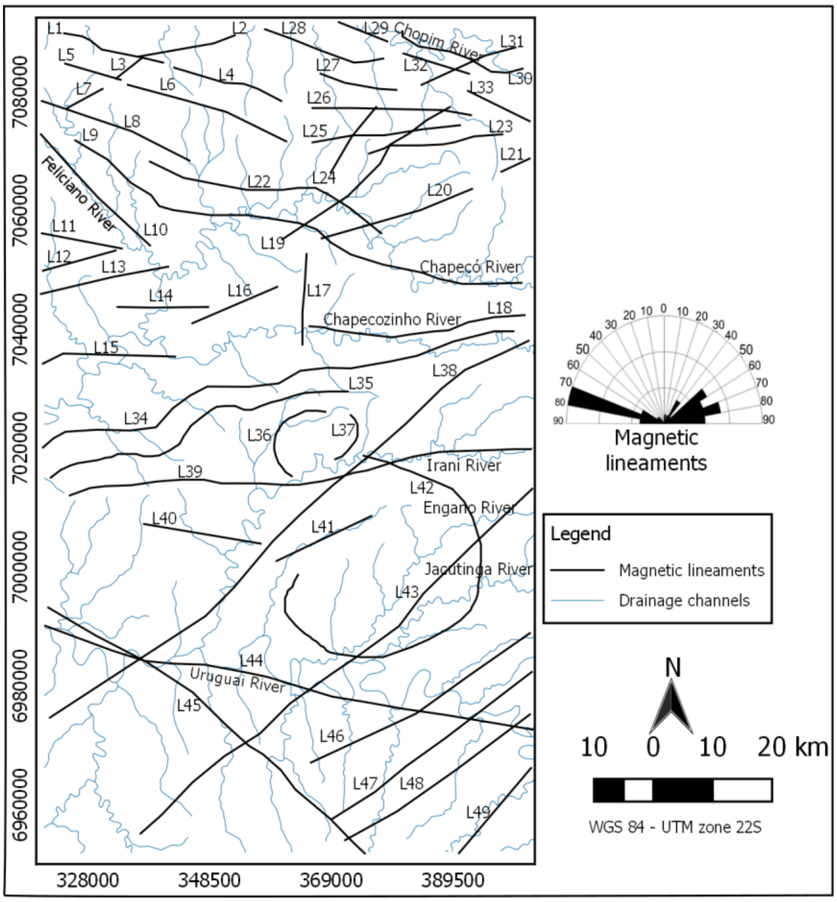

Figure 10. Magnetic lineaments associated with local drainage.

The upper third of the Chapecó River, for example, is adjusted to large magnetic lineaments mapped in the study area (L9; L22), which demonstrates the structural influence in this river. This type of influence has already been indicated by Fujita et al. (2017) who, by analyzing the cross-sectional profile, identified three compartments in this basin. The compartment that corresponds to the upper third of the basin of the Chapecó River was characterized as an ascending block. Moreover, according to these authors, this river presents numerous waterfalls that may be associated with neotectonic processes. In addition to the aforementioned rivers, other important fluvial channels in the study area are correlated with magnetic lineaments: Chopim River (L29; L30; L31; L32; L33), Chapecozinho River (L18), Feliciano River (L10), Irani River (L38; L39), and the Engano and Jacutinga rivers (L43). This demonstrates that river direction is controlled by tectonic structures.

The data analysis shows that magnetic lineaments, faults/fractures, and geomorphological lineaments present as their most important trends (modal classes) the **NW-SE** orientations. This indicates that structures with this orientation have the greatest influence in the study area.

4. Final Considerations

The processing and interpretation of airborne magnetic geophysical data allowed the identification of 49 magnetic lineaments in the study area (L1...L49). These lineaments are mostly oriented following the main structural trends of the Paraná basin (**NW-SE, NE-SW** and **E-W**). In addition to these trends, a **N-S** lineament was mapped, which is an unusual structural direction in the Paraná basin, as well as three lineament arcs that had not been identified previously by other studies in the area.

The disposition of this set of lineaments allowed to subdivide the study area into three geotectonic compartments. These compartments presented a good correlation with the structural blocks of the Paraná basin: Southeast Platform, Três Pinheiros/Matos Costa High, and Tangará Low. The presence of lineament arcs in two of the structural blocks, the Southeast Platform and Tangará Low, suggests the occurrence of tectonic thrusts, with movement in a **SE-NW** direction, related to the transport of rocky masses that converged and formed the supercontinent Gondwana (~460 Ma). These thrusts would have led to the Três Pinheiros/Matos Costa High fold.

The correlation of the magnetic lineaments with surface structural and geomorphological elements showed that the NW trends are the most important for the study area. Moreover, faults/fractures either overlap magnetic lineaments or occur parallel to them. This indicates that the magnetic lineaments correspond to tectonic structures that extend from the basement to the surface.

Geomorphological lineaments also presented good correlation with the magnetic lineaments, reinforcing the idea that these correspond to tectonic structures that extend from the basement of the Paraná basin to the surface. This suggests that these structures have an important role in local geomorphology, which becomes more evident with the drainage that shows the main water courses adjusted to relevant magnetic lineaments.

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