COMPARISON BETWEEN MAGNETIC RESONANCE IMAGING LOG AND CONVENTIONAL EVALUATION BASED ON ELECTRICAL LOGS: A CASE HISTORY.

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Abstract

The current evaluation level of hydrocarbon reservoirs associated with low salinity formation water consists on the use of drilling fluids promoting a salinity contrast in the flushed zone, allowing the use of microresistivity logs for fluid identification. This method, however, is not free from inaccuracies in quantifying light hydrocarbons, whenever present in the formation.
One of several applications of the magnetic resonance log has been the fluid mobility index in the reservoir. It is obtained from direct records of effective porosity and volume of irreducible fluid, from which a qualitative relationship of permeability is achieved. Another application which is gaining large acceptance between the oil industry is the direct fluid typing with particular relevance for those hydrocarbon reservoirs associated with low salinity water.
This paper is aimed to correlate the conventional evaluation routinely used by the oil industry, based on electrical logs, with the results from the magnetic resonance imaging log (MRIL)® and the formation evaluation through cased well.

INTRODUCTION

A group of 13 low viscosity oil fields was discovered along a structural trend, in the superior and medium section of cretaceous formations. The reservoirs comprise thick units of coarse grain sandstones deposited by fluvial system which yielded a continous production flow due to the performance of a strong bottom aquifer .
The association between low density, high mobility oil with low salinity formation water always posed a problem for formation evaluation, which is an actual technological challenge for the accurate identification and quantification of the discovered volumes.
Because conventional methods of evaluation have been showing inappropriate for this low salinity water-bearing formation, being constantly necessary to confirm the volumes discovered with drill steam tests or wireline tests, several techniques were developed by Petrobras to minimize this problem, some with great success, as the relationship between Sxo with Sw (Silva and Sarzensky, 1980). This last one proved to be more effective in the evaluation of heavy oil-bearing reservoirs. Attempts with tools based on the water dieletric property - eletromagnetic propagation tool -(Abbadia and Carrascoza, 1988), showed that accuracy is also strongly dependent on the water formation salinity.

CHARACTERISTICS OF THE TOOL

The magnetic resonance tool is composed by three basic elements: a permanent magnet, a radio-frequency transmitter and a receiving antenna. The base of the measurement process begins with protons alignment in the formation pores (hydrogen nuclei) trigered by the permanent magnet. A sequence of radio-frequency signals is applied in the formation causing a perpendicular re-orientation to the direction of the permanent magnetic field.
After the pulse sequence, the protons align themselves perpendicularly to the permanent field, emitting a signal which is captured by the receiving antenna. In this condition these protons vibrate to a certain resonance frequency, emitting a signal with intensity calibrated to be proportional to the rock porosity (Austin and Faulkner, 1993). The signal decaying with time is inverted as a multi-exponential model related to pore sizes and fluids characteristics. This curves so inverted is known as transverse relaxation time (T_2) distribution , or simply stated: the T_2 distribution curve, which represents, on each of its T_2 bins, the partial porosities associated to each T_2 domain. Analysis of this distribution may supply information on porosity, pore sizes distribution, clay content and fluid identification.
The tool may be activated in the following mode of operations: EFFECTIVE POROSITY obtaining records starting from 4,0 ms and presented in 8 or more bins (2^n ms; n= 2,3...) in the T_2 distribution spectrum; TOTAL POROSITY, recording decaying times starting from 0,5 ms aimed to supply information on the reservoir shalyness.
The tool resorts on other activations such as the ones for hydrocarbon identification: the DIFFERENCIAL SPECTRUM and the SHIFTED SPECTRUM (Akkurt et all, 1996).

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PRESENTATION OF RESULTS

The main fluid characteristics in the oil-bearing reservoirs are presented in Table I.

Table I: Rock and fluid data

ZONE	DEPTH (m)	TEMP (°F)	WATER SALIN. (mg/l)	PHIm (%)	Km (mD)	VISCOSITY (cp)
X	970	124	500	19/21	1000	16
Y	1240	129	500	22/24	2000	4

Because there was an increase in the amplitude in the T_2 distribution spectrum on the 9^{th} bin, i.e. on 512 ms, as a response to low oil viscosity in these reservoirs, it was adopted as a working strategy the selection of this anomaly as a possible oil indication (Reis et all, 1998). In addition, another strategy was also encompassed which consisted in computing ratio of the sum of the presumed oil bearing bins 7 and 8 to the sum of the water associated bins 5 and 6. Figure 1 depicts the results of this approach which discriminates the oil-bearing zones.

ZONE x

Due to the oil characteristics (low viscosity), the reservoirs of this zone typically present low resistivity contrast between the oil-bearing and water-bearing zones. In this well the same is observed, whose oil zone discrimination was only possible after a quantitative analysis.
The analysis of the MRIL with the effective porosity method exhibits a strong signal in 512ms bin, indicating oil (Figure 1). It is possible to place an oil/water contact coincident with the expected depth for this contact in this field. The logging pass made with the differencial spectrum confirms the oil signal. The well was completed in this zone producing an initial oil daily flow rate of 36,7 m^3, without water production.
Based on qualitative analysis of conventional logs a another reservoir is observed like an oil-bearing one with porosity of 22% and the resistivity curves indicate the presence of fluid mobility (permeability). The quantitative analysis calculated a Sw= 60%, compatible with the quick look interpretation. During the well completion, based on these information, it was proposed a test to identify the fluid. However, inspecting the magnetic resonance log (Figure 1), the authors noticed a T_2 distribution concentrated on 4 and 8 ms, therefore, below the movable/irreducible fluids T2 cut-off (33ms). In the effective porosity of 18%, calculated from the measurements, free fluid is practically non existent. In this case, the magnetic resonance log provided a necessary information to avoid testing a low productivity interval, resulting in economy in the evaluation process.

ZONE Y

The evaluation from conventional logs indicated 2 intervals with possible oil occurrence (Figure 2). The upper interval (987/990m) was tested by wireline tool, identifying oil. Through conventional logs, the lower interval (1000/1003 m) was also interpreted as a probable oil-bearing reservoir and it was suggested a fluid test identification. However, the analysis of the resonance log, using both the effective porosity and differencial spectrum, indicate oil signal only in the 512 ms bin in the upper interval (Figure 2).
It is still observed in the oil-bearing interval a variation between the effective porosity supplied by the resonance log (16%) and that given by the quantitative analysis (20%) of the conventional logs. This porosity variation could be due to a low hydrogen index of this oil. Fluid identification tests were accomplished in both intervals. The upper interval (987/990m) produced oil and the lower produced water, both confirming the interpretation of the magnetic resonance log. Table II presents a summary of the fluid interpretation data obtained by the magnetic resonance log, the conventional evaluation and the cased hole tests.

Table II: Comparative results of fluids Identification.

ZONE	DEPTH (m)	PHIE LOG (%)	NP LOG (m)	Sw LOG (%)	PROBABLE FLUID LOG	MRIL	FLUID IDENTIF. TESTS
Y	1000/1002				OIL	WATER	WATER
X	1238/1246	20	2,5	50	OIL O/W? *	OIL O/W OK!	OIL

(*) The conventional logs did not show clearly the oil/water contact.

CONCLUSIONS

-in spite of not being the main product of the magnetic resonance tool, it is viable its use in fluid typing, mainly in reservoirs associated to low salinity water , where the method now in use is quite frequently inconclusive. The use of both, the conventional evaluation and MRIL® logs would be a major progress in reservoir evaluation resulting in an optimization in the fluid identification tests.

-the analysis of the T_2 distribution spectrum was used as a qualitative oil indicator. It was observed the presence and relative intensity of signal in the 512 ms bin. Another necessary condition is that the signal is not dispersed for the whole spectrum, but preferentialy presenting a bimodal character or very marked trimodal.

-the qualitative oil index ratio proposed by the authors (the sum of the bins 7 and 8 divided by the sum of the bins 5 and 6) was applied in all the analyzed zones, with satisfactory results. The utilization of this ratio among the bins is useful to increase the visual contrast between zones with different fluids.

-the oil time relaxation (T_2) varies as a function of its viscosity. However, in the analyzed reservoirs it was observed that oils with viscosities of 4 and 16 cP presented T_2 signal in bin 512 ms. That can be understood considering that, in reservoir conditions, the influence of parameters as temperature, pressure and gas saturation can alter the viscosity towards lower values, then, favoring the oil detection. Besides, the inversion algorithm used to calculate the T_2 distribution spectrum, working with discreet values was limited to 8 bins (from 4 ms to 512 ms), may have pushed any oil bearing signal greater than this value to this limiting 8th bin (512 ms).

- oil identification on the T_2 distribution spectrum still depends on a minimum volume of residual oil in the flushed zone and also of a high signal / noise ratio during the acquisition, once the noise tends to attenuate the width of the signal and to spread it over the adjacent bins, reducing the oil signal (Georgi et all, 1995).

-It was verified the microresistivity tool responds not only to the presence of residual oil, but also to the existence of high irreducible fresh water saturations, which are not always discriminated by conventional log analysis. In these situations, the possibility of misinterpretation of fluid type, based exclusively on conventional logs, may be fairly high.

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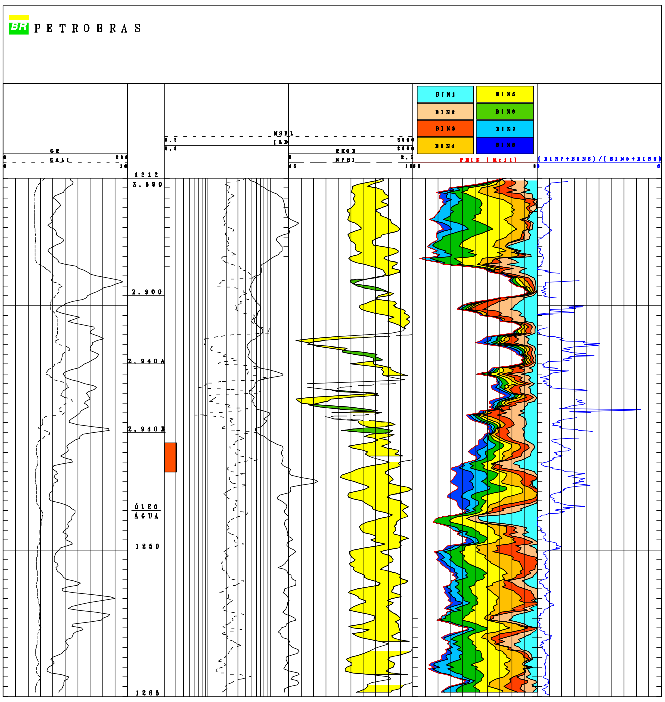

Figure 1: Comparison among the conventional logs (tracks 1, 2 and 3) and pore size distribution classes of the magnetic resonance log (track 4). The bins 7 and 8 are related to the presence of oil. Track 5 shows the ratio among the sum of the bins 7 and 8 divided by the sum of the bins 5 and 6 as proposed by the authors. Note that the oil/water contact is clearly identified through this ratio among the bins.

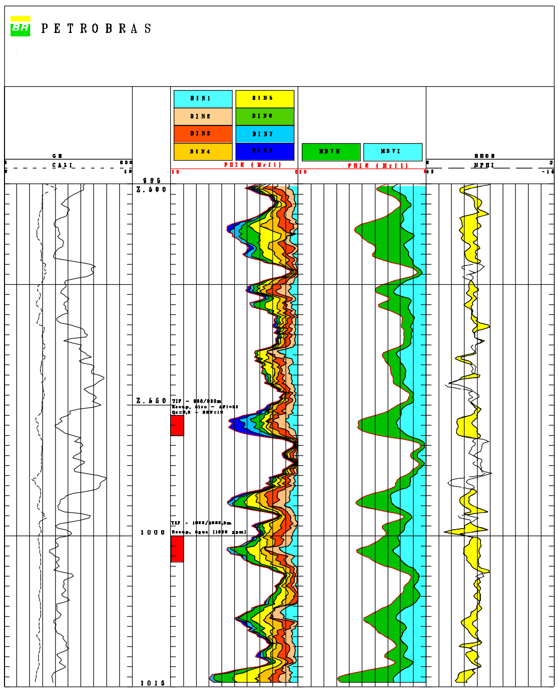

Figure 2: Cumulative T2 distribution by pore sizes classes (track 2). In the track 3 the blue shading (MBVI) represents the volume of irreducible water and the green shading (MBVM) represents the volume of movable fluid. It is noticed the oil occurrence in the top of the zone 550, indicated by the predominance of the bins 7 and 8 compared to the other bins related to movable fluid. The other reservoirs are water saturated.