Study of Electromagnetic Data Applied to Hydrogeology, in the region of Samambaia PE

Ana Luiza Carvalho Chaves (Obsis / IG - UnB) & Mônica Giannoccaro Von Huelsen (Obsis / IG - UnB) – Observatório Sismológico (Obsis), Instituto de Geociência (IG), Universidade de Brasília (UNB) - luizaanac@gmail.com; monisis@unb.br

This paper was prepared for presentation during the 18th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 October 2023.

Abstract

In possession of geological and hydrological information this work has as objective the geophysical study of the area of Samambaia PE using the electromagnetic method to assist in the drilling of tubular wells, through the localization of favorable structures to the storage of underground water. This characterization brings important subsidies that will serve as a basis for a study that aims to encourage the exploitation of water resources in the Northeast region, in order to improve the supply of this population that is inserted in the critical semi-arid climate of the polygon of droughts. The long and intense droughts that occur in the Northeast of Brazil aggravate the socio-economic problems of the region. The lack of water affects not only local subsistence, but also the economy of large plantations. The difficulty of exploiting water resources has brought the need to find an arbitrary way to obtain it, such as underground wells.

Introduction

The substratum of the Northeast is approximately 50% composed of crystalline rocks that present very low permeability, but can acquire a greater permeability according to the degree of weathering and fracturing. The group of rocks in question is classified, by Singhal and Gupta (1999), as mainly of two types; non-volcanic igneous rocks and metamorphic rocks, both with occurrence of underground water located in the weathering mantle and in discontinuities, for example, joints, faults and foliation planes. Therefore, despite the primary nature of the crystalline rock not being favorable for the deposition and percolation of fluids, it is understood that zones of recurrent geological events of stresses and strains are of interest.

The Samambaia area is located in the municipality of Custodia, PE, delimited by UTM coordinates: 630000E - 64000E / 9079000N - 9092000N and is limited geographically by the municipalities of Iguaraci, Carnaiba, Flores, Ibimirim, Floresta, Betania and Sertania, with an area of 104 km^2. According to GoogleMaps, the locality is 395 km from Recife and 55 km from BR-232. It is located in the northern portion of the microregion Alto Vale do Rio Moxoto.

The rainfall is irregular over the year, presenting seven dry months, June to December (Nimer *et al*., 1979), and the average annual rainfall in Custódia is 708.8 mm (Morais *et al*., 1999). There are no surpluses in the water reserves of the soil during March, April, and May, because those are used. The average annual temperature is 23.5ºC.

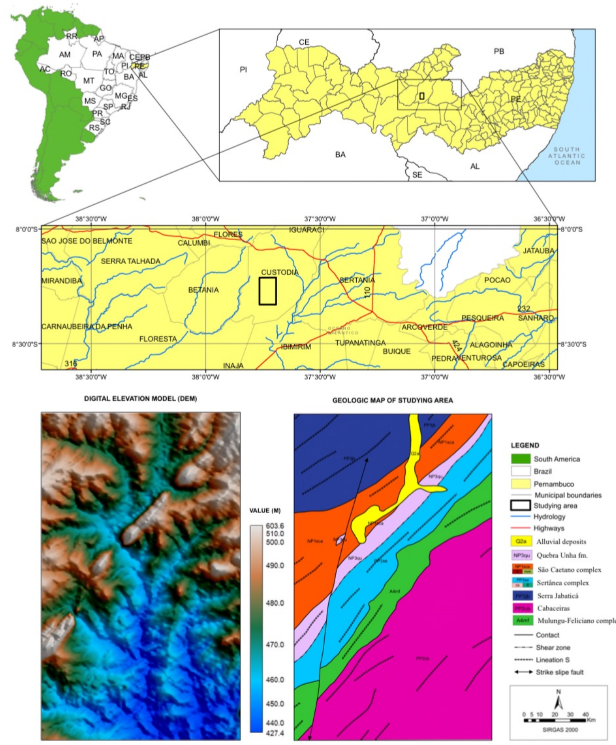

Figure 1: Location, digital elevation and geological map of the study area, Samambaia / PE.

Method

Geology

In the Custódia region, two shear faults occur, Custódia and Samambaia, oriented to N15E. Among the lithological types present in the Custódia sheet (CPRM, 1999), seven of them are found in the survey area: Alluvial deposits (Q2a); Quebra Unha Formation (NP3qu); garnet-biotite schists/gnaisses, locally migmatitic containing tourmaline and/or muscovite (NP1sca) being belonging to the São Caetano Complex; biotite gneisses/ schists to garnet and muscovite, mostly migmatitic (PP3se) belonging to the Sertânia Complex; Serra de Jabaticá (PP3jb); Cabaceiras (PP2cb) and Mulungu-Feliciano Complex.

The structures identified within the survey area are tectonic in nature. It is constituted by a sinistral transcurrent movement character and a sequence of minor faults varying from N20W to N-S of sinistral movement and with another direction N70-80E of dextral behavior. This set of ruptures is part of the Caiçara shear zone with NW compression and NE extension. East and west of Samambaia features with abrupt, steep, "S" shaped edges were named, resembling depressions and basin structures in the same direction as the shear zone, suggesting neotectonic reactivations of the efforts that generate the sinistral transcurrent fault. The ductile tectonics of the area is reflected in the kilometer-long fault and N-NNE direction characterized by directional movements provoked by axes in the zone of greater compression and greater relief in the horizontal, regionally stretching features, unevenness of blocks, sedimentation and weak metamorphism appear.

The crystalline basement represents 70% of the semiarid region, (Carvalho *et al.*, 1973). Crystalline rocks receive this name due to their composition of crystallized minerals that give specific characteristics of resistance and deformability, so there is a possibility of the existence of water in the subsoil due to fractures and alluvium. The area of interest combines the susceptibility of fractured crystalline rocks to store groundwater with the semi-arid climate of the Northeast region, which does not provide the development of the weathering mantle to compose the aquifer and thus, in most cases, low productivity is ruled out.

The Electromagnetic Induction Method

The active electromagnetic methods are based on the contrast of the electromagnetic properties of the soil. The feasibility of using this method to study an anomalous body depends on the contrast of properties of the environment around it, the nature of the materials, the depth, the way they are arranged, and their proximity to the water table. If these contrasts are large enough, then the anomalies will be detected.

The methodology applied in this work is based on the basic theory of the electromagnetic method in the frequency domain. The theoretical basis consists of circulating an alternating electric current, which has a constant frequency, in a transmitting coil (Tx), resulting in a primary electromagnetic field (Hp). The propagation of this field underground, where the conductive medium induces secondary electrical currents that produce a secondary electromagnetic field (Hs) proportional to the induced current. A part of the secondary field induces electric

currents in a receiving coil (Rx), positioned within the area of influence of the primary and secondary fields. The potential difference (d.d.p.) associated with the electrical current induced in the receiving coil is directly proportional to the electrical conductivity of the terrain. Assuming that the ratio between Hs and Hp is linear, it is possible to take direct readings of the electrical conductivity of materials in the subsurface, by measuring the values of both fields (McNeill, 1990).

$$\sigma = \frac{4}{\omega \mu_0 s^2} \frac{Hs}{Hp}$$

where f = frequency of the electric current flowing in the coil (Tx), in Hz; ω = angular frequency, in rad / s; = magnetic permeability of the vacuum, in H / m; s = spacing between coils Tx and Rx, in meters. This relation allows the construction of instruments that make a direct reading of the electrical conductivity (Siemens/m) at a predetermined depth.

Inversion

The model in the inversion follows the solution of the direct modeling equation:

$$G.m = d$$

where ($m=[m_1,m_2,...m_m]^T$) is the model vector that contains the values of the physical properties of the cells; ($d=[d_1,d_2,...d_m]^T$) is the data in the vector matrix, and (G) is the sensitivity matrix that quantifies the contribution of related cells to the observed data value (Ellis *et al*. 2012; Richarte *et al*. 2018).

The conductivity inversion was performed from the VOXI Earth Modeling package in SeequentTM. The input for performing the inversion in this package generates a 3D geophysical model from the three-dimensional mesh (block model) that results in the final voxel.

The number of cells defined for the three-dimensional mesh for the inversion consists of:

Active Volume

	X	Y	Z
Cell sizes (m)	100	100	2
Dimensions (cells)	85	136	97

A priori information: conductivity distribution with positive values - Functional positivity
Sharpening: Sharpen positive end of property distribution
Computational Error Tolerance: 0.002

Acquisition and Processing

The data used for the development of this article were obtained by LASA Engenharia e Prospecções S/A employing an airborne electro-magnetometric survey with an artificial source in the frequency domain (FDEM). This is part of the PROASNE project (Underground Water Project in Northeast Brazil) developed by the partnership between the Geological Service of Brazil (CPRM) and the Geological Service of Canada (GSC), whose main objective was to research the conditions of water storage and percolation underground in crystalline terrain.

The data acquisition phase was carried out through an HB-350 helicopter (Esquilo), equipped with various geophysical equipment, among them the 5-frequency electromagnetic system (FDEM), Aerodat DSP 99, with a towed sensor by a towed bird cable, with the following configuration: 3 pairs of horizontal and coplanar coils (CP1 ~ 900 Hz; CP2 ~ 4500 Hz; CP3 ~ 33,000 Hz) and two pairs of vertical coils (CX1 ~ 900 Hz; CX2 ~ 4500 Hz). The system allows 10 readings per second of the phase and quadrature components of each of the five frequencies. The data survey adds up to 4,465.7 km of electromagnetic profiles (Proasne). The flight (LV) and control (LC) lines were acquired and spaced from 100m and 500m, and the directions of the lines were E-W (LV) and N-S (LC). And the georeferencing was acquired through the GPS (Novatel), 12 channels.

Data processing was performed using the GEOSOFT ™ software (Geosoft, 2019), Oasis Montaj. The data interpolator method used was Krigagem. The applied filters were Hanning and Directional Cosine, adjusting the necessary parameters for each conductivity image. 3 conductivity images were generated using the three frequencies: low (900 Hz), medium (4,500 Hz), and high (33,000 Hz) for the coaxial and coplanar arrangements, but here the best results, which were from the coplanar arrangement, will be presented.

Results

A ternary CMY image composite was made with the high (cyan), intermediate (magenta) and low (yellow) frequency coplanar conductivity images with overlay of the conductive and geologic structures. The black areas show the conductive anomalies that are present in the shallow, medium and deep depths, the blue region shows the shallow conductors and yellow highlights the deepest bodies. It is observed that the preferential direction of the conductive structures is NE/SW and that there is a NW conductive behavior different from the SE region.

Regionally, the main geological structures have NE/SW, E-W and SE/NW direction with the presence of active faults in the region of the Pernambuco lineament; locally they present themselves mainly in the NE/SW direction, with emphasis on the fault that cuts the N-NE/SW direction and are not active. According to Soares, *et al.* (2019), this geological fault displaces in the central west the magnetic and conductive anomalies of NE/SW direction. These extensive anomalies divide the area into two portions: the southeast characterized by magnetic highs and conductive lows; and the northwest characterized by predominantly magnetic lows and conductive highs.

The conductive structures present themselves mostly with NE/SW direction, with the exception of two segments, in the southeastern part, with NW/SE direction. In the southeastern part of the conductive structures magnetic highs predominate and to the northwest the conductive structures are in the magnetic gradient.

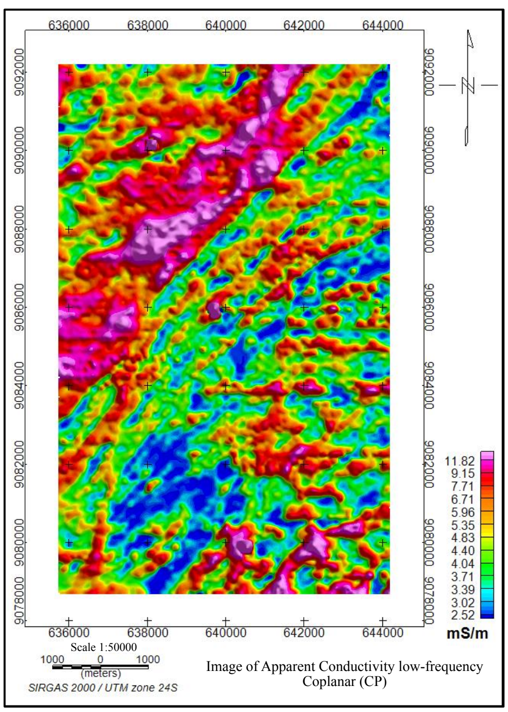

Figure 2: ***Image of Apparent Conductivity in a low-frequency coplanar configuration.***

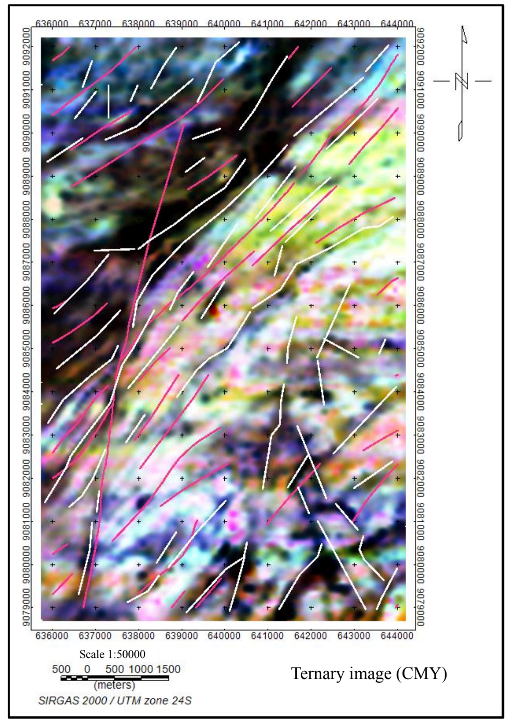

Figure 3: Ternary image (CMY) ***with electromagnetics structures (white) and geological structures (pink).***

With the results of the inversion, we can observe a conductive layer with thickness varying between 5 and 20 m (pink), just below a layer with conductivity around 0.0001 S/m (yellow) with about 2 m, a third layer with conductivity around 0.000035 S/m with thickness of 3 m and in some points reaching the thickness of 25 meters and connecting with vertical conductive bodies. The deviation of the fault can be seen in the first 100 m depth up to elevation 466 m. On the northern section of the fault, it can be seen that the fault (NE/SW direction) area presents a slight dip towards NW. In general, more verticalized conductive bodies appear in the SE part of the fault with respect to the NW part.

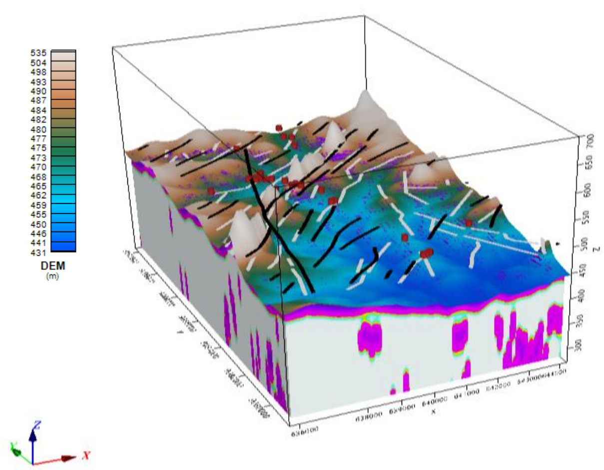

Figure 4: Conductivity image with DEM overlay, wells (red cylinder) geological structures (black) and structures made on the low frequency conductivity image (deeper; gray).

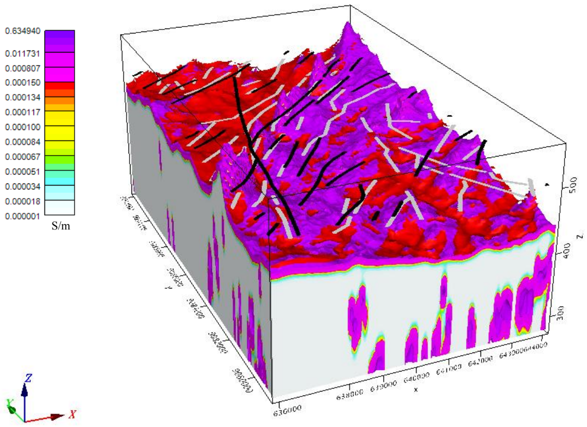

Figure 5: Conductivity image (between 0 and 0.047S/m) with overlay of the 0.0685 S/m conductivity isosurface of the geologic structures (black) and structures performed on the low frequency conductivity image (from greater depth; gray).

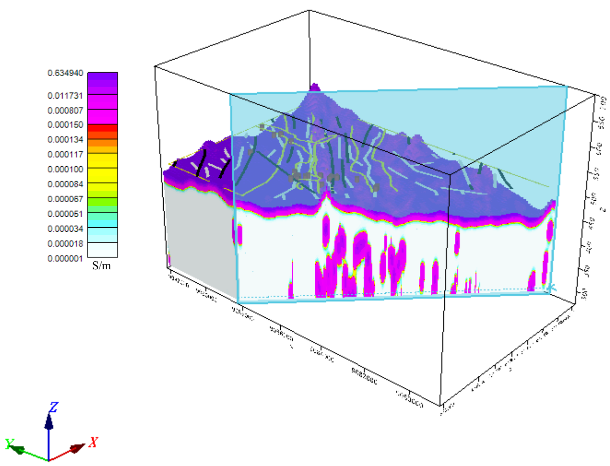

Figure 6: Cutting northern part of the fault.

Conclusions

The region of interest combines the susceptibility of the fractured crystalline rocks to store groundwater with the semi-arid climate of the Northeast region that does not provide the development of the weathering mantle to compose the aquifer, and thus low productivity is ruled out in most cases. In this way, once characterized the area in terms of conductive structures, this research follows with the proposal of a better characterization of the region in which it provides for the integration with gravimetric and magnetic data in order to generate new 2D models representative of the area, in addition to studies for well drilling.

References

LASA ENGENHARIA e PROSPECÇÕES S/A, 2001, Projeto Aerogeofísico Água Subterrânea no Nordeste do Brasil, Blocos Samambaia (PE). Relatório final do levantamento e processamento dos dados magnetométricos e eletromagnetométricos e seleção das anomalias eletromagnéticas. Texto técnico. Cooperação Canadá-Brasil / PROASNE. Brasília.

SOUZA FILHO, O. A. de; Remacre, A. Z.; Silva, A. M.; Sancevero, S. S.; McCafferty, A. E.; Perrotta, M. M. 2006b. Airborne Electromagnetic Data as External Variable to Predict Groundwater Electrical Conductivity in the Crystalline Domain of Irauçuba Region – Ceará, Brazil. 2006b Hydrogeophysics Symposium, Vancouver. Society of Exploration Geophysicists, Tulsa, abstracts.

SOARES DE QUIROZ, M. C.; VON HUELSEN, MÔNICA G.; CHAVES, A. L. C.; 2019, Interpretação de estruturas magnéticas e eletromagnéticas na região de Samambaia-PE, aplicadas a reservatórios de águas subterrâneas. 16th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil.

SANTOS MEDEIROS, L. R. dos; Guerra, S. M. S.; Tavares, U. E.; Cruz Pinheiro, L. da; Borba Espíndola, M. C.; Barros, P. Â, de, 2008, Base de dados geoambientais da região de Samambaia, Custódia, PE. II Simpósio Brasileiro de Ciências Geodésicas e Tecnologias da Geoinformação. p001-004.

ANDRADE AMARAL, C. de, 2001, Contexto morfoestrutural e hidrogeologia da região de Caiçara-Samambaia (Custódia-PE). IV Simpósio de Hidrogeologia do Nordeste. p205-203.

FUNDAÇÃO KONRAD ADENAUER, 2002, Água e desenvolvimento sustentável no semiárido. Série de debates nº24. Fortaleza, Brasil. p001-170.

NEVES, 2005, Ánalise integrada aplicada à exploração de água subterrânea na Bacia do Rio Jundiaí. Capítulo 5; Hidrologia de Rochas Cristalinas. São Paulo, Brasil. p001-28.

NABIGHIAN, M.N., 1991a, Eletromagnetic Methods in Applied Geophysics. In: Investigations in Geophysics, No. 3, Vol. 1 – Theory. Ed. Misac N. Nabighian, SEG, Tulsa, U.S., 505 p. il.

SUASSUNA, J., 2005, Potencialidades hídricas no Nordeste brasileiro. Seminários temáticos para a III Conferência Nacional de C,T&I. p01-26.

MINISTÉRIO DA INTEGRAÇÃO NACIONAL, 2017. Relatório final da delimitação do Semiárido. Grupo de trabalho; Portaria n. 196, de 27 de maio de 2014. p000-429.

MORAIS, Franklin de. Produtividade e qualidade da água dos poços no meio fissural do Alto Vale do rio Moxotó. Dissertação de Mestrado - Universidade Federal de Pernambuco, 2000.

AQUINO ANGELIM, L. A. de; Andrade Amaral, C. de; T. G. GaLvão, M. J. da, 2002, CPRM/ Projeto Água Subterrânea no Nordeste do Brasil (PROASNE). Geologia da área piloto Caiçara-Samambaia.

SERVIÇO GEOLÓGICO DO BRASIL, 1999, Estudo hidrogeológico sucinto para a locação de poços nas localidades de São José e Maravilha de cima – Custódia/PE. Recife, Brasil.