EM and airborne magnetic gradiometry studies for Groundwater Resource Evaluation in Guaribas – Piaui State in semiarid northeast Brazil

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Abstract

This paper reports on the preliminary integrated geophysical studies including several EM techniques (MT, CSAMT, TEM) and airborne -magnetic gradiometry data in the border of Parnaiba basin for groundwater assessment in Guaribas region, Piaui State in semi-arid north East Brazil. Thirty five MT-CSAMT-TEM broadband soundings (100 KHz – 0.01Hz) were completed in the area. The aerogeophysical data has been acquired and the survey area is 30 Km by 40 Km. The total coverage includes approximately 1200 line-kilometers of flight lines flown in drape survey with a 100 m terrain clearance. Two –dimensional modeling of EM data show a resistive block (resistivities ≥ than 1000 Ω.m.) crossing most of the Guaribas profile at depths varying between about 100 m and 300 m. We can also observe lower resistivity values under the intrusive resistive block. If the conductive material observed at the Guaribas profile is a porous sedimentary layer, it is very likely that it contains a good confined acquifer yet unexplored. A deep exploratory borehole should be drilled in Guaribas in order to confirm the geophysical observations.

Introduction

The Parnaiba basin is an intracratonic basin located in the northeast portion of Brazil. For the past ten years, Observatório Nacional researchers and collaborators have been involved in geophysical studies in this basin for subsurface structural mapping and groundwater resource evaluation (Meju and Fontes, 1993; Meju et al., 1999; Fontes et al. 1999; Mohamed et al., 2003). More recently, researchers from Federal Government Research Institutions of Brazil (Centro de Tecnologia Mineral – CETEM, Instituto de Radiodosimetria – IRD) came together to propose a multi-institutional and interdisciplinary project aiming at a sustainable development of the Brazilian semi-arid. As part of this effort, a pilot study was initiated in Guaribas, South Piaui in the border of Parnaiba basin for groundwater assessment. Guaribas is among the towns in Brazil with lowest HDI (Human Development Index) and has been chosen by the Brazilian government to start a major program to fight hunger.

This paper report on the preliminary integrated geophysical studies including several EM techniques (magnetotellurics - MT, controlled source audiomagnetotelluric - CSAMT, transient electromagnetics - TEM) and airborne -magnetic gradiometry data.

As well established by many studies, geophysical information is essential for a good evaluation of groundwater resources and should always precede any program for locating wells.

Method

The EM methods provide the means by which the electrical conductivity distribution of the Earth's subsurface can be estimated from either naturally occurring transient electric and magnetic fields (MT technique) or artificially generated fields (CSAMT, TEM).

The EM fields exist (or can be generated) over a wide spectrum of frequencies and diffuse into the Earth inducing electric currents – the telluric currents – which in turn result in secondary magnetic fields. This diffusion process is controlled by the movement of electrons or ions in the earth interior in response to the EM fields. The importance of determining the conductivity structure of a particular region is very much enhanced by the fact that conductivity values are related to a number of other physical parameters, namely, temperature, porosity, fluid content, pressure, as well as the rock lithology.

In the MT and CSAMT techniques, magnetic (H) and electric (E) variations are measured in two orthogonal components, usually the magnetic north (X) and magnetic east (Y) and the apparent resistivity for the two directions, as a fucntion of the angular frequency w, are given by:

$$\rho_{xy}(\omega) = \frac{1}{\omega\mu_o}\left|\frac{E_x(\omega)}{H_y(\omega)}\right|^2 \quad \text{and} \quad \rho_{yx}(\omega) = \frac{1}{\omega\mu_o}\left|\frac{E_y(\omega)}{H_x(\omega)}\right|^2$$

The phases between E and H are indepent information and can be written as:

$$\phi_{xy}(\omega) = \tan^{-1}\left(\frac{E_x}{H_y}\right) \quad \text{and} \quad \phi_{xy}(\omega) = \tan^{-1}\left(\frac{E_y}{H_x}\right)$$

whereμ_o is the free-space magnetic permeability. Note that these expressions holds for the CSAMT technique when the plane wave assumption is valid, i.e. the artificial source is at about a mimimum distance of 3 skin-depths.

In the TEM technique, an electric current is transmitted to insulated wire loops laid on the surface of the ground in the form of a square or retangle. The current has a waveform which is tipically a train of square bipolar pulses with an off-time between pulses. TEM data is based on magnetic fields only and is free from static shift that can affect the MT sounding curves due to electric fields. For that reason, TEM soundings are now routinely used for correcting DC shifts in MT apparent resistivity curves.

Airborne magnetic gradiometry data is an important geophysical tool for structural mapping as well as for mining exploration. In this study, we want to assess its effectiveness in groundwater resources evaluation together with EM data.

Geological Setting

The Parnaiba basin is located on the northeastern portion of the South American platform, overlaying strongly structured basement which was formed or deeply affected during the Brasiliano cycle. The South american platform has been consolidated in late Proterozoic and Early Phanerozoic (700 – 450 Ma). In the studied area situated in the southeastern border of Parnaiba basin, the sedimentary sequences overlain a transition region constituted of gneisses and migmatites (belonging to the Rio Preto fold belt) and metasediments, mainly gneisses. These latter rocks are cut by several granitic intrusions. In this segment, the structural directions of the basement remain sub-paralell to the basin border. According to Góes and Feijó (1994), the basement is overlain by the Silurian Serra Grande Group consisting of the Ipú Formation (arenitic conglomerates and quartz pebbles), the Tianguá Formation (shales and siltstones) and Jaicós Formation (coarse sandstones with quartz pebbles). The Canindé Group overlain the Serra Grande Group and consists of the Itaim Formation (fine sandstones), Pimenteiras Formation (marine shales), Cabeças Formation (fine sandstones), Longá Formation (dark marine shales and siltstones) and the Poti formation (sandstones intercalated by shales and siltstones). Several other groups and formations are known to exist in the Parnaiba basin but they are not present in the studied area.

Data acquisition

The area of study is shown in Figures 1 and 2. Fig. 1 presents covered area where aerogradiometric data has just been acquired by Fugro. The survey area is 30 Km by 40 Km and the total coverage includes approximately 1200 line-kilometers of flight lines flown in drape survey with a 100 m terrain clearance. The sampling of the magnetic field in each individual sensor is 7 meters along the flight lines and the navigation with differential GPS allows an accuracy of about 5 meters in the positioning of the measurements. The measurement of the magnetic field has been carried out with the Cesium vapor magnetometers having a sensitivity of 0.001 nT. With filtering applied during the data processing phase, the mapped total magnetic intensity anomalies show an accuracy better than 0.1 nT. The spatial resolution along the flight lines is 14 meters in the range 125-250 meters (half-wavelenght).

In Fig. 2 we see all the site locations. MT data was acquired using two EMI MT systems. Magnetic north and east directions were used in the electric and magnetic sensors set up. TEM data was acquired using a Sirotem MK3 from GeoInstrumens using 50 meters sided loops and the central loop configuration was adopted.

Thirty five MT-CSAMT-TEM broadband soundings (100 KHz – 0.01Hz) were completed in the area. Data quality were generally good and they were processed by using a robust technique (Egbert, 1997). Both regional strike direction and undistorted sounding curves were estimated by using the Groom and Bailey decomposition technique. Static shift was observed in some MT soundings and its correction was performed by using the TEM data as off-sets for the apparent resistivity curves.

Results and conclusions

Two-dimensional MT models for the Guaribas, Angico and Caracol profiles are given in Figures 3 - 5 (Winglink Geosystem software). We observe a resistive block (resistivities ≥ than 1000 Ω.m.) crossing most of the Guaribas profile at depths varying between about 100 m and 300 m. We can also observe lower resistivity values under the intrusive resistive block. Angico and Caracol models show similar patterns but with higher resistivities. If the conductive material observed at the Guaribas profile is a porous sedimentary layer, it is very likely that it contains a good confined acquifer yet unexplored. On the prelilminary magnetic results given by the total magnetic intensity anomaly map (TMI) shown in Fig.1, the main depicted features are the well resolved crystalline terrains – sedimentary basin limit on the bottom portion of the TMI map and an apparently folded structure within the sedimentary basin close to its border. We are now working on 2D and 3D magnetic modeling constrained by the MT information aiming at a more realistic model of the subsurface structure and lithology. This will allow a better understanding of the hydrogeological potential of the studied area. A deep exploratory borehole (about 600 m) should be drilled in Guaribas area on the northwestern portion of the profile (close to the conductive feature shown on the geoelectrical model of Fig. 3) in order to confirm the geophysical observations.

Acknowledgments

This work was funded by the Brazilian Ministry of Science and Technology under the CETEM-IRD-ON Agreement. We thank Emanuele F. La Terra , Robinson Almeida and Roberto Pereira for invaluable field assistance.

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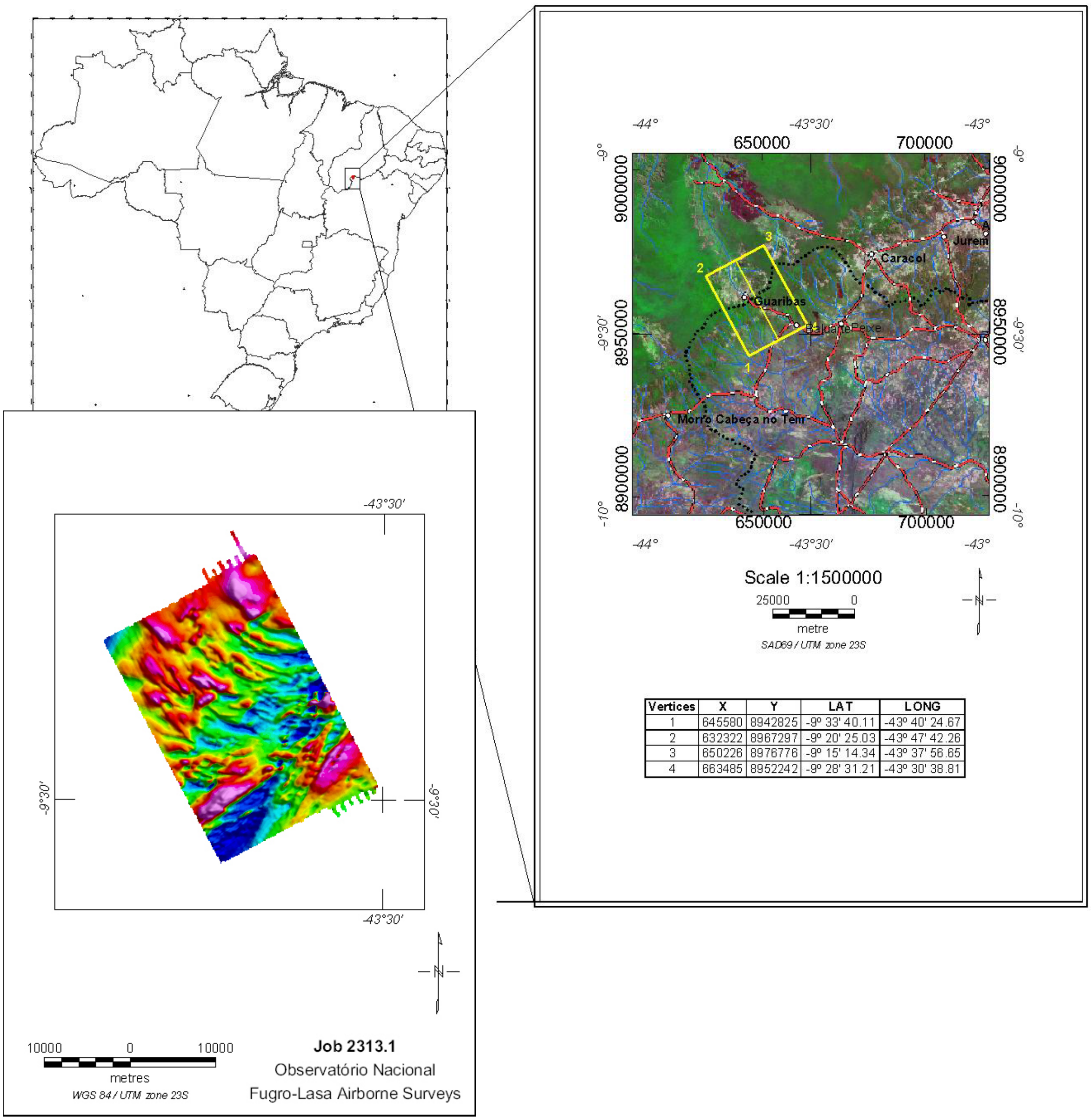

Vertices	X	Y	LAT	LONG
1	645580	8942825	-9º 33' 40.11	-43º 40' 24.67
2	632322	8967297	-9º 20' 25.03	-43º 47' 42.26
3	650226	8976776	-9º 15' 14.34	-43º 37' 56.65
4	663485	8952242	-9º 28' 31.21	-43º 30' 38.81

Fig. 1 - Location map of the airborne magnetic gradiometry in Guaribas, Piaui State, north-east Brazil. The covered area is shown in yellow on the satelite image (top) and the total magnetic anomaly map (enhanced TMI) is shown on the bottom.

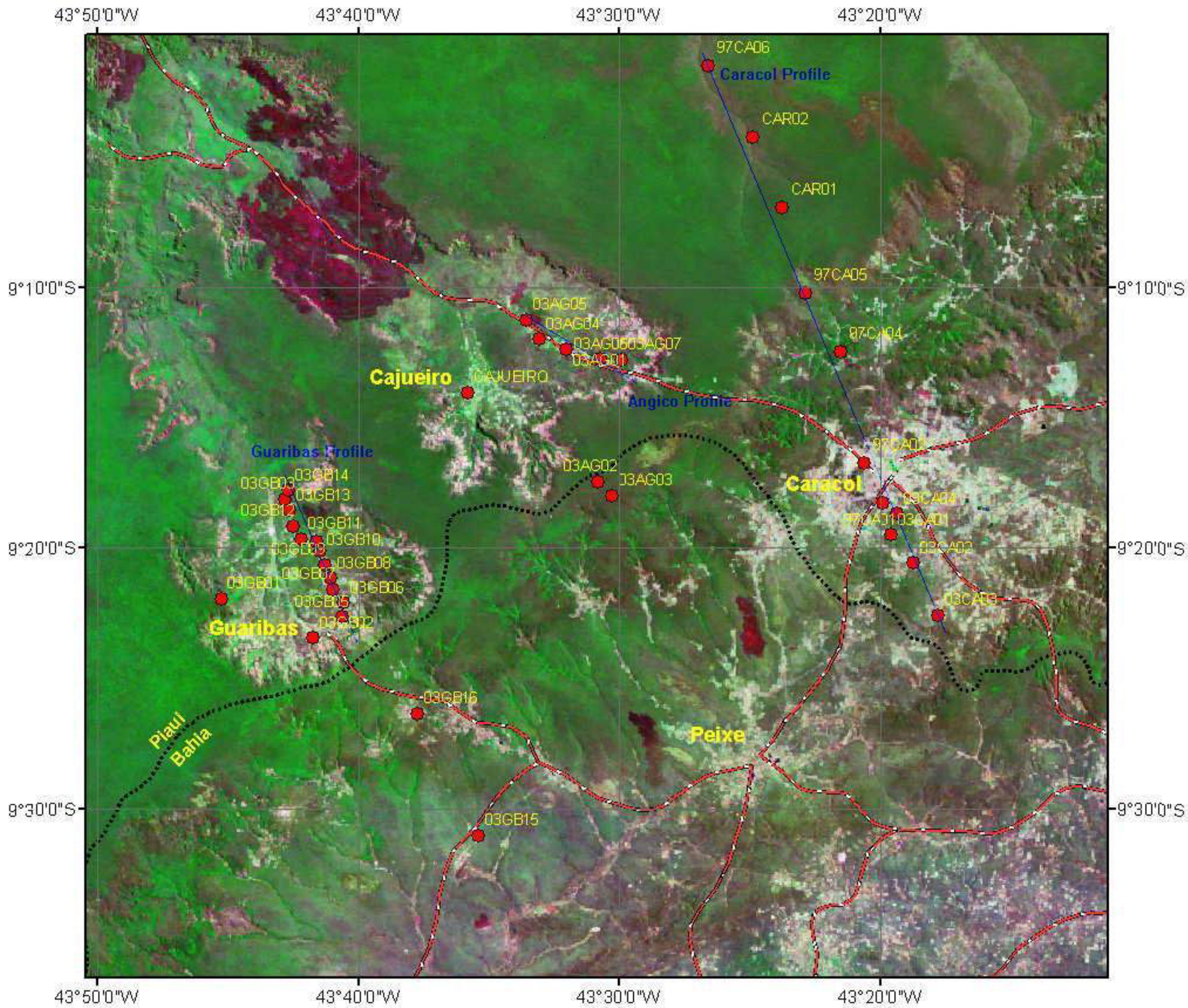

Fig. 2 - Location of MT-CSAMT-TEM soundings (red circles) in Guaribas region - Piauí State.

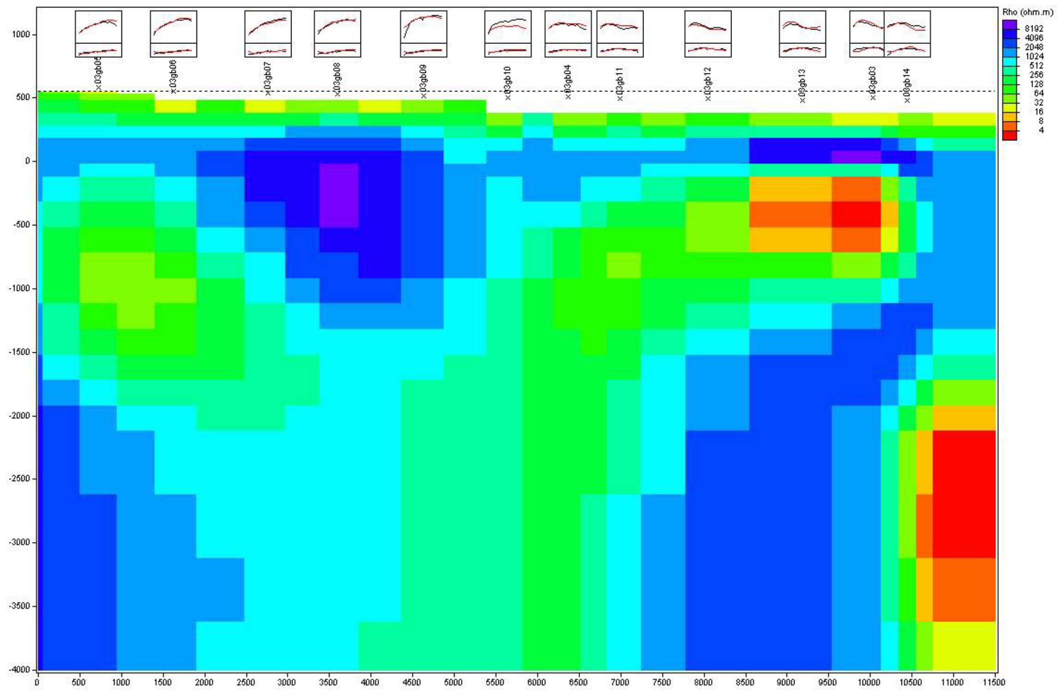

Fig. 3 – 2D geoelectrical model for the Guaribas profile. Small retangles at the top show the fitting between observed and calculated data for the TE mode.

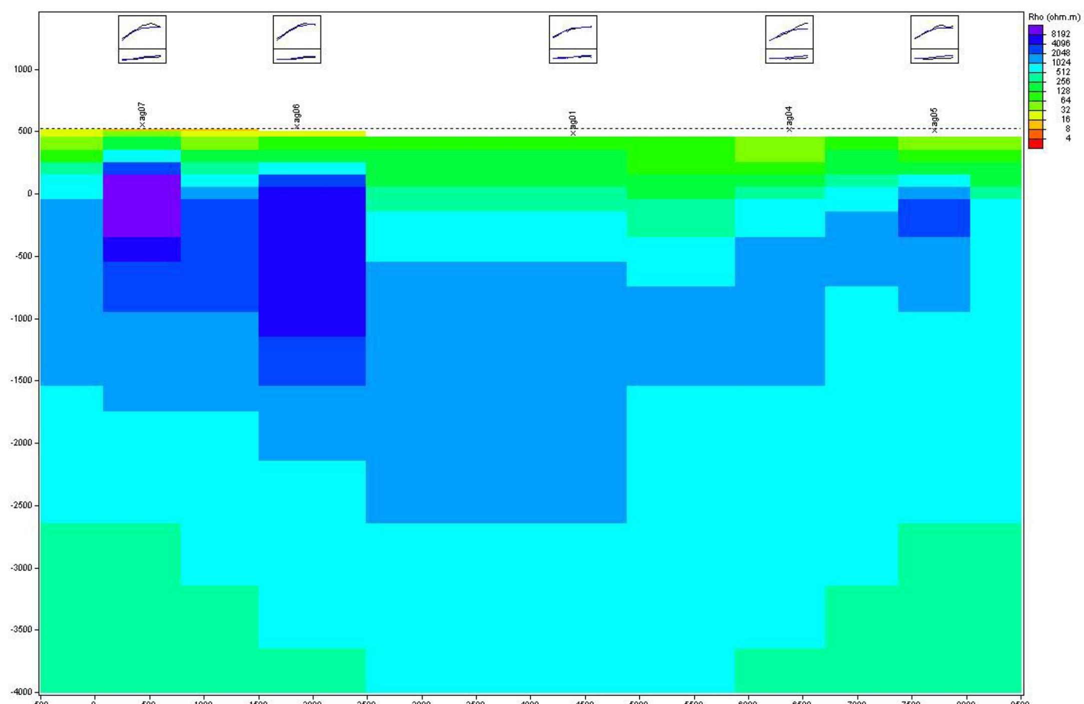

Fig. 4 – 2D geoelectrical model for the Angico profile. Small retangles at the top *show the fitting between observed and calculated data for the TM mode.*

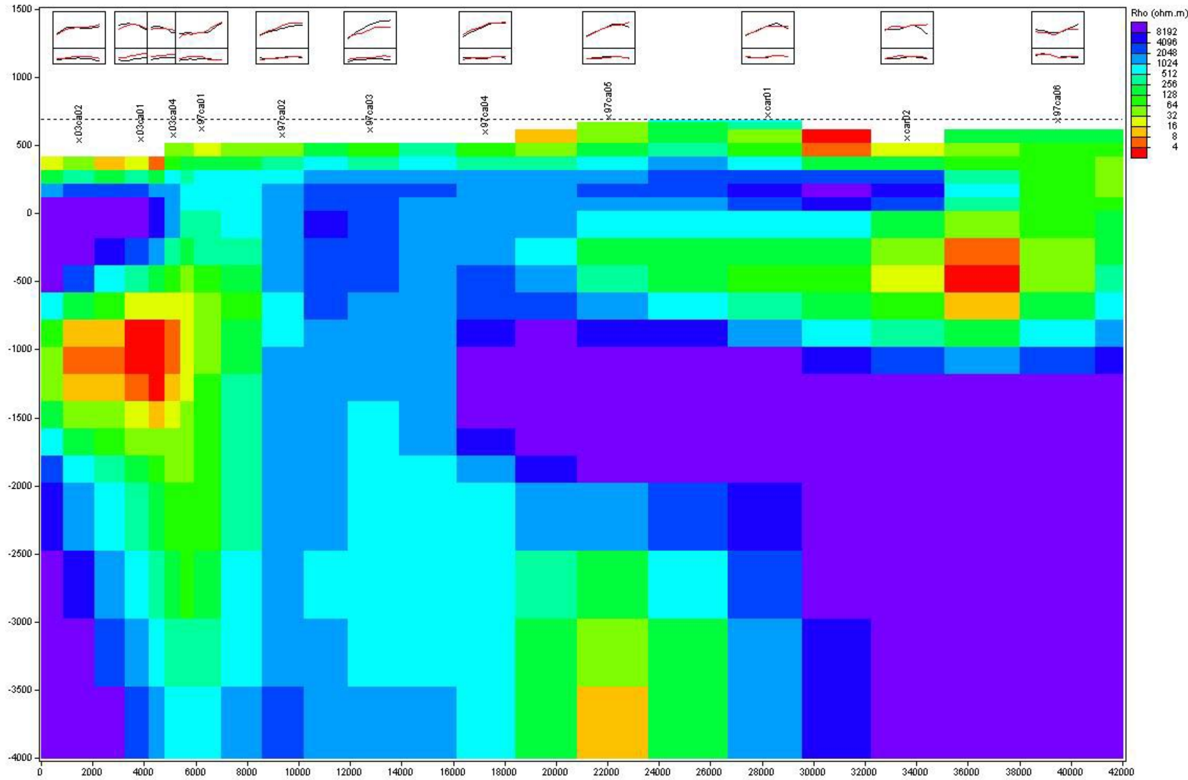

Fig. 5– 2D geoelectrical model for the Caracol profile. Small retangles at the top *show the fitting between observed and calculated data for the TE mode.*