Electrical Resistivity analysis of lateritic materials at campus Morro do Cruzeiro, Ouro Preto - MG

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Abstract

In Brazil, the interest in laterites have been at the spotlight in recent decades due to the relationship between these materials and their importance for some geological scenarios, as aquifer recharge in hydrogeology context, geotechnical challenges and the genesis of natural cavities in rock formations. In that regard, this paper aims to apply the electrical resistivity method to investigate lateritic facies from the Morro do Cruzeiro (Ouro Preto, Minas Gerais). The study site was chosen by the variety of geological types of laterites in addition to the availability of previous studies in the literature. In this work, the electric resistivity tomography (ERT) method was adopted using the dipole-dipole array through four sections with 50 m of extension, each one. Data analysis, inversion and three-dimensional interpolation were developed. The results include a conceptual and simplified geophysical model where the resistivity variations were correlated to the laterite facies mapped to the area of interest.

Introduction

The Quadrilátero Ferrífero is located in the south-central region of the state of Minas Gerais. With great economic importance, this region is historically explored due to its variety of mineral resources available, including iron ore, gold, manganese, bauxite and gemological minerals. Other relevant geological materials are the aluminous and ferruginous duricrusts that occur as a product of alteration of various lithological types and may be associated with varied dynamic processes (Augustin *et al.* 2013).

The presence of lateritic materials has its importance in different contexts. In mineral exploration there are described the occurrence of 24 deposits of bauxite in the Quadrilátero Ferrífero (Varajão, 1988); in hydrogeology there are discussions regarding the capping of important aquifers (Mourão 2007, Beato et al. 2005, Coelho 2018) and their contribution to their recharge. It is also possible to highlight the understanding of the water behavior in lateritic materials for environmental (Takahasi & Meirelles 2014) and speleological purposes - regarding genesis (Simmons 1963, Calux 2013, Calux et al. 2019) and cavity geotechnics (Brandi 2018).

Lateritic materials depict genetic and evolutionary complexity. Augustin et al. (2013) highlight different possible processes for the development of lateritic profiles; however, two main contexts are used to explain the Quadrilátero Ferrífero genesis: the first one refers to the laterization of transported materials, while the second type refers to materials that have undergone the laterization process in situ (Varajão, 1988).

This work has as main objective to develop an indirect analysis of lateritic materials using the electrical resistivity method at the Morro do Cruzeiro campus of the Federal University of Ouro Preto, city of Ouro Preto, Minas Gerais – Brazil (Figure 1). The study site was chosen by the variety of geological types of laterites, where ferruginous laterites are found juxtaposed with aluminous ones (bauxites), in addition to the availability of previous studies in the literature.

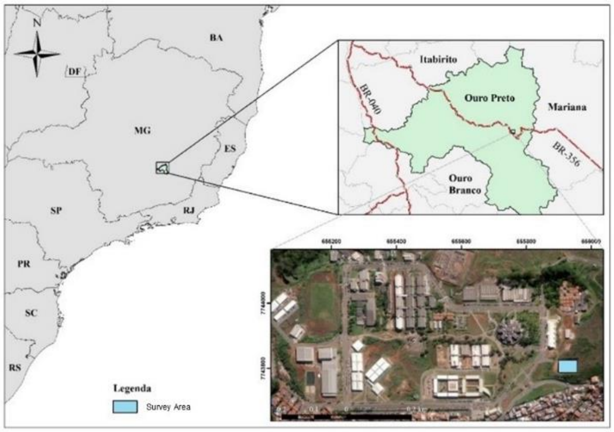

Figure 1 – Location of the study area (References: DNIT –National Department of Transport Infrastructure, IBGE - Brazilian Institute of Geography and Statistics, *Basemap* ESRI, access in 11/04/2020).

Finally, the purpose was to evaluate the progress of the presented methodology and to verify if the variations of electrical resistivity responses can be correlated to compositional and/or structural variations of the investigated geological material.

Methodology

The approach to electrical resistivity analysis in this study is based on the use of the method for resistivity data acquisition, followed by the data analysis, the inversion processing, and three-dimensional interpolation.

The geophysical survey was carried out on June 8, 2019. The dipole-dipole array was applied trough electric resistivity tomography (ERT). The array and technique were chosen trying to find more accurately evaluation of the lateral variations of the medium and expecting a better surface resolution.

Four lines, parallel to each other, were planned, each 50 meters long. The spacing between the lines was 10 meters, totaling a study polygonal of approximately 200 m². The spacing adopted for the electrodes was 5 meters, a level of detail that was considered adequate to the work proposal. In addition, 6 levels of investigation were conducted, reaching a theoretical depth (without inversion) estimated at approximately 17.5 meters.

The exploratory data analysis was conducted using Python scripts – some libraries were applied, as Numpy (1.19.1) for computational algebra; Matplotlib (3.3.1) and Seaborn (0.10.1) to data visualization and Pandas library for data analysis.

For the inversion and production of the resistivity profiles, the software RES2DINV was applied joined by Oasis Montaj 9.8 software for 3D visualization and data integration – geophysical response and geological contacts.

Exploratory Data Analysis

Using the concept of descriptive statistics, categorized among measures of location, shape and spreading (Isaaks & Srivastava, 1989), the database was analyzed from the perspective of parameters that are presented in Table 1. These results were used in order to support the stage of processing and interpretation of products.

Comparing the discrepancy between the mean and median, it is noted that the data have asymmetry. This condition can be confirmed by observing the values of variance and standard deviation. Anyway, for the first approach, it is not necessarily a problem with the database – this condition can be a response to a measure of electrical resistivity in a natural and heterogeneous material.

Table 1 – Summary of parameters, descriptive statistics, of the sample.

Parameter	Value	Type
Total Data	132	-
Minimum	0.060	-
Maximum	2637.600	-
Mean	207.364	Localization
Median	3.365	Localization
25%	1.940	Localization
50%	3.365	Localization
75%	142.975	Localization
Variance	238096.758	Spreading
Standard Deviation	487.952	Spreading

Shape measurements were calculated - asymmetry coefficient and variation coefficient, given respectively by Equation 1 and Equation 2. The values CS= 2.000 and CV= 3.412 confirmed the accumulation of low resistivities in the sample.

$$CS = \frac{\frac{1}{n}\sum_{i=1}^{n}(v_i - m)^{3}}{\sigma^{3}} \qquad \text{(Equation 1)}$$

$$CV = \frac{\sigma}{m} \qquad \text{(Equation 2)}$$

These parameters are important to geostatistical evaluation since they are normalized by measures of the sample. Therefore, by the results of both, there are a confirmation of the asymmetry of the sample. The asymmetry can be confirmed by the histogram of the data – Figure 2.

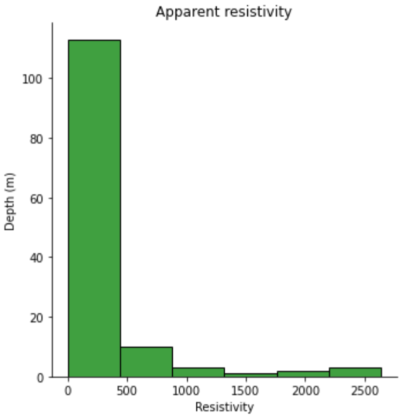

Figure 2 – Histogram of apparent resistivity.

In order to advance in the exploratory analysis, it was sought to understand whether low resistivities were allocated to specific lines of the survey or whether this was a response distributed throughout the investigation area. In this sense, boxplot graphics were constructed for each of the survey lines (Figure 3) and subsequently the data were allocated in 2D (Figure 4) and 3D (Figure 5) environments in order to allow the visualization of the discrepant resistivity zones.

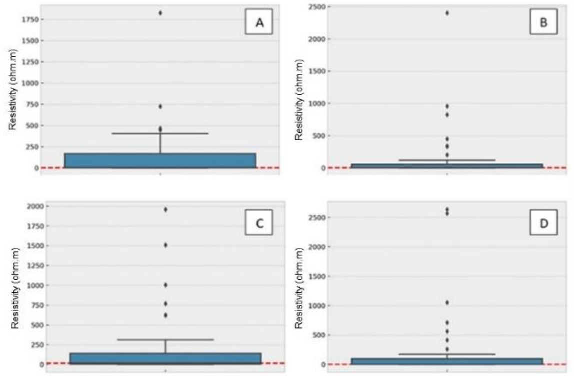

Figure 3 – Boxplot chart for each geophysical survey line, corresponding to the letters A, B, C and D, respectively as lines 01, 02, 03 and 04. In red and dashed, the median line stands out.

Approaches of data visualization were applied trying to understand the spatial distribution of the resistivity and to help verifying the adherence at the geophysical inversion stage.

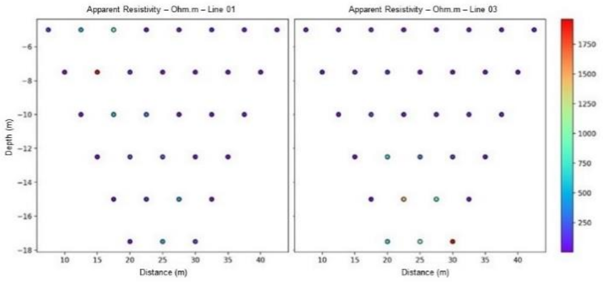

Figure 4 – Electrical resistivity points for lines 01 and 03.

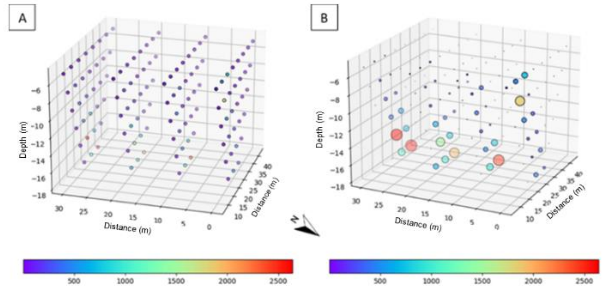

Figure 5 – 3D integration of the theoretical depths and apparent resistiviy. Image B weighs the spot size by the intensity of the resistivity.

From the presented graphical and numerical analysis of the data, it is evident that low resistivity were distributed along all the area of the survey, proving the coherence of the database.

Data Integration and Results

The interpretation of geophysical data was conducted based on data from regional mapping (Baltazar 2005), and, mainly, by the literature related to the characterization of the laterites of the site of study (Assis 2018) – the product made possible to define areas of aluminous and ferruginous resistivity response – Figure 6.

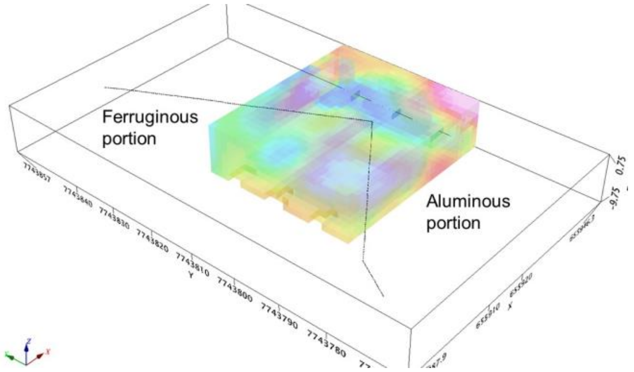

Figure 6 – Resistivity model and geological units described by Baltazar (2005).

The limits were model, initially, in the definition of zones with the highest expectation of the existence of humidity (low resistivity) up to the most resistive zones, which, in the first approach, are not expected to have a significant presence of water.

The resistivity responses were grouped based on the expected morphologies and described in the field for the cangas facies present in the study area. Thus, it should be emphasized that in a generic way the laterites of the area, both aluminous and ferruginous, present facies that are distributed in tabular geometries. This geometry expectation was even important to define the qualitative adherence of the inversion products by the smoothness-constrained least-squares method.

The first level grouped during modeling represents the interpolated resistivity data by kriging up to -100 (Figure 7). This unit was defined as a unit of low resistivity and tabular morphology concentrated at the top of the model. This set of resistivities is concentrated in the aluminous portion, although in the ferruginous portion this level of resistivity is found in the most superficial portion investigated.

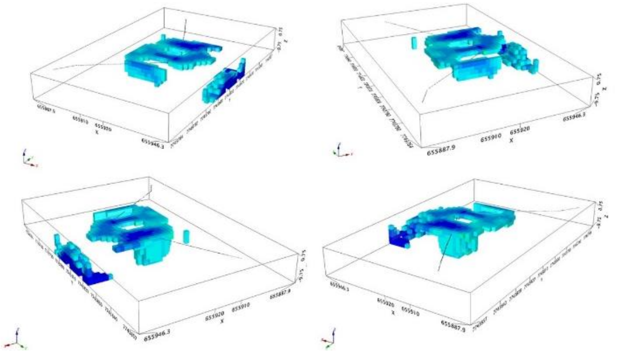

Figure 7 – Spatial arrangement of low resistivities in relation to the geological contact of the literature.

The second level of resistivities consisted of grouping the most resistive portions (above 1000 Ohm.m), with a more pronounced concentration in the lower portion of the generated model, extending to the surface in the portions where the occurrence of ferruginous canga is described (Figure 8). The geometry of this unit has more spheroidal characteristics and is not distributed in a planar way as described for low resistivities.

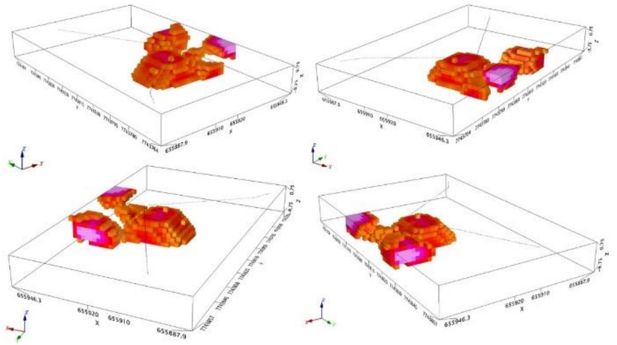

Figure 8 – Spatial arrangement of high resistivities in relation to the geological contact of the literature.

The units of intermediate resistivities correspond to most of the sample. Although they make up most of the model, they do not tend to be diagnostic for the study. Thus, the third grouping interpreted, accounts for values between -100 and 1000 Ohm.m of the interpolated model (Figure 9).

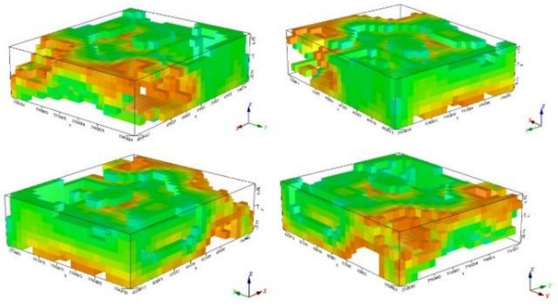

Figure 9 – Spatial arrangement of intermediate resistivities in relation to the geological contact of the literature.

Integrating the physical properties of the materials in the area, described by Assis (2018), it is possible to propose correlations with the responses indicated by the electroresistance models. The aluminous laterites have a significant amount of clay minerals in the massive facies, while the ferruginous laterites have pockets of fragmented material in the middle of the massive facies, which is associated with a preferential water path.

Seeking a correlation with the geophysical data, it is first possible to consider that the amount of clay minerals (low permeability) in the aluminous canga facilitated the accumulation of high resistivities in that portion.

In the portion modeled as ferruginous canga, especially in the “massive / fragmented” facies, punctual accumulations of low resistivity were observed.

In general, for both types of laterites (aluminous and ferruginous) were observed a significant increase of resistivity with the increase of the investigated depth. This result fits with the idea of greater difficulty of water infiltration in the medium, except for the presence of specific textural characteristics that favors this infiltration / presence of water.

It is important to highlight that resistive responses do not indicate flow and do not respond specifically to a type of material, but are very well associated with moisture in the medium, which potentially indicates the presence of water associated with low resistivity responses and the absence of water in high resistivity zones.

In the present work, it is understood that the degree of saturation may occasionally have less influence on the resistivity of the medium, however, in the case of clays, the resistive response may be conditioned directly to the volumetric humidity as presented by Aquino (2010) and Campos (2015).

Conclusions

The applied methodology, based on the integration of different tools, from free resources such as Python data analysis to the geophysical data inversion using RES2DINV and Oasis Montaj for 3D visualization, enabled a complete analysis of the dataset and an interpretation with more confidence in the product.

The survey relied on a relatively restricted size dataset, on the other hand, data analysis (before and after processing), statistical approaches and geological modeling resources allowed to extract information that contributed to the comprehension of the medium and to develop a simplified analysis of the geology.

Regarding the processing of the resistivity data, it can be said that the inversion resources by least-squares presented, for the specific case, results more consistent with the geological context, of facies more oriented to a planar distribution. Eventually, more significant linearity breaks may still be associated with the transition between facies, however, the transition indicated consists of a simplification where, in the field, these variations tend to be more gradual.

The inverted products indicated a great amount of noise, recommending the absolute effort of the survey operator to suppress the unwanted influences on the data. However, this condition may be potentially associated with the characteristics of the material, and the resistivities measured during the survey were very dispersed.

The generated model is applicable to support the understanding of the investigated geological context, more specifically to distinguish aluminous and ferruginous zones.

The array and spacing applied were sufficient for the sampling of the study conducted, on the other hand, they did not have significant resolution in the most superficial facies (canga facies and nodular facies, respectively for ferrous and aluminous material). For the characterization of this portion of the geological material, it is recommended to use smaller spacing without compromising good field practices, such as contact resistance control.

The generated products made it possible to characterize units of low, intermediate and high resistivity, which presented relative spatial concentration. From the interpreted model, integrating geology and geophysics, a more abrupt transition of resistivity levels was observed in the investigated aluminous portion, while ferruginous laterite showed more punctual responses of low resistivity. Such distribution of physical property was associated with the presence of water (or the variation in humidity) and subsequently interpreted as a result of the textural peculiarities of each material, meeting the objectives proposed for the work.

Therefore, the proposed methodology proved to be effective for in-depth characterization of more aluminous and ferruginous areas in laterites. In this way, the resource can be replicated to different areas with a similar geological context, bringing advantages such as non-invasive, indirect three-dimensional visualization, maximizing results and decreasing costs.

Acknowledgments

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