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Geophysical characterization of the Detrital-Lateritic Cover and its aquifer in Chapadão de São Gabriel do Oeste, Mato Grosso do Sul

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Abstract

The geophysical characterization of the detritus-lateritic cover existing in Chapadão de São Gabriel do Oeste has fundamental economic importance for the agriculture in the region, and it was the object of study in this research. We highlighted the associated laterite yokes, widely used in the primary coating of more than 3000 km of municipal highways. We aimed to evaluate the effectiveness of the GPR geophysical method in identifying lateritic yokes in the subsurface and in detecting lithological contacts between the TQdl and the underlying layers. A focus was placed on verifying the continuity of the Serra Geral Formation in the study area, obtaining the iso-thickness map. In addition, a preliminary characterization of the aquifer related to the coverage that has not yet been individualized was carried out. To achieve these goals, geophysical data was obtained with GPR, electroresistivity and geological and hydrogeological data. As final results, we can list: the feasibility of using GPR to identify cangas; the thickness of the detrital-laterite cover and its contacts; the definition of the distribution and thickness of the basalts. Serra Geral and the definition of the potentiometric map of the aquifer represented by the cover. Additionally, a geological profile was obtained seeking a better understanding of the geological-structural framework, which summarizes the interpretation of stratigraphic relationships in the area.

KEYWORDS: TQdl Coverage, TQdl Aquifer. Serra Geral formation.

1 INTRODUCTION

The detritus-laterite cover, of Cenozoic age, which for simplification purposes in the sequence of this work was simply called detritus-laterite cover, is found in several places in Brazil and worldwide; They are often associated with mineral deposits of high added value.

They are formed from the chemical weathering of ultramafic or non-ultramafic rocks, which removes the more soluble elements (Mg, Ca and Si) and it concentrates the less soluble ones (Fe, Ni, Mn, among others) (MARSH; ERIC; GRAY, 2013).

This type of coverage has been extensively studied around the world (BUTT; ZEEGERS, 1992; ELIAS, 2002; HORTON, 2008; OGURA, 1986). In Brazil, there are studies such as those by (GOLIGHTLY, 2010; MOTTA; JÚNIOR, 2016; SEOANE et al., 2009), works that used geophysics as an investigation methodology.

The detritus-lateritic cover existing in Chapadão de São Gabriel do Oeste (SGO) has great geomorphological importance, as it "supports" the hydrogeological scarp (AB'SABER, 2008), considering that it provides almost all of the water consumed in the rural area of the area covered by this Chapadão (UECHI et. al., 2022; CENTURIÃO; SILVA; GABAS, 2020; FERRARO; GABAS; LASTORIA, 2015; SOUZA et al., 2014), and it also provides for commercial and financial, as well as for the region and the State of Mato Grosso do Sul (IBGE, 2021).

This importance is due to the fact that the main wealth and source of income for the local population is agriculture, mainly the production of soybeans, corn and pig farming. The basis of support is the quality of the soil; in other words, the detritus-laterite cover that we seek to characterize here is the region's main natural and income-generating resource.

Additionally, the laterite cangas, present in this deposit, are currently explored to remove material for paving, being the main source of this material in the region. In the case of the town São Gabriel do Oeste, these laterite cangas are extremely necessary, since, in the town alone, there are more than 3,000 km of unpaved local roads and, therefore, they need to be pebbled periodically, in order to be suitable for transporting the region's grain harvest. Therefore, coverage has great economic relevance for the micro-region.

However, when it comes to the study area of this research, despite the geological/geomorphological and economic importance, there is a lack of specific studies on the geological/geophysical characterization of this cover and, mainly, there is no study on the laterite cangas, which makes any type of planning and investment difficult in the adequate exploration of these materials and in the correct use of the natural resources existing in the detritus-lateritic cover.

Although not so conventional, the use of geophysics in the mining planning of laterite cangas and its consequent geospatial delimitation in three dimensions (3D) is increasingly used nationally and worldwide; particularly the ground penetrating radar (GPR) method has great potential for understanding the geology of exploratory projects, resource delimitation and mining planning problems due to its high resolution.

Based on the importance of this area, the general objective of this research is the geophysical characterization of the detrital-lateritic cover in the Chapadão de São Gabriel do Oeste and its stratigraphic relationships with the underlying rocks. As a geophysical characterization, we propose the spatial definition of the detrital-lateritic cover, its thickness, its base contacts with the various formations above it and the existence or not of a continuous basaltic extract.

In addition to this general objective, the following definitions are specific for the Chapadão de SGO study area:

- Definition of the contacts of the detrital-lateritic coverings with other underlying formations;

- Definition of the distribution and extent of basalt spills;

- Definition of the thickness of the deposit Debris-lateritic coverings;

- Definition of the potentiometric map of the detrital-laterite coverage.

The region in which the target area is located began to be occupied around the 1950s by coffee growing. However, this activity proved to be inappropriate, as the climate with strong frosts, which hit the region, had caused the death of this culture; however, from the 1970s onwards, there was a strong agricultural expansion in the town.

In this place, the region's average annual precipitation varies between 1,500 mm and 1,750 mm, with an annual water surplus of 800 mm to 1,200 mm and an annual water deficiency of between 350 mm and 500 mm (ANA, 2014). It is located at an altitude of 609 meters.

More recently, since the beginning of this century, another important change occurred in the region's agricultural economy, with the accelerated implementation of the pig production chain. In the State of Mato Grosso do Sul, this activity was developed largely by immigrants from the southern region of Brazil, and at the state level the municipality of São Gabriel do Oeste is today the largest producer of pigs, with approximately 50% of the town revenue (SOUZA et al., 2014).

In the SGO plateau area, the detritus-lateritic cover with ferruginous concretions of Cenozoic age emerges, this cover is the object of the geophysical characterization proposed for this research.

The area of detritus-laterite coverage is susceptible to contamination (CENTURIÃO; SILVA; GABAS, 2020; SOUZA et al., 2014); therefore, a more detailed knowledge about the geology of this detritus-laterite cover is of great relevance both for the environmental and economic areas of the region, since the water coming from the wells existing in the detritus-

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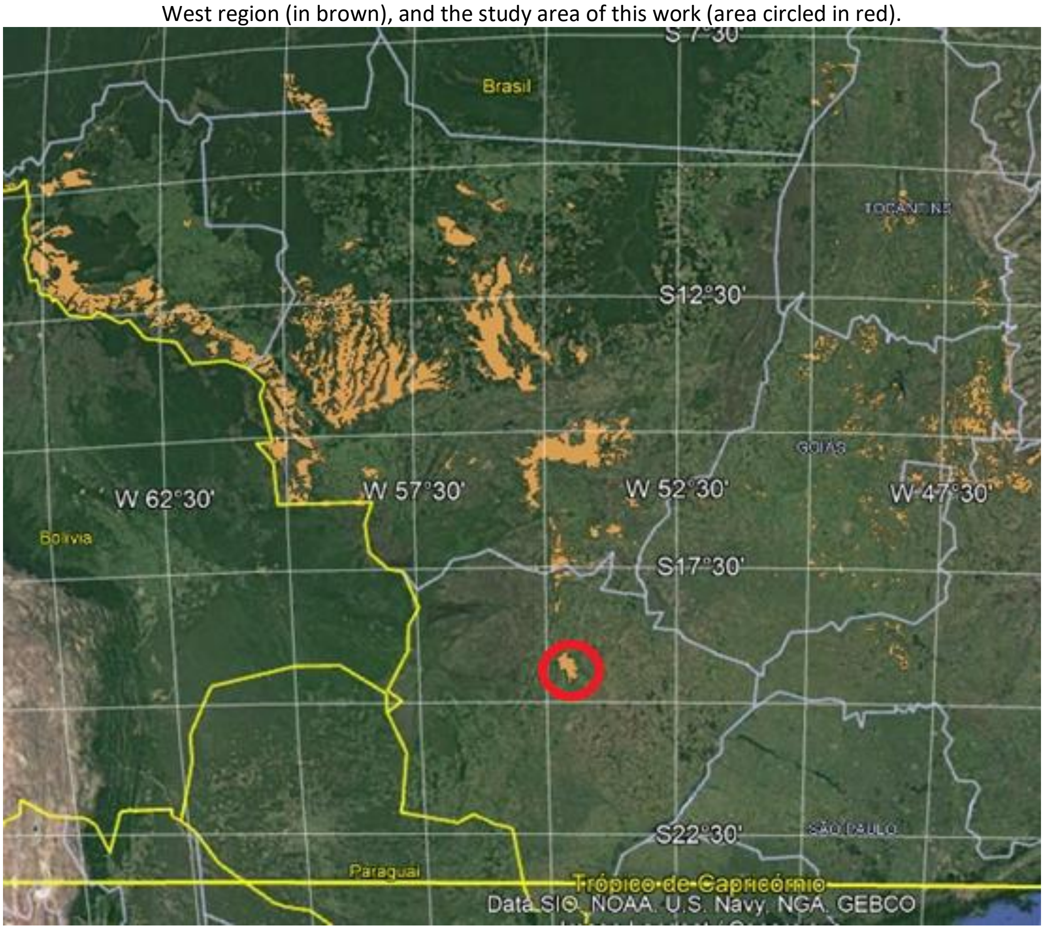
laterite cover is used to supply rural properties and is necessary for the continuity of the town's agricultural development.

In relation to the polluting sources, the covers have characteristics of low retention, fixation and elimination of pollutants, with high permeability, thus making them prone to contamination (ANA, 2014).

According to CPRM (2013), the study area is classified as DCDL and, more specifically, as DCDLi, in which ferruginous crusts occur. There are sandy-clay and sandy-silty deposits, rich in ferruginous concretions; clayey horizon, ferruginous, concretionary or columnar laterite crust, in addition to colluvial and eluvial materials rich in laterite debris and quartz fragments.

As it can be seen on the map in Figure 1, there is a large presence of detrital-laterite coverage, not only in the study area, but throughout the central-western region of Brazil, characterized by its extensions of great regional importance.

Figure 1 - Geological characterization, where we can see the outcrop areas of this type of coverage, the Central-West region (in brown), and the study area of this work (area circled in red).



Source: Vectors (CPRM, 2006), Image (Google Earth, 2022), modified by the author.

2 MATERIALS AND METHODS

To guide the geophysical work of this research, the raw geophysical data provided by (ANA, 2014) was used. However, these were processed and interpreted with a focus on the objectives proposed by this research, that is, the characterization of the detrital-lateritic cover

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and its contact with the underlying layers, in addition to studies on the Fm. Serra Geral. The raw data was processed and interpreted seeking to detail this shallower surface layer. These procedures are explained below when detailing the geophysical methods, as well as the interpretations of the geophysical data were carried out taking into account pre-existing geological knowledge and using information from existing wells in the area.

To interpret these data, sandstones from the Botucatu and Fm formations were considered. Pirambóia as being a single lithology, as they are a single hydraulic system and geophysics, does not have the resolution to correctly separate these extracts. Thus, the descriptions that follow these lithologies will be united and referred to simply as the Aquífero Guarani.

2.1 Geophysical methodology using electroresistivity

Two different techniques from the electroresistivity method were used in this research, namely Vertical Electrical Soundings (SEV's) and Electrical Paths (CE).

These techniques for measuring soil resistivity have the specific objective of this study to better characterize the detritus-laterite layer, in terms of its distribution and thickness, as well as to deepen the understanding of the structural/stratigraphic framework of the region, more specifically determining the existence and thickness of the basaltic layer of the Fm. Serra Geral.

2.1.1 Vertical electrical soundings (SEV's)

The SEV data were processed with the help of Resix software from the company Interpex (INTERPEX LIMITED, 2002). For data modeling, an Anderson-style adaptive linear digital filter was used, for more common matrices, in order to obtain resistivity contrasts. Considering that, this program uses an Inman-style regression approach of non-linear least squares curve fitting, which made it possible to obtain stable results for the inversions.

In it, the values of the sounding curves are entered as apparent resistivity as a function of spacing and direct modeling allows calculating a synthetic resistivity sounding curve for a model with up to ten layers.

Resistivity sounding curves are calculated using linear filters and the shift of data with overlapping curve segments is automatically handled by shifting the synthetic curve to match the shifts between segments in the data. This is done by assuming that the data for the longer spacings are correct and shifting the segments at shorter spacings to match the data at longer spacings (ORELLANA, 1972).

Remembering that, in addition to the model assumed in the best fit of the curve, maximum and minimum thickness, depth and resistivity values that the curve can assume in the modeling are determined, as the solution obtained through a geophysical inversion model is not unique, due to to the ambiguity inherent in indirect data. Variations resulting from the anisotropy of the study area can be considered and the best model for the study area may not be the one with the smallest error (ANA, 2014).

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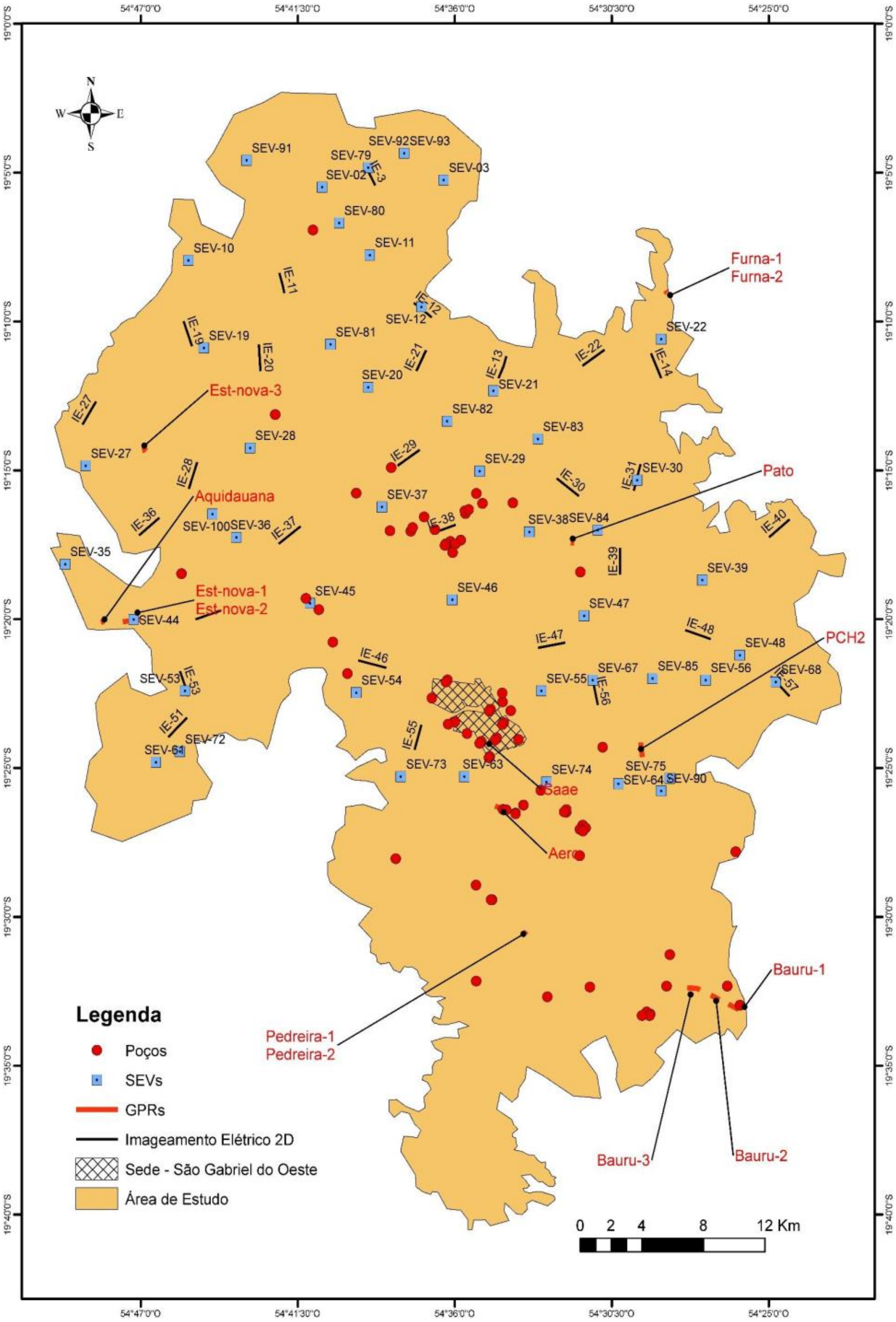
In field surveys to collect data from SEVs, (ANA, 2014) used the SYSCAL PRO model equipment, which has software inside it capable of eliminating undesirable noise, measuring only the potential relative to the transmitted current. This equipment, using cables with an AB opening of 2,048 meters, can penetrate the ground in approximately 512 meters.

Of the one hundred (100) SEVs acquired by (ANA, 2014), forty-three (43) are in the study area, whose location is shown in Figure 2.

Figure 2. Map with the position of Geophysical surveys and existing wells in the study area.



Source: Authors (2023)

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2.1.2 Electric pathways (CE)

The 2D surveys, with the (CE) technique, aimed to determine the spatial distribution of the detrital-lateritic layers in the Chapadão de São Gabriel do Oeste area, their thickness, their different facies, that is, the same objectives of the SEVs technique. However, this technique is complementary, since in addition to measuring the variation in conductivity vertically, it allows measuring the variation in the horizontal direction along the section to be executed.

In this study, a spacing between electrodes of 20 meters was used, which allowed the construction of sections of 1,680 meters each. This opening, and the use of 840 meter cables with a single opening, made it possible to penetrate approximately 240 meters into the ground.

The CE data were processed with the help of Res2dInv from the company Geotomo, which uses the inversion method known as smoothness constrained least-squares method (GROOT-HEDLIN, CONSTABLE, 1990) to model them.

An advantage of this method is that the damping factor and flatness filters can be adjusted to suit different types of data. A detailed description of the different variations of the smoothness constrained least squares method (LOKE, 2001).

The program supports a new implementation of the least squares method based on a quasi-Newton optimization technique. This technique is significantly faster than the conventional least squares method for large data sets and requires less memory. Furthermore, it allows the use of the conventional Gauss-Newton method (GROOT-HEDLIN, CONSTABLE, 1990).

In 2D imaging, the pseudosection is the method normally used to represent the distribution of resistivity values. It is worth mentioning that this pseudosection is an initial guide to establish quantitative interpretations and not a final image of the true subsurface resistivity.

In field surveys, to collect Electrical Tracking data, (ANA, 2014) used the SUPER STING R8/IP model equipment, which has software inside it capable of eliminating undesirable noise, measuring only the potential relative to the transmitted current.

From the sixty-one (61) electrical images carried out by (ANA, 2014), twenty-eight (28) of these are within the study area defined for this research (Figure 2).

2.2 Ground Penetrating Radar (GPR)

For the development of this study, GPR equipment model RAMAC from the Swedish manufacturer MALA inc. was used, equipped with 50 MHz unshielded antennas, antennas that offer the best relationship between penetration depth and resolution required for this research.

To configure data acquisition, the following parameters were used:

- Antenna frequency: 50 MHz (Unshielded)
- Distance between antennas: 4.2 meters
- Time Window: 1,247 nanoseconds
- Sampling Frequency: 410.53 MHz
- Spatial sampling interval: Approx. 20 cm
- Number of samples in time: 512
- Stack: 32

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● Stacking time: 0.16384 seconds.

Regarding the surveys with the GPR method, they were distributed in such a way as to cover the majority of the detritus-lateritic cover. To choose the points, the layer whose cover is underlaid and the existence or not of laterite yokes were taken into consideration. Thus, the location of the profiles was based on the possible contacts of the cover with the rocks observed in the region: Bauru Group, Fm. Serra Geral, Fm. Botucatu-Pirambóia, Fm. Estrada Nova and Fm. Aquidauana.

2.3 Hydrogeological information from licensed wells

To obtain hydrogeological data for the area, the two existing databases relating to this subject were analyzed, the Groundwater Information System (SIAGAS), which belongs to the Companhia Brasileria de Recursos Minerais (CPRM) of national scope, and the SIRIEMA (State), environmental information system of the body responsible at state level for managing water resources, the Mato Grosso do Sul Environmental Institute (IMASUL), and in Figure 2, there is an overview of the wells in the town and the region.

At the state level we have the SIRIEMA database, in which every user of water resources in the State of Mato Grosso do Sul has the obligation to register, this is done through a Water Resources User Declaration (DURH). For those who use more than 600 m3 of water per month or have wells in an area served by a public supply network, in addition to this DURH, they will have to obtain a grant for the right to use water resources.

When considering the focus of this research, the following data that exists in the databases stands out and can be of extreme value for the construction of thematic maps that characterize the study area: the exact position of the well, position of the capture filters within of the well, when drilled the well receives two types of casing, the smooth casing that does not allow water from the aquifer to pass into the well and the perforated casing, which allows water to enter at specific points determined by the geologist after drilling .

With this information, it can be said which aquifer or aquifers the water exploited by the well comes from. Thus, it was possible to define which wells are using water from the detrital-lateritic cover.

3 RESULTS

At this stage, the results of the geophysical surveys are presented, and in this article we briefly present an example of each method used.

3.1 GPR data

For each point studied, an aerial photo is presented, which also serves as a sketch of the survey, photos of the work being carried out in the field and the respective geophysical sections acquired. Each GPR section is marked with a red line, where its beginning will be indicated by the letter “i” and its end by the letter “F”.

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Figures 3 and 4 show the survey location at the contact of the Aquífero Guarani with the detritus-laterite cover. At the beginning of the GPR section (Figure 5), there is no detritus-lateritic cover, which increases in thickness and at the end of the section it already appears approximately 10 meters long. This thickening of the coverage is evident in the quality of the agricultural soil, where its increase in thickness visibly reflects on the quality of the plantations in the area.

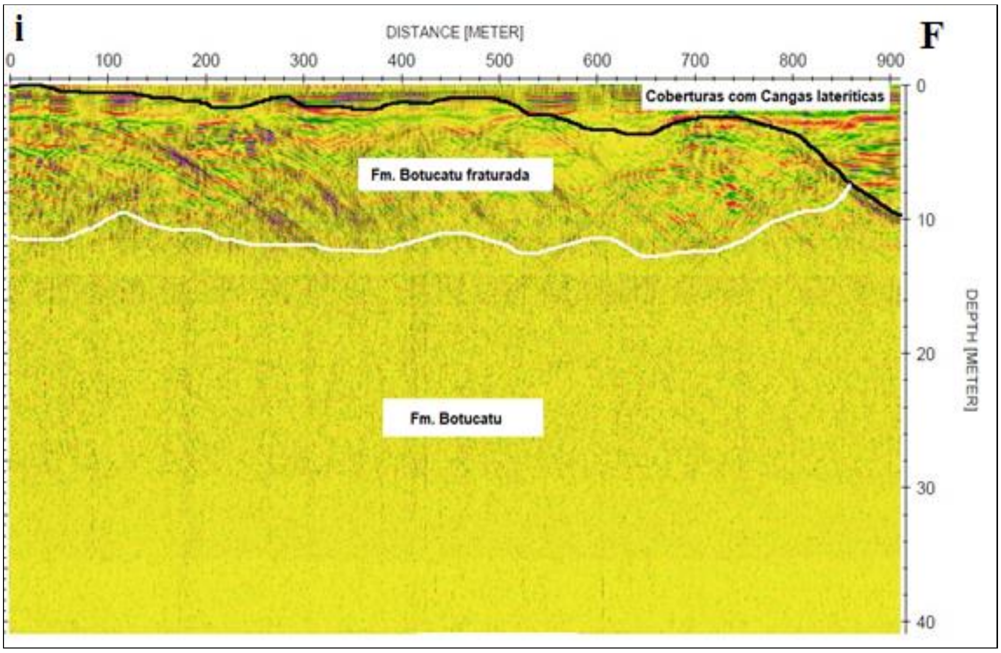
Figure 3. Location of the GPR survey at PCH Ponte Alta, Detritus-lateritic cover over Botucatu Formation (Aquífero Guarani) – PCH Section.

Source: (Google Earth, 2022), modified by the author.

Figure 4. GPR survey at PCH Ponte Alta.

Source: Authors (2023)

Figure 5. Interpreted radargram of the GPR Section - PCH



Source: Authors (2023)

In Figure 3, it can be seen that the plantations next to the GPR line are only very green (good quality in the last 150 meters) where the radargram shows us a coverage already about 5 meters thick, and with a whitish green color on the central part of the line, where the thickness goes from almost zero to approximately 2.5 meters and at the beginning of the GPR line where the Aquífero Guarani emerges, farmers prefer not to plant at all, and the GPR signal presents a great contrast when finding the contact between these layers, which makes defining this contact much easier.

3.2 Geoelectric data

The interpretations of SEVs and CE were supported by the defined geoelectric model, surface geology information and data from deep wells, and in general, the morphological analysis of the SEV curves and CE sections obtained in the field allowed the identification four main electrofacies.

The first is the detritus-lateritic cover that covers the entire Chapadão de São Gabriel study area, which has average resistivities around 300 to 1000 Ohm.m. Large variations in electrical resistivity were detected due to the presence of laterite canga lenses and the great variability in humidity levels, compaction and, mainly, quantity of clay.

The second is the basalts of the Serra Geral formation, which is just below the detrital-lateritic cover in almost the entire study area, with average resistivities of around 4000 to 6000 Ohm.m. Variations in these values were detected, mainly due to the level of saturation, alteration and fracturing of this geological formation.

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The third electrofacies, underneath Fm. São Geral, in a large part of the study area, almost the entire area, presents sandstones from the Aquífero Guarani System, formed by the Botucatu and Pirambóia formations; These sandstones have average resistivities of around 100 to 700 Ohm.m, and the electrical variation in this stratum was small, due to it being quite homogeneous and already in the saturated zone.

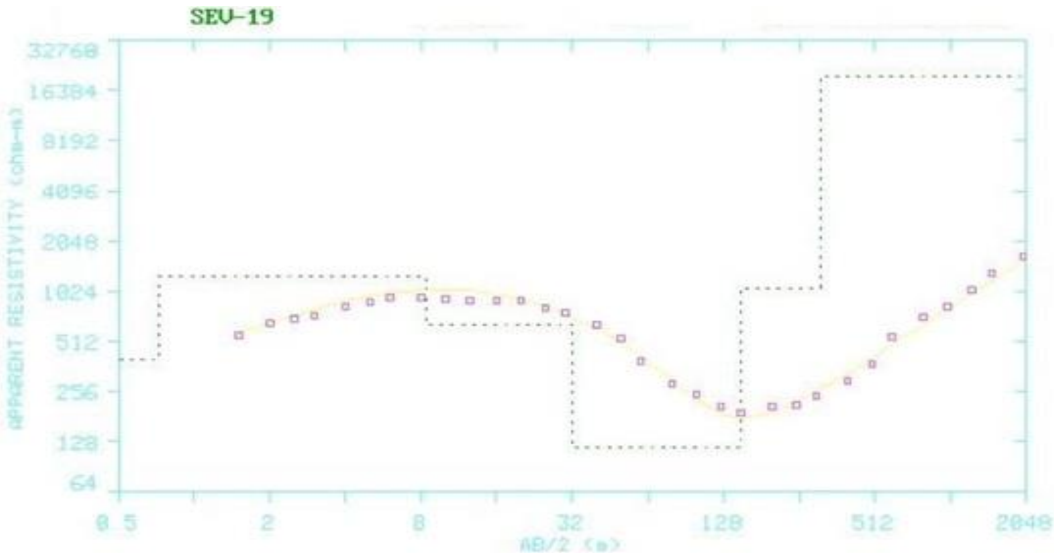
The fourth electrofacies, normally overlapping the Aquífero Guarani System, is the Aquidauana Formation, found throughout the study area. It was detected with average resistivities around 1500 to 4000 Ohm.m, with variations in these values being mainly due to its degree of compaction and fracturing.

In addition to these four main formations, it is worth noting that the presence of the Ponta Grossa Formation was detected in geophysical studies, which is below the Aquidauana Formation and has average resistivities of around 4000 to 6000 Ohm.m. This formation was not described in all surveys, given its great top depth in almost every area of study.

And finally, geophysical surveys detected the presence of the Estrada Nova Formation, with thicknesses between 10 and 68 meters, located on the Aquidauana Formation in the western portion of Chapadão de São Gabriel do Oeste. The FM. Estrada Nova was located at outcrop points (IE 45, SEV 44) and in other surveys it was located below the Fm. Serra Geral (IE 28, IE, 36, IE 37) and just below the Aquífero Guarani (IE 19).

Below we can see an example of SEV and CE acquired in this research, these with their respective interpretations.

Figure 6. Vertical Electrical Sounding processed and interpreted



Litologia	Topo (m)	Base (m)	Espessura (m)	Resistividade média (Ohm.m)
Cobertura detrito-laterítica	0	32	32	800
Aquífero Guarani	32	122	90	120
Fm. Estrada Nova	122	167	45	1000
Formação Aquidauana	167	Indefinida	Indefinida	8000

Source: Authors (2023)

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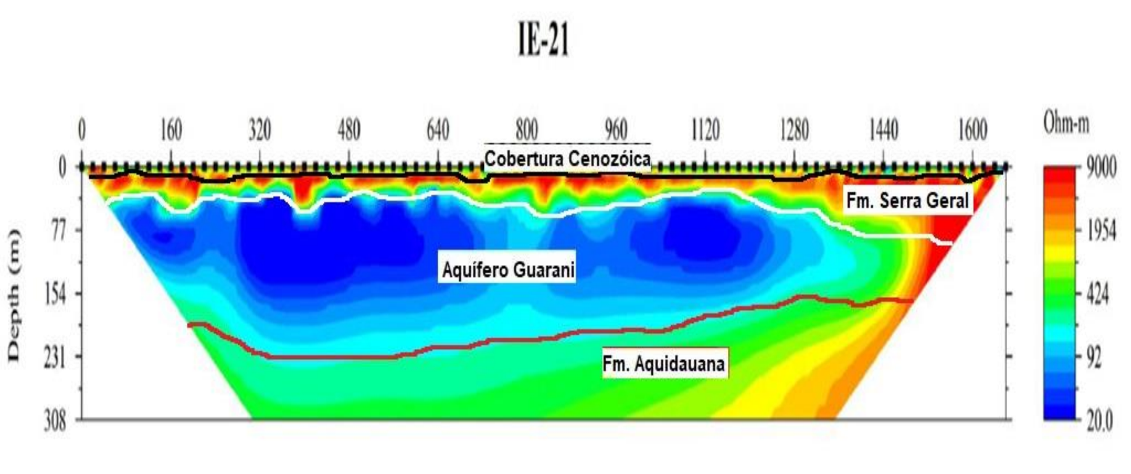
Figure 7. Electrical Path processed and interpreted



Source: Authors (2023)

The data composed of stratigraphic profiles prepared based on the descriptions of the geological profiles of the tubular wells registered in the SIRIEMA system of IMASUL and SIAGAS, the geophysical data of the GPR method and the geoelectrical sections of the vertical electrical surveys and 2D electrical imaging, concatenated with the Existing geological surveys of the study area made it possible to infer the configuration of the geological framework of the area and, mainly, to characterize in more detail the existing detritus-laterite cover and how the laterite canga lenses present there appear.

The presence of the Estrada Nova Formation was identified. The Estrada Nova Formation was identified and mapped in only a few outcrops in the western region of the São Gabriel do Oeste plateau area, and was not observed in the limits of the escarpments to the east.

In no well registered in the area, the occurrence of the Estrada Nova Formation in the subsurface was recorded. This infers that this unit dips gently, from the western edge of the plateau, towards the axis of the basin, in agreement with the other geological units that occur in the area, corroborating the dip pattern on a regional scale of the stratigraphic units of the Geological Basin of the Paraná. This is the conceptual model proposed by (ANA, 2014) and consistent with the data in this work. With the geophysical surveys carried out in this research, it was possible to verify its existence and spatial scope and the variations in thickness of this formation in the Chapadão de São Gabriel do Oeste. It was also possible to infer the spatial and depth coverage of other shallower formations, such as the detritus-laterite cover and the Serra Geral Formation.

With this it was possible to generate isopach maps of the detrital-lateritic cover (Figure 8) and the Serra Geral Formation (Figure 9).

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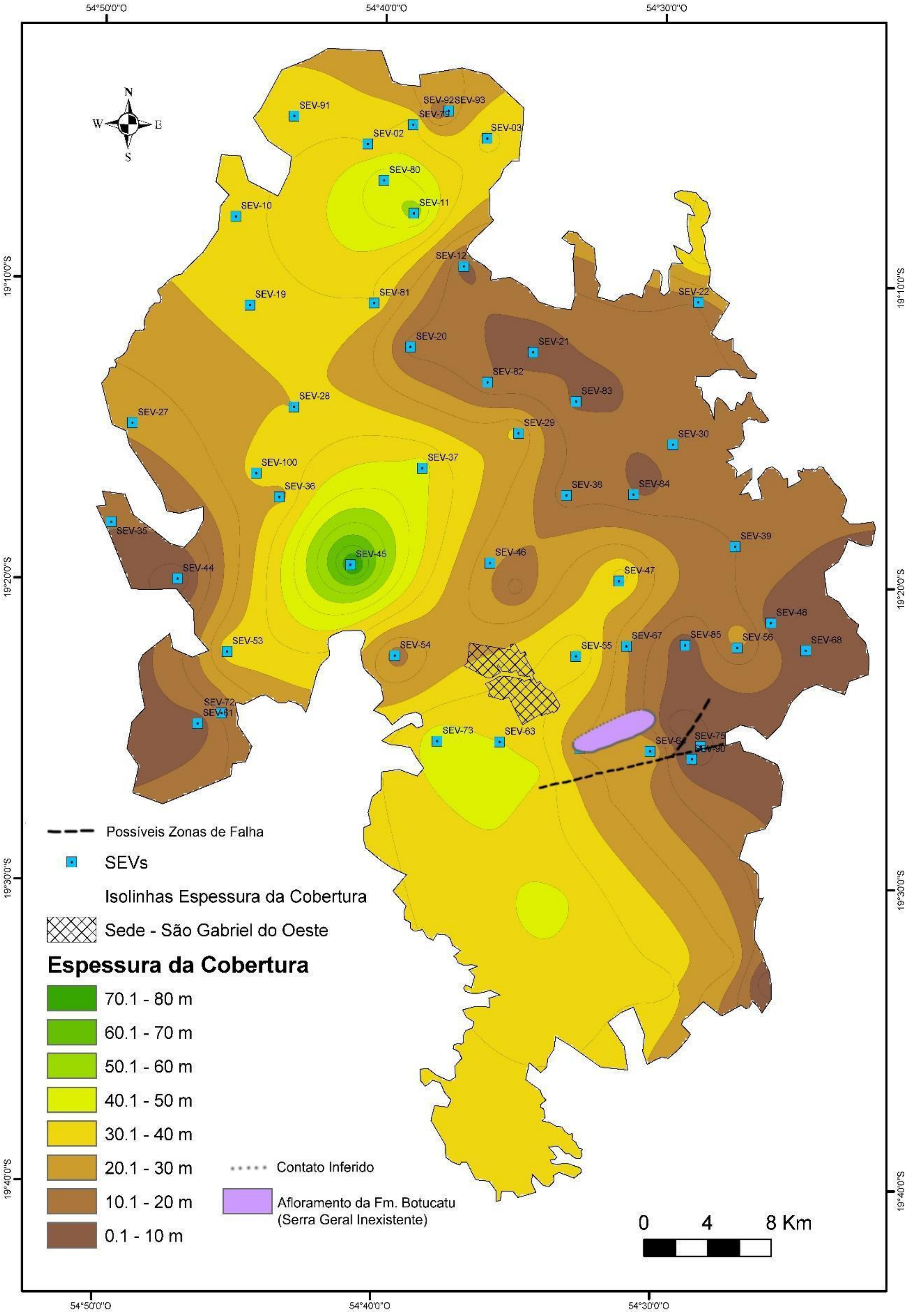
Figure 8. Isopach map of the Detritus-Laterite Cover



Source: Authors (2023)

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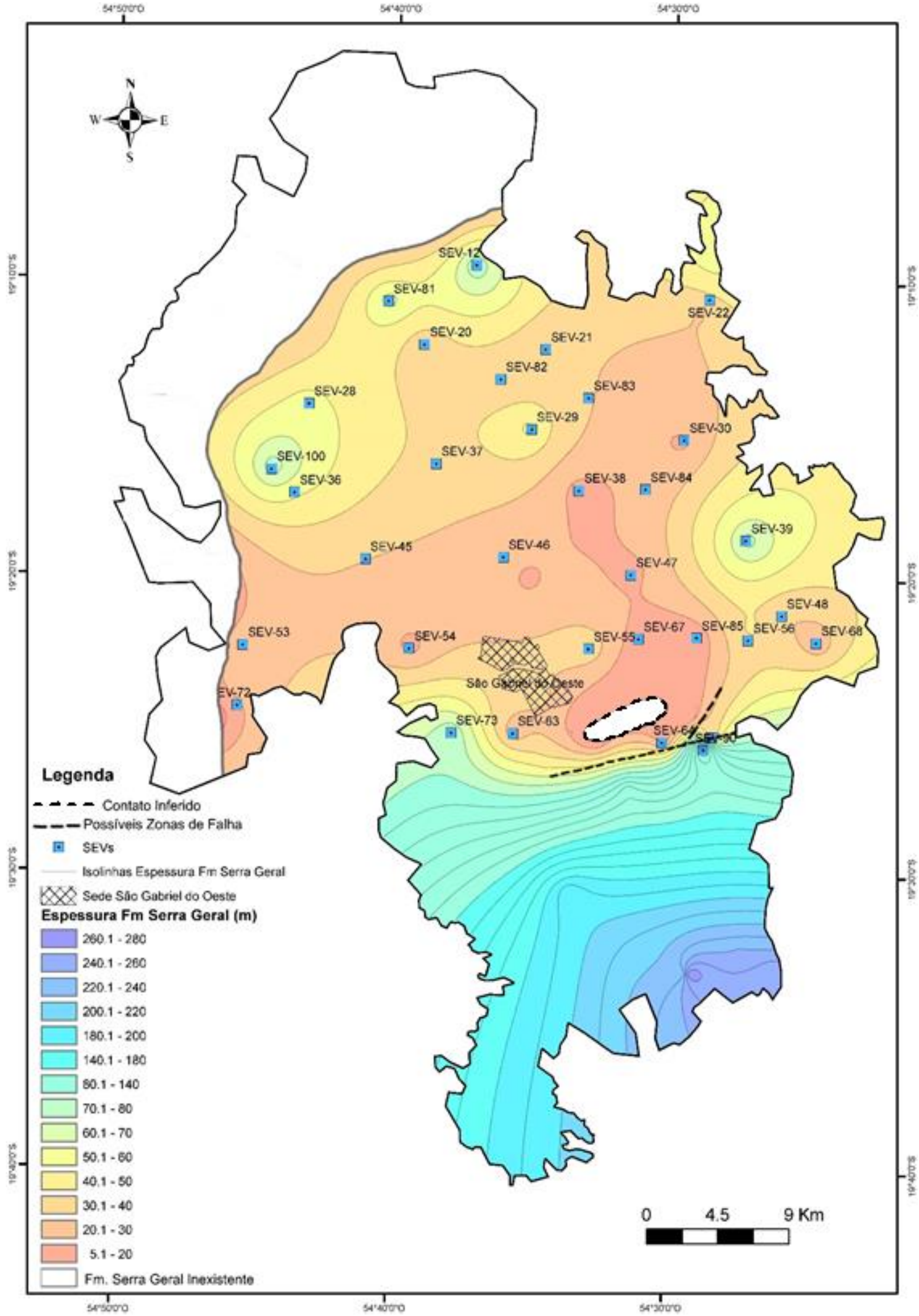
Figure 9. Isopach map of the Serra Geral Formation



Source: Authors (2023)

From the geophysical data and wells, it can be seen that the detrital-lateritic cover of the Chapadão de São Gabriel do Oeste, extends in angular and erosive unconformity over older rocks, whose age increases progressively from east to west and they are dipping towards the center of the basin; the cover covers all these formations with a practically flat-parallel deposition.

Therefore, starting from the eastern edge towards the west, the sediments of the detrital-lateritic cover are deposited on the basalts of the Serra Geral Formation and, as one advances towards the extreme West, this cover consecutively covers the Botucatu, Pirambóia, Estrada Nova and Aquidauana.

It is worth mentioning that throughout the studied area of Chapadão de SGO, where there is Fm. Serra Geral, this sedimentary cover is based on the basalts of the formation, with the exception of a small surface, close to the water intake for the PCH of the Rio Coxim, where the Fm. Botucatu.

According to the ANA's report (2014), this structural situation is due to flexural movements produced by the accentuated sedimentary/igneous overload in the depocenter of the basin, reflecting the uplift of the marginal layers, later eroded and covered by Cenozoic sediments.

This detritus-lateritic cover was detected in GPR and geoelectric profiles with maximum thicknesses of around 80 meters in the central portion of its area of occurrence, and many variations in thickness. These must be controlled by the topography of the terrain and irregularities in the basal contact with the underlying layers, as can be seen in the isopach map (Figure 8).

Regarding the basaltic rocks of the Serra Geral Formation, they cover the Botucatu Formation and, in some points, are laid directly on the Estrada Nova (IE 37, IE 28) and Aquidauana (IE 51, IE 53) formations, outcropping in a small area on the eastern edge of Chapadão de São Gabriel. Under the detritus-lateritic cover, these rocks gradually decrease in thickness, until their complete absence, towards the western limit of the plateau, as can be seen in the isopach map of the formation (Figure 9).

Its thickness in the study area varies on average from 30 to 40 meters, in some points it can be only 10 meters and in others reaching more than 270 meters, and this formation is based on the Fm. Botucatu to the South and East of the area, in the North and West portions, it is based on the Aquidauana and Estrada Nova formations.

This formation appears continuously throughout almost the entire area, it was only not detected on the extreme western edge of Chapadão, where basalt flows no longer occurred and in a small portion (white spot) which is located close to SEV-64, At this point, there is an outcrop of the Fm. Botucatu, which is normally below Fm. Serra Geral, this is very possibly due to the existence of structural faults at the site, this occurrence made the Fm. Botucatu emerges at this point.

Another important aspect observed refers to a strong thickening of the Serra Geral Formation south of the city of SGO, and at the southern limit of the urban area the basalt thickness is 38 meters, proven with the geological profile of the SAAE well (Durh nº 01466), and just 6 kilometers south of this point there is a well from Cooperativa Aurora (Durh nº 016450) with a basalt thickness of 116 meters and if you walk another 11 kilometers south on the edge of the SGO plateau on the border with the In the municipality of Bandeirantes, there are wells from COOASGO (Durh's nº 15078 and 20994) that show basalt thicknesses exceeding 270 meters.

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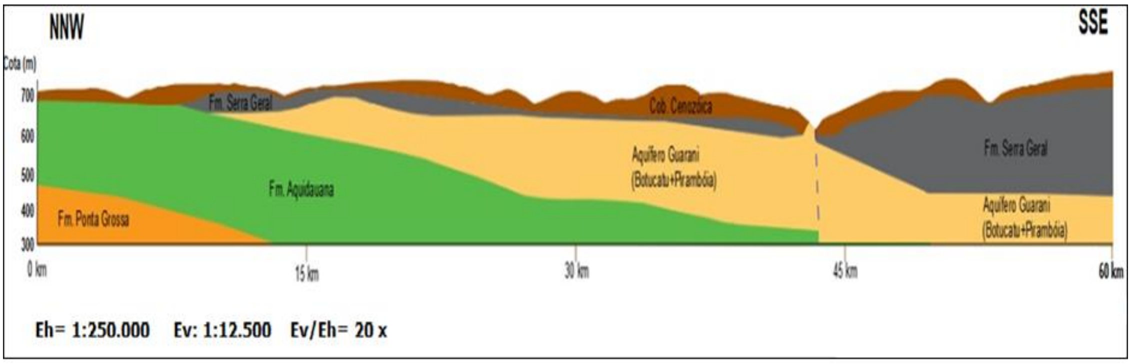
This thickening leads us to believe in the hypothesis of the existence of a fault zone just south of the city of São Gabriel do Oeste, as there is a very strong and disruptive accretion of this formation. This possible fault zone is outlined on the map in Figure 8 with a black dotted line.

Based on these field observations (outcrop of Fm. Botucatu) south of the City of SGO, plus hydrogeological data showing the thickening of Fm. Serra Geral also to the south of the city, and from the data from the reinterpreted SEVs, it can be said that the model with faults appears to be more consistent than the model without the occurrence of faults.

In this research, it was possible to generate the geological profile of the structural framework of the study area in the NNW-SSE direction (Figure 10). This profile is unprecedented for this area, even the (ANA, 2014) report had only generated the East-West profile. In this NNW-SSE profile, the presence of a fault zone was also included, to better adapt the data observed and acquired in the field.

Figure 10. Schematic NNW-SSE geological profile showing an interpretation of the structural configuration of the study area, with competing faults (blue dotted line with inferred position).



Source: Authors (2023)

This profile was generated from data from reinterpreted SEVs and south of the city of SGO (area outside the ANA project), hydrogeological profile data from wells registered with IMASUL were used. Furthermore, in the south of the city GPR profiles and field control were carried out.

In this geological profile, one can observe, in section, the distribution of geological layers in the subsurface. The blue line represents the probable fault zone existing at the location. It is worth highlighting the great variability in the thickness of the layers existing in the area.

In this profile, Fm was not represented. Estrada Nova, as it is only found in a small section on the western edge of Chapadão. This is just below the Fm. Serra Geral and above Fm. Aquidauana, with outcrops of it at some points.

Proof of the continuity of the Serra Geral Formation in the Chapadão de São Gabriel area obtained in this research is of utmost importance for the geological and hydrogeological characterization of the region, as this continuity of the basaltic layer, practically impermeable, and other data collected and interpreted, allow us to conclude Since this detritus-lateritic cover is not part of the Aquífero Guarani, with the exception of a very small area, the covers are not

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in contact with the SAG, as they are isolated from it by the continuous presence of the Fm. Serra Geral.

It is therefore recommended that more specific hydrogeological studies be carried out to confirm and characterize this area as being an aquifer unit, and currently these covers are linked to the Aquífero Guarani in the State Water Resources Program, which was created based on existing data.

With the static level data from existing wells in the area and from the geophysical data, it was possible to generate the potentiometric map of the free aquifer existing in Chapadão de São Gabriel (Figure 11), which is inserted in the detritus-lateritic cover.

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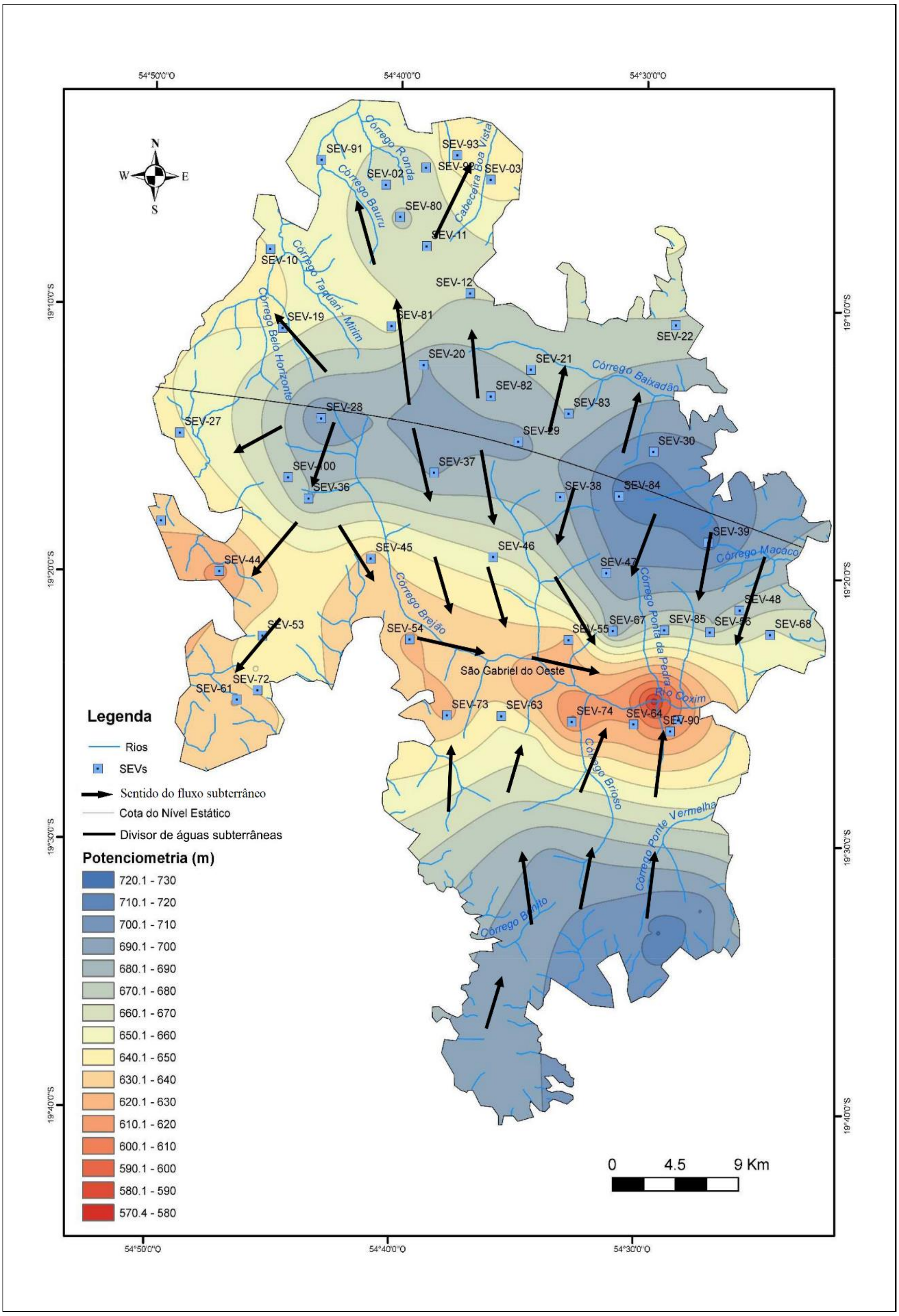
Figure 11. Potentiometric map of the free aquifer in the study area



Source: Authors (2023)

Hydrogeologically, this change in regional potentiometry, when considering a new hydraulic system operating in the region, will change the way we currently consider the

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underground water flow that is released into each existing basin in the Chapadão de São Gabriel do Oeste area, as can be seen on the potentiometric map of the free aquifer existing in the tertiary layer (Figure 11).

It is worth noting that the data from wells south of the city of SGO are more prone to possible errors, as they are declaratory data existing in the IMASUL database, and these may not have had complete scientific rigor in their collection.

However, it should be noted that this potentiometric map is of utmost importance for the hydrogeological characterization of the region, as this is the first map created for Chapadão de SGO, in order to cover it in its entirety.

4 DISCUSSIONS

We can verify the existence of a groundwater divider, which accompanies the surface water divider, demarcated with a black line, which divides the underground hydraulic load, directing the groundwater in two directions, one preferential (Bacia do Rio Coxim) and the other secondary towards the North of the Chapadão de SGO area, the direction of the underground flow is demarcated with black arrows.

In general, we can see on this map that the preferred directions of underground flow tend to follow the distribution of existing water bodies in the study area, following the direction from the headwaters to the lower regions.

The data acquired with GPR made it possible to detect contact between the Bauru Group and the detrital-lateritic cover, which occurs well to the south of the study area, on the border with the town Bandeirantes, this contact had not been mapped until the time. This detection was carried out thanks to the high resolution of this method, which was able to delineate this transition zone.

Finally, it is noted that the different geophysical techniques applied in this study achieved the proposed objectives and the use of more than one geophysical technique, together with geological survey data and well registration, minimized ambiguities that occur in acquisitions that use indirect investigation methods.

For future research, it is recommended that hydrogeological studies continue (hydrochemistry, hydraulic data, etc.) to confirm the detritus-laterite cover as a free and isolated aquifer from the SAG.

Furthermore, it would be ideal to obtain more deep geophysical data to better characterize the possible fault zone of the Fm. Serra Geral and the installation of wells to monitor the static level of the free aquifer in the region south of the urban area of São Gabriel do Oeste, MS to improve the resolution of the potentiometric map in this region.

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5 CONCLUSIONS

After completing the fieldwork and applying the methodology proposed here, some important conclusions were reached, both in the geological and geophysical scope, which were the central objectives of this research, and in relation to hydrogeology. It is concluded, positively, in relation to the applicability of geophysical methods for geological/structural characterization with the electroresistivity and GPR methods.

Regarding the general objective of the research, we can say that it was possible to define the extent and thickness of the detrital-lateritic cover, with a variation of less than 5 meters on the West and East borders and reaching more than 80 meters in the central-west region of the area, represented on the isopach map and on the NNW-SSE geological profile.

Regarding the specific objectives of defining the contacts of the detritus-laterite cover with other underlying formations, we can highlight that it was possible to detect and localize (through GPR) the contact between the detritus-laterite cover and the Bauru Group, this contact which until now had not been mapped in the Chapadão de São Gabriel do Oeste area.

Furthermore, it was possible to verify the presence of the Estrada Nova Formation, not mapped by geophysical methods in Mato Grosso do Sul, only located in some outcrops; in addition to its detection at several points, its depths and thicknesses were obtained.

Regarding the specific objective of defining the distribution and extension of the basalt cover (existence or not of the Serra Geral Fm. in the area), the existence and continuity of the Serra Geral Formation in almost the entire area of the Chapadão de São Gabriel do Oeste, showing that the basalt bodies found in the region are not just isolated igneous intrusions such as diabase sills. To the south of the urban area of the town São Gabriel do Oeste, there is a large increase in the thickness of the Serra Geral Formation, whose disruptive thickening leads us to infer the existence of a fault zone in this location. This interpretation is consistent with one of the models proposed by (ANA, 2014), which is more appropriate.

Finally, regarding the definition of the potentiometric map of the detrital-laterite coverage, the potentiometry of the free aquifer existing in the area was generated, and based on the data acquired in this study, we can conclude that this aquifer should not be directly associated with the Aquífero Guarani System (SAG), as stated in the State Water Resources Plan.

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