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Spatial remodeling through systematic geological mapping of the Itambé stock of the Estrela do Sul Granitic Suite, Southern Brasília Belt

Remodelamento espacial por mapeamento geológico sistemático do stock Itambé da Suíte Granítica Estrela do Sul, porção Meridional da Faixa Brasília

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Abstract: The Itambé Granite is one of the seven stocks belonging to the Estrela do Sul Granite Suite in Minas Gerais, occurring near the city of the same name. This Neoproterozoic magmatism is intruded into the metasedimentary sequence of the Araxá Group in the southern portion of the Brasília Belt. This study arose from the urgent need to update the geological maps of the area, as a preliminary analysis, which included satellite image processing, existing maps, and photointerpretation, revealed inconsistencies related to the regional geological map. These inconsistencies are justified by the broad scale of the map, presenting dimensions, extensions, and shapes different from those observed in a detailed scale. It was possible to update the dimensions and extents of the Itambé Granite by using remote sensing and geoprocessing techniques, utilizing Sentinel-2A multispectral satellite images and a digital elevation model, combined with systematic geological mapping, thereby updating the information on the Itambé Granite. The process resulted in the spatial redefinition of the granitic stock, now delineated by an approximate area of 6.2 km², aiming for a better understanding of local and regional geology.

Keywords: Stock Itambé; Estrela do Sul Granite Suite; Southern Brasília Belt.

Resumo: O Granito Itambé constitui um dos sete *stocks* pertencentes à Suíte Granítica Estrela do Sul em Minas Gerais, ocorrendo nas proximidades da cidade homônima. Esse magmatismo de idade neoproterozoica ocorre intrudido na sequência metassedimentar do Grupo Araxá na porção meridional da Faixa Brasília. Este trabalho surgiu da urgente necessidade de atualizar os mapas geológicos da área, pois em uma análise preliminar, que incluiu o tratamento de imagens de satélite, mapas existentes e foto interpretação, revelou inconsistências relacionadas ao mapa geológico regional justificadas pela ampla escala do mapa, apresentando dimensões, extensões e formatos distintos do observado em escala de detalhe. Foi possível atualizar as dimensões e extensões do granito Itambé, pela utilização de técnicas de sensoriamento remoto e geoprocessamento, utilizando imagens de satélite multiespectral Sentinel-2A e modelo digital de elevação do terreno, aliadas ao mapeamento geológico sistemático, realizando assim uma atualização das informações do Granito Itambé. O processo resultou na redefinição espacial do stock granítico, agora delimitado por uma área aproximada de 6,2 km², visando assim um melhor conhecimento da geologia local e regional.

Palavras-chave: Stock Itambé; Suíte Granítica Estrela do Sul; Faixa Brasília Meridional.

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1. Introduction

The Alto Paranaíba region features a variety of magmatic rocks of different ages, located in the southern portion of the Brasília Belt in Minas Gerais. Among them, a notable Neoproterozoic magmatism is primarily represented by the Estrela do Sul Granite Suite, located in the municipality of the same name and its surrounding area. The Estrela do Sul Granitic Suite comprises seven stocks, embedded in the metasedimentary rocks of the Araxá Group, the Monte Carmelo Complex, and the Goiandira Orthogneiss. One of these bodies is the Itambé Stock, situated southwest of the municipality of Estrela do Sul and the focus of this work.

The granites of this suite were initially identified and described through the first studies on the Araxá Group, where authors such as Barbosa et al. (1970) observed granitic rocks near the city of Estrela do Sul, analyzing their intrusion into fine schists. Brod et al. (1991) described granitoid bodies in the municipality of Abadia dos Dourados, MG, as intrusive bodies petrologically like those described in the municipality of Araxá, MG.

Pimentel et al. (1999) attempted to understand the granitic intrusions to analyze the evolution of the Brasília Belt with the aim of reconstructing the tectonic history of the orogenic belt. Seer (1999) observed the structural evolution of the Araxá Group, reporting the presence of various magmatic rocks classified as two-mica leucogranites, peraluminous, with collisional geochemical signatures, containing xenoliths of the host rocks. Subsequently, Seer et al. (2005) analyzed granitic bodies occurring in the municipality of Araxá, MG (Quebra Anzol, Pirapetinga, Serra Velha, and Tamanduá granites), showing that these rocks appear as tabular and concordant bodies, which constitute two petrographic types: one as biotite granites and the other as biotite-muscovite granites, with mineralogical signatures similar to those of collisional-type granites.

More recent works, such as Seer and Moraes (2013), Chaves and Dias (2017), and Santos (2019), generally characterize these small granitic bodies as probably post-collisional deformations, observed more intensely in the outer parts of the bodies (edges). The authors also describe petrographically observed characteristics in these bodies, such as grayish coloration, phaneritic and inequigranular texture, with a mineralogy composed of quartz, feldspar (orthoclase and microcline), plagioclase (oligoclase), biotite, muscovite, and opaque minerals, sometimes presenting accessory minerals such as monazite, apatite, garnet, and tourmaline.

Despite the existence of regional geological information about this important Neoproterozoic magmatism, although insufficient, it provides comprehensive information on the individual units that form this granitic suite. However, detailed scale studies are lacking, which would show the actual dimensions of the stocks with precise spatial coverage, enabling visualization of their geological contacts, as well as a detailed petrographic characterization to understand the magmatism in the regional geotectonic context.

In response to the need to address the outdated geological data, systematic mapping was conducted with the collection of geological data in the field. The aim of this study was to present the Itambé Stock through the integration of field data and laboratory analyses. This integration enabled the delineation of the Itambé Stock and contributed to the production of the geological and facies maps as final research products.

This study represents one of the research outcomes and presents a refined spatial definition of the Itambé Stock, closer to its actual dimensional reality. Additionally, it provides a final geological map at a more representative scale. This enables distinct analyses and observations of the Estrela do Sul Granite Suite, with broader coverage than previous geological maps.

The study area is located in the municipality of Estrela do Sul, belonging to the Alto Paranaiba mesoregion (Minas Gerais), approximately 40.3 km from the municipality of Monte Carmelo, where the Geology undergraduate course of the Universidade Federal de Uberlândia (UFU) is located. Access is via the MG-190 highway to the junction with the MG-223, following the latter for about 29.5 km towards Estrela do Sul. The rest of the journey is made by local roads, as shown in Figure 1. The study area covers approximately 63 km², with delimiting coordinates: 18°45'19"S / 47°44'28"W and 18°50'48"S / 47°40'50"W.

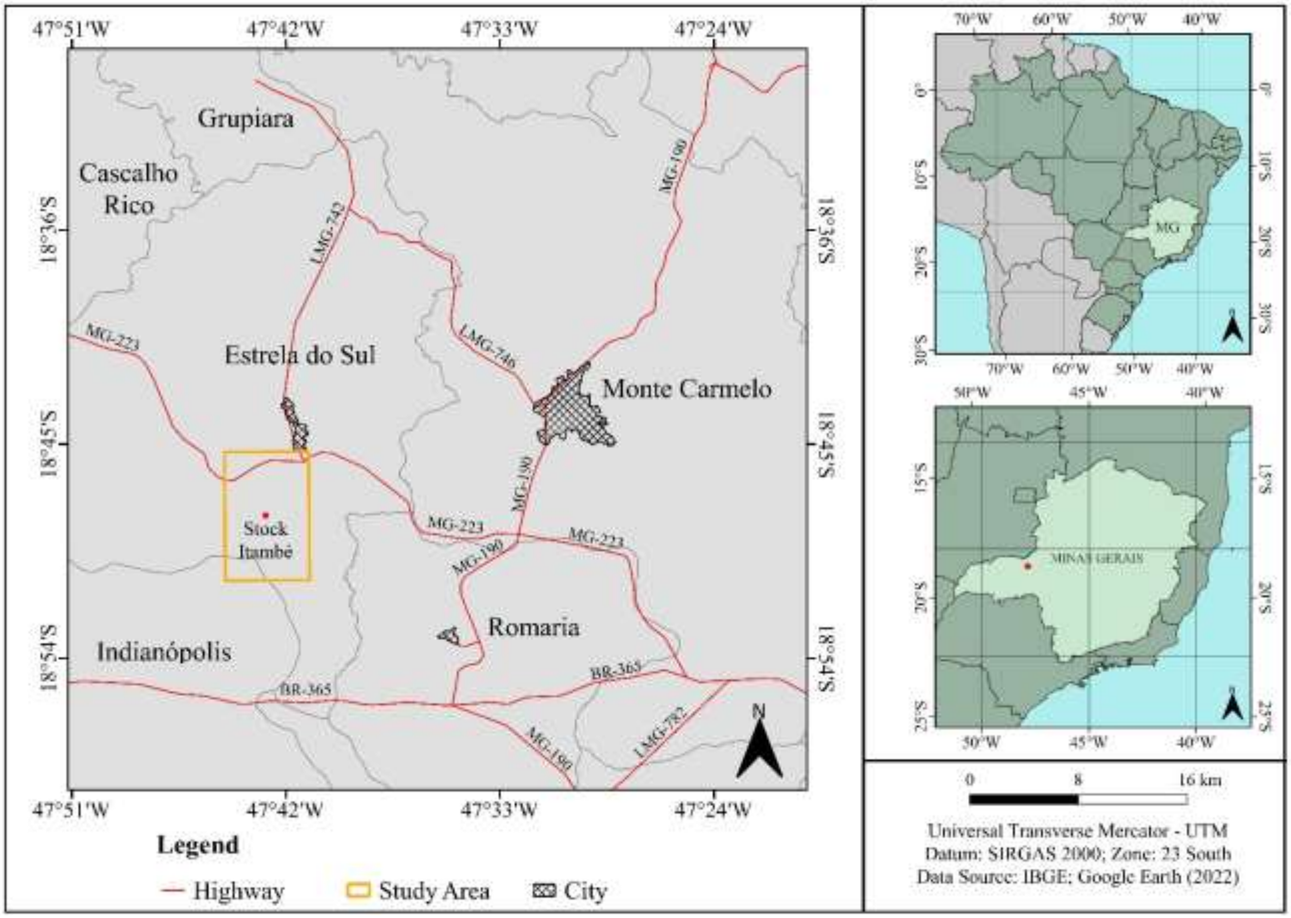

Figure 1 – Location map of the Granite Itambé research area.
Source: Ferraz (2023),

2. Methodology

To facilitate the application of the methods and techniques, five distinct stages were proposed for the implementation of this research. First stage: This stage involved surveys, literature reviews, and the organization of a bibliographic database to facilitate the verification of existing studies, whether in the form of monographs, dissertations, theses, articles, or queries to websites of institutions such as IBGE, federal universities, private institutions, and specialized portals for publications and technical reports.

In addition, regional maps were surveyed, including geological and thematic maps produced by CODEMIG (Companhia de Desenvolvimento de Minas Gerais), with the aim of understanding the regional geological, tectonic context, and characteristics of the suite (Figure 2). Due to the increased exposure area and the characterization of the stock as a unit within the Southern Star Granite Suite, the study named it the Itambé Stock, receiving this name in homage to the farm located in the study area that dates back to 1850.

The second stage involved constructing a database from freely available data to create a thematic location map of the area. Additionally, based on field data, the database was populated with geological information to redefine the granite body. To ensure precise delineation that aligns with the reality observed at a 1:25,000 scale, raster files were integrated into the database. These files were obtained from the multispectral Sentinel-2A satellite for true color composition using bands 04 (Red), 03 (Green), and 02 (Blue), and from the digital elevation model (ALOS PALSAR). For the hillshade, standard data from QGIS software was used, meeting the research analysis needs with a z factor of 1, a solar azimuth of 315.00°, and an altitude of 45°.

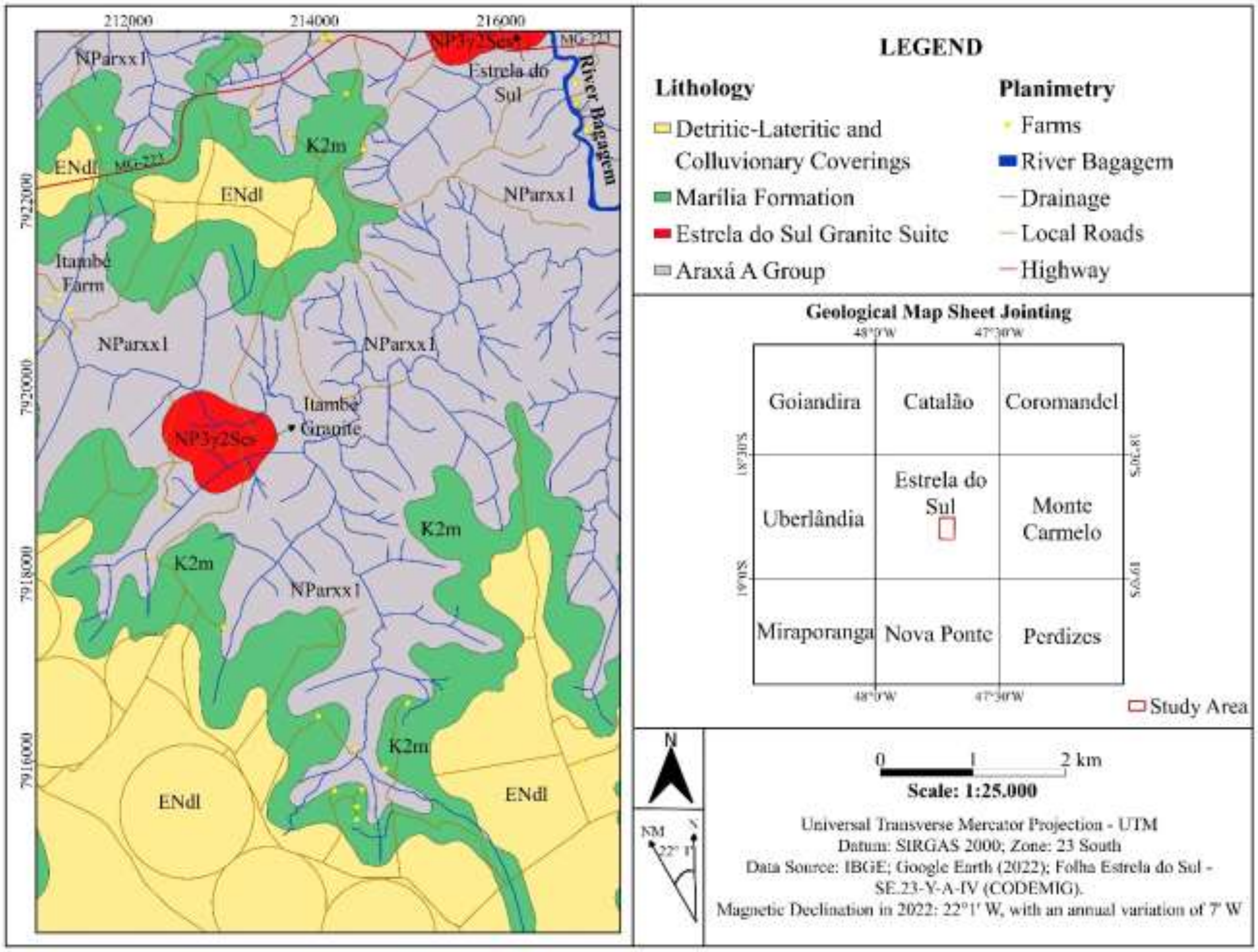

Figure 2 – Geological context of the Estrela do Sul region, MG.
Source: Adapted from Chaves and Dias (2017) - CODEMIG.

Using topographic models such as hillshade and the three-dimensional model, along with the RGB composite of the Sentinel-2A satellite and the Digital Elevation Model (DEM), geological information such as lithologies, fault structures, and fracturing systems, as well as relief features such as drainage and local relief interpretations, were extracted. The integrated interpretation of this information made it possible to separate and delineate the intrusive body, in this case the Itambé Stock, and the other enclosing lithological units, culminating in the production of a preliminary geological map of the area.

The third stage was characterized by the field data acquisition phase, which consisted of seven days of fieldwork carried out in October 2022, January, and February 2023. Through fieldwork - traverses - geographical coordinates were collected, which enabled and validated information such as lithologies, facies, and structural data.

The cartographic analyses followed a detailed scale pattern (1:25,000), enabling the integration of post-field data into the database, updating and validating the existing information. During this stage, representative samples of the intrusive body were also collected to prepare slides and obtain lithological data for subsequent petrographic description, analysis of structures and textures. This helped to establish the boundaries and divisions of the internal facies of the Itambé Stock, which belongs to the Estrela do Sul Suite.

The final stage consisted of analyzing, integrating, and interpreting the data. Through the results obtained with the images created in QGIS 3.22 software, along with fieldwork, it was possible to redefine the intrusive body and its structures.

3. Regional Geological Context

The study area is located in the southern part of the Tocantins Province in the southern portion of the Brasília Belt, in the Alto Paranaíba region of Minas Gerais. It is characterized by lithological types mainly belonging to the Araxá Group, such as mica schist, quartzites, and lenses of amphibolites, as well as the Neoproterozoic-aged Estrela do Sul Granitic Suite. In some areas, the higher portions are partially covered by sandstones of the Marília Formation, belonging to the Bauru Group.

Almeida et al. (1977) initially described the Tocantins Province as a north-south-directed orogenic system that developed during the Brasiliano/Pan-African event. Pimentel (2016) suggests that the Tocantins Province is the result of the collision of three large continental blocks: the Amazon Craton, the São Francisco/Congo, and finally the Paranapanema, the latter currently covered by Phanerozoic rocks from the Paraná Basin. This province is compartmentalized into the Paraguay and Araguaia Belts, which border the Amazon Craton, and the Brasília Belt, which borders the São Francisco Craton (ALMEIDA et al., 1977; ALMEIDA et al., 1981; VALERIANO et al., 2004).

The granites that comprise the Estrela do Sul Granitic Suite have been known and described since the early studies on the Araxá Group. Barbosa et al. (1970) were the first to observe the presence of granitic rocks near the city of Estrela do Sul, analyzing their intrusion into fine schists. Brod et al. (1991) described granitoid bodies in the region of Abadia dos Dourados, MG, as petrographically similar to those described in the Araxá region, MG. Pimentel et al. (2001) attempted to understand the granitic intrusions to analyze the evolution of the Brasília Belt, aiming to reconstruct the tectonic history of the belt. Seer (1999), studying the structural evolution of the Araxá Group, reported the presence of magmatic rocks classified as two-mica leucogranites, peraluminous, with collisional geochemical signatures, containing xenoliths of the host rocks.

In Seer et al. (2005), granite bodies in the Araxá region of MG were studied and identified as Quebra Anzol, Pirapetinga, Serra Velha, and Tamanduá. These are classified as leucogranites and appear as tabular, concordant bodies, formed by two distinct petrographic types: one composed of biotite granites, peralkaline, and the other of biotite-muscovite granites, peraluminous. Both types have mineralogical signatures similar to those of collisional granites.

The geochronological studies began with the quantification of collisional activity, which is well characterized and had its peak metamorphism between 640 and 637 Ma (SEER et al., 2010). U/Pb dating on zircon crystals determines the crystallization age to be 632 ± 3.2 Ma. Data obtained through isotopic chemistry of Sm/Nd show a TDM model age of 1.68 Ga and negative values of εNd (-7.224), suggesting that the magma resulted from the reworking of Mesoproterozoic crust with possible contribution from partial melting of sediments from the Araxá Group (SEER et al., 2005; SEER; MORAES, 2013).

According to Seer and Moraes (2013), the intrusive granitic rocks in the Araxá Group represent a total of fourteen (14) intrusions distributed between the cities of Araxá, MG, and Catalão, GO. These intrusions comprise three magmatic episodes, separated by distinct ages, and constitute the main occurrences in the region.

The first episode occurred around 833 Ma, responsible for generating the Quebra Anzol Granite. This granite presents an elongated and deformed body, located in the frontal part of the Araxá Nappe. It is associated with a significant volume of amphibolites, indicating a probable mantle source with little crustal contamination. However, the granite was affected by post-magmatic hydrothermal alteration and mylonitization.

The second episode, with an age of 790 Ma, is represented by the Monte Carmelo Complex, whose origin is associated with a pre-collisional magmatic arc environment.

The last magmatic episode, with an age of 642 to 630 Ma, encompasses the granites Serra Velha, Tamanduá, Pirapetinga, Galheirinho, Perdizes, Estrela do Sul, and Cascalho Rico. These rocks, composed of muscovite and garnet, may or may not contain tourmaline, and have a peraluminous character. Such characteristics suggest a possible generation process in a collisional environment. In figure 3 of Seer and Moraes (2013), shown below, we can observe the granitic bodies that are the results of the magmatic episodes.

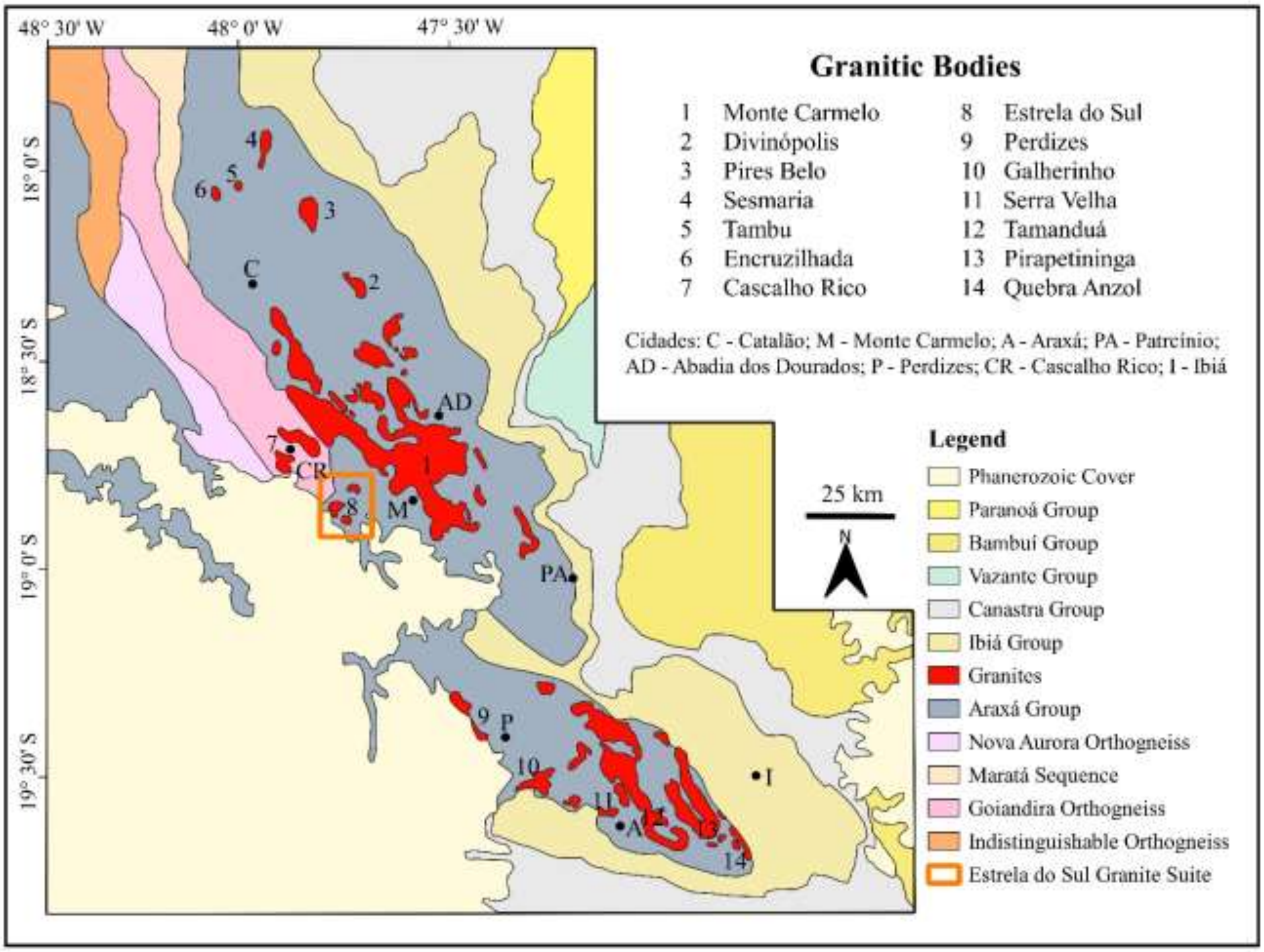

Figure 3 – Granitic Bodies in the Araxá Group, Southeast of the Brasília Belt. Highlighting body 8 representing the Estrela do Sul Granite Suite – MG.
Source: Modified from Seer and Moraes (2013).

4. Results

4.1 Local Geology

The local geology represents the data acquisition stage through systematic field surveys. These surveys were conducted over seven field campaigns and resulted in the mapping of the Itambé Stock, making it possible to identify a variety of lithologies defined by the rocks of the Araxá Group units, the Estrela do Sul Granite Suite, and the Botucatu Formation.

4.2 Araxá Group

The most extensive lithological unit in the area is the Araxá Group, which forms the main host for various intrusive magmatisms along the southern portion of the Brasília Belt. This metasedimentary unit exhibits a diversity of schists. In the study area, biotite-muscovite schist with garnet was predominantly identified, and locally, bands of sericite schist and lenses of fine-grained amphibolite can occur.

The main unit of the Araxá Group, represented by biotite-muscovite schists, outcrops in the form of blocks, foliated boulders, and road cuts (Figures 4 A and B), at altitudes ranging from 790 to 915 m. It exhibits well-defined foliation with a preferential orientation of biotite and muscovite arranged parallelly, displaying a lepidoblastic texture in a NW-SE direction. Variations in the coloration of the schists were observed, with a more grayish color (Figure 4 D) for the sericite schists and a pinkish hue for the biotite-muscovite schists with garnet (Figures 4 B and C).

The primary mineralogy of the most frequent schist in the area consists of quartz, biotite, muscovite, and garnet, despite the slight degree of weathering of the collected sample. The contact between this unit and the granite is abrupt, with a steep inclination of the schists near the granites. The transformations undergone by this lithology are reflected in the soil profile of the area, which shows an advanced stage of development, with micaceous soils and a yellow-reddish color. In contrast, in areas with granite outcrops, the soils are less developed, with a sandy-quartz texture and a whitish color.

In the study area, amphibolites were observed in the northern portion as lenses intercalated with mica schists. In the southwestern portion, mafic dikes were occasionally identified (Figures 5 A and B). Both feature a black coloration, fine to very fine grain size, minimal weathering, and blocky shapes at altitudes ranging from 910 to 916 meters.

In the outcrops of biotite-muscovite schist with garnet, a variation in schistosity was observed, with directions NE and NW, and dips to the northeast and southeast. In the eastern portion, the schistosity exhibits a NW direction and dips to the NE (61/65; 45/60; 51/60; 45/50 and 50/60). In the western region, there is foliation with a NE direction and SE dip (93/55; 90/50). In the central-southern portion, the foliation directions vary between NE and NW, as do the dips, which vary to SE and NE (170/60; 80/55; 73/60).

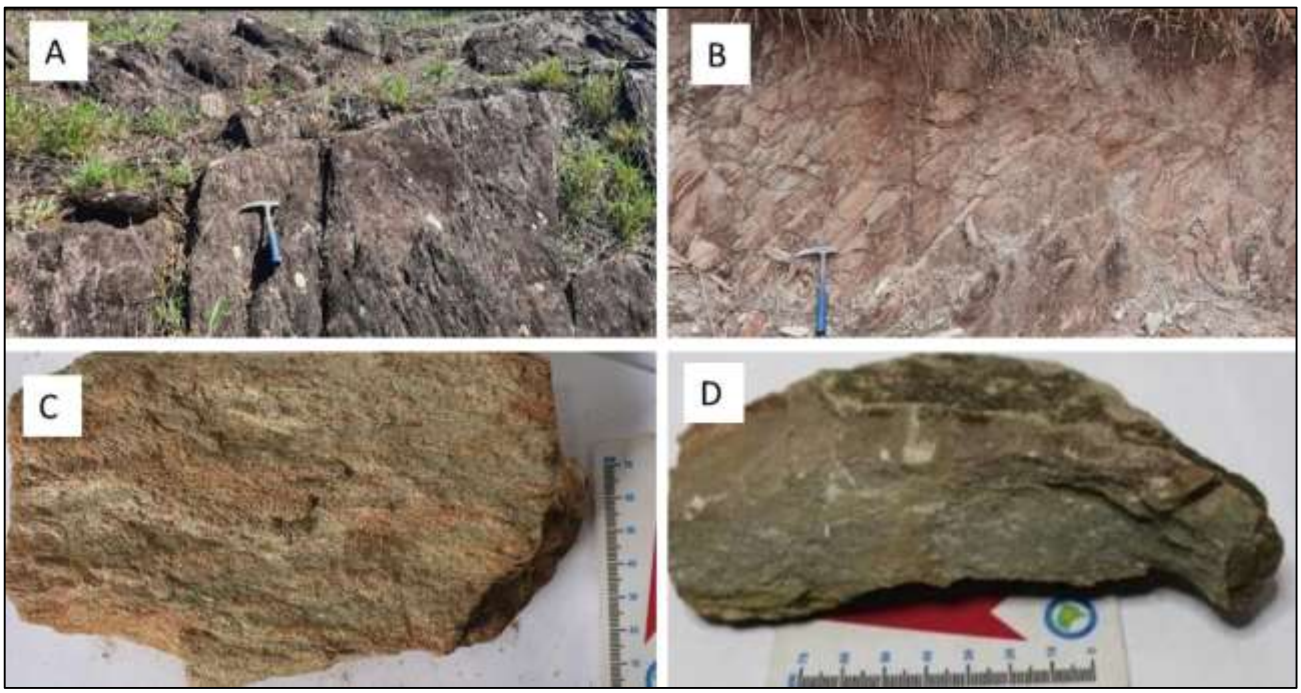

Figure 4 – (A) Outcropping biotite-muscovite schist blocks, located north of the granitic body. (B) Outcrop of muscovite schist, vicinal road. (C) Sample of biotite-muscovite schist with weathered garnet, fine to medium grain, pinkish coloration.
Source: Ferraz (2023).

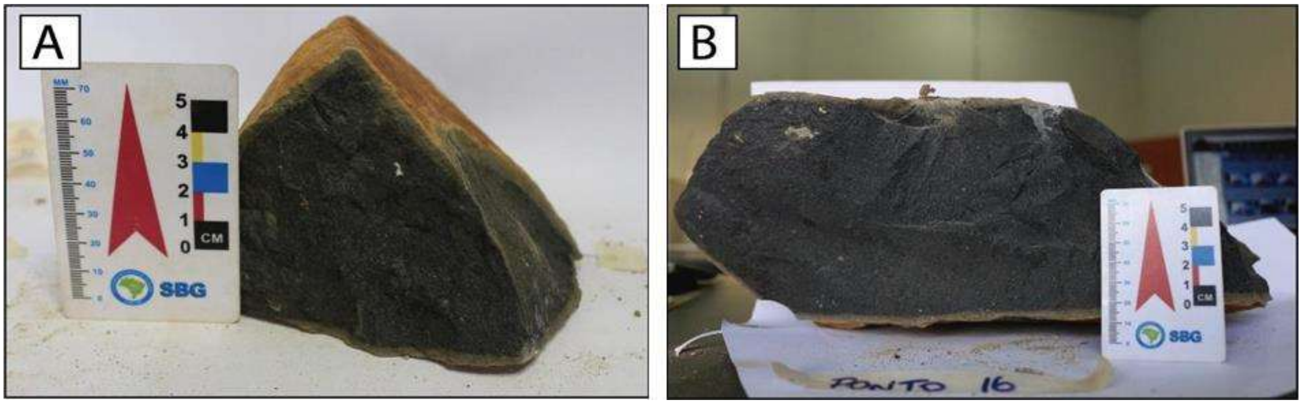

Figure 5 – Sample of Mafic dikes with very fine texture.
Source: Ferraz (2023).

In the central-western portion of the granite, occurrences of xenoliths/enclaves of micaceous schist were observed, which were not observed in other parts of the study area, as indicated in Figure 6. The biotite-quartz schist outcrops in the form of extremely rigid blocks, in a region of intense weathering at altitudes ranging from 840 to 850 m. Its mineralogy is mainly composed of quartz and biotite, with fine grain, presenting a preferential orientation of minerals, conferring a lepidoblastic texture. It exhibits a compositional banding parallel to the foliation plane, with alternating felsic and mafic bands (Figure 6 A and B).

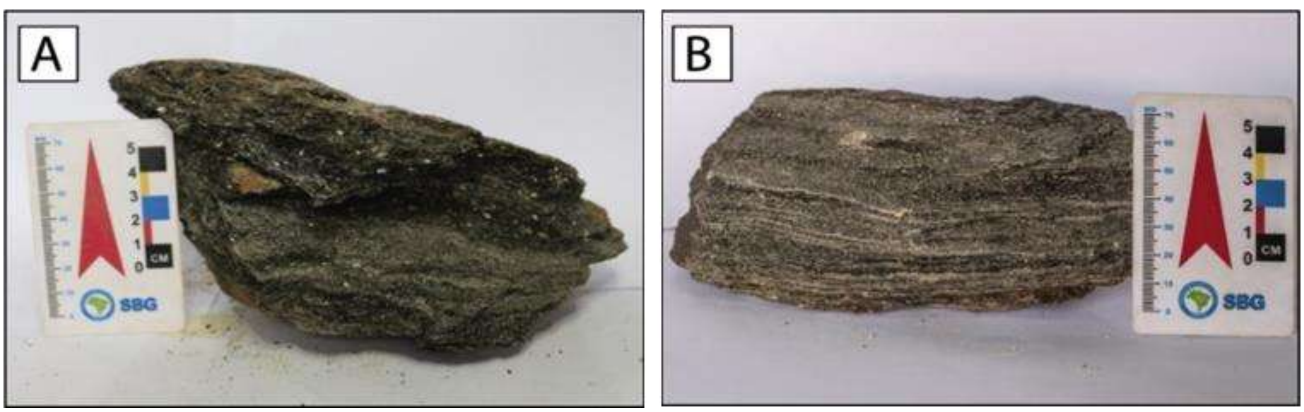

Figure 6 – A and B Sample of biotite-quartz schist with fine grain, exhibiting compositional banding.
Source: Ferraz (2023).

4.3 Estrela do Sul Granite Suite

The Itambé Stock, part of the Estrela do Sul Granite Suite, initially described in the literature as a smaller spatially extensive body, is located southwest of the city of the same name. It covers an area of 6.2 km², outcropping in the form of blocks (Figure 7 A and B) and boulders (Figure 7 C) at altitudes ranging from 800 to 950 m. The lithologies comprising the Itambé Granite exhibit five differentiated facies named as tourmaline-biotite monzogranite facies, biotite monzogranite facies, gray to pink biotite-muscovite monzogranite facies, muscovite monzogranite facies, and muscovite-biotite monzogranite facies. These predominantly exhibit a massive structure; however, in some localized portions, these lithotypes are affected by a regional fault zone, where, in certain locations, they may exhibit mylonitic foliation.

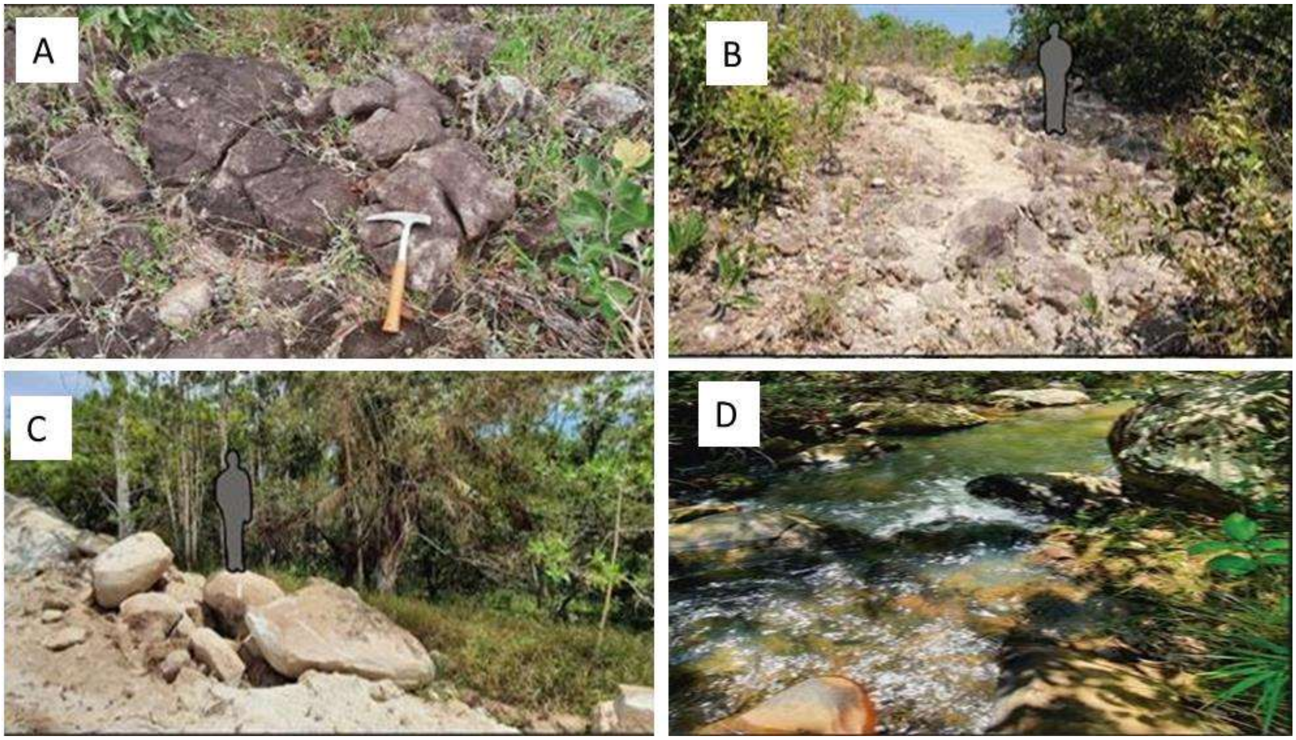

Figure 7 – (A) Blocks in the western portion of the granite. (B) Area located in the central portion of the granite, with a high degree of weathering on the outcropping rocks. (C) Blocks with spheroidal weathering, situated in the northern portion of the granite. (D) Granite outcropping in the drainages of the central portion of the Itambé Stock.
Source: Ferraz (2023).

An analysis of samples from the Itambé Stock revealed variations in its grain size. Facies with finer or even coarser characteristics were observed, generally equigranular and isotropic. However, as previously mentioned, they can locally present inequigranular and other anisotropic features, constituting a concordant intrusion with the country rock. The coloration observed in this unit ranges from light gray to dark gray and pink.

In the western portion of the granite, a fault zone was observed, which features an inset drainage, dividing the Araxá Group schists from the studied granites. This fault zone extends into the central portion of the body, describing a slight curvature towards the southern portion, where another inset drainage is also found, once again dividing the Araxá Group from the Estrela do Sul Granite Suite. Its main mineralogy is composed of quartz, plagioclase, potassium feldspar, biotite, and muscovite, with possible accessory minerals including garnet, tourmaline, epidote, apatite, rutile, zircon, clay minerals, and opaque minerals.

4.4 Botucatu Formation

The Botucatu Formation is observed in the higher portions of the study area, at elevations ranging from 890 to 920 m, situated on the mid and high slopes, in the form of blocks or boulders (Figure 8 A and B), exhibiting well-silicified/vitrified sandstone (Figure 8 B and C), with fine to medium grain size, pinkish coloration, well-selected, predominantly composed of rounded grains of quartz, with high sphericity.

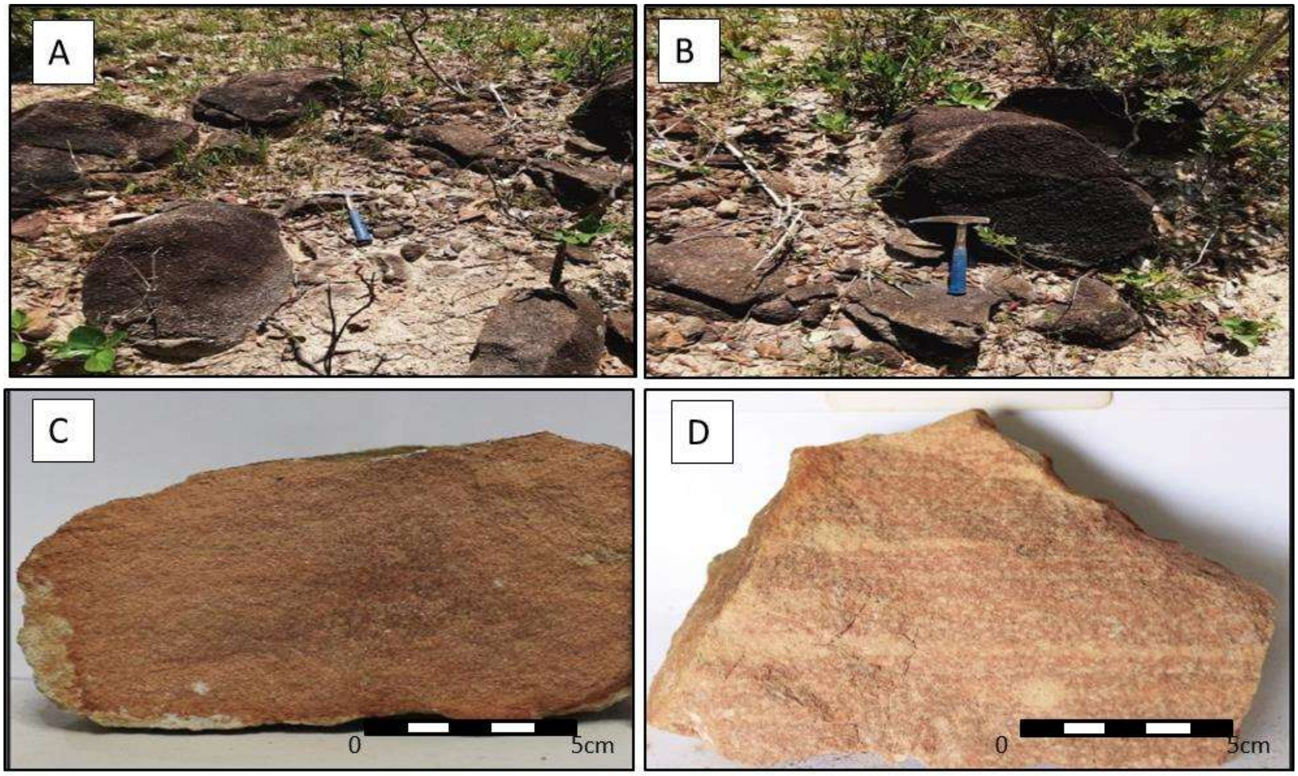

Figure 8 – (A and B) Sandstone blocks occurring at elevations of 900 m. (C and D) Samples of sandstone from the Botucatu Formation exhibiting pinkish coloration.
Source: Ferraz (2023).

4.5 The geoprocessing data of the Estrela do Sul Granite Suite

Through systematic mapping of the study area, 220 analysis points were carried out. With this data collection, it was possible to create a point map, aiming to guide the identification of lithological variations, defined by the rocks of the Araxá Group, Estrela do Sul Granite Suite, and Botucatu Formation units.

The Itambé Stock shows a significant increase in volume and dimensions, resulting in the division into six distinct facies, as illustrated in figure 9. These are named: tourmaline-biotite monzogranite facies; biotite monzogranite facies; gray biotite-muscovite monzogranite facies; pink biotite-muscovite monzogranite facies; muscovite monzogranite facies; and muscovite-biotite monzogranite facies. The "amoeboid" shape of the stock is notable, validated through the geoprocessing of information that allowed for the definition of the fault zone as well as the measurement of structures in outcrops. Fault zones promote changes in lithology due to erosive and modifying processes.

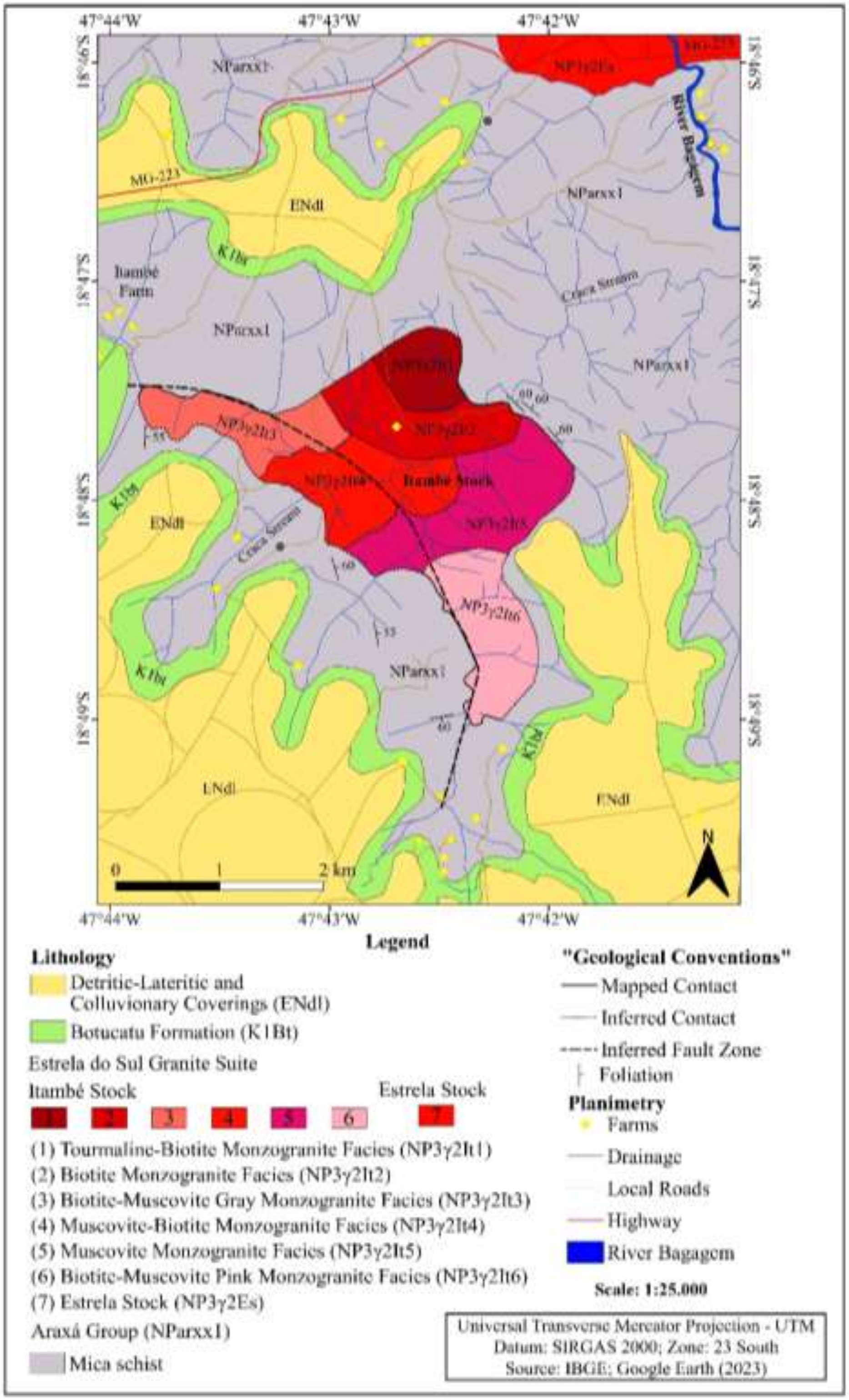

Figure 9 – Final map of the Itambé Granite.
Source: Ferraz (2023).

The variations in the facies of the Itambé Stock occur according to the characteristics related to compositions, mineralogical structures, and textures that occur along different topographic levels, with a variation from 816 to 950 meters. These facies are distributed from outcrops present in drainages and depressions to locations with intense tectonic movement, such as shear zones, and extend across terrains ranging from gentle hills to rugged ones.

The tourmaline-biotite monzogranite facies (Figure 10 A) occurs in the northern portion of the Itambé Granite, covering an area of 0.56 km². Displaying massive, phaneritic, isotropic, holocrystalline rocks, with medium texture and light gray coloration, forming a slightly undulating relief, these granitic facies, with a more resistant mineralogy, managed to withstand erosive processes, maintaining altitudes of up to 950 meters.

The biotite monzogranite facies (Figure 10 B) is situated in the central-northern region, covering an area of 0.98 km², and exhibits massive rocks with medium texture and dark gray coloration. This facies is characterized by being phaneritic, anisotropic, and holocrystalline, with an orientation of minerals such as biotite and muscovite. Its relief is irregular and rugged, with a higher portion where the material is more massive and preserved, and a more rugged portion with an incised drainage system. In these areas, erosion and weathering products are observed, with the formation of clay minerals such as kaolinite and illite associated with Fe oxyhydroxide (goethite) and Al hydroxide (gibbsite). Together, they form a weathering horizon of the granite, with remnants of commonly dismantled quartz veins associated with blocks and boulders with spheroidal exfoliation, as well as laterites resulting from weathering alteration. Elevations range from 875 to 896 meters.

The gray biotite-muscovite monzogranite facies (Figure 10 C) outcrops in the western portion of the Itambé Granite, covering an area of 0.87 km², with a light gray coloration, massive structure, isotropic texture, phaneritic, holocrystalline, and medium to coarse grain size. Concentrations of muscovite scattered across the soil were observed, facilitated by the decomposition of these materials due to their lower competence. These rocks stand out in a gentle relief with installed depressions where drainages appear at elevations ranging from 853 to 875 meters.

The biotite-muscovite pink monzogranite facies (Figure 10 D) is characterized by massive and anisotropic rocks, exhibiting mineral orientation. Being phaneritic and holocrystalline, it has a texture ranging from fine to medium and predominantly pink coloration, with more weathered portions showing a light gray hue. This facies represents the second-largest extent of the Itambé Granite, occurring in the southern portion over an area of 1.11 km². In this region, there is a higher concentration of drainage and more rugged relief resulting from intensified erosive processes due to the presence of minerals with cleavage planes, such as biotite and muscovite, making it more susceptible to relief modification processes. Elevations range from 853 to 875 meters.

The muscovite monzogranite facies (Figure 10 E), located in the central-eastern region of the intrusion, represents the largest facies of the Itambé Granite, occurring in an area of 1.5 km². The relief is low and irregular, intersected by drainage channels from different directions. Blocks and boulders are abundant with spheroidal weathering and significant alteration due to the action of water from the drainage, evidenced by the distribution of muscovite minerals in the sandy soil. This portion features massive, isotropic, phaneritic, and holocrystalline rocks, displaying dark gray coloration and medium to coarse texture. Its elevations range from the lowest, varying little from 816 to 853 m.

The muscovite-biotite monzogranite facies (Figure 10 F) features rocks with massive, isotropic, phaneritic, and holocrystalline characteristics, exhibiting a fine to medium texture and light gray to dark gray coloration. This facies is located in the central-western portion of the Itambé Granite, covering an area of 1.17 km² in a region characterized by low, irregular relief, divided between drainage and shear zone, where alteration material from the granite can be observed, ranging in color from white to yellowish, forming a fine sandy soil consisting of clay minerals and muscovite and biotite minerals distributed on its surface. In the central region of this facies, enclaves of biotite-quartz schists were observed. Elevation ranges for this facies vary between 875 to 853 meters.

The region where Stock Itambé is located may locally show mineralogical and textural variations that directly influence the competence of the rock, allowing the material to be more preserved or altered, shaping the forms of the relief. Afonso and Silva (2014) suggest that different types of rocks, under identical climatic regime conditions, undergo weathering to varying degrees. The susceptibility of rocks to weathering and erosion depends heavily on their mineral composition. Rocks with a high content of soluble minerals are more prone to chemical weathering. In this region, a clear relationship can be observed between the area's geology and its topography. More cohesive rocks, characterized by a higher degree of crystallographic organization and composed of more resistant minerals, tend to exhibit a more preserved topography with less erosion. This, in turn, contributes to the preservation of higher elevations. On the other hand, less cohesive rocks, perhaps due to their more fragile mineral composition, are more susceptible to weathering and erosion, resulting in an irregular, undulating topography shaped by the development of erosional zones or entrenched drainage systems, further accentuating the irregularity of the terrain.

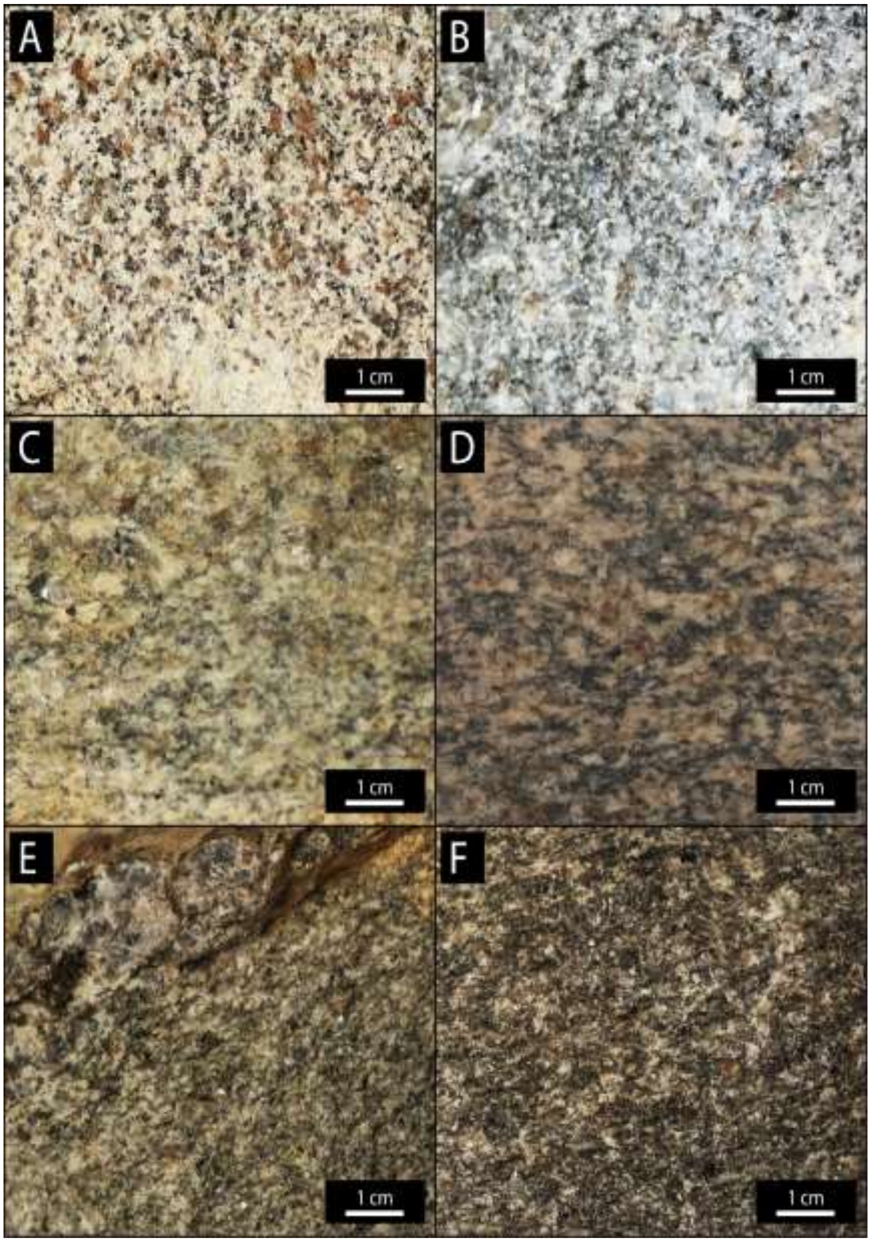

Figure 10 – Photographs presenting the macroscopic aspects of the different facies of Granito Itambé. (A) Tourmaline-biotite monzogranite, (B) Biotite monzogranite, (C) Gray biotite-muscovite monzogranite, (D) Pink biotite-muscovite monzogranite, (E) Muscovite monzogranite, and (F) Muscovite-biotite monzogranite.
Source: Ferraz et al. (2023).

The topographic model in Figure 11 shows an inferred fault zone in the NW direction, located in the southwest portion of the body, possibly responsible for its elongated shape at the southern and western ends. In these locations, the contact between the granite and the Araxá Group is observed, particularly in areas where the drainage is more entrenched. In the central portion of the granite, the fault zone can be observed in thin sections, which exhibit microfractures sometimes filled with secondary muscovite or biotite, recrystallization, and wavy extinction of quartz.

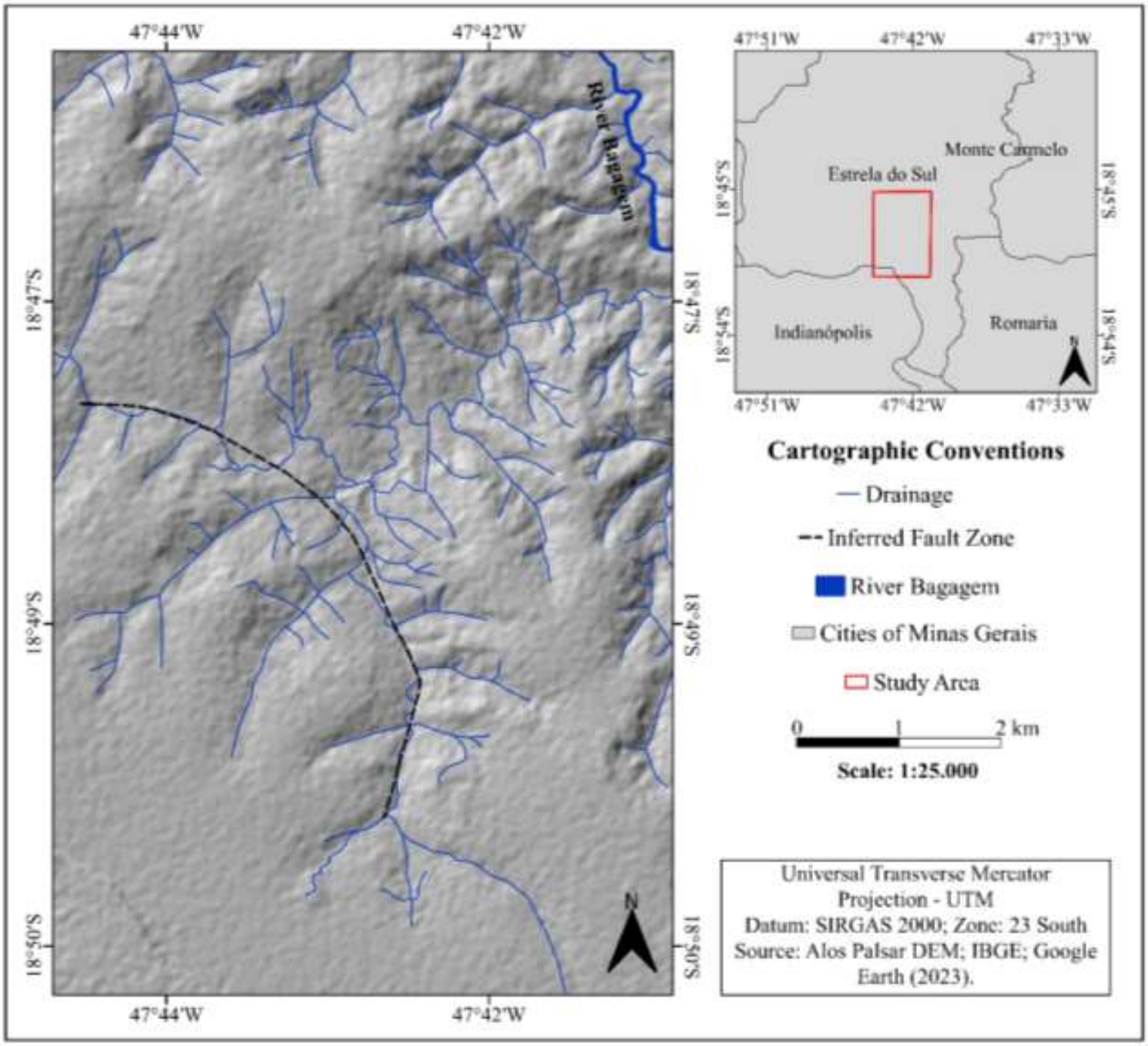

Figure 11 – Hillshade topographic modeling of Granito Itambé.
Source: Ferraz (2023).

The three-dimensional model of the terrain allows analyses regarding the dynamics that compose the landscape present in Stock Itambé, as well as its surroundings. With the aim of facilitating understanding of the location and its shape, a comparative three-dimensional mapping was carried out (Figure 12 A and B), which demonstrates the 3D visualization of the hypsometric map with altimetric information and the 3D visualization of the RGB composition (432) in natural color.

In Figure 12A, it can be observed that the region presents a flat relief, with approximate altitudes of 918 m, while the valley incisions have altitudes varying around 816 m. Similar observations can be made through Figure 12B, with the delineation of granite, showing that the intrusion occurs from the lower to the higher portions of the slope, presenting a rougher aspect on the terrain, where it was possible to observe granite exposure in the field.

The interpretations regarding the landscape's behavior around the body indicate an area predominantly devoted to agriculture with few areas designated for pasture. This behavior is justified by the presence of minerals rich in chemical elements that confer greater fertility to the soil, thus favoring cultivation. It can also be observed that the body is positioned in a micro-basin of the Bagagem River, which may influence the behavior of the granite body due to the weather conditions in the region.

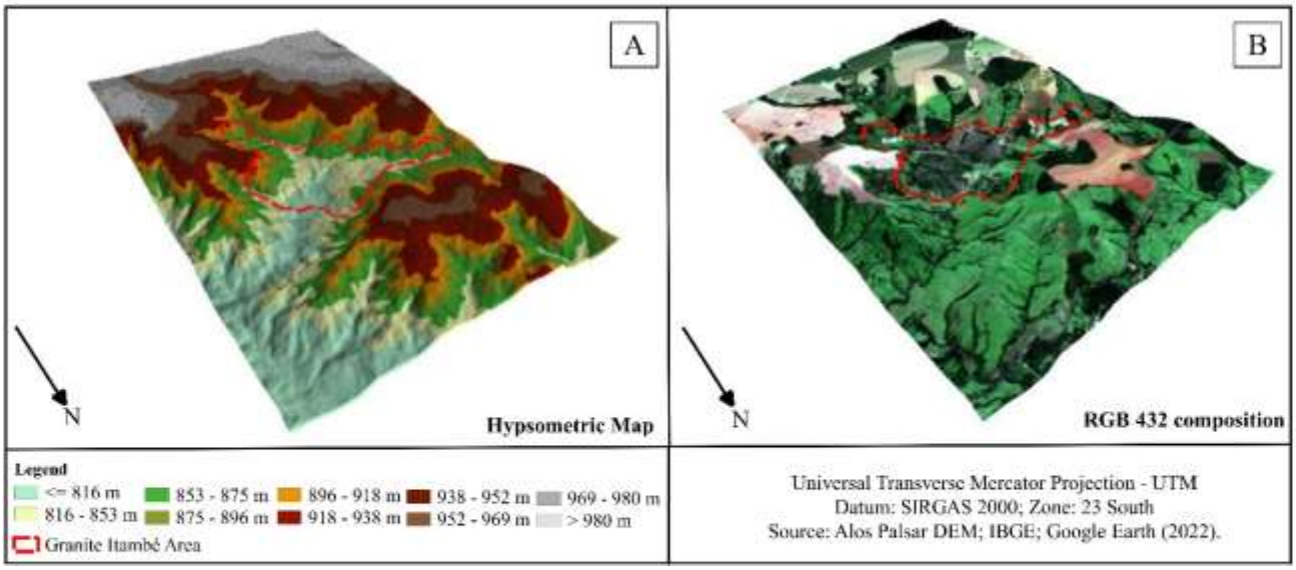

Figure 12 – 3D Map of Itambé Granite. Three-dimensional modeling (A) - Hypsometric Map and (B) Natural Color Composition (RGB - 432).
Source: Ferraz (2023).

5. Final considerations

This study is of fundamental relevance because, in addition to updating the geological data of a region with limited geological studies at a detailed scale, it allowed for the presentation of the real shape and spatial extent of the Estrela do Sul Granite Suite. Through the delineation and systematic mapping of the area, it was possible to individualize and delimit the intrusive body called Itambé Stock, outcropping in the form of a granite stock. Initially, the measured area was 0.8 km²; however, after detailed analysis, its spatial expansion was found to occupy about 6.2 km², enabling the creation of a new geological map.

The six facies named tourmaline-biotite monzogranite facies, biotite monzogranite facies, gray biotite-muscovite monzogranite facies, pink biotite-muscovite monzogranite facies, muscovite monzogranite facies, and muscovite-biotite monzogranite facies, have specific structural, mineralogical, and textural varieties, which confer varied degrees of competence to the granite, distributed across topographic elevations ranging from 816 to 950 m.

Petrographically, it possesses mineralogy composed of quartz, microcline, and plagioclase, along with the minerals biotite and muscovite, thus defining a granite of the S-type with two micas. In this geological context, a fault zone is actively present, with a NW direction, clearly delineated in the area as shown in the three-dimensional terrain model (hillshade). Geologically, in these portions, faults promote changes in lithology that are reflected in the relief, due to erosive and modifying processes, generating secondary minerals.

Through systematic mapping and petrographic description, it was possible to analyze the biotite-quartz schist, considered in this study as a xenolith in the rocks of the Estrela do Sul Suite. This suite belongs to a more basal region of the Araxá Group and is partially assimilated, having ascended along with the rocks of the granite intrusion, first described in the Monte Carmelo region, MG.

Therefore, with the new geological map of the Itambé Granite, it was possible to conclude that the chosen mapping scale was appropriate, as it provided a range of unprecedented details regarding the Estrela do Sul Granite Suite. Presenting new information to the scientific community about its actual extent, varied mineralogy, presence of shear zones, and how these geological structures influence the body. Future work could further explore the economic aspects of the area (checking for the presence of minerals or chemical elements of value for exploitation), as well as mineral chemistry and U/Pb, Sm/Nd dating on monazite and zircon to determine the geochronological ages of origin, evolution, and emplacement of the body, thus narrating the geological and evolutionary history of this important magmatic suite. It is worth noting that proposals for remodeling on a more detailed scale are of utmost importance, as they allow for a detailed understanding of the geological-geographical dynamics of the region.

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