A013
Contribution to Oil Exploration and Development - A Successful Inductive Multi-Frequency EM Survey On-Shore Brazil

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SUMMARY

In this work we discuss the results of an experimental study performed using a multi-frequency electromagnetic method over a mature oil field in Recôncavo basin, Bahia-Brazil. Five 1.8 km transects, 200 m apart, were surveyed over a selected oil reservoir block. The processed EM data are represented as cross-sections and maps of apparent resistivity and induced polarization parameter, using a consistent plotting procedure. All the sections, controlled by well logging data, allow to recognize the following geological features: (i) the oil sandstone horizons and their trapping shales; (ii) the oil-water interface and some zones of water invasion; and (iii) lateral electric contrasts representing fault zones. These results suggest the real possibility of the use of the spectral EM method in the direct detection of hydrocarbons, as well as for monitoring the efficiency of the artificial fluid injection used for secondary recovery. Also, this experiment brings about a further development in the inductive measurement of IP and introduces, for the first time, the use of this property in oil reservoir exploration and characterization.

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Introduction

The electronic and computing developments are bringing notable progresses in the performance and resolution of EM methods. We have available today: (i) a high precision and versatile equipment with capacity, coupled to a powerful computer, to register and process a larger amount of field data; and (ii) good techniques for inverting and representing the EM data. The limitations associated to the resolution of EM methods and environmental and cultural noise effects, normally present in oil field, have been overwhelmed by the use of a dense and multiple data acquisition, a careful data processing and an effective integration of the available geophysical and geological informations. In a structural geological block, having dimensions of 800 m by 1,800 m by 1,000 m depth, the frequency domain EM experiment has been made (Figure 1).

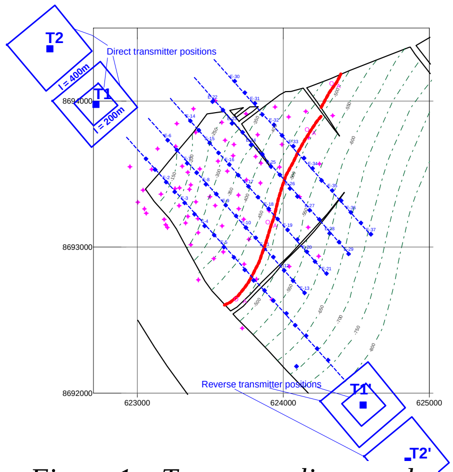

Figure 1 – Transverse lines, and transmitter and receiver stations

Methodology

The experiment was performed over the selected structural block, along the lines shown in Figure 1. Five transects 200 m spaced were surveyed along the dip direction of the geological strata.

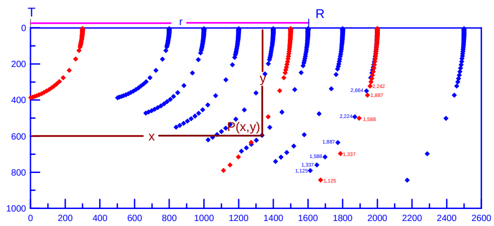

Figure 2 – Proposed scheme to plot the EM results in a depth profile.

The receiver stations were selected not only to cover, in detail, the whole extension of the oil reservoir, but also a representative portion of its water zone. The transmitter stations were defined to assure a depth of exploration between 300 and 1,000m within the range of T-R distances used in the survey.

In each transect two transmitter positions, separated by 500 m, were used at each side of the target block, both to increase depth of exploration and to correct distortions caused by lateral heterogeneities and anisotropy.

Receiver System – Three high sensitivity coils of 0.82 m length are laid on the ground, with one of them oriented radially to the transmitter loop center. Simultaneous measurements of the absolute value of in-phase and quadrature components of the magnetic field along r, φ and z, are obtained for each frequency. In this work, only the radial component has been worked.

Transmitter System – The spectral EM transmitter is composed of: a square horizontal loop having 200 m or 400 m of side, having a maximum dipole moment of 2.5 x 10^6 A.m^2; an electronic control unit whose function is to impose to a loop, successively AC current at cycles in 54 frequency values; and a motor-generator to energize the loop. The frequency range is from 1.125 Hz to 10,473 Hz, in values given as $f = 1.125x1.8819^{n-1}$; $n = 1, \ldots, 54$.

Data Plotting - The calculated pair ($\rho_a, \sigma_i / |\sigma_a|$) is plotted at a subsurface point, as shown in Figure 2, given by the following cartesian coordinates:

$$x = \frac{r}{1+(\eta\delta_d / r)^2}; \qquad y = \frac{\eta\delta_d}{1+(\eta\delta_d / r)^2},$$

where δ_d is the vertical skin depth of the dipole field, and η a calibration coefficient, taken to be here equal to 0.4.

Data Resolution - Resolution in this method can be defined as half the variation in the coordinates x and y (see data plotting), by a change of frequency from a value to the next in the sequence of the measurements taken by the equipment for a given r (T-R separation). By varying r in the range 0.8 Km to 2.5 Km, in a geological environment having resistivity values from 1Ωm to 3,500Ωm, and the frequency ranging from approximately 1Hz until 10kHz, the resolution is given by $\Delta x \cong 4$ to 25 m and $\Delta y \cong 3$ to 45 m, except at a very narrow interval of the parameter $\theta = (2\pi\mu_o f\sigma/2)^{1/2} r$ around 6, where it could be two times as larger (Figure 3).

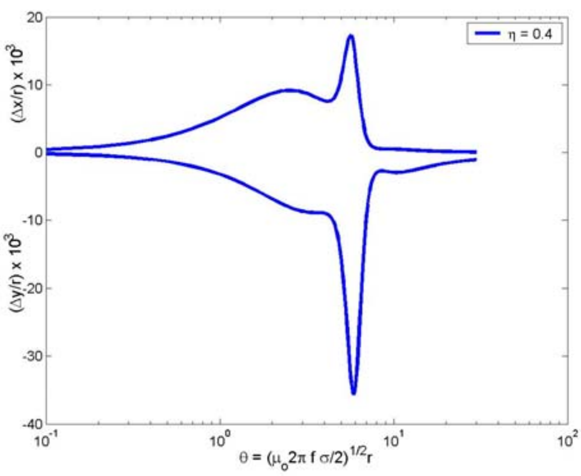

Figure 3: Horizontal and vertical resolution versus induction number

Results

In Figures 3 and 4 we show the averaged resistivity and IP parameter sections for the two direct transmitter (see Figure 3) positions obtained in line 800. Our geological interpretation is superposed on these images to emphasize the complementarity of the geoelectrical information. In Figure 5, this interpretation is checked against the geological section constructed from well logging data obtained along the same line.

In general, there is a good correspondence between the interpreted EM sections and maps with the subsurface geology, except by some distortions caused by the procedure used to compute the coordinates of the main attribution points.

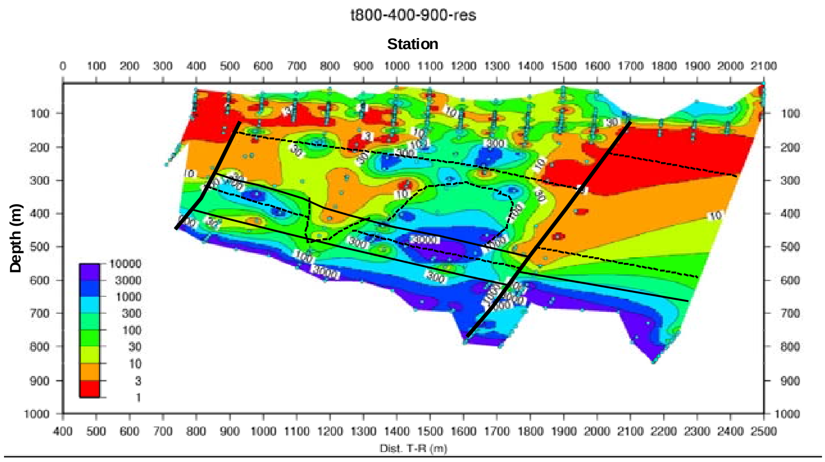

Figure 4 – Apparent resistivity section along line 800.

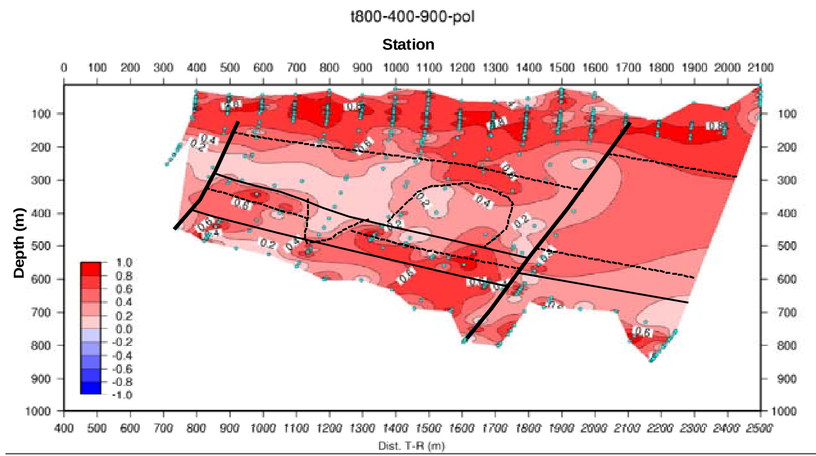

Figure 5 – Apparent IP parameter section along line 800.

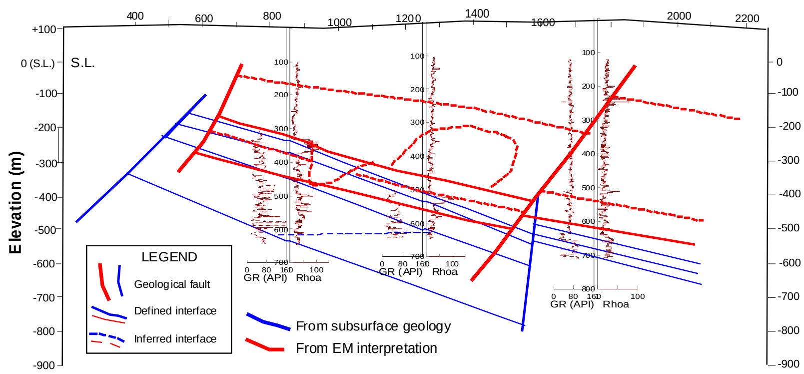

Figure 6 – Comparison between the EM interpretation and the geological section along line 800

Conclusions

In general, the consistency of the electromagnetic information obtained in this experiment is fully satisfactory in confrontation to the available geological and well log data. Effects of cultural noises, mainly at high frequencies, were effectively removed during the processing stage. Thus, in most cases, the combination of IP and resistivity data was enough to delineate the geoelectrical models for the studied block. The maps and sections allow to conclude that: i) the lithological interfaces and the faults are well marked by distinct contrast of IP and resistivity; ii) the Sergi formation storing oil is shown as a zone of high resistivity and IP parameter; iii) the distinction of oil/water contacts are also electrically notable at most sections and maps. Furthermore, the following inferences can be drawn from the EM data: a) a certain region at the top of the Sergi reservoir is being better drained in terms of oil production. Within it an expressive lowering of apparent resistivity and IP effect from north to south, may be representing a progressive replacement of oil by water, in the central zone of the studied block; b) the original oil/water interface within the Sergi sandstone appears to have been displaced a short distance away, mainly in a sub vertical direction, in response to the forceful injection of water; c) in several sections and on the shallower maps we observe another possible influence of the water injection pattern used for secondary recovery. This occurs in the shape of a resistive anomaly penetrating the upper shales of Candeias Formation. In this zone we also observe a slightly increase in the induced polarization parameter, probably due to injection of oil or fresher water than native formation water, into fractures.

Small distortions are observed when comparing a geoelectrical section with the corresponding geological section constructed using well log data: a) the images appear a little bit larger toward depth; b) the faults are somehow curved in the direction of the transmitter position, for the lower frequencies.

Sato (1979) and we now, in this experiment, are the first ones to make inductive IP measurements, in the frequency domain. The high consistency and the reproductiveness of the measured parameters and their location in subsurface, practically invariant by transmitter and receiver positions, are the warranty of the intrinsic value of this new method.

Acknowledgments

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