GEOPHYSICAL PROSPECTING OF GROUND WATER IN CRYSTALLINE ROCKS IN AN ARID REGION OF NORTHEAST BRAZIL.

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RESUMO

Perfis de resistividade horizontal foram conduzidos em área de rochas Precambrianas ígneas e metamórficas na região semi-árida do Estado de Pernambuco, nordeste do Brasil, com a finalidade de contribuir para a analise dos fatores que controlam a grande variação na vazão em poços localizados a pequena distancia entre si. Dezesseis linhas de resistividade paralelas e com direção 345 Az e espaçamento de 15 metros foram conduzidas, com separação de 15 metros entre estações de medidas ao longo das linhas. Os resultados mostraram que as zonas de condutividade podem não estar diretamente relacionadas a zonas de maior densidade de fraturas e, consequentemente, maior saturação de água. As feições litológicas e estruturais, que não foram observadas diretamente em função da cobertura de solo possuem grande importância. Os perfis geofísicos associados a trabalho de campo de detalhe, através de observações em cacimbas escavadas para suprimento de água mostrou que para este caso a elevada capacidade de armazenamento de água subterrânea esta relacionada a dobramentos e ao sistema de fraturas em gnaisses intercalados com *sheets* de rochas graníticas.

Palavras Chave: água subterrânea, perfis geofísicos, rochas precambrianas, geologia de campo.

ABSTRACT

Resistivity horizontal profiles were performed in an area of Precambrian igneous and metamorphic rocks of the semi-arid region of the State of Pernambuco, northeast Brazil, aiming to contribute to the analysis of the factors controlling the wide range of yields produced from closely spaced wells. Sixteen parallel resistivity lines bearing 345 Az and distant 15 meters from each other were carried out, with separation of 15 meters between measurement stations along the lines. The results show that the zones of conductive cannot always be related to zones of high fracture density and, consequently higher water saturation. Lithologic and structural features, which were not directly observed due to soil covering, have great importance. The geophysical profiles allied with detailed geological field work based upon observations of artificial hollows for water supply show that in the present case higher groundwater storage is related to folding and fracturing of gneisses and intercalated granitic sheets.

Keywords: groundwater, geophysical profiles, Preambrian rocks, geological field work.

INTRODUCTION

The semi-arid region of northeastern Brazil show high temperatures, low rainfall and intense solar radiation, throughout the year. These characteristics, associated with the predominance of igneous and metamorphic rocks result in a water deficit that has been affecting the local population and livestock for many centuries. To compensate this water deficit several alternatives have been developed. Among them, the use of water from stored in alluvium deposits and from fracture-controlled aquifer are the most common.

In places were the alluvium deposits are reduced or absent, the fracture-controlled aquifer becomes a very important source of water for public supply for small communities which are submitted to long dry periods (in average 8 months per year). This type of aquifer is anisotropic, heterogeneous and discontinuous posing one of the most difficult problems in hydrogeology. The occurrence and distribution of the underground fractures are random and dependent on the response of the rocks to the tectonic efforts to which they were submitted. Being so, it is very difficult to ascertain whether a well in crystalline rocks will produce a good yield or even if it will produce any water at all.

Site selection for drilling wells in crystalline rocks with the aid of geophysical methods has shown good results. The geoeletric methods have proved to be very satisfactory in detecting and mapping geologic features capable of groundwater storage. This work shows the results of a detailed geophysical study using the electroresistivity method in an area of 405 m X 225 m, as an attempt to understand the field conditions that control the pumping discharge, and to improve the well site selection techniques in crystalline rocks.

The study area is located in the Alagoinhas County, State of Pernambuco, northeastern Brazil. The area was selected based on the existence of three closely spaced wells yielding very distinct discharges (10.0 m³/h, 4.2 m³/h and 2.0 m³/h.).

REGIONAL GEOLOGY

The region encircling the area under study is known as the Borborema Province, which comprises the central portion of a Brasiliano (Pan-African) orogenic belt developed from the collisions of the São Luís and West African cratons; and São Francisco and Congo Kasai cratons, at the end of the Neoproterozoic (Brito Neves & Cordani, 1991; Santos, 1995; Van Schmus *et al*.,1995).

The study area is located in the Pernambuco-Alagoas terrain, 14 km to the south of a major east-west transcurrent shear zone named Pernambuco Lineament. The main geologic unit occurring in the area is the Cabrobó Complex (Gomes, 2001), characterized by biotite muscovite gneisses, micaschists, metagreywackes and migmatites, with quartzite (qt) and marble levels (ca) and coarse to medium-grained leucogranitic orthogneisses (Fig. 1).

This area is covered by a grey to white sand derived from the leucogranitic orthogneisses. However, observations from ponds and dug wells, which serve as water sources for livestock during the summer season, show that micaschists dominate in the northern part and that granitic sheets intrude the orthogneisses in its southern part. In both cases, the foliation dips gently southwards.

GEOPHYSICAL METHOD

The electroresistivity is a direct current geoelectric method which makes use of artificial electric fields. The main goal of the method is to obtain underground geologic information through mapping and analyzing resistivity contrasts, both in vertical and horizontal directions. In the first case a technique named Vertical Electrical

Sounding (VES) is applied, while in the latter resistivity profiles are run (Orellana, 1972). For both techniques a current (i) is sent into the ground by means of two metallic electrodes A and B, symmetrical with respect to a central point O. The potential drop (ÄV) is measured between two other metallic electrodes M and N placed in between electrodes A an B and also symmetric with respect to the same central point O. In the present study the four electrode arrangement was set to keep the ratio MN/AB always equal or less than 1/5 configuring the so called Schlumberger array. (Karous & Gruntorád, 1984).

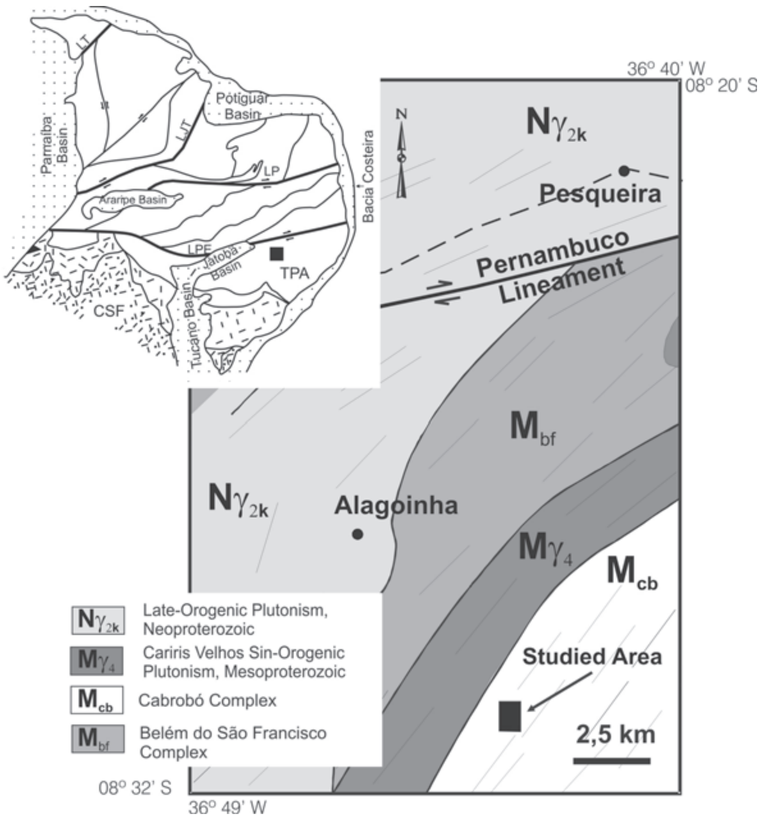

Figure 1. Geologic and location map showing the study area. TPA: Pernambuco-Alagoas Terrain; LT: Transbrasiliano Lineament; LJT: shear zone Jaguaribe-Tatajuba; LP: Patos Lineament; LPE: Pernambuco Lineament. After Santos, 1999.

Once crystalline terrains do not fit a stratified model, VES is seldom used with them for groundwater prospecting, even in cases where soil or weathered rock cover occur.

Vertical Electrical Soundings are nevertheless required on crystalline rocks for the purpose of determining the spacing between current electrodes A and B, which are to be adopted for running the resistivity profiles. The main target of electroresistivity profiles on crystalline rocks is to identify and map promising fracture or shear/fault zones, which are characterized by low resistivity values (Astier, 1975). During the investigation the AMNB array is moved laterally keeping constant the spacing between the electrodes. This procedure results in the recording of the apparent resistivity of a certain slab of rock at a depth which is dependent upon the AB spacing.

In the study area, two vertical electrical soundings were done along the road from Perpétuo Socorro to Alagoinhas, and sixteen resistivity profiles were run bearing 345 Az and arranged according to a regular grid with spacing of 15 meters between nodes. The Schlumberger array was used with both techniques. The qualitative analysis of the VESs showed that the lateral profiles were to be run with AB and MN spacing of 80 meters and 5 meters, respectively, in order to obtain the desired information (Fig. 2).

The distribution of the vertical electric soundings and of the measurement stations along the lateral profiles are shown in Figure 3.

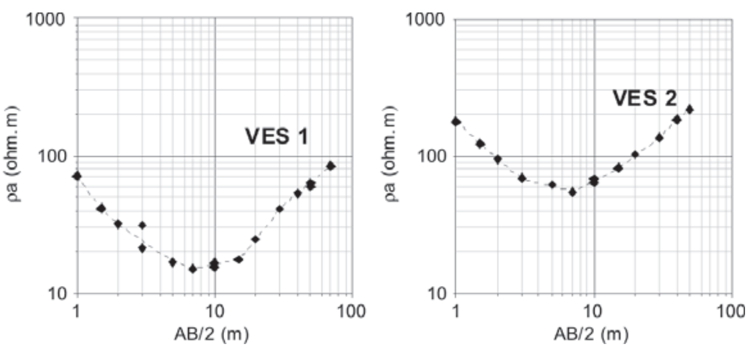

Figure 2. Vertical Electrical Sounding curves obtained in the study area.

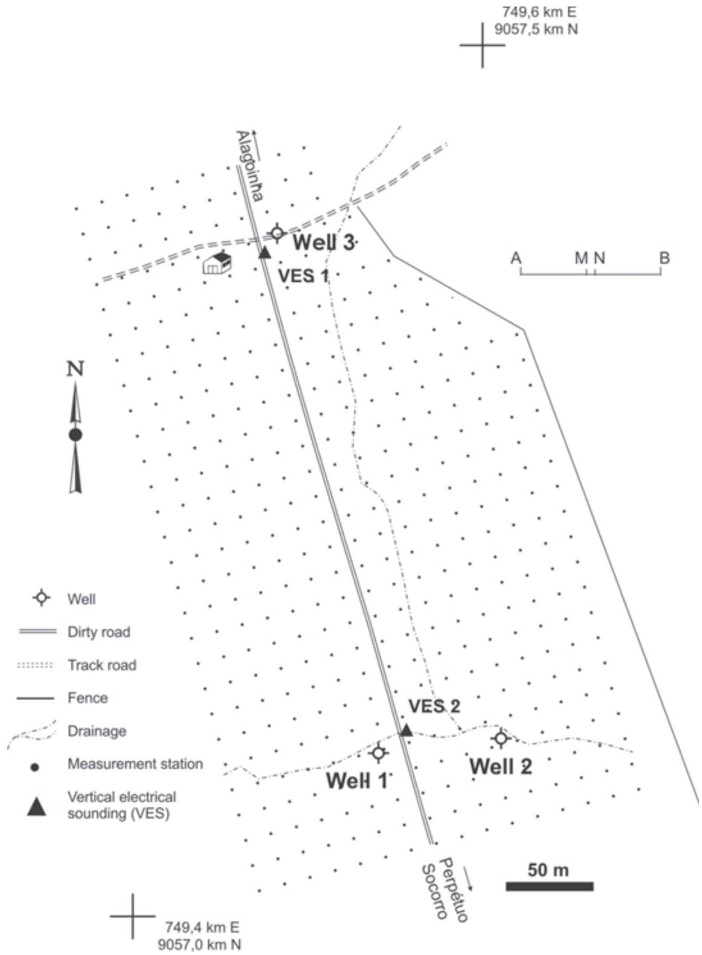

Figure 3. Distribution of the vertical electric soundings and of the measurement stations along the lateral profiles.

RESULTS

Analysis and interpretation of the geophysical data allowed the construction of an apparent resistivity map, using the statistical kriging interpolation method. Figure 4 shows the scale of colors used in the apparent resistivity map. In this map the black color represents the maximum value of apparent resistivity, grading towards lower values which are shown in gray shades. The white color represents the lowest values of apparent resistivity.

The northern portion of the map is characterized by a fair homogeneity as deduced from the low values and gradients of the apparent resistivity measurements. In the central and southern portions, the gradients are higher and resistive and conductive zones alternate, developing noticeable belts arching towards north. These features are understood as the electric response to a syncline whose axis plunges 20 to 25 degrees south. Field measurements of foliation are also plotted in figure 5 which support this interpretation.

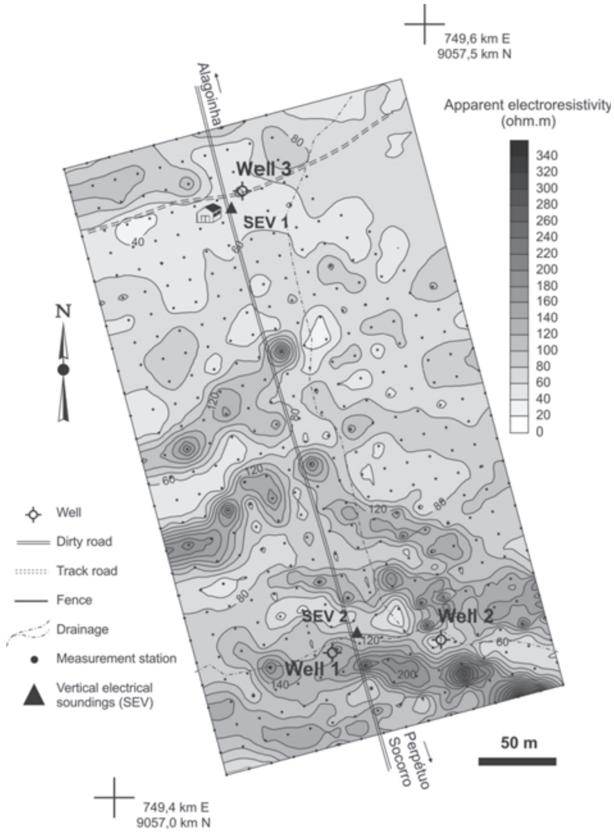

Figure 4. Apparent electroresistivity map of the study area.

DISCUSSION

Well 1 is located in a resistive zone but, contrary to what was expected, it shows the highest exploitation discharge (10.0 m³/h). Its position, close to the inferred axis of the plunging syncline (Fig. 5), suggests an important role of the hinge zone in the yielding ability of wells. As a matter of fact, the hinge zones of folds are prone to undergo more intense fracturing, what is thought to turn them into more suitable zones for locating water wells. Feitosa (1994) and Ferreira (1996) based on aerial photographs traced fractures close to well 1, extending approximately 2.5 km N-S and running parallel to the fold axis. Taking for granted that the high discharge of well 1 is dependent upon the proximity to the fold axis, why well 2, located away from the fold axis, yields more water (4,23 m³/h) as compared with well 3 which is closer to this axis (2,00 m³/h). This apparently anomalous behavior can be explained by the geology of the study area. The northern portion of the area, where well 3 is located, is dominated by schists, whose ductile behavior prevented it from significant fracturing during folding. The southern portion of the area, where well 2 is located, is characterized on the other hand by granitic sheets intruded along the foliation of gneisses.

These rocks probably were more competent and showed a brittle behavior during deformation, developing thus significant fracture systems which became fair groundwater reservoirs. In this way, well 1 yields greater discharge not only due to its position in the vicinity of the hinge zone of the syncline, but also on account of the brittle rocks of the southern portion of the area, in which it was drilled.

With regard to the meaning of the electric measurements, the statements just presented in the preceding paragraph imply that the alternating conductive and resistive zones are a response to the electric contrast between granite, schist and gneisses. This resistivity pattern, indeed, is believed to arise mainly from field relationships between these rocks, where gray fine-grained granite intrudes along the foliation of gneisses.

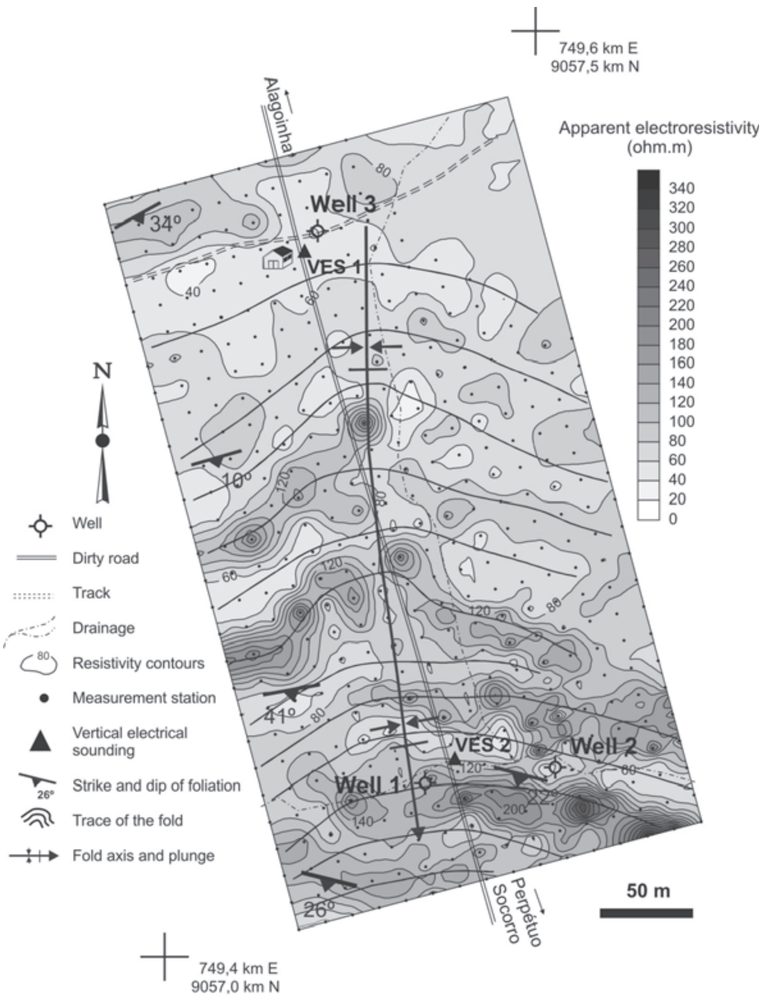

Figure 5. Structural contour map of the fold based on field geology and geophysical data, showing the location of the study wells.

Research developed in west Africa, with the objective to apply methods of prospection of groundwater in crystalline rocks, show that not all the anomalies detected by the EM method correspond the fractured zones bearing water, being some of them coincident with magnetic anomalies or geologic features (geologic contacts), indicating control by lithologic relationships (Boeckh, 1992).

The most important result of the present study, therefore, is the awareness of the fact that, in crystalline territories, lithology play a role by no means negligible in explaining apparent resistivity anomalies. It may so happen, therefore, as is the case, which conductive anomalies not always mean higher density of water bearing fractures, as previously believed. They may be sometimes explained simply by low resistivity tracts of schists inserted in between high resistivity gneisses, for instance.

CONCLUSION

The main contribution of the present study is the recognition that mapping electric conductive anomalies cannot in itself ascertain the most favorable sites for water well location. It is necessary a good deal of field geology so that geophysicists may get geological clues to rely on, thus avoiding misleading interpretations.

In the present case the main clue was concerned with field observation showing that conductive and resistive anomalies were related to gneiss and granite belts respectively, as said previously.

That being so, conductive zones in the area under study are not necessarily related to water bearing fracturing as believed earlier.

In the present case, water wells must rather be located as near as possible to the hinge zone of the syncline and on the resistive belts associated with the brittle gneisses.

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