NUCLEAR MAGNETIC RESONANCE LOG EVALUATION OF LOW RESISTIVITY SANDSTONE RESERVOIRS BY-PASSED BY CONVENTIONAL LOGGING ANALYSIS

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ABSTRACT

The combination of conventional logs such as density, neutron and resistivity logs is proven to be very effective in the evaluation of normal reservoirs. For low resistivity reservoirs, however, an accurate determination of the petrophysical parameters with the conventional log reservoirs is very difficult. This paper presents two cases of low resistivity reservoirs and low contrast resistivity reservoirs where conventional logs fail to determine the petrophysical properties of reservoirs, mainly, low resistivity and low contrast resistivity reservoirs.

This paper shows that in the case of low resistivity reservoirs NMR is very cost-effective tool and helps to accurately determine the reservoir rock petrophysical properties. In 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. This paper presents four examples of low resistivity reservoirs. Analysis of NMR data of low resistivity reservoirs has helped to identify the productivity of these zones, to determine lithology independent porosity and to distinguish between bound and free water. For the case of low contrast resistivity reservoir 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.

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 porosity. The strength of the NMR signal is proportional to the number of hydrogen atoms in NMR tool dependent rock volume. In zones containing light hydrocarbon, where the hydrogen index is less than unity, NMR porosity will typically underestimate true porosity in proportion to the hydrogen index. In this formation there is a separation between density and neutron porosity, which indicates light hydrocarbon. For oil and water, NMR results can be expressed as percentage of fluid volume of the rock volume. The number of hydrogen atoms in gas depends strongly on temperature and pressure. Hence it is important to estimate accurately pressure and temperature to account for their effect on NMR results in natural gas reservoirs. (Akkurt et al, 1996; Menger and Prammer, 1998).

NMR and FLUIDS NATURE

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 based contrast 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. 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 (Coates et al, 1997; Menger and Prammer, 1998; Hamada et al, 1999).

FIELD EXAMPLES

Field Example 1

Figure 1 presents logging data for a gas well drilled in the Western Desert, Egypt. The main producing formation in this well is Middle Cretaceous Kharita formation. Kharita is a shaly sand formation. This glauconitic sandstone is very heterogeneous; 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 brine water saturation (80%-90%), water salinity of about 250,000 ppm, however, the wells produce water free hydrocarbon. The main mechanism of this case is being the microporosity and the high capillarity, (Menger and Prammer, 1998). The NMR data shown in **Figure 1** 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 cut-off value of 33 ms that was based on NMR experience in this field example from western desert, Egypt and shown in track 3. The true porosity is derived from density log other than NMR and neutron logs. At depth A all porosity logs (MSIG total porosity, the entire fluid fraction measured by NMR; PNSS is the formation porosity measured by Neutron log and PDSS is the formation porosity measured by density log) are going down to about 10 p.u. while the true porosity is about 25 p.u. The case of this well is common in the Western Desert fields, thereupon, it is recommended to run NMR in new wells to better identify these low resistivity reservoirs.

Field Example 2

This is an example of low contrast resistivity Early Cretaceous sandstone reservoir, Saudi Arabia, (Hassoun and Zainalabedin, 1997). In these 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. These sandstone reservoirs are characterized by high level of irreducible water saturation that provokes more resistivity depression. The relatively high water zone resistivity and low pay resistivity created low contrast resistivity between pay zone and water zone. This low contrast resistivity makes the pay zone identification from resistivity log a very tedious job. **Figure 2** presents a logging suite run in oil producing well from 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, these are typical values for water bearing zone (Sw > 80 % in the 3 sands) which is not true. NMR logging was used to solve this problem of low resistivity contrast between oil and water zones. 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). The technique of Modified Differential Spectrum (MDS) was used to isolate water signal from hydrocarbon signal. This modified model has 3 passes at three waiting time groups. The MDS in **Figure 2** has shown water signal and oil signal at two different waiting times. Afterwards, wireline formation tester has retrieved oil sample in all 3 sands. The use of MDS in this example was because of the absence of nearby water zone required to observe T2 distribution change between water zone and oil zone on the normal T2 distribution curve, (Hamada et al, 1999).

CONCLUSIONS

NMR technology proves to be very essential in formation evaluation and more specifically in low resistivity reservoirs. The capability of NMR to differentiate between movable and immovable fluids has helped the log analysts to more accurate estimate of the reserves through the identification of low resistivity reservoirs that have already been bypassed by the resistivity logging interpretation. However, the interpretation of NMR data requires caution and experience to ensure that the suitable cut-off values are selected and that reliable conclusions are reached from the measured and calculated parameters especially in carbonate reservoirs. The fact that the depth of investigation of NMR is likely greater than the normal mud invasion depth makes the NMR identification of reservoir fluid nature and determination of formation effective porosity much less affected by the mud filtrate in the flushed zone. Consequently these petrophysical parameters would be more accurately determined using NMR logging technique.

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. Such reservoirs have not been often identified, heretofore, with resistivity data interpretation. 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.

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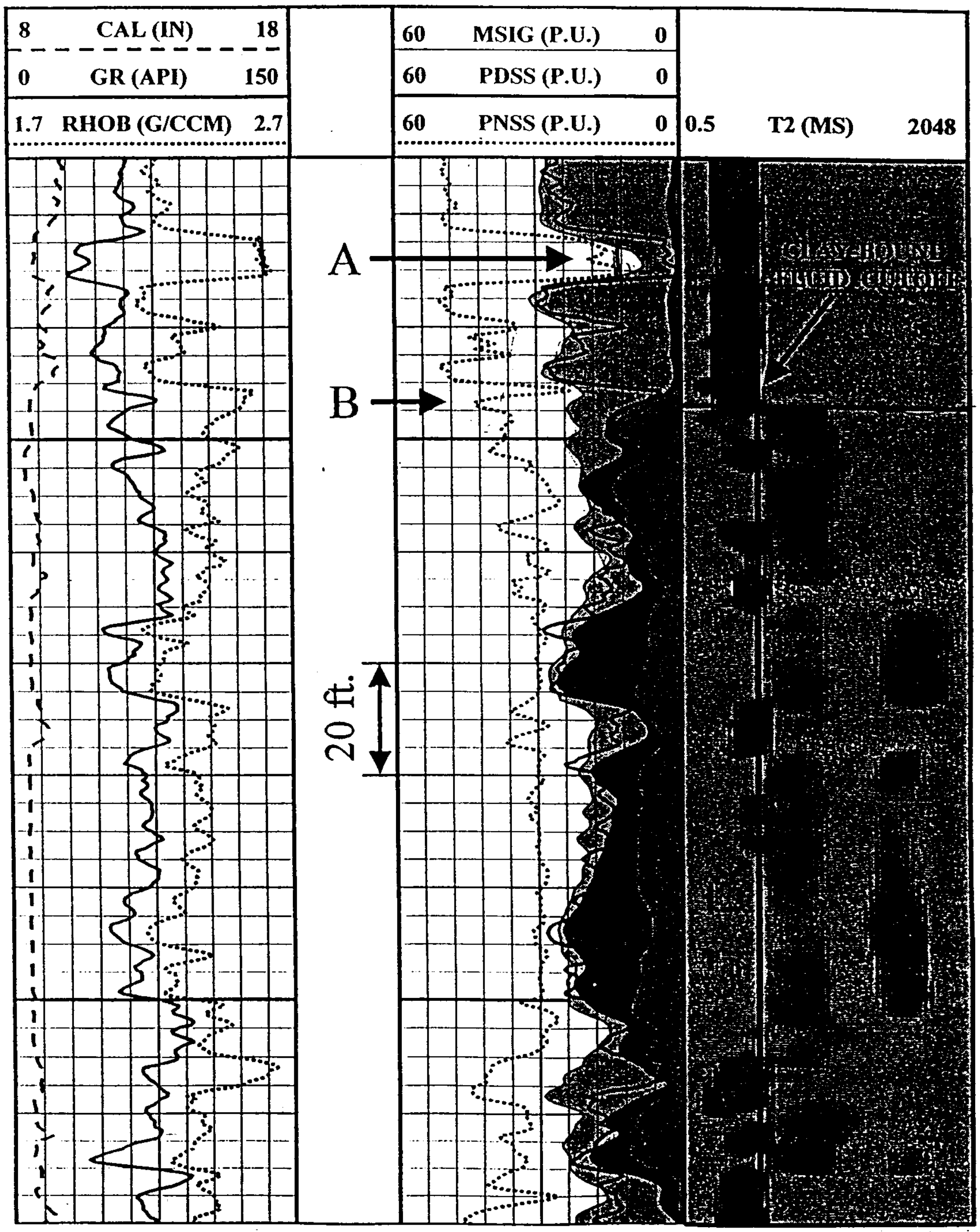

Fig. 1 Logging suite for a well drilled in low resistivity sandstone reservoir, (Menger and Prammer, 1998).

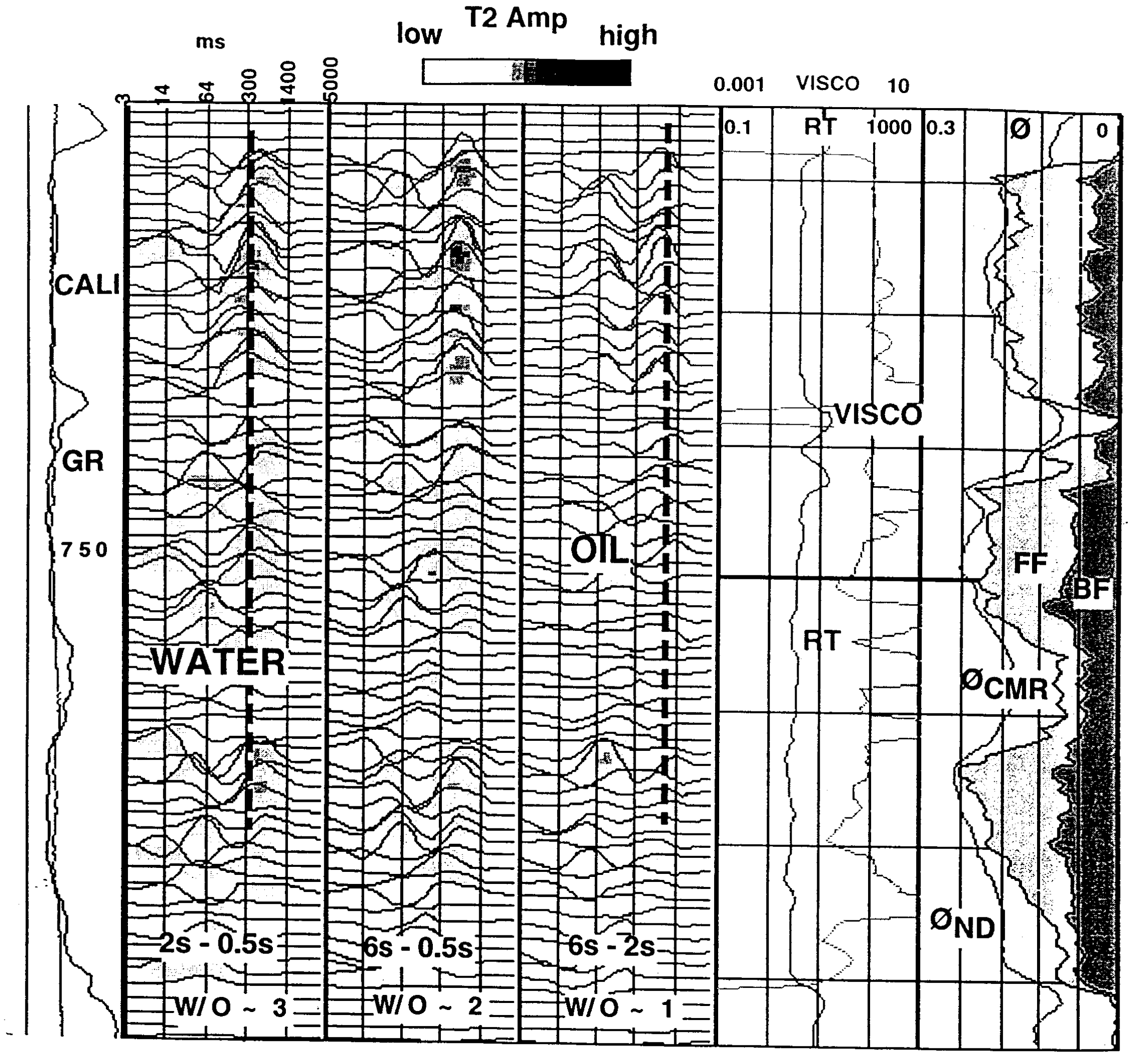

Fig. 2 Modified differential spectrum and logging suite for a well in low contrast resistivity reservoir in Saudi Arabia, (Hasson and Zainalabedin, 1997).