INTEGRATION OF GEOPHYSICAL METHODS TO DEFINE THE GEOLOGICAL INTERFACES FOR A FUTURE METRO STATION LOCATED IN BRASILIA – DF, BRAZIL

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RESUMO – Neste trabalho foram utilizados os métodos geofísicos de eletrorresistividade e sísmica de refração rasa em uma quadra do bairro da Asa Norte em Brasília-DF, onde haverá uma futura subestação de metrô. O objetivo deste estudo é elaborar um modelo geofísico 2D da subsuperfície e observar qual a profundidade ideal para construção desta subestação de metrô. Nas aquisições dos dados de sísmica de refração foram usados geofones de 14 Hz; na eletrorresistividade utilizou-se o arranjo dipolo-dipolo. Os resultados geofísicos foram correlacionados e o modelo interpretativo obtido com base nos resultados geofísicos apresentou três camadas distintas. Observou-se uma boa correlação entre as profundidades da primeira interface obtidas com os dois métodos.
Palavras-chave: Brasília, metrô, eletrorresistividade, sísmica de refração.

ABSTRACT – In this paper the geophysical methods used were electrical resistivity imaging and shallow seismic refraction in an area at Asa Norte in Brasília-DF, where will be constructed a future substation for the metro subway. The objective of this study is to develop a 2D geophysical model of the subsurface and observe which is the ideal depth for the construction of the foundation of the metro station. For the data acquisitions on seismic refraction were used 14 Hz geophones; for resistivity was used the dipole-dipole array. The results were correlated and geophysical interpretation model obtained based on the geophysical results showed three distinct layers. There was a good correlation between the depths of the first interface obtained by the two methods.
Keywords: Brasilia, metro, electrical resistivity imaging, seismic refraction.

INTRODUCTION

Geophysical studies in geotechnical problems can be used for guidance on what procedures may be adopted to minimize: time, costs, and even the chance of occurrence of accidents during the constructions. The main advantage on using geophysical methods is that these are indirect and non-destructive methods; in other words, provide information of the subsurface, without the use of boring (Soupios et al., 2007). However the geophysical methods will not substitute completely the use of boreholes. These methods are also used to study conditions of a specific location or environment, such as study of dump sites (Cavalcanti et al., 2011; Costa & Malagutti Filho, 2008).

There are several studies using geophysical methods in engineering problems, as in the detection of ancient foundations (e.g. Soupios et al., 2007; Boudreault et al., 2010) and planning on building a new neighborhood (e.g. Khalil & Hanafy, 2008; Silva, 2011). In Brazil the geophysical methods most used in geotechnical studies are the resistivity and seismic refraction methods (Braga, 1997; Prado, 2000).

In this work was used resistivity and seismic refraction investigations to study the shallow subsurface of a site where will be installed a substation for the future expansion of the metro of Brasilia, Brazil. The objective of this work is to generate a geophysical model of the subsurface from geophysical results, to identify the rock properties variations of the subsurface providing information which may help during the planning and construction of the metro expansion. Also to verify the effectiveness of the application of such methods in an urban area of Brasilia.

STUDY AREA AND GEOLOGY

The city of Brasilia is located between the south latitudes 15º30' and 16º03' and the west longitudes 47º25' e 48°12', in the Midwest Region of Brazil (Figure 1). The study site is inside of the metro expansion area of Brasilia, next to the Asa Norte Block 116 (SQN 116). The investigated section has a total length of 590 meters.

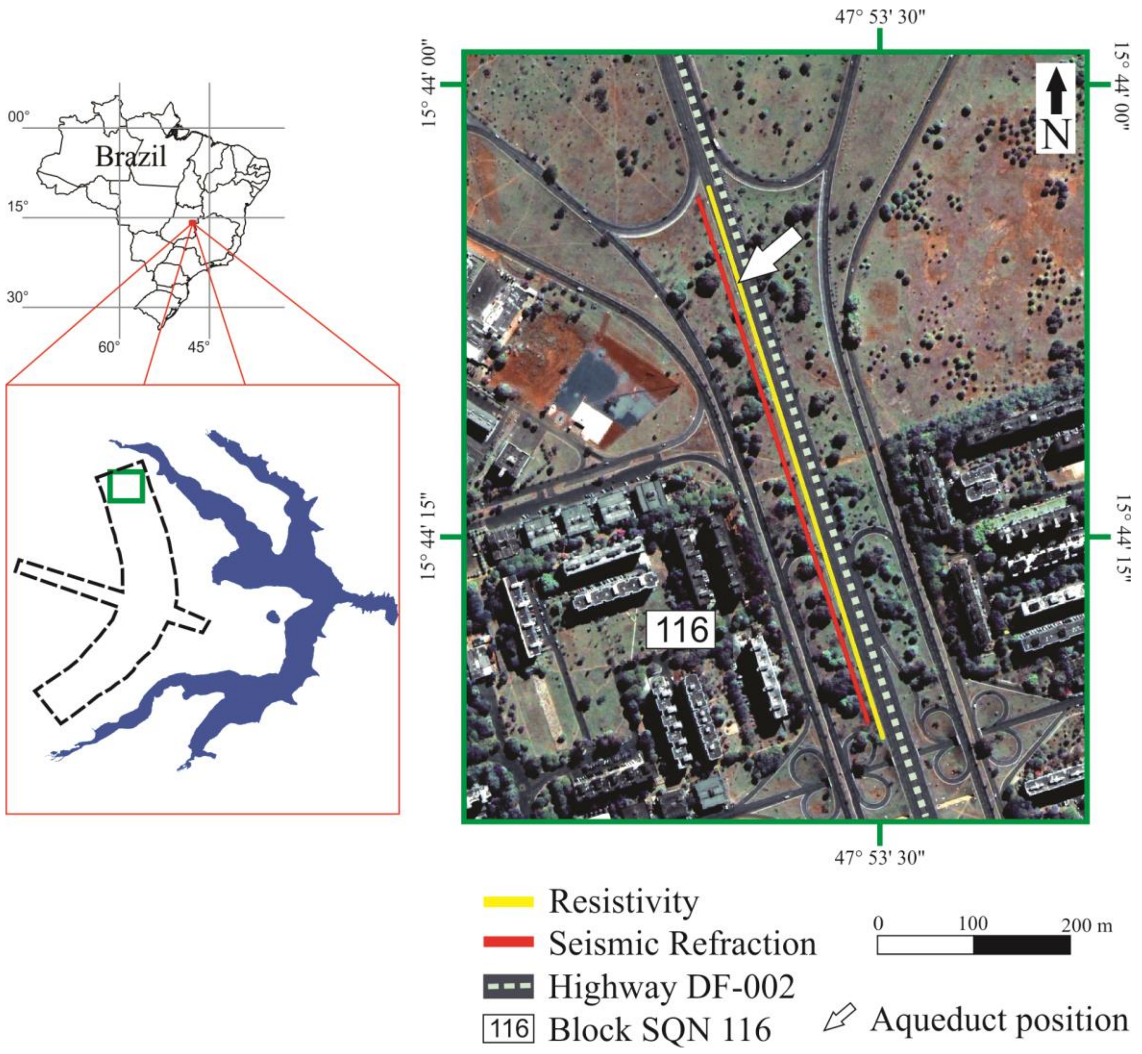

Figure 1. Study area location.The black dashed line is the main urban area of Brasilia (Plano Piloto), Brazil and in blue represents the Paranoá Lake. The W Road is between the Block SQN 116 and DF-002.

The predominant soil in Brasilia is the Red Latosol (EMBRAPA, 1978). The morphological sequence consists in the horizons moderated *A*, latossolic *B* and *C*. The surface horizon *A* is developed with a thicknesses between 20 and 50 cm, with dark red color. In this horizon the abundant presence of roots shows a portion of the near surface, darker than the upper surface, indicating lower presence of organic material in the upper level caused by human activities on the ground, since the area is served as a profile for constructions and gardening. In general the *A* horizon has granular structure, being very friable when humid (Martins, 2000). The subsurface horizon *B* exhibits an important stage of weathering with clay and weak granular structure with a thickness often greater than 250 cm. This horizon can be subdivided into layers *Bw1* and *Bw2*. However, they have little or no differentiation between them. The *C* horizon is characterized as a layer below the *solum* (*A* and *B* horizons), less affected by pedogenic processes while maintaining the original characteristics of the rock (altered rock or saprolite).

A regionally study of Brasília was made by Freitas-Silva & Campos (1998) and ZEE-DF (2012). The study area is located inside of the Paranoa Group (Figure 2). This group has eleven geologic units: Sao Miguel Conglomerate (SM), Metarhythmite (R1), Quartzite (Q1), Metarhythmite (R2), Conglomerate Quartzite (Q2), Argillaceous Metasiltite (S), Slate (A), Arenaceous Metarhythmite (R3), Medium Quartzite (Q3), Argillaceous Metarhythmite (R4), Metapelitic and Dolostones (PPC) (Freitas-Silva & Campos, 1998). In the site of the study area only two geological units occurs: the Argillaceous Metasiltite (S) and the Slate (A). The S Unit has an average thickness of 500 meters, consisting in a set of homogeneous argillaceous metasiltstones with color of gray-green to yellow when fresh, moving the pink and dark red shades when increased the weathering. The A Unit has a maximum thickness of 70 meters, consisting of purple slates when changed or gray-green when fresh and always looking smooth.

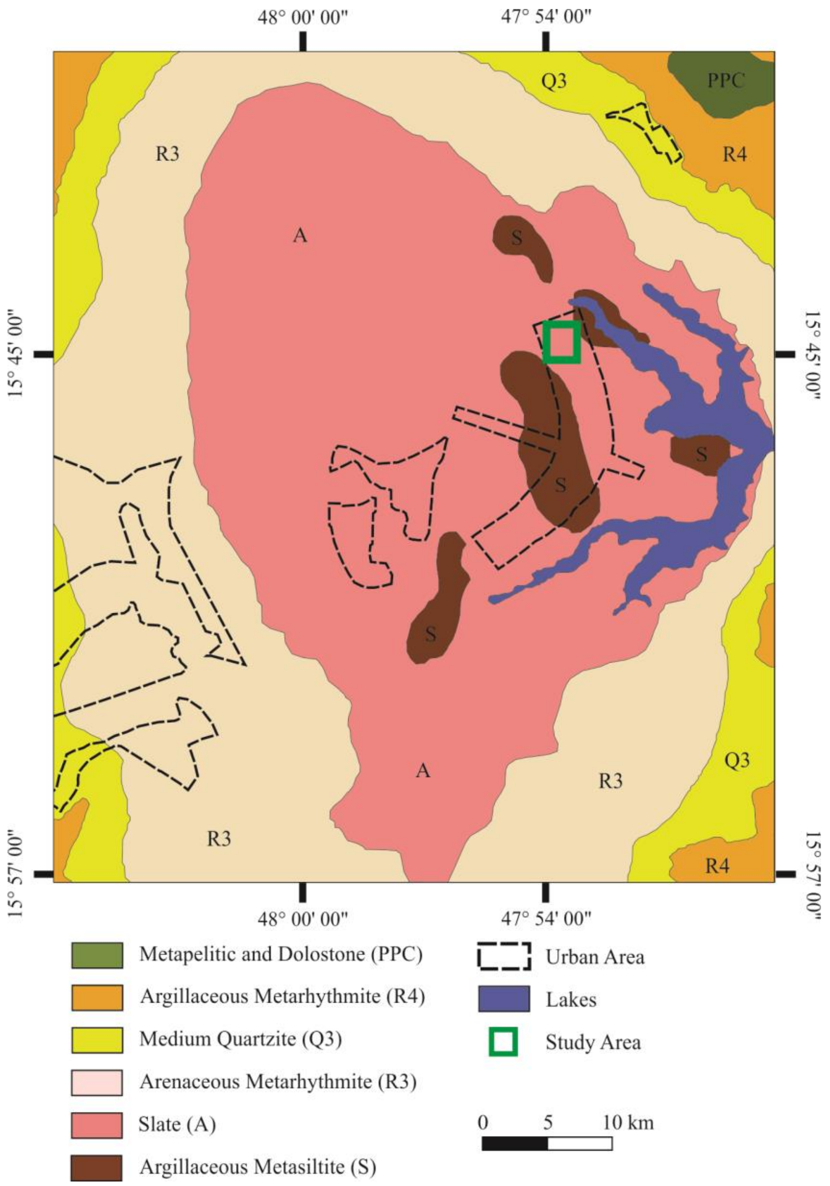

Figure 2. Simplified geologic map showing central part of the Paranoa Group (modified from Freitas-Silva & Campos, 1998).

THEORETICAL PRINCIPLES

Resistivity

The electrical resistivity method measures the apparent resistivity (ρ_a) parameter of the ground/rock. The principle consists of an electric current (I) injected into the ground by means of a transmitter (batteries or generator) connected to a pair of electrodes A and B, and the resulting potential difference (ΔV) generated can be measured between two electrodes M and N in the surface (Loke, 2010). With the current and the potential difference, it is possible to calculate the apparent resistivity by the equation 1.

$$\rho_a = \frac{\Delta V}{I} K \quad (1).$$

Where K is the geometric factor defined by the geometry of the dipoles AB and MN during the measurements, according to the equation 2.

$$K = \frac{2\pi}{\left(\frac{1}{AM}\right) - \left(\frac{1}{MB}\right) - \left(\frac{1}{AN}\right) + \left(\frac{1}{NB}\right)} \quad (2).$$

Seismic Refraction

The seismic method is based on mechanical wave's (seismic waves) propagation, and is used to obtain the velocity distribution of the subsurface, since the velocity depends on the elastic properties of the rock. The seismic waves are generated by artificial sources (hammer, explosive seismic rifle, etc.) and are detected by receivers (geophones) fixed on the ground and separated by a constant distance.

The seismic refraction method is based on the detection of the first arrive of the seismic wave in the receivers (direct waves and critical refracted waves). The time measured by several receivers associated to the distance has a linear behavior. The parameters provide the velocity (slope) and the intercept time (linear coefficient). From this parameters and using the Snell Law, it is possible to obtain the thickness and depth of each layer. In order to use this method, the velocities needs to increase with the depth. More details of the method can be found KNODEL *et al.*, 2007 and KEAREY *et al.*, 2009.

METHODOLOGY AND DATA ACQUISITION

The data acquisition occurred only on Sundays because the traffic in the highway DF-002 is interrupted by the city administration for the leisure activities for the citizens. The idea was to reduce the level of seismic noise caused by car traffics and also to spread the instruments crossing the access path to DF-002, also interrupted in those days.

Resistivity

The most common electrical methods used in engineering and environmental investigations are vertical electrical soundings (VES) and electrical resistivity imaging (ERI). In VES, the distance between the current and potential electrodes is expanded in a regular manner between readings, increasing the depth and thus yielding information of the electrical properties of subsurface. With ERI the electrode spacing are fixed and measurements are taken at successive intervals along a profile (Butler, 2005). The advantage of using resistivity imaging is the exploiting ability and the capacity to observe and analyze large numbers of electrode combinations, developing a detailed resistivity image of the subsurface. Instead of creating simple layering information, the resistivity imaging can settle and show small and irregular anomalies, even in areas of complex geometry.

In this work was used multi-electrode resistivity SYSCAL PRO 72 (manufactured by Iris Instruments) with 60 steel electrodes. The electrode arrangement used was dipole-dipole, due to a better lateral resolution, resistivity contrast and sensitive to detect the bedrock (Ward, 1990). The spacing between the electrodes where 10 meters, leaving the profile with a total length of 590 meters. The acquisition protocol enabled the imaging of 29 levels with 1218 points of investigation, reaching about 71 meters of depth. The data were processed and modeled with the software RES2DINV (Geotomo, 2010).

Seismic Refraction

To implement the refraction method in this work six profiles were performed in sequence, each profile were 94 meters long, having a total length of 584 meters (Figure 1). During the acquisitions were used 48 channels with geophones of 14 Hz, spacing two meters between them. The positions of the seismic sources for each line were -2, 47 and 96 meters away from the first geophone, considering it the position zero for each line. A sledgehammer with eight kilograms of weight was used as source and hammered 20 times against a metallic plate at each shot point, in order to increase the signal/noise ratio by summing the signal generated by each impact.

During the first acquisition tests, even during the traffic interruption of the DF-002, was observed a high noise level on the seismograms, especially for the geophones more distant to the source location (Figure 3a). Due to this fact, a new acquisition test was made by increasing the number of shots (from 20 to 60 shots). During the acquisition was notice just after the 20th shot there was no improvement in the quality of the data, signal received. The equipment used for data acquisition was a GEODE (Geometrics Inc). For the data processing, the program used was SEISIMAGER 2D, by OYO Corporation.

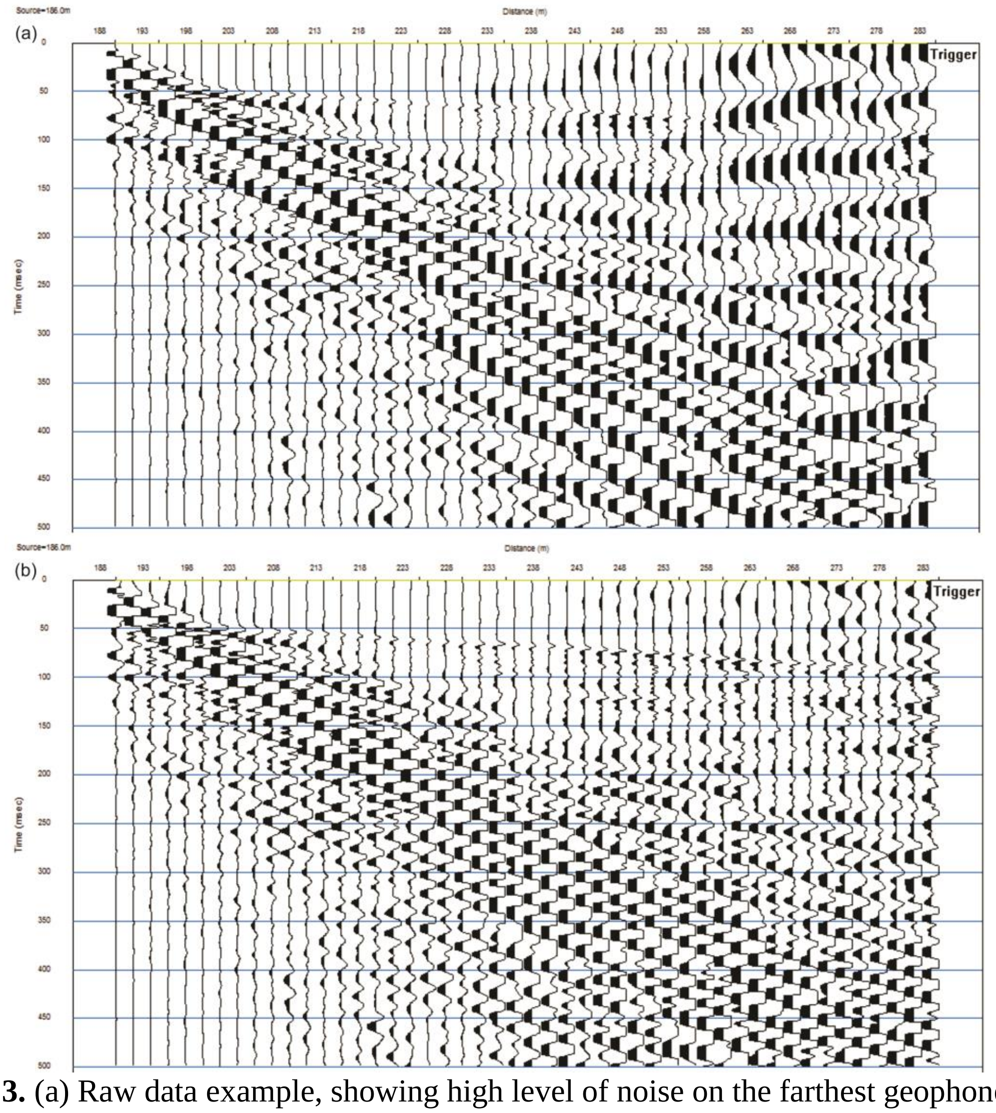

Figure 3. (a) Raw data example, showing high level of noise on the farthest geophones. The position of the source point is 186 meters. (b) Filtered data with Low Cut Frequency (LCF) of 37.96Hz.

RESULTS AND DISCUSSIONS

Comparing the results obtained with seismic refraction and resistivity methods, was possible to prepare an interpretative model of the geology of the study area (Figure 4). In Figure 4c, is proposed a model with three distinct layers, where the first was interpreted as soil and embankment, the second has saprolite characteristics and the third interpreted as the fresh rock.

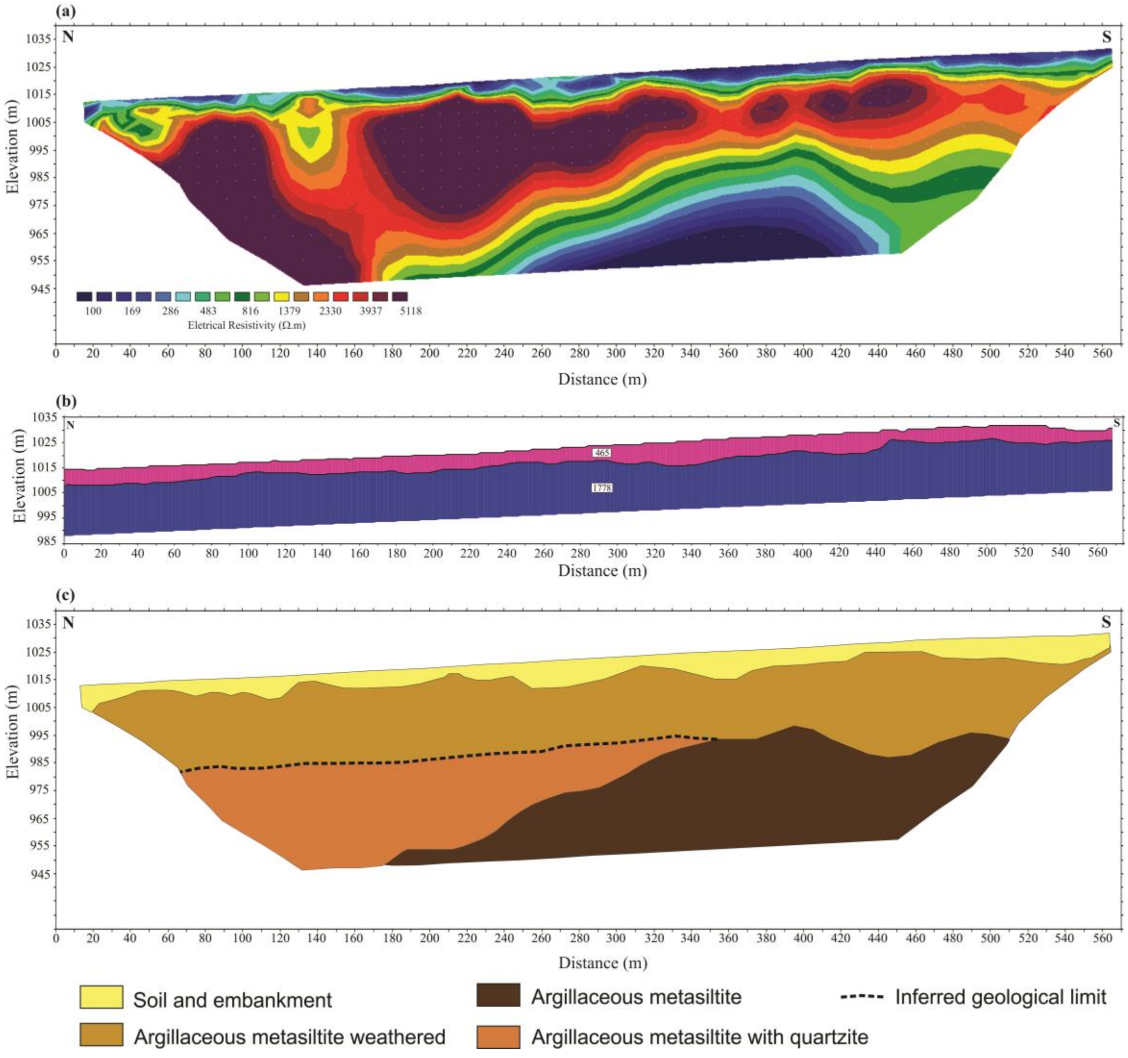

Figure 4. Results and model generated. (a) Result of the resistivity. (b) Result of the seismic refraction.(c) Interpretive model.

Due to the presence of high seismic noise in the study area, and also due to the low energy generated by the only available source, it was not possible to detect the third layer with the seismic method, been only possible to observe the first interface. From the seismic results (Figure 4b), the first layer has an average velocity of 465 m/s, typical of soil, with a thickness ranging from 4 to 10 meters. The second layer has an average velocity of 1778 m/s.

Greater depths were reached with the resistivity method (Figure 4a), being possible to observe a third layer. The surface layer has an apparent resistivity ranging between 100 and 818 Ω.m, with a thickness ranging between 4 and 11 meters, with good correlation to the thickness obtained by seismic refraction. The second layer shows apparent resistivity ranging between 1379 and 5118 Ω.m, with a minimum thickness of 22 meters. In this layer was not possible to detect the lower limits. The third layer has apparent resistivity ranging between 100 and 816 Ω.m.

The obtained results can be correlated with the main geological units described by Campos (2004). The superficial layer can be related to soil, including pedological horizons *A* and *B*. Nevertheless, this layer may have other material contributions, such as embankment, since the study area is located in an urban part of Brasilia, have been influenced by the construction of the city.

The second layer is more expressive in the whole profile (Figure 4b). The average P-wave velocity in this layer is higher than the first layer, indicating that this material is more compact. Regarding the electrical property, this layer has the highest resistivity obtained, indicating lower porosity if compared with the upper layer, due to witch this layer showed values of high resistivity. This layer was interpreted as saprolite from the metamorphic rocks of the S Unit of the Paranoa Group (argillaceous metasiltite - Campos, 2004). The geoelectrical behavior of this layer is heterogeneous, with significant thickness and lateral variations of resistivity, must been related to alternations between the packages of weathered argillaceous metassiltites (low resistivity) and quartzites (high resistivity).

As described by Freitas-Silva & Campos (1998), the Slate Unit (A) of the Paranoa Group, occurs in the final portion of the Asa Norte. In this unit occurs quartzite metrical lens, and thus, is expected a predominant pattern of low resistivity (slates) with small intercalations of high resistivity (quartzites). In the analyses was observed a low resistivity anomaly on the bottom of our model with horizontal length greater than 100 meters. Believing this anomaly is not related to the slate, because the electrical pattern in this case should be the opposite of what is been observed, in other words, the second layer should have low resistivity and the third layer should have high resistivity. Therefore, the third layer was interpreted as argillaceous metasiltite low weathered, indicating that does not have Slate along the profile, differently from what is shown in the geological map (Freitas-Silva & Campos, 1998).

However, this interpretation could not be supported if is considered the weathered level, which is not homogenous. Due to this fact, the high resistivity pattern, on the same depths of the third geoelectrical layer (north portion of the model), maybe related to the presence of quartzite (figure 4c). Due to the similarity of the values of electrical resistivity between the weathered quartzite (part of the second layer) and quartzite with less weathering, could not discriminate them in the geoelectrical profile (Figure 4c), being their boundary, designed according to the top of argillaceous metasiltite. Moreover, the shapes of the high conductivity anomalies suggest that the third geoelectric layer dips to the NW, in agreement with the regional structural control.

The velocity of the seismic wave can be used to define the rippability of a given medium (Weaver, 1975; Caterpillar Tractor Company, 1988; McCann & Fenning, 1995). According to Weaver (1975), materials with P-wave velocity up to 2000 m/s are considered rippable. The velocities observed for the first two layers, are lower than the limit suggested by Weaver (1975), indicating the rippability of this layers, without the need of especial equipment's for the excavation. For the future construction of the metro station, is suggested that the tunneling be completely built inside the second layer because it represents a more consolidated layer.

In the resistivity results is observed an anomaly between the positions 125 and 145 meters with depth of 2 meters. The resistivity value is close to 1800 Ω.m. This anomaly is related with an aqueduct.

CONCLUSIONS

The geophysical methods used in this work have proven to be effective in the elaboration mapping shallow geological structures in the study area.

The thickness of the first layer obtained with both geophysical methods are very similar, and better resolution of the seismic method, due the short geophone spacing, helped to define this layer in the model. This layer has thickness values between 4 and 11 meters, and was interpreted as the soil and embankment from the construction of Brasilia.

Due to the high ambient seismic noise in the study area, there were limitations to the application for the seismic refraction method not been possible to map deeper structures found with the electrical resistivity method. In order to access information from deeper layers using seismic refraction in Brasilia is necessary to use a more powerful seismic source than the sledgehammer, such as weight drop or seismic riffle.

Based on the results, for the second and third layer, was concluded that the Slate Unit does not occur in the study area, differently from what is observed in the geological map proposed by Freitas-Silva & Campos (1998). The second layer was interpreted as saprolite from argillaceous metasiltites and quartzites of the S Unit of the Paranoa Group. The third layer was interpreted as the argillaceous metasiltites low weathered (low resistivity portion), and argillaceous metasiltites low weathered with presence of quartzite (high resistivity portion).

The first and second layers are considered to be rippable, easy to excavate with appropriated equipments. The more appropriate layer for the construction of the substation or tunnel of the metro is the second layer, since the material of this layer is more consolidated than the first.

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