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CAN NMR SOLVE CONVENTIONAL LOGS INTERPRETATION PROBLEMS IN LOW RESISTIVITY BEDS EVALUATION

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ABSTRACT

This paper presents some cases of low resistivity reservoirs and low contrast resistivity reservoirs where conventional logs fail to determine the petrophysical properties of formation. The problems of these reservoirs are that conventional logging interpretation shows high water saturation zones, but water free hydrocarbon would be produced. In case of low resistivity contrast reservoirs it is difficult to determine oil-water contact with resistivity logs. Nuclear magnetic resonance (NMR) log has been only available as a supplement tool to provide additional information on the producibility of the reservoirs. This paper shows that, in the case of low resistivity reservoirs, NMR logging is very effective tool, which helps to accurately determine the reservoir rock petrophysical properties. For the analysis of NMR data, several aspects of NMR technique have been used; 1) T1/T2 ratio, for fluid identification, 2) the difference between NMR derived porosity and total porosity, to determine the types of clay minerals, 3) NMR relaxation properties, to identify fluids nature and rock properties of low contrast / low resistivity reservoirs. This paper presents three examples of low resistivity reservoirs. Analysis of NMR data of low resistivity zones has helped to identify the producibility of these reservoirs zones has helped to identify the producibility of these zones, to determine lithology independent porosity and to distinguish between bound and free water. In case of low contrast resistivity reservoirs where there was little resistivity contrast between water bearing formation and oil-bearing formation, NMR has been able to identify the fluid nature of the two formations and then the height of the oil column. This was based mainly on high contrast of NMR relaxation parameters.

Keywords: NMR, Resistivity logs, Porosity logs, Low resistivity and Low resistivity contrast

I. INTRODUCTION

The problem with low resistivity pay zones is that the resistivity data interpretation indicates high water saturation, but oil or even dry oil will be produced. The reasons for low resistivity phenomenon are classified mainly into two groups. The first group is concerned with reservoirs where the actual water saturation can be high, but water - free hydrocarbons are produced. The mechanism responsible for such high water saturation is usually described as being caused by microporosity. The second group is concerned with reservoirs where the calculated water saturation is higher than the true water saturation. The mechanism responsible for this high water saturation is described as being caused by the presence of conductive minerals such as clay minerals, metal sulfides, graphite and pyrite in a clean reservoir rock.[1] The problem of low resistivity reservoirs usually is not one of being able to determine the presence of hydrocarbons. Generally, standard log analysis will identify the hydrocarbon bearing zones. The problem is to be able to predict that little or no water will be produced even though log analyses indicate that the formation has high water saturation. NMR log can identify water free production zones, correlate bound fluid volume with clay minerals inclusions in the reservoir, and identify hydrocarbon type. [2-5]

The phenomenon of low contrast resistivity pay zones is encountered in reservoirs where there is little resistivity difference between water bearing and oil bearing zones. The use of NMR log has clearly solved this problem. The problem is so-called low contrast resistivity reservoirs showing high contrast NMR relaxation times. [6]

Three field examples will be presented; two examples are for low resistivity reservoirs and third example showing a low contrast resistivity reservoir.

II. NMR POROSITY

The fact that NMR porosity depends only on the fluids content of the formation, unlike density/neutron porosity which is influenced by both fluids and surrounding rocks makes NMR measurements much more capable than conventional logs to furnish clay-corrected porosity, non-productive and productive porosities. The strength of the NMR signal is proportional to the number of hydrogen atoms in NMR tool dependent rock volume.[7-11] Figure 1 shows the standard rock porosity model for all pore fluids. MSIG denotes the total porosity. MPHI is the effective porosity from NMR (fluid fractions of rock), except for clay bound fluids, with T2 above 3 ms). MCBW represents the clay- bound water porosity with T2 < 3 ms. MFFI, the free fluid index, which includes all movable fluids (hydrocarbon and free water) with T2 > 33 ms in sandstone. MBVI, the capillary bound water, is defined as all porosities measured with T2 between 3 and 33 ms. MBVWT represents bulk volume of water (free, capillary and clay bound water).

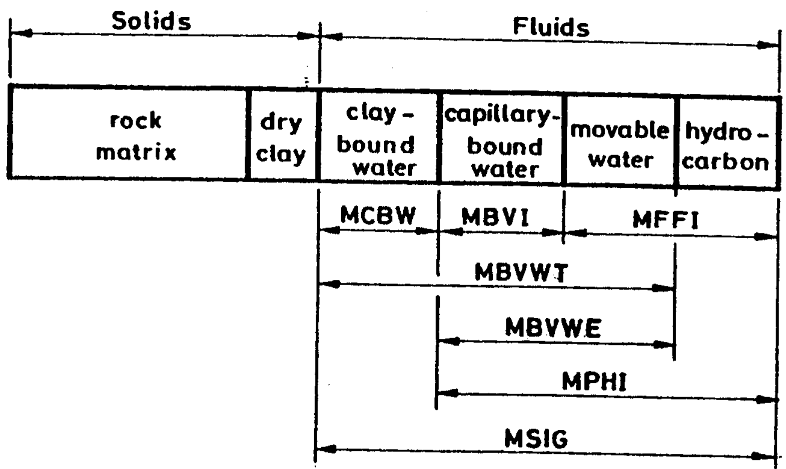

Fig. (1) The standard rock porosity model for all pore fluids.[10]

III. NMR AND FLUIDS TYPE

New methods for acquiring and processing NMR log data enable signals from gas, oil and water to be unambiguously separated and, in many cases, quantified. These methods exploit the combined effects of T1 and diffusion contrast based on log response. The T1 contrast separates the water and light hydrocarbon (oil and gas). Gas and oil signals are then separated based on the large contrast in the diffusion-induced T2 relaxation times for gas versus liquid. Figure 2 shows ,in a qualitative way, NMR properties for water, oil and gas under typical reservoir conditions. Laboratory NMR data show that both T1 and T2 vary over several orders of magnitude depending on fluid type. Hence to allow reliable fluid typing, linear gradient field NMR tools have to be capable of measuring relaxation times from less than 1 ms to several seconds.[13-15]

IV. FIELD EXAMPLES

In the case of low resistivity reservoirs, resistivity logs analysis shows high water saturation but water free hydrocarbon will be produced. The standard logs fail to predict this phenomenon. This section presents different field examples to show how NMR log can help to solve this problem.

Field Example 1

Figure 3 shows a suite of logs from an offshore Gulf of Mexico well drilled in low- resistivity Pleistocene sandstone formation[3]. Water saturation calculations, from induction resistivity log and using resistivity exponents measured on 12 core samples, have shown that water saturation is generally greater than 50 %, where the water

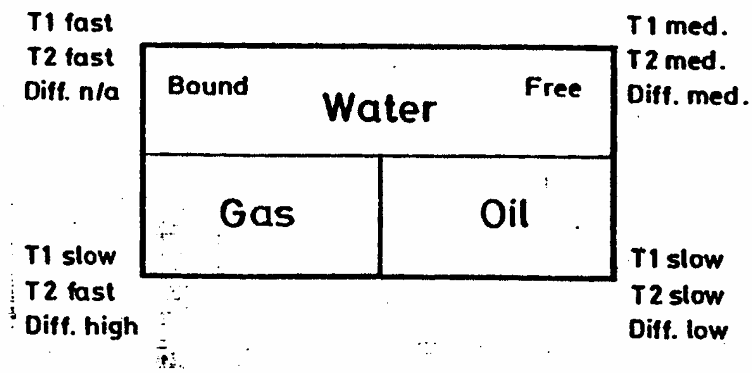

Fig. (2) NMR parameters (T1, T2 and Diffusion) for water, oil and gas under reservoir conditions

saturation values go from 25% to 74%. Figure 4a shows water saturation from induction log and density porosity as a function of surface area. The core analyses shows that these oil sands are not clean and that there are clay/silt size inclusions. The samples consist of 14 to 34 % by weight of less than 30 μm gain size material. These clays present high surface area on which water adheres, and the water, which is only of several molecular layers thick on the surfaces, is bound and cannot move. The induction log responds to the total water (free and bound); therefore, water saturation has exceeded 50% and water free hydrocarbons are produced. Capillary analyses of these dirty cores have shown high irreducible water saturation.

NMR measurements on sidewall core samples are the most readily technique to identify these low resistivity reservoirs. The proposed technique is applied in the studied as follow:

1. NMR surface area measurements were conducted on the 12 core samples
2. Specific surface areas (As) using equation ($As = A_{NMR}[(1-\phi)/\phi]\rho_{ma}$) were calculated
3. S_{wi} from capillary pressure curves is plotted versus As as shown in Figure 4b
   The correlation equation between Swi and As for each sample is
   $S_{wi} = 1 - e^{(-0.0047As+0.24)}$, r = 0.982) where r is the correlation coefficient.
4. Water saturation (S_w) from induction log and density log data were found
5. Compare between S_w and S_{wi}, water free hydrocarbon will be produced over the interval where S_w < or = S_{wi}.

Water will be produced where S_w is > S_{wi}. The comparison between Figures 4a and 4b shows that S_w is generally less than S_{wi}, which indicate that this well section will produce water free hydrocarbon. This was confirmed when the well was tested and showed dry oil production.

Field Example 2

Figure 5 presents logging data for Abu-Gharadig gas well drilled in the Western Desert, Egypt. The main producing formation in this well is Middle Cretaceous Kharita formation which is a shaly sand formation[16]. This glauconitic sandstone is very heterogeneous; since it is a mixture of silt, very fine sands and glauconite. This complex lithology formation is characterized by high grain surface area, thus, its irreducible water saturation is high. Resistivity logs read about 1 Ω.m. against pay zones and the log analyses have shown high water saturation (80%-90%), however, the wells produce water free hydrocarbon. The main mechanism of such case is being the micoporosity and the high capillarity,[10]. The NMR data shown in Figure 5 indicates that there is a considerable amount of free fluid (gas and water) below depth B while there is very little free fluid above depth B as shown in track 2. This was based on the cutoff value of 33 ms as shown in track 3. The true porosity is derived from density log rather than NMR and neutron logs. At depth A all porosity logs (MSIG, PNSS and PDSS) are going down to about 10 p.u. while the true porosity is about 25 p.u.

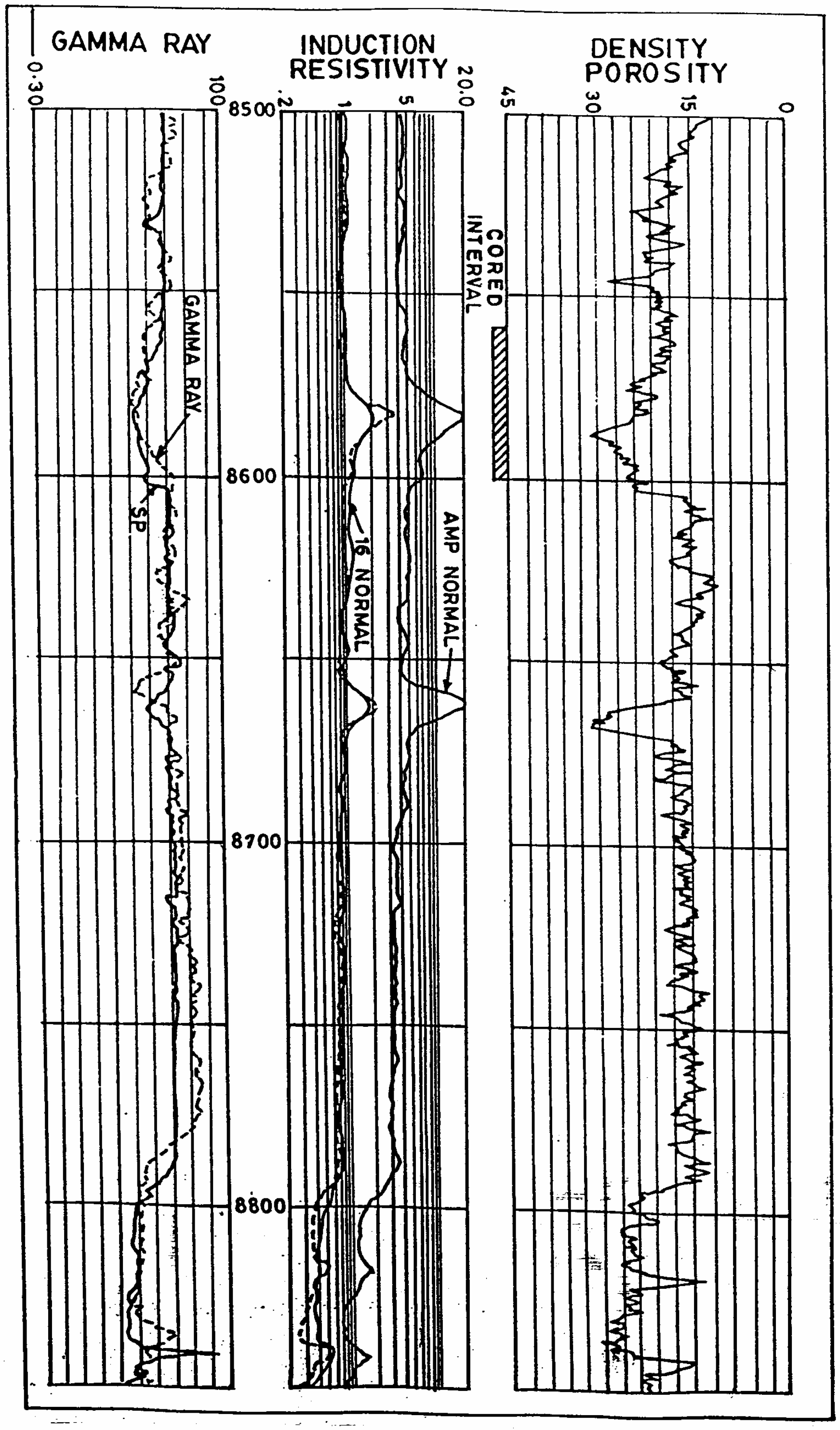

Fig. (3) Logs for well in low resistivity water

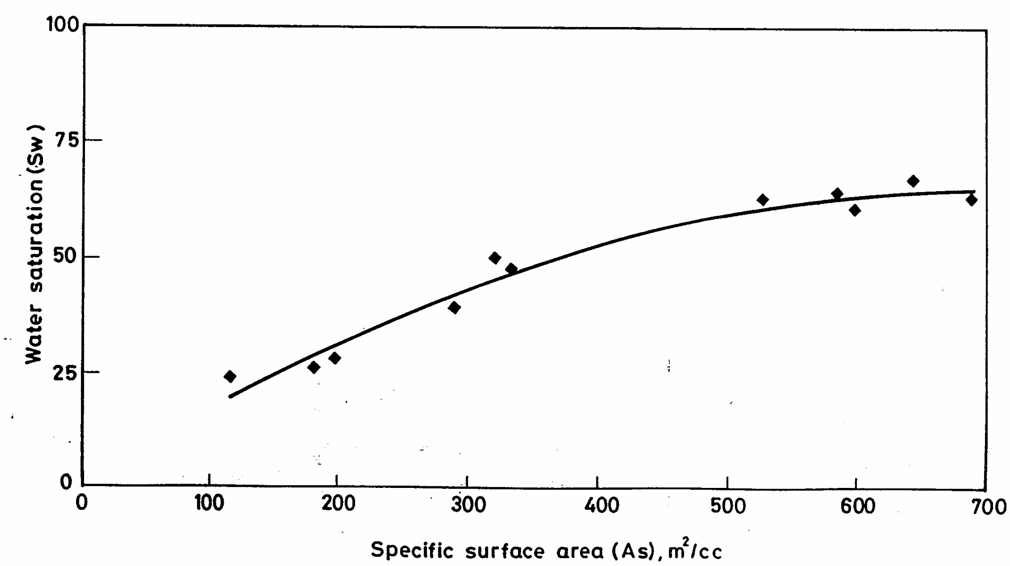

Fig. (4a) Water saturation from induction log versus grains surface area

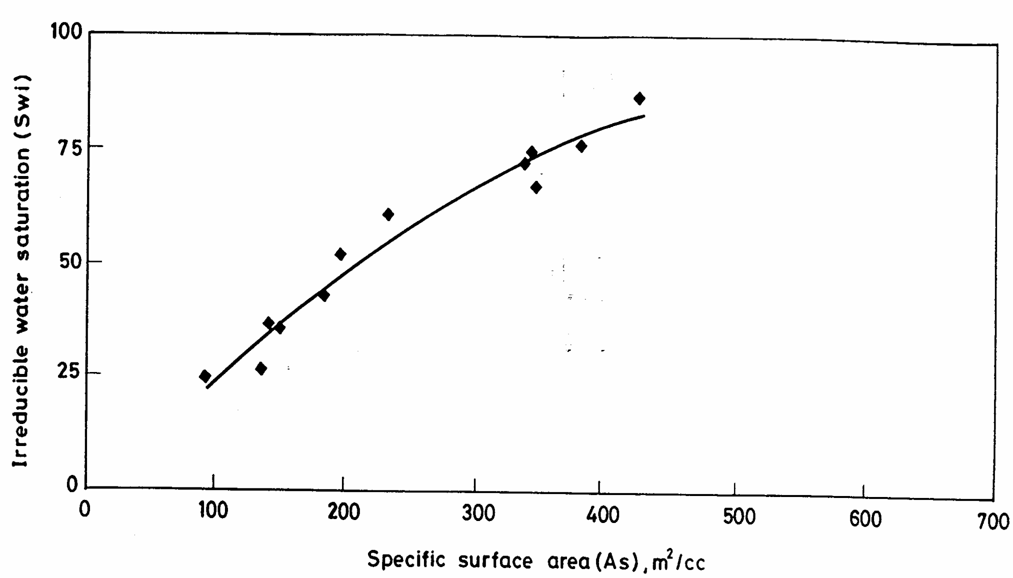

Fig. (4b) Irreducible water saturation versus grain surface area

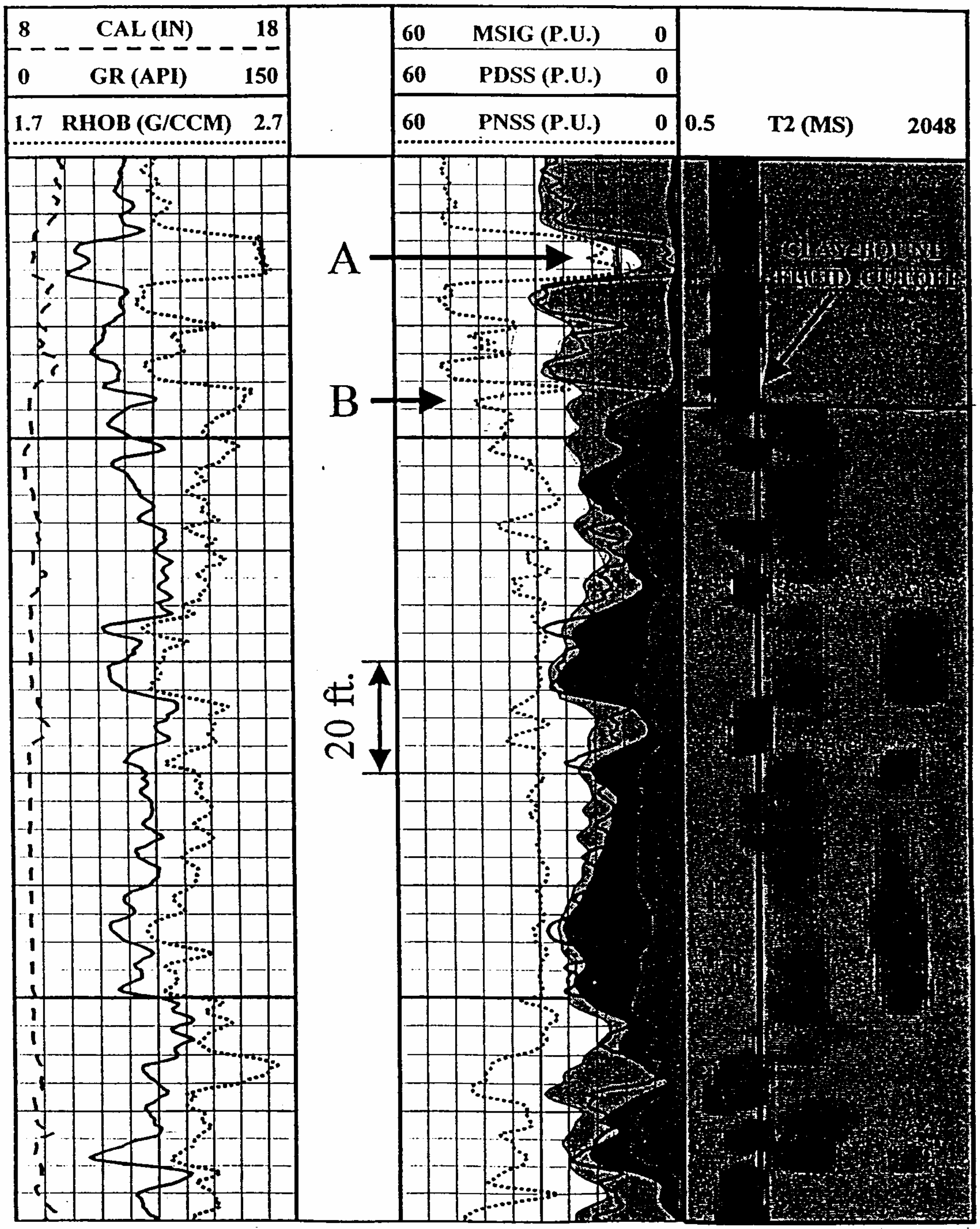

Fig. (5) Logging Suite for Well in Low Resistivity Sandstone Reservoir

Field Example 3

This is an example of low contrast resistivity in Early Cretaceous sandstone reservoir, Saudi Arabia,[6]. In such sandstone reservoirs, the water bearing formations contain relatively fresh water, thus show high resistivity. The pay zones contain mixed water (brine and fresh) which make formation resistivity variable and lower than the normal values. This low contrast resistivity makes the pay zone identification from resistivity log a very tedious job. Figure 6 presents a logging suite run in one oil producing well from a low contrast resistivity reservoir. In track 1, GR shows that there are three sand bodies and the resistivity reading in track 5 shows resistivity values in the range of 3-

4 Ω.m., which are typical resistivity values for water bearing zones in central Saudi Arabia fields[4]. This well is producing hydrocarbon with little water. NMR logging was used to solve this resistivity interpretation problem. The NMR logging technique works well in the low contrast resistivity reservoirs, based on the contrast in the relaxation parameters (T1, T2, and diffusion) between water (free and bound) and hydrocarbon (oil and gas), as shown in Figure 2. The technique of Modified Differential Spectrum (MDS)[6] was used to isolate water signal from hydrocarbon signal. The modified model has 3 passes at three waiting time groups. The use of MDS was to overcome the NMR interpretation problem due the absence of nearby water zone required to observe T2 distribution change between water zone and oil zone on the normal T2 distribution curve.

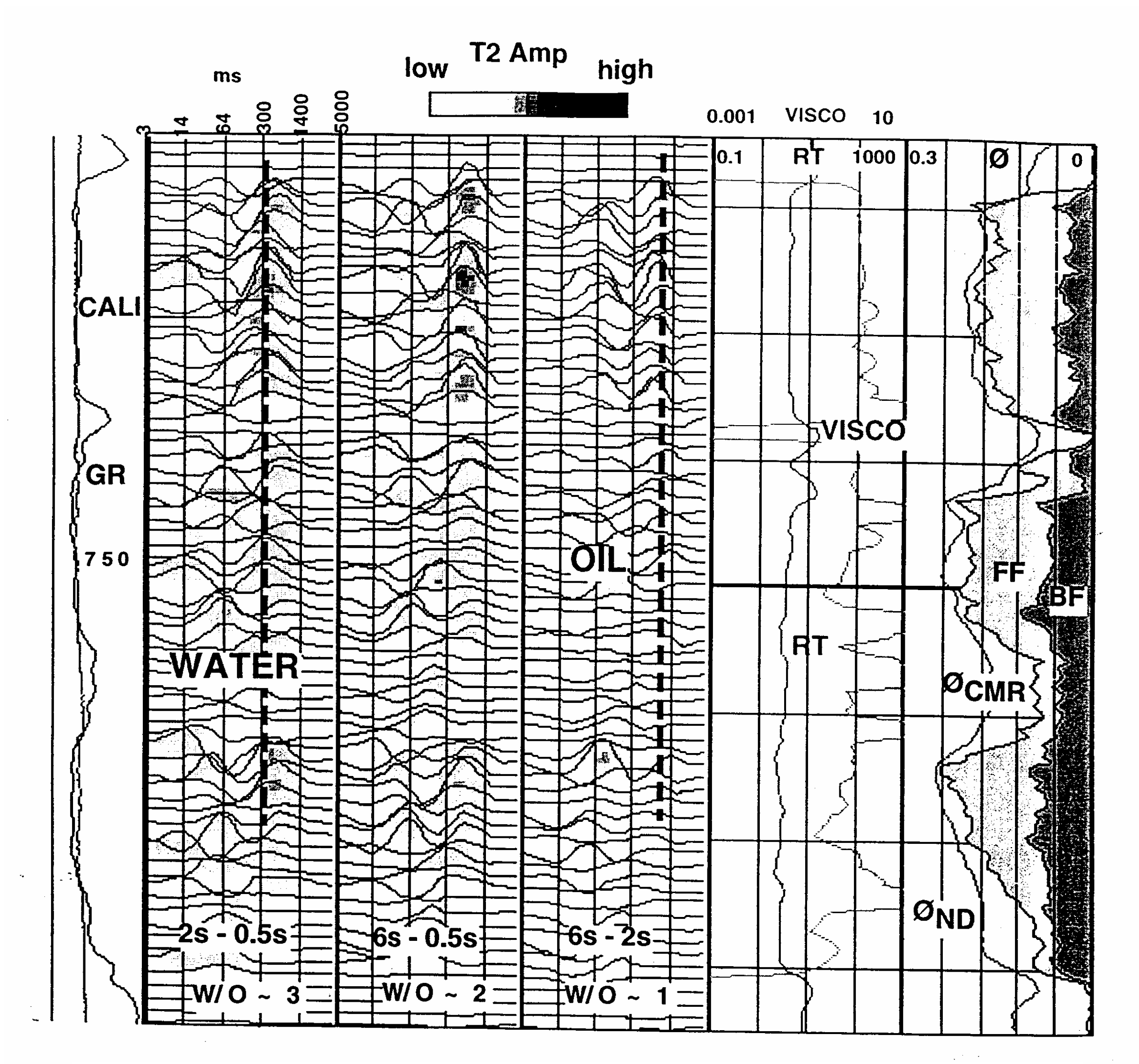

Fig. (6) Modifies differential spectrum and logging suite for well in low contrast resistivity reservoir

The illustrated model in Figure 7 was developed for T_{1oil}=1.0 s and $T_{1\ water}$=2.5s. The model includes three T2 distributions at 6s, 2s and 0.5s waiting times (Figure7a-c) and 3 passes of MDSs with varying water/oil ratios (Figure7d-f). MDS have shown symmetrical spectrum around the peak at 300 ms, in the case of water, for all waiting times which are shown by the broken curve in the models (Figures 7a-f). But in case of oil and water, the model spectrum (solid curve) lost symmetry and shifted, with respect to the ideal water peak, for all waiting time groupes, Figure 6.while the oil peak was observed at 1200ms. Neutron/density porosity (ND) and CMR porosity profiles are shown in track 6. The three MDS passes shown in tracks 2, 3 and 4 identified oil signal at 1200 ms and water signal at 300ms. Free fluid index shown in track 6 illustrates that oil will be produced. Formation tester was run afterward and confirmed oil in all three sand bodies.

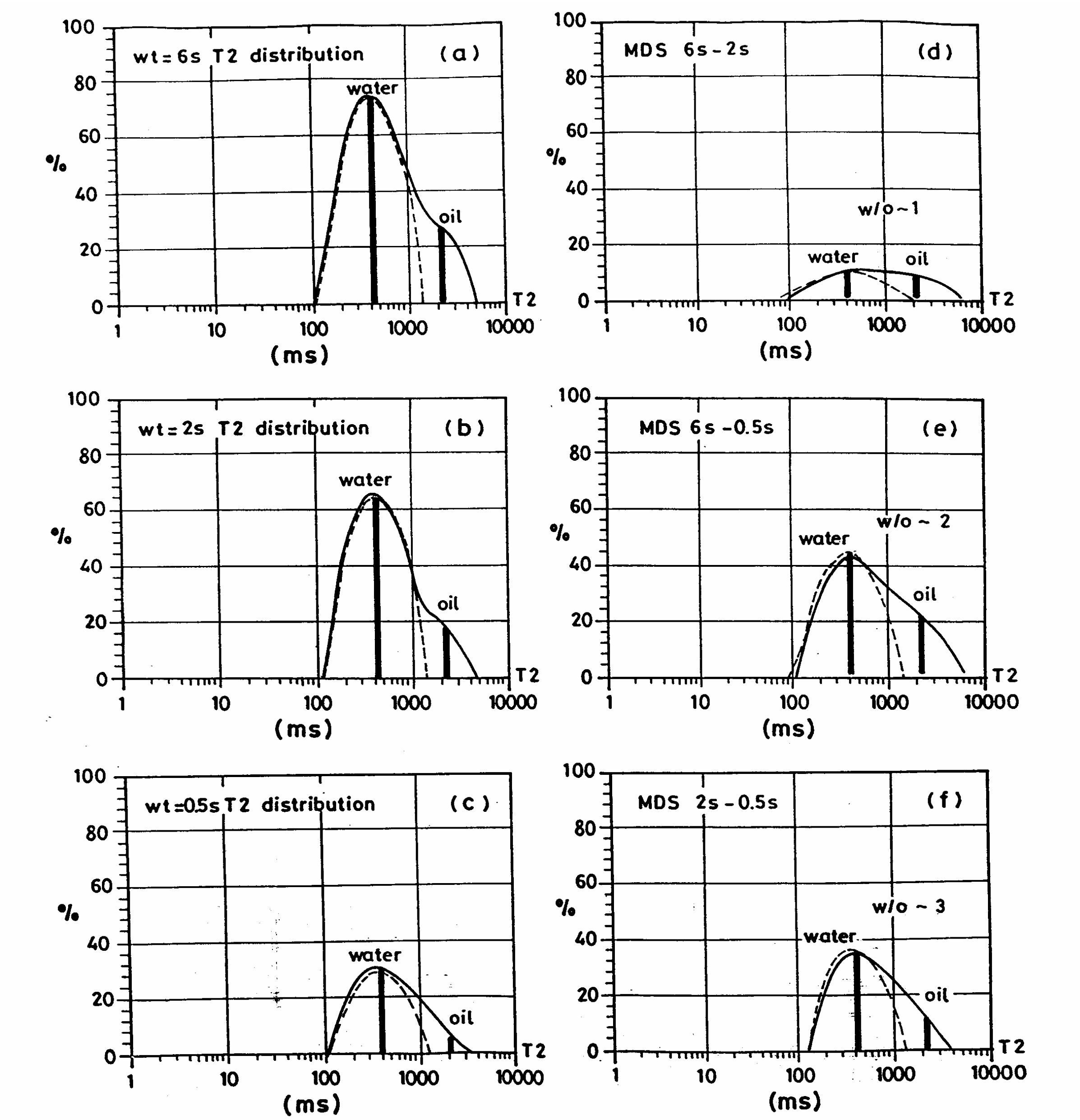

Fig. (7) Modified differential spectrum and T2 distribution at different waiting times and varying water/oil ratio for well in low contrast resistivity reservoir

CONCLUSIONS

The capability of NMR to differentiate between movable and immovable fluids has helped the log analysts to get more accurate estimate of the reserves through the identification of low resistivity reservoirs that have already been bypassed by the resistivity logging interpretation. Also NMR can define fluid nature and determine porosity much better than density / neutron combination.

The contribution of NMR information in the evaluation of the field examples discussed in this paper is twofold. Firstly, NMR helped to identify low resistivity reservoirs and low contrast resistivity reservoirs. Secondly, NMR can provide 1) detailed porosity information, and thus it can replace conventional porosity logs as porosity tool and fluids type identifier, 2) quantitative information about pore fluids (clay bound water, capillary bound water, free water, oil and gas) and 3) prediction of little or water free oil production even though the resistivity log indicates high water saturation.

REFERENCES

1. Clavier, C., Coates, G. and Dumanoir, J., The Theoretical and Experimental Basis for the Dual Water Model for the Interpretation of Shaly Sand: The Log Analyst, Vol. 24, pp. 153-168.,1984
2. Murphy, R.P. and Owens, W.W., A New Approach for Low Resistivity Sand Log Analysis, JPT, pp. 1302-1306.,1972
3. Zemanek, J. , Low Resistivity Hydrocarbon Bearing Sand Reservoir: JPTFE, pp. 515-521.,1989
4. Hamada, G.M. and Al-Awad, M.N.J. , Petrophysical Evaluation of Low Resistivity Sandstone Reservoirs: SCA 9851, 1998 International Symposium of Core Analysts, The Hague, September 14-16, 1998.
5. La Torraca, G.A., Dunn, K.J. and Bergman, D.J. 1995 Magnetic Susceptibility Contrast Effects on NMR T2 Logging. SPWLA 36th Annual Logging Symposium, Paris, June 26-29, 1995.
6. Hassoun, T.H. and Zainalabedin, K., Hydrocarbon Detection in Low Contrast Resistivity Pay Zones, Capillary Pressure and ROS Determination with NMR Logging in Saudi Arabia. SPE Paper 37770, 10th MEOS, Bahrain, March 15-18, 1997.
7. Ayan, C., Haq, S.A., and Boyd, A., Integration of NMR, WireLine Tester, Core and Open Hole Log Data for Dynamic Reservoir Properties. SPE Paper 53273, 10th MEOS, Bahrain, March 15-18.,1997
8. Akkurt, R., Vinegar, H.J., Tutunjian, P.N. and Guillorty., NMR Logging of Natural Gas Reservoir: The Log Analyst Vol. 37, No. 6, pp. 33-42.,1996
9. Hamada, G.M., Al-Blehed, M.S. and Al-Awad, M.N.J., 1999" Nuclear Magnetic Resonance Log Evaluation of Low-Resistivity Sandstone Reservoir", Jr. of Enginerring and Applied Science, Vol. 46, No. 5, p. 951-970.
10. Menger, S. and Prammer, M. " Can NMR Porosity Replace Conventional Porosity in Formation Evaluation. SPWLA 39th Annual Logging Symposium, Keystone,Paper RR, May 26-29.,1998
11. Slot-Petersen,C., Eidsemo, T., White, J. and Rueslatten, H.G. . NMR Formation Evaluation Application in a Complex Low Resistivity Hydrocarbon Reservoir. SPWLA 39th Annual Logging Symposium, Paper TT, Keystone, May 26-29.,1998
12. Timur, A., Effective Porosity and Permeability of Sandstones Investigated Through Nuclear Magnetic Principles: The Log Analyst, Vol. 10, No. 1, pp. 3-11,1969.
13. Coates, G.R., Menger, S. and Miller, D., Applying Total and Effective NMR Porosity to Formation Evaluation: SPE Paper 38736, SPE Annual Technical Conference and Exhibition.,1997
14. Hamada, G.M., Al-Blehed, M.S. and Al-Awad, M.N.J., NMR Logs Find Reservoirs By-passed by Conventional Analysis, Oil & Gas Journal Sept 27, p. 76-80.,1999
15. Freedman, R., Chanh, C.M., Gubelin, G.,Freeman, J.J., McGinnes, T., Terry,B. and Rawlence, D., Combining NMR and Porosity Logs for Petrophysical Analysis in Gas Bearing Formation. SPWLA 39th Annual Logging Symposium, Paper II, Kaystone, May 26-29, 1998
16. Kenawy, F.A., "Exploitation of Abu Gharadig Field, Western Desert, Egypt" SPE Paper 18607, SPE International Meeting of Petroleum Engineering, Tianjin, Nov.1-4, 1998.