Transient electromagnetic sounding in Sao Tome Cape – RJ - Brazil

Emanuele Laterra[1] and Abel Carrasquilla[2]

[1]Geophysics Coordination, National Observatory, General Jose Cristino Street, 77, Sao Cristovao, Rio de Janeiro, 20921-400
[2]Petroleum Engineering and Exploration Laboratory, Darcy Ribeiro Northern Rio de Janeiro State University, Km 163 Amaral Peixoto Highway, Brennand Avenue S/N, Imboassica, Macae-RJ, 27930-480.

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Abstract

In 1959, Petrobras drilled the wellbore 2-CST-0001-RJ in Sao Tome Cape-RJ, the first one in Campos Basin. This well of 2600 m was discarded because there were not enough hydrocarbons to be produce. But, just before, lithological data and well logs were collected. Currently, we decided to carry out a survey close to this area using the transient electromagnetic geophysical method. The primary objective of the study was to verify the technique ability to solve quaternary and tertiary layers in this type of geological environment, and at the same time to compare the results with the data mentioned above. The results show the existence of a strong correlation between modeled and distinct layers of shale, sandstone and conglomerate. On the other hand, the anomalies of the spontaneous potential log have a clear coincidence with the interfaces of the geological layers.

Introduction

Transient electromagnetics (also time domain electromagnetics - TDEM) is a geophysical technique utilized in Sao Tome Cape, Rio de Janeiro (Figure 1), near to Petrobras 2-CST-0001-RJ abandoned well (Petrobras, 1959). The objective of the survey was to correlate the responses with the spontaneous potential (SP) log and lithological description of the well in its first hundred meters depth.

The geology in this area is formed by the Campos Group, which was deposited in the final phase of the thermal subsidence of the Campos Basin, and is composed of the Embore, Ubatuba, Carapebus and Barreiras Formations (Figure 2). Proximal sediments of the Embore Formation, forming by sand, conglomerate and carbonate, are found gradating to shale in the distal portion (Ubatuba Formation), with the presence of intercalated turbidite sandstone of Carapebus Formation (Milani et al., 2001). The Barreiras Formation only is found in the emergent portion of the Campos Basin, being marked by deposits of continental and fluvial origin (Figure 1). This formation was described by Schaller (1973) and only considered in the stratigraphic chart of Winter et al. (2007).

Method

TDEM is a geophysical exploration technique which a current transient pulse induces electrical and magnetic in subsoil. Subsequently, a decay response of the secondary magnetic field is measured (Figure 3). The method is generally able to determine subsurface electrical properties but, it is also sensitive to subsurface magnetic properties (Fitterman & Stewart, 1986). The surveys are a very common surface technique used throughout the world in both onshore and offshore applications. Its applications go through UXO (unexploded ordnance) detection and characterization, mineral search, groundwater exploration and, environmental mapping (Meju et al., 1993).

The configuration of the acquisition was a central loop mode and the survey point was in the Garoupa Farm, where the borehole is located. In this arrangement, the transmitter is a square loop - TX and, to measure the vertical magnetic field - Hz, the receiver induction coil - RX is located at the center of the ring (Carrasquilla & Ulugergerli, 2006). The characteristics of the research layout were: a) transmitter loop (TX) with a 100 m square loop, 10,000 m^2 area, 2.5 mm^2 wire and 7 Amp current; b) receiver coil (RX) with single channel induction coil of 10000 m^2, being considered as a vertical dipole Hz (Figure 4).

To reduce the noise from the houses, the measurements were performed 200 m NW from the wellhead position, being that, this displacement does not change the result of the comparison with lithological description, because it is a sedimentary basin where the layers are stratified and horizontal in that zone. In the acquisition, windows of the decay of the magnetic field Hz as a function of time with 53 samples were used, the triggering command was done manually, the intensity of the current was enough to induce magnetic fields up to 300 m depth and the composite mode was between 10^{-2} to 10^{2} msec because the possible saturating fluids make the resistivity values low. The survey was planned to compare TDEM resistivity, SP log and lithological description in depth (Figure 5).

The licensed WinGlink (2018) program was used for editing and processing of field data, necessary to remove outliers in the measurements and remain only with the exponential decay points of the Hz field. The 1D Occam smoothed inversion (Constable et al., 1997) was performed using a parametrization of 20-layers, with a stop criterion of 20 iterations and root mean square (rms) misfit of 1.5 % of root mean square error (rms). The result was used as input in the inversion process, obtaining a model of 7-layers in real data fit. The error in the modeling was 1.5 % rms with 99 iterations. A fine-tuning of 0.94 rms was achieved after completing all the iterations.

Results

The lithological description of the well up to 270 m depth can be visualized in Figure 6 (Petrobras, 1959). The sedimentary rock is divided into shale and sandstone intercalations until this depth. The sandstone is from the surface till 25 m (yellow, Embore Formation, São Tomé Member, Quaternary), then comes the Barreiras Formation (Tertiary), where sandstone is yellow, shale is green, and conglomerate is brown. The sandstone formation is intercalated with shale as far as 1950 m, where there is a basalt spillage of Lower Cretaceous Cabiunas Formation. The Precambrian gneissic basement occurs at 2600 m, which is defined as economic basement (Gomes, 2013).

A layer of sandstone from surface to 30 m with resistivity of 250 ohm.m is shown in the 1D model and, associated to Embore Formation (Figure 7). From 30 to 100 m the resistivity falls to 70 ohm.m, with the lithological description displaying intercalations of shale and sandstone associated to Barreiras Formation. At 100 m depth, a strong conductor of 1 ohm.m and 25 m thickness arise in the model, which was interpreted as a conglomerate associated with the Barreiras Formation maybe saturated by salty water. Above 100 m depth, there are many intercalations of shale and sandstone layers, resulting in resistivities close 70 ohm.m and 50 m thickness, together with another with 30 ohm.m and 400 m thickness. These responses may be caused by intercalations, which cause a different resistivity of the sandstone and the shale, with sandstone presenting resistivity values of two decades higher than the shale (Telford, 1990). A conductive layer is found at 1000 m with 2 ohm.m, perhaps composed of sandstone and shale intercalations and, impregnated with brine water. Over this depth, the method does not present a definition, so it is not possible to interpret.

Many agreements are observed between the low SP log anomalies and the shale layers along the well. Figure 6 exemplifies the previously declared, through coincidences among the red arrow connections with the different shale layers and the anomalies, for example, in 25, 50, 60 m depths, etc. Figure 8, on the other hand, shows the coincidences between the anomalies of the SP log, the different lithologies and the layers resulting from the 1D interpretation.

Conclusions

The result of the survey shows that the local stratification is well explained by coincidences between TDEM resistivity, lithological description and SP anomalies. The data inversion displays seven layers up to 1000 m, in this order: 1) associated with sandstone; 2) sandstone, where the resistivity decreases with the shale intercalations; 3) strong conductive layer associated with conglomerate, probably containing brackish water; 4 and 5) two layers in succession, possibly being sandstone with numerous intercalations of shale layers; 6) another conductive layer, which can be interpreted as a sandstone having salty water; and, 7) above 1000 m, where the method does not present resolution, so it is not possible to make an interpretation. This means that, in the tested geological environment, the TDEM method resolution can solve and to differentiate the geological strata.

Acknowledgments

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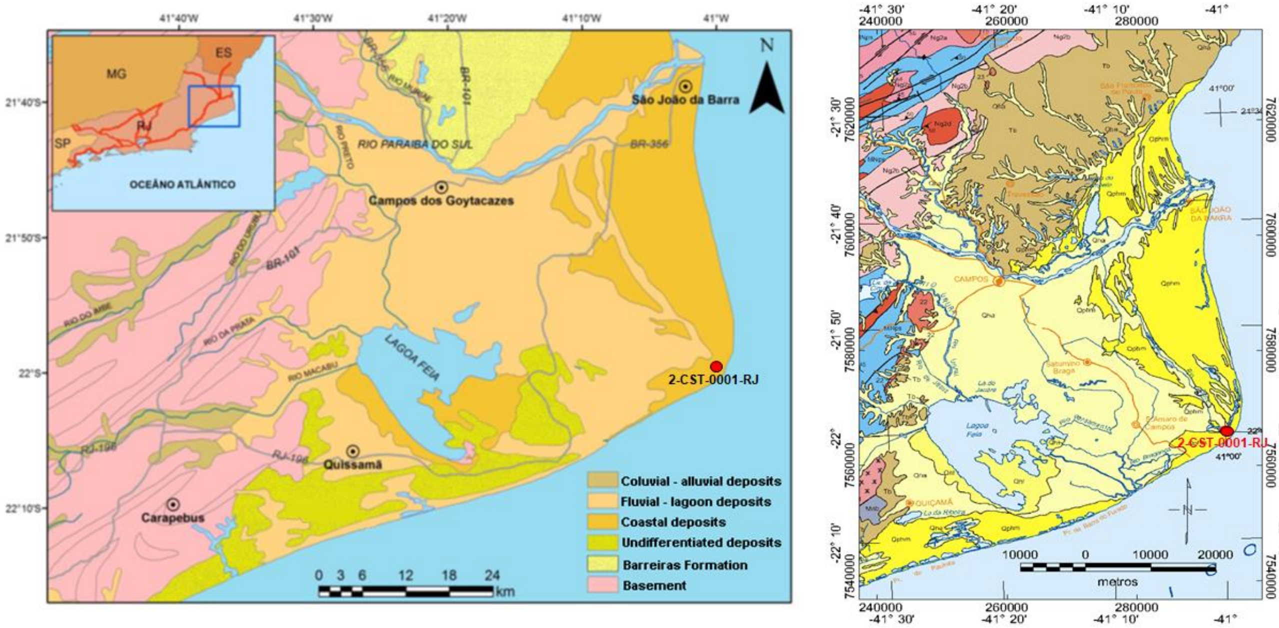

Figure 1. Geological map of the continental portion of Campos Basin. Left, the map with greater geological details. Right, the yellowish colors are geological formations of the quaternary (Embore, Ubatuba and Carapebus Formations), whereas the brown ones are of the Tertiary (Barreiras Formation). The red dot indicates the position of the well 2-CST-0001-RJ (modified from Villela, 2015).

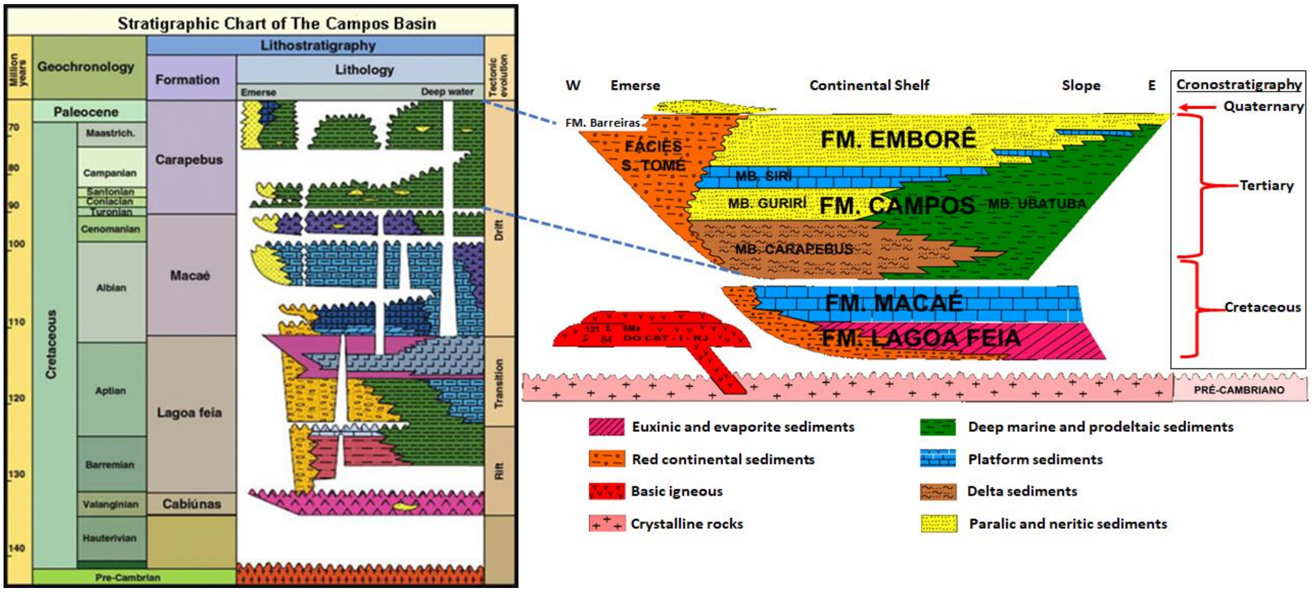

Figure 2. Lithostratigraphic column of the Campos Basin (modified from Schaller, 1973).

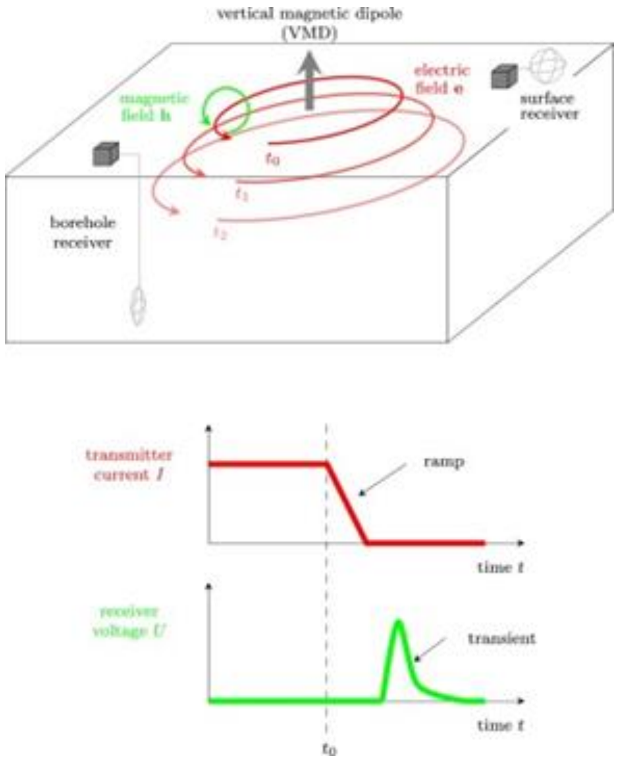

Figure 3. Above, subsurface induced currents that generate secondary fields measured as receptor. Below, transient in the transmitter current and measured voltage in the receiver (modified from Carrasquilla & Ulugergerli, 2006).

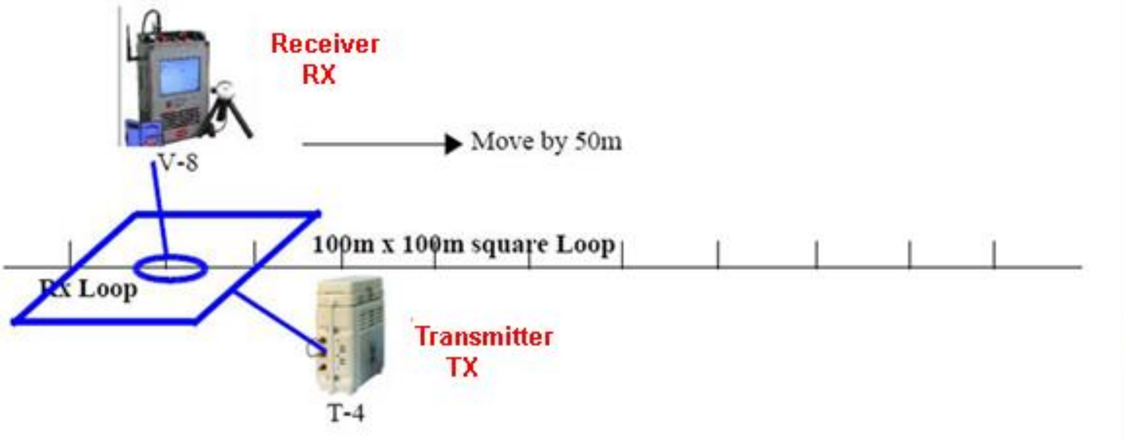

Figure 4. Central-Loop data acquisition configuration.

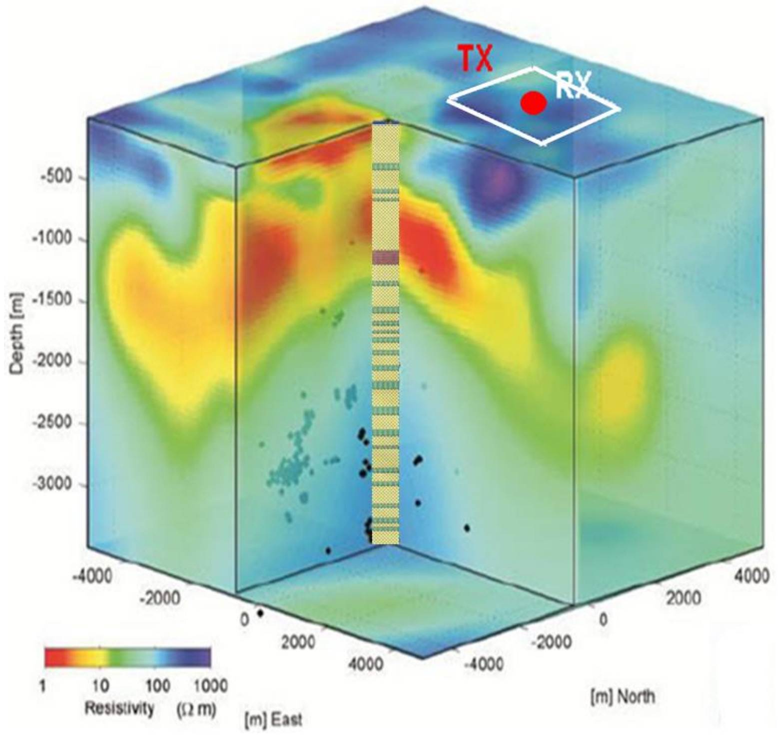

Figure 5. Data acquisition scheme with the TDEM method and compare with the lithological description, SP log anomalies and depth resistivity changes along the well.

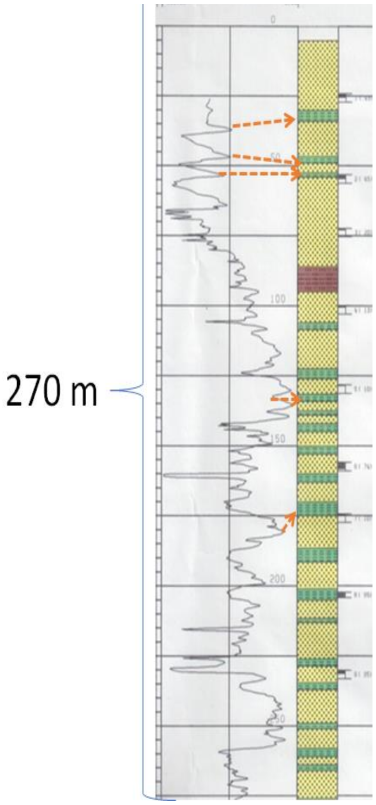

Figure 6. The coincidence of low values of the SP log with the shale layers are shown through some arrows. In the borehole, sandstone is yellow, shale is green, and conglomerate is brown (Petrobras, 1959).

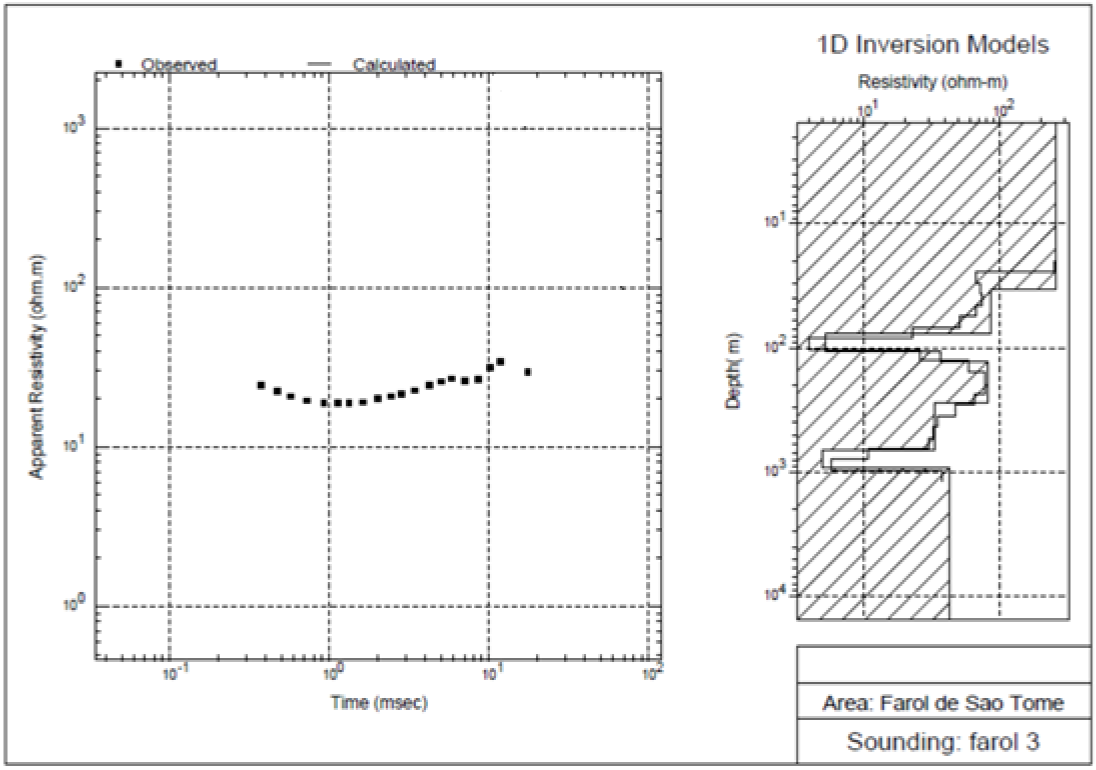

Figure 7. On the left panel the values of the resistivity measurements with TDEM and the right panel the 1D layer inversion model.

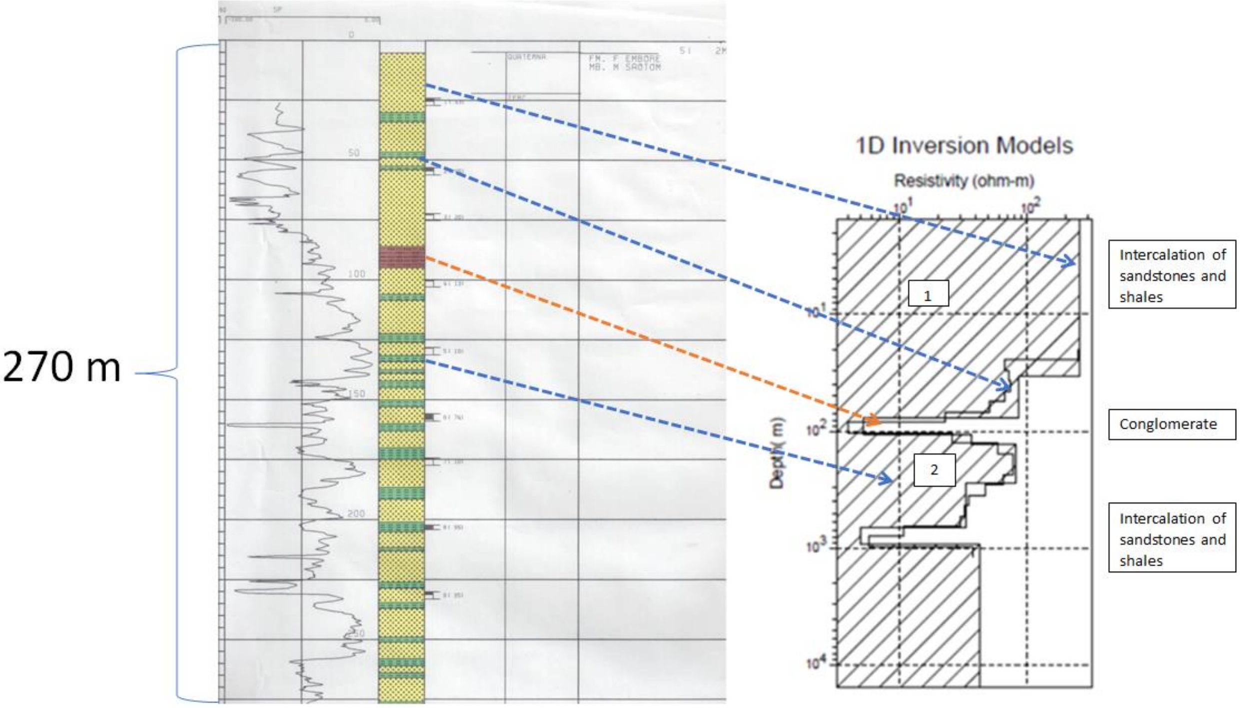

Figure 8. Comparison of the SP log and lithological profile of the 2-CST-0001-RJ well with the inverted 1D layer model. In evidence the low resistivity value of the Barreiras Formation conglomerate (in brown).