Geoelectrical characterization of the Hydrogeological System in the part west of the Potiguar Basin applying the Vertical Electric Sounding method

José Pedro Rebés Lima FUNCEME / DEHID, Ceará, BRAZIL

Abstract

This work presents the results of a research project that it had as motivation to obtain a better knowledge of the Hydrogeological System of the Chapada do Apodi, which is an area in the which the federal and state governments are implementing important irrigation projects whose the viability and success are directly related with the considerable volumes exploitation warranty of physical-chemistry good quality groundwater. It has been intensive the increasing of drinking water supply coming from the regional aquifers Alluvium, Jandaira and Açu, This continuous withdraw has resulted in such problems as the decline of the groundwater levels in the regional aquifers. It is known based on previous hydrogeological studies in the Potiguar Basin that the Açu Formation presents outstanding lithologic and hydrologic heterogeneities that should be taken in account in groundwater exploitation for domestic, agricultural or industrial uses. Previous geophysical studies in others areas of the Potiguar Basin used the Electrical Resistivity method, however in the area studied in this work that corresponds to the Medio-Baixo Jaguaribe where the Açu Formation recovers an area of 1.100 km^2 they were not still accomplished geophysical studies and consequently one doesn't know your thickness. Due to this fact the research project had as objective to obtain a geoelectrical model of the subsurface that describes in depth the stratigraphic sequence and its lateral variation along some profiles, identifying the Açu and Jandaira Formation's thickness in the Medio-Baixo Jaguaribe's central portion that is localized in the west part of the Potiguar Basin. As it intended to map in depth the stratigraphic sequence the electrical resistivity survey was carried out using the Schlumberger configuration array. In the study area the crystalline basement is at the depth that varies from -100 m to –300 m in relation to the sea level, consequently the 23 vertical electric soundings (VES) stations were made and interpreted using the array of current electrode up to a maximum spacing AB/2 of 1 km. For the computational processing of the field data it was applied "ridge regression" inversion outline and used as *priore* information a lithostratigraphic log profile of a 250 m deep well. The results obtained by the geophysical investigation are analyzed and interpreted in terms of a hydrogeologic model of the deep regional Açu Aquifer.

Introduction

This project concentrated on the direct contribution of the application of the geophysics for a larger knowledge concerning to the hydrogeology of the west part of the Potiguar Basin specifically in the Medio-Baixo Jaguaribe area. After bibliographical research it was verified that there was a lack of information concerning the behavior and occurrence of groundwater in the studied area denominated Chapada do Apodi. So on the geophysical survey was accomplished on the Chapada do Apodi describing the representative lithostratigraphic sequence of an area of 400 km^2 along a profile of 40 km in the part of the west of the Potiguar Basin denominated Plataforma de Aracati (Figure 1).

A fundamental tool for hydrogeological studies is the application of geophysical methods. Souza et al. (1984) using data of formation tests, electric, acoustic, radioactive and lithologic logs profiles of a considerable number of wells in the Potiguar Basin elaborated a model for hydrocarbon secondary migration in the Açu aquifer. These studies evidenced hydraulic gradients of until 5 m/km and lithologic heterogeneities very defined that resulted in a division of the Açu aquifer in four different electrofacies in their capacities to store and to transmit groundwater. They also verified that the Açu Formation shows outstanding lithologic and hydrogeologic heterogeneities that should be take in account to groundwater exploitation for domestic, agricultural or industrial uses. Previous geophysical studies in the Potiguar Basin used the Electrical Resistivity method that was accomplished in the Baixo Jaguaribe area for structural geology studies (Maia *et al*., 1993). However in the Medio-Baixo Jaguaribe area where the Açu Formation recovers an area of 1.100 km^2 were not still accomplished geophysical studies and consequently one doesn't know its thickness (Feitosa, 1996). The Vertical Electrical Sounding method has been used lonely (Zohdy, 1969) and combined with other electromagnetic methods with success for groundwater prospecting in sedimentary basins (Patra, 1967; Lima, 2000; Carrasquila *et al*., 1997). As the application of the method became more used it has been trying to develop better techniques for the resistivity data interpretation. After the beginning of the 70´s decade when there was an enormous progress in the processing capacity for computers it was possible to develop new interpretation techniques applying the quasi-linear mathematical method of no-linear resistivity inversion problems using different inversion outlines (Inman *et al*., 1973; Inman, 1975; Bichara and Lakshmanan, 1976; Jupp and Vozoff, 1975; Johansen, 1977; Parker, 1984; Constable *et al*., 1987; Simms and Morgan, 1992).

Methodology

The VES stations were projected in a profile line of longitudinal orientation to the axis of the Basin (SSW-NNE) (Figure 1).

The computational mathematic processing of the field data was consisted of the application of layers inversion technique using “ridge regression” inversion outline (Inman, 1975). The initial layers models were based on hydrogeologic and lithostratigraphic *priori* information using log profile description data of a 250 m depth exploitation well that supply information concerning on the base of Jandaira Formation / top of Superior Açu Aquifer and the top of the Medium Açu Aquifer. The final models obtained by 1D inversion in each station (depth x resistivity) were projected on a line forming a long profile of SSW-NNE direction. These 1D models were interpolated and then obtained one transverse resistivity composed section (pseudo 2D section) that maps the lateral variation of the lithostratigraphic sequence along the profile. Based on the resistivity composed section was elaborated and interpreted the hydrogeologic model indicating depths, thickness and resistivity values of the aquifers and also inferring the possible presence of faults along the profile.

For the Vertical Electrical Sounding measurements it was used an electroresistivimeter with electric output power up to 500 W, maximum output tension of 1000 V and output maximum current of 1000 mA.

Hydrogeology

The Apodi Group is the sedimentary mantle of the Potiguar constituted by the Açu and Jandaira Formations. The Açu Formation represents the basal sedimentary part of the basin and is composed of clear arenite inserted by shale and silt in the base and is covered by the Jandaira Formation is put upon to the Açu Formation that is composed by bioclastic limestones (Figure 2).

The Jandaira Formation outcrops an area of 1,500 km2 with thickness varying of some dozens of meters up to 450 m. The dominant lithology is constituted by compact, hard and fractured limestone. The relief presents very plane and little undulating of mudding soil and forming scarps where it contacts oldest sandstones. The Jandaira Formation exhibits a karst zone where the storage and the circulation of water occurs in fissures originating from dissolution being limited in the base by mudding levels of the Açu Formation. The depth of the exploitation wells varies up to 100 m. The medium yield is of 1.88 m^3/h reaching a maximum yield of 2.5 m^3/h (Ceara, 1992). The recharge occurs through rainfall and ascending vertical infiltrations from the Açu Formation. The discharges zones are the springs, the ponds, the Açu Formation, the drainage net and the evapotranspiration.

The Açu Formation outcrop an area of 1,100 km^2 and one doesn't know its thickness as well as its hydrodynamic parameters for the Medio-Baixo Jaguaribe region (Verissimo *et al*., 1996). It exhibits a behavior of free aquifer in the outcropping zones (that are the recharge zones) and confined aquifer where is covered by its most high mudding level or by the Jandaira Formation. White conglomerate arenite, inserted shales layers, silt and calcarenite constitute its lithology. The depth of the wells varies between 60 m and 100 m. The medium yield varies from 2.4 m^3/h up to 4.7 m^3/h (Bianchi *et al.,* 1982). The recharge occurs predominantly by rainfall in the outcrop zone and by the superior aquifer that functions as transferring environment. The discharge zones are the drainage net, evapotranspiration and the Jandaira Formation (ascending vertical filtrations). The Açu Formation exhibits a regional character of recharge area and in Medio-Baixo Jaguaribe's area outcrops in the border of the basin.

Results and Interpretations

In a first approach the mathematical inversions were made using the Occam inversion technique and it was verified that the same converge in terms of mathematical adjustment between the model data and the field data however it is very far away from the real solution that expresses what one knows about the regional hydrogeology.

The applied inversion methodology uses the “ridge regression” scheme and it was firstly accomplished in a controlled way at a station with a 250 m deep exploitation well containing information concerning the depths of Jandaira Formation's base and of the top and base of the Açu Superior Formation or Unit Açu 4. The obtained model and the adjustment of the model are illustrated in the figure 3. The controlled inversion procedures were in agreement with the known stratigraphic sequence and initial models based on the results of the control station that result in obtained mathematical models compatible with real geological models for all the stations.

The results of 1D layers inversion were projected in a line that form a long profile of direction SSW-NNE (Figure 1) and the obtained results of resistivity *versus* depth were interpolated resulting in 2D Pseudo Geoelectrical Sections that images the lateral variation along the profile of the Potiguar Basin stratigraphic sequence. The distributions of the resistivity *versus* depth values were interpreted in terms of stratigraphic and hydrogeologic sequence based on the 2D Pseudo Geoelectrical Section resulting in the 2D Hydrogeological Model (Figure 4).

For the interpretation of the stratigraphic sequence it was used as guide indicator the contact Jandaira Formation base’s shale / mud layer associated with the Açu Superior Formation’s top denominated in the last works as Unit of Correlation Açu 4 that corresponds to an electric response of low resistivity value. In the same way the indicator guide of the Açu Medio Formation’s top that it corresponds in the new subdivision of the Açu Formation to the Units Açu 3 and Açu 2 it is the arenite layer that corresponds to an electric response of resistivity value more resistive than the base of the Açu Superior Formation (Unit Açu 4) associated with an arenite/mud layer. For the identification of the Açu Inferior Formation’s top that it corresponds to the Unit of Correlation Açu 1 the indicator is an arenite layer of more resistive than the arenite of the Açu Medio Formation. Finally it was adopted a resisitivity value above 2000 ohm-m for the identification of the basement depth in agreement with the work of Rijo *et al.* (1977) that associates this value for the response of the presence of the crystalline basement.

Analyzing the 2D Hydrogeological model we can say that the interpretations for the thickness of the layer corresponding to the Jandaira Formation as well as for the depth of the Unit Açu 4´s top and base and for the crystalline basement's depth are much defined. However, the interpretations of the depth of the tops of the Units Açu 2 and Açu 1 are much subjective. To differentiate the Unit Açu 3 of the Unit Açu 2 it was adopted a methodology used in the work of Lima (2000) where for correlation of lithostratigraphic and hydrogeologic description with the Geoelectrical Model obtained it was adopted as representative resistivity value of a good regional aquifer in arenitic reservoirs the range of 150 ohm-m to 250 ohm-m. Also the Açu Formation's subdivision in four electrofacies described by Souza *et al*. (1984) was correlated with the subdivision in four Units described by Vasconcelos *et al.* (1990) it was concluded that the Unit Açu 4 is an aquiclude and the Unit Açu 2 is a good aquifer.

Analyzing the SSW-NNE profile (Figure 4) it is verified that the sedimentary layers corresponding to Jandaira and Açu Formations are thickening in to the sea direction corresponding to the longitudinal direction to the Potiguar Basin's central axis. We can also infer the presence of a fault that would be related with the Linha de Charneira Areia Branca structure that is the SE / E limit of the Plataforma de Aracati what it means that some stations would be in the west limit of the Apodi Graben and other stations in the Plataforma de Aracati. We can also observe that the profile G-H cuts a long fracture represented in the geological map.

Conclusions and Recommendations

The applied geophysical method (Electrical Resistivity) was efficient in: mapping the Jandaira Formation's base / Açu Formation's top and therefore the thickness of the Jandaira Formation; mapping the crystalline basement depth and therefore the Açu Formation's thickness; to infer the presence of the fault related with the Linha de Charneira de Areia Branca structure that is the SE / E limit of the Plataforma de Aracati; to delineate in a subjective manner the interfaces of the units of correlation Açu 4 / Açu 3 and Açu 2 / Açu 1.

Also it was verified that in the Plataforma de Aracati the sedimentary beds are thickening in the SW-NE direction following longitudinally the Potiguar Basin's central axis.

Due to the occurrence of heterogeneities especially in the Jandaira Formation's stratigraphic sequence and to the limitation of the VES survey logistics for deep investigation that require large open areas it is strongly recommended the employment of the VES / TEM / MT integrated geophysical survey methodology (Lima, 2000; Meju *et al*., 1996). The use of this methodology for deep investigations possibilities to carry out a larger number of stations, to decrease the effects related with the presence of heterogeneities and to decrease the ambiguity in the interpretation resulting in a most accurate interpretation compare with studies where it are used a lonely geophysical method.

Acknowledgments

The author of this work, Dr. José Pedro Rebés Lima, thanks the financial support from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), promoter Government Brazilian Entity of the scientific and technological development by the DCR grant at UFC and from the Fundo Setorial de Energia (CT-Energ) by the SET grant at FUNCEME through CNPq. Also thanks the support from the Departamento de Geologia and from the Departamento de Física da Universidade Federal do Ceará (UFC) and financial support from Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico (FUNCAP).

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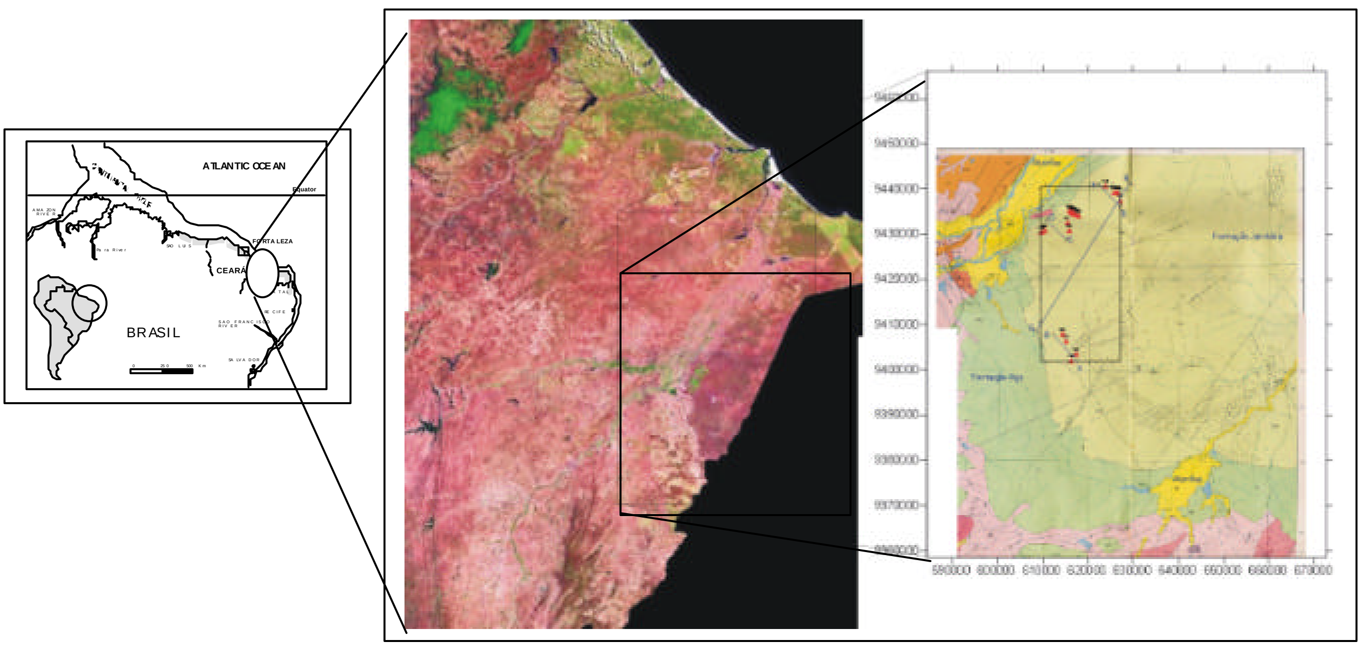
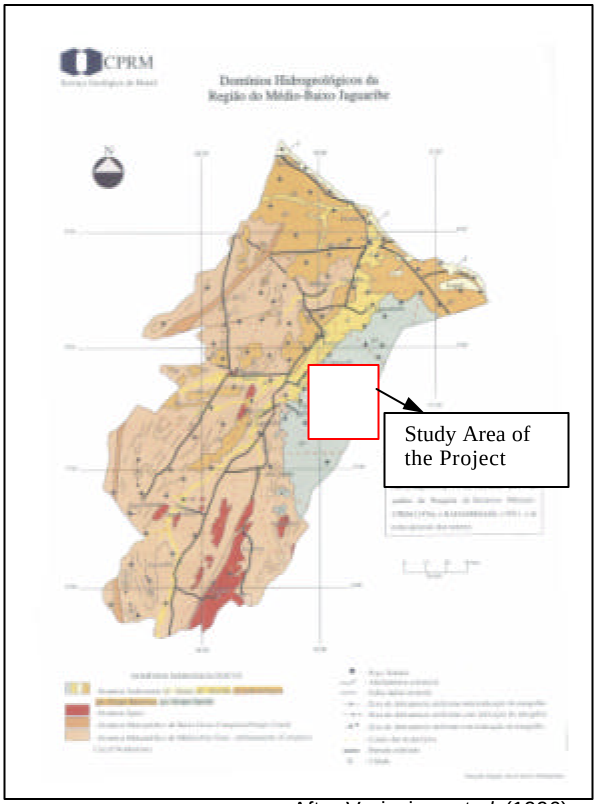
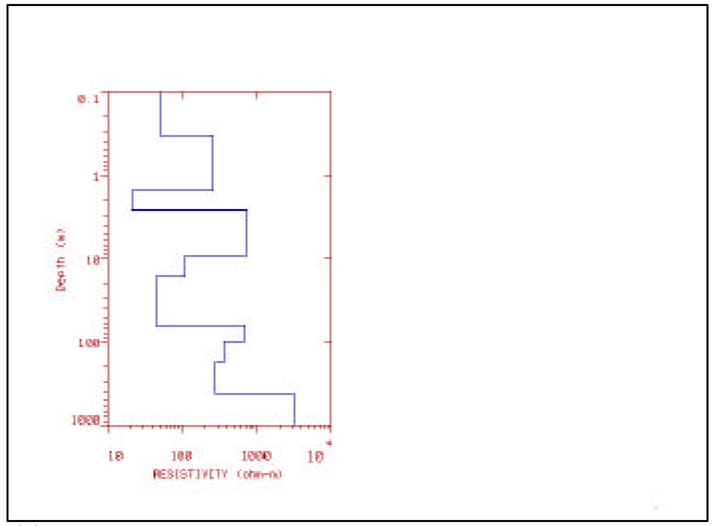


Figure 1 – Study Area and the projected Hydrogeological Profile.

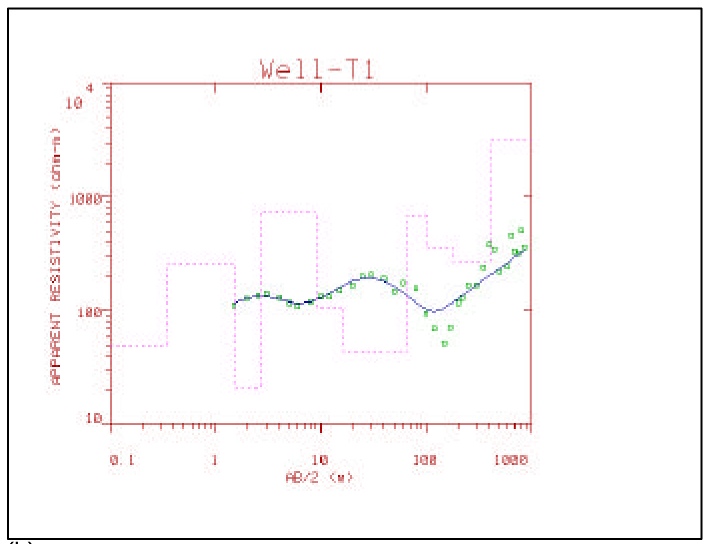


After Verissimo *et al.* (1996).

Figure 2 – Hydrogeological Domains Map of the Medio-Baixo Jaguaribe region indicating the study area of the Project.



(a)



(b)

Figure 3 – Geoelectrical Model obtained by controlled 1D inversion using the ridge regression scheme at site of a 250 m deep exploitation well that has stratigraphic log profile: (a) layers model obtained; (b) model's mathematical fit curve and the observed data.

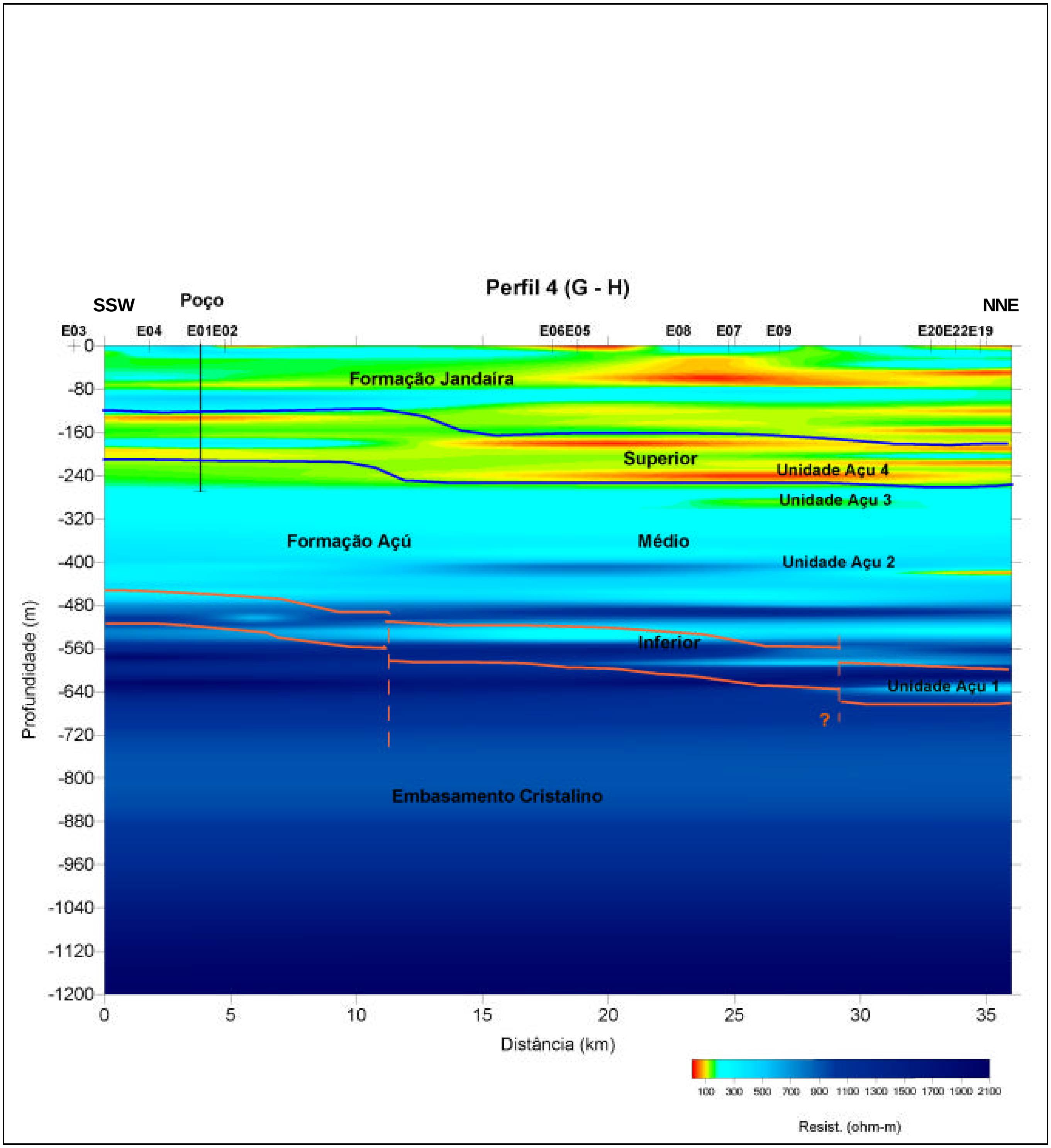


Figure 4 – 2D Hydrogeological Model based on the 2D Pseudo Geoelectrical Section of the SSW-NNE Perfil in the Plataforma de Aracati region of the Potiguar Basin.