STANDARDIZATION OF NMR T2 CUT OFF AND BETTER ELECTROFACIES MODELLING OF LOW RESISTIVITY CARBONATES WITH MULTI POROSITY SYSTEM*

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Petrophysical evaluation and proper interpretation of carbonate reservoir is always a challenging task. The difficulty increases as the inherent heterogeneity increases in the reservoir due to its lithology, mineralogy, pore structure, pore distribution, etc. This study investigates the change in the petrophysical parameters and improved electrofacies classification for low resistivity in carbonates in India. Two independent inversion techniques have been adapted in our study to find out correct NMR T2 cut off and the corresponding fluid fractions. Due to the lack of lab data it is a difficult task to calibrate the NMR permeability with the *in situ* permeability of the reservoir. The study shows a compact framework in modeling permeability and free fluid volume (FFV) derived from NMR log. The outputs with the modified T2 cut off has been used for better electrofacies modelling. The free fluid volume and modified effective thickness of improved facies plays a crucial role for explaining the producibility of the pay. The results computed from the two methods have been validated with the available core data and they are showing promising agreements.

Key words: low resistivity carbonate, NMR T2 cut off, factor analysis, wireline formation tester, mobility, electrofacies.

1. INTRODUCTION

Carbonate reservoirs comprise about 50% of world's oil and gas reserves and more than 60% in their respective production. But the inherent heterogeneity leads to difficulty in the interpretation of carbonate reservoirs due to its petrophysical properties like mineralogy, porosity, their distribution (Macro, Meso and Micro), pore throat tortuosity, permeability, capillary pressure, irreducible water saturation, wettability, pore throat radius and many more. The low resistivity (LR) carbonate reservoirs are most challenging in the domain of petrophysical evaluation and their interpretations. Nuclear Magnetic Resonance (NMR) tool gives very useful information for the characterization of reservoir (George, 1999). It gives the porosity types (whether bound or free fluid), distribution of pore sizes and type of fluids present in the reservoir. Due to the movement of protons (Hydrogen), the T2 distribution is obtained and the T2 cut off is the most critical parameter in the whole processing as this parameter strongly influences the computation of permeability and porosity distributions. Our study area consists of the low resistivity pay (LR) in the Ratnagiri formation (L-III carbonate), which is aligned along the spurs extending from west of main Mumbai High Field in the NE–SW direction. The water filled micro-porosities and presence of Micrites have been thought to be cause of low resistivity signature of the carbonate reservoirs in this area. Due to the unavailability of lab data it is difficult to calibrate the NMR permeability with the *in situ* permeability of the formation. The free fluid volume (FFV) also plays a critical role in the quality of the prolific zone for further production testing. We have applied two different inversion methods to standardize the T2 cut off value for the low resistivity pay with nine wells in the area. Recomputed T2 cut off is

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used to evaluate free fluid volumes, permeability and effective reservoir thickness (H_{e}), which holds better with the production testing results. For the first time so far, we attempted to integrate different inversion methods and correlated them with available core data to standardize the T2 cut off for the low resistivity carbonate. The statistical electrofacies modeling is also done for the computation of improved H_e with the wire line data, Permeability and FFV over set intervals.

2. CHALLENGES WITH THE CONVENTIONAL T2 CUT OFF

NMR data in petrophysics has been mostly used to compute the porosity and permeability factor in the reservoir. The T2-distribution is a combined influence of the pore size, pore shape, wettability, pore structure distribution and the fluid type. In absence of core data, a global reference value of 33 ms (for sandstones) and 100 ms (for carbonates) is used. However, this value is found to be varying, depending upon the relaxivity of protons. These relaxations are associated with the surface to volume ratio of the pore, density and diffusivity (viscosity) of the fluid and the magnetic field gradient. It has been observed that the production testing results are not supporting the preliminary interpretation and even sometimes the petrophysical volumetric analysis (stochastic model) derived porosities rather suggests the NMR measurements to be in lower side in the LR pay of our study area. Which clearly indicates the underestimation of free fluid volume (FFV) and permeability. The modification or any change in the cut off value needs to be validated with the laboratory results. But as in every case it is difficult to get the laboratory data in time to influence the decisions for testing or object identification.

3. STANDARDIZATION OF T2 CUT OFF

3.1. T2 CUT OFF FROM INVERSION WITH MDT DATA

During the pretest of the Formation Tester logging, draw-down mobility is derived from transient flow data along with the corresponding down hole temperature and formation pressure. After applying the temperature and pressure correction it is quite reliable to calibrate the *in situ* mobility derived effective permeability with the Timur–Coates permeability (KTIM) that is derived from NMR log (Haldia *et al.*, 2013). After performing the workflow of initial Nonlinear Inversion with echo signals of one station or two substation readings, we have computed the NMR permeability of nine wells at different cut off values ranging from 30–120 ms. The NMR permeability and Formation Tester derived permeability holds very good correlation at the cut off value around 60 ms than 100 ms in the carbonate formation of our study area (L-III Layer), Figs. 1a and 1b, respectively.

3.2. T2 FROM NMR FACTOR ANALYSIS

In another approach, we have used NMR Factor Analysis for finding T2 cut off. The algorithm looks for similar T2-distribution in the depth log and clusters the entire interval in different factors (Jain *et al.*, 2013). These factors are representative of poro-fluid facies (such, as capillary-bound, clay-bound, water, hydrocarbons, fractures and so on). With this approach, it is now quite convenient to have an estimate on the T2 cut off (independent of core data). In this work, we have applied this technique on nine wells in the Western Offshore Basin field. Most of the results are suggesting the T2 in the range of 50–65 ms. For example, we have shown the T2 cut off obtained from NMR data of Well-X is about 60.33 ms (Fig. 1c).

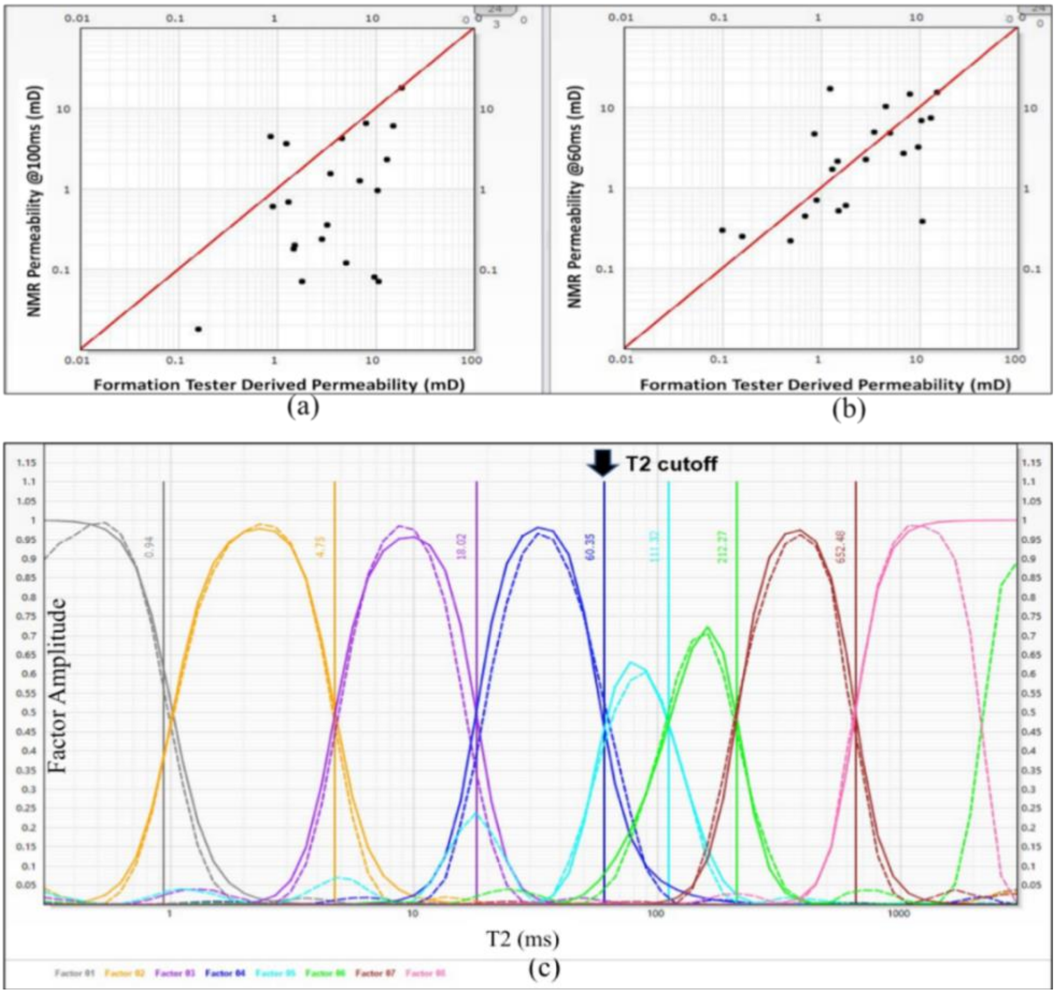

Fig. 1 – Correlation of MDT permeability with NMR derived permeability with 100 ms (a) and 60 ms T2 cut off for nine wells in L-III (b); T2 cut off derived from NMR Factor Analysis for Well-X in L-III (c).

4. RESULTS AND COMPARISON WITH CORE DATA

To validate our computations, we used the available core analysis that has been done on some wells (*e.g.,* Well-Y) in ONGC laboratory. The core report suggests the presence of Micrites with wackestone and packstone in the formation and SEM has indicated the significant presence of micro porosities along with meso and macro pores (Fig. 2a). T2 cut off values are generated with the help of NMR core analysis on fully water saturated samples and samples at residual water saturations in two ONGC laboratories independently. The core derived T2 cut off values are in the range of 53 ms to 68 ms (*e.g.,* Fig. 2b). This result is having promising match without pre computed inversion results from two methods, which suggested the NMR T2 cut off to be in the range of 50–65 ms in the L-III carbonate. Hence our results provide an evidence that the study is an effective method of NMR T2 cut off computation. Therefore, we have taken T2 cut off ~60 ms for our further studies.

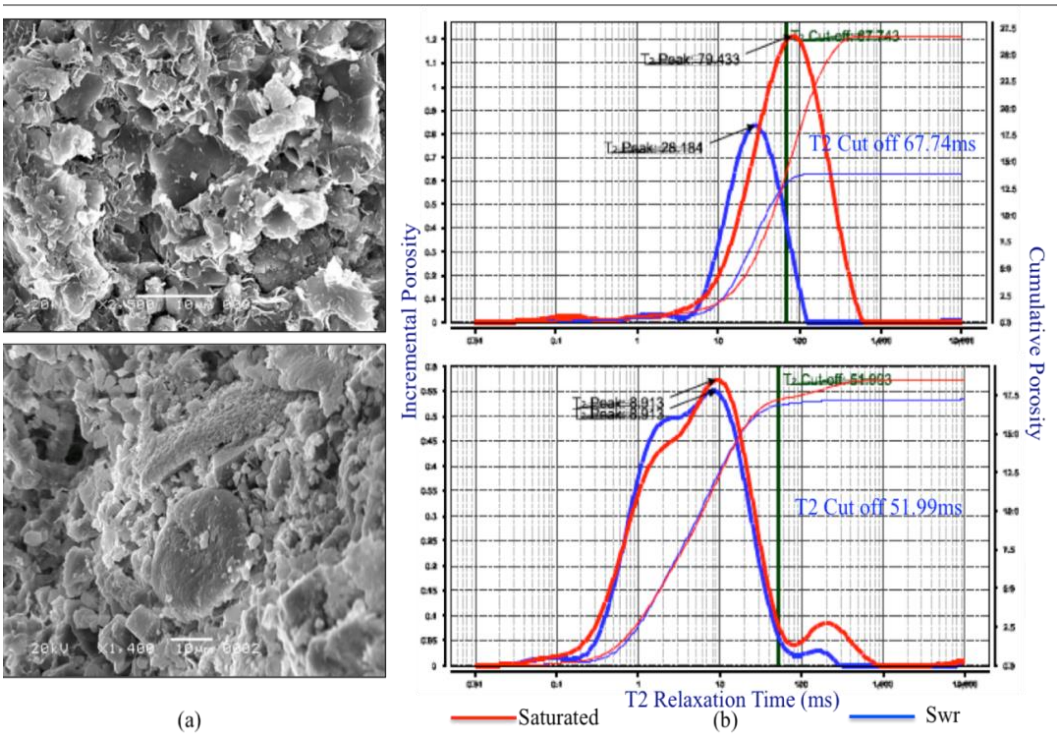

Fig. 2 – SEM analysis of cores showing significant micro porosity with presence of Micrites in the formation (a) and Core derived T2 cut off values from NMR study (core of Well-Y in L-III) (b).

5. APPLICATION IN ELECTROFACIES ANALYSIS

Robust mathematical methods are used for the reduction of uncertainties and create more reliable the results to minimize exploration risks in terms of time and costs. Artificial Neural Networks (ANN) (Haykin, 1999) is the most used artificial intelligence technologies in geosciences. Self-Organizing Maps (SOM), which is basically an ANN is used for the classification and modeling of electrofacies (Kushwaha *et al.*, 2018; Puskarczyk, 2020). The IPSOM module in TechLog is having the capability to predict and propagate the classification groups for better interpretation. It is majorly used for geological interpretation of well log data and facies prediction and optimum derivation of petrophysical properties. SOM is also called as Kohonen self-organizing feature map (KSOM). This is a learning algorithm without supervisor (*i.e.*, unsupervised learning) for mapping all the points in a high-dimensional source space into a 2 to 3-dimensional target space. After the reduction of dimensionality, the distance and proximity relationships are tried to be preserved as much as possible (Kohonen, 1982). The Kohonen network is unique and distinguishable from other networks in that it preserves the mapping of the neighbourhood of the input space. The algorithm is based on a competitive learning process, in which only one computational unit output, also called BMU (Best Matching Unit).

In our study we have taken 6 inputs (Fig. 3a) with convention logs such as Gamma Ray, Bulk Density, Neutron Porosity, Secondary porosity fraction, Calibrated NMR Permeability and FFV over set intervals for better Electrofacies modeling in the low resistivity pay. Several trials were conducted to find a representative number of the total facies. Six facies were found to be representative to distinguish higher reservoir quality, medium reservoir quality, low reservoir quality, tight and two shale units. The classification is given in Figure 3b.

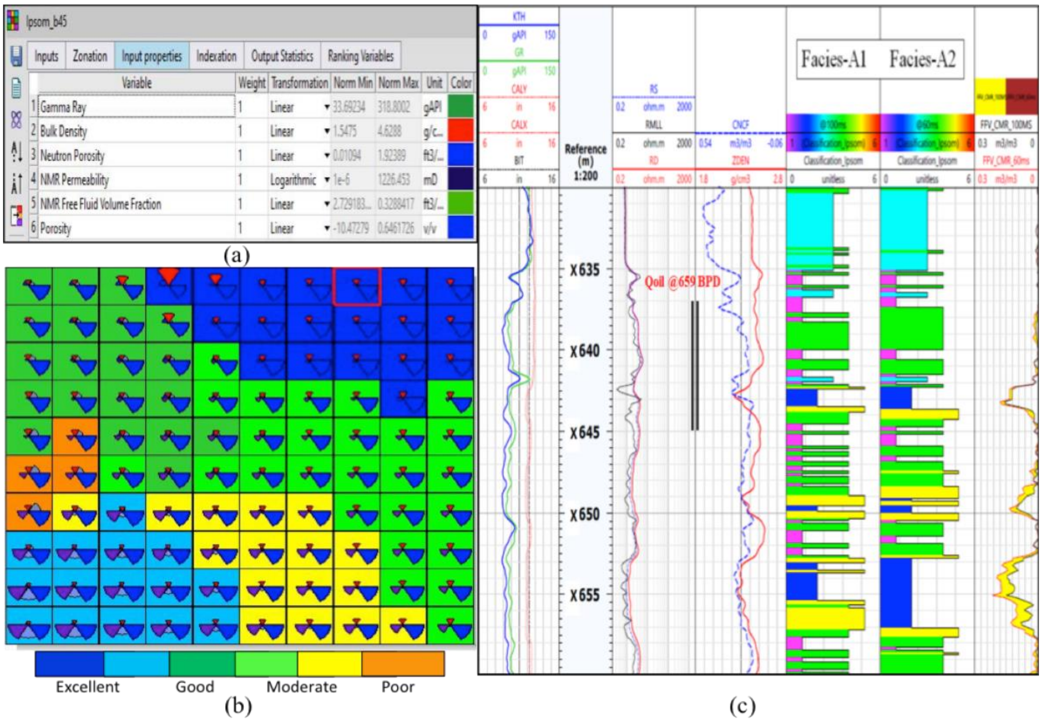

Fig. 3 – SOM regression input vector (a), Classification Indexing (b), Classified Electrofacies for Well-Z in L-III (c).

For example, In Well-Z, petrophysical volume is created which shows the interval X637.0 m to X645.0 m is having effective porosity in the range of 15–20% with resistivity in the range of 2–4 ohm-m, which is hydrocarbon bearing. In NMR log responses the interval is showing insignificant amount of free fluid and less permeability in major portion. But on testing the zone produced Oil (Qoil: 660 BPD) at Flowing pressure: 230 psi. Hence, this clear contradiction between the flow ability of a zone and its interpretation from NMR log responses in the low resistivity pay. Electrofacies is generated with the parameters calculated from 100 ms and 60 ms T2 cut off values, which are Facies-A1 and Facies-A2, respectively, with 6 classes (Fig. 3c). From the SOM classification of Facies-A1, it is clear that the perforated zone is showing combination of good and moderate facies and the effective reservoir thickness is around 4.5 m only. Electrofacies correspond to 60 ms cut off, *i.e.*, Facies-A2, shows that the FFV is increased by 3–4% followed by improving the computed water saturation, *i.e.*, 65–70%. The increase in permeability and the good facies indicates H_e around 6.5 m. Hence the Productivity is explainable in better way from the modified NMR derived porosity and permeability as Productivity Index is a function of H_e and Permeability (Alarifi *et al.*, 2015).

6. CONCLUSION

In our study it has been shown that the application of 100 ms T2 is not appropriate for the computation of porosity classes and permeability in low resistivity carbonates in Ratnagiri Formation. Integrated approach of NMR data inversion with MDT and NMR Factor Analysis can be used for the remodelling of FFV and Permeability with modified T2 cut off, which is in the range of 50–60 ms. The core data suggested the presence of Micrites and SEM data suggested the presence of significant micro porosities. This combination leads to the increase in surface to volume ratio and hence boosts the T2 distribution at shorter relaxation times (as those are inversely proportional). Micritic components may the only small pore components with the capacity to hold capillary water, thus the T2 cut off can be shifted downwards from its default position at 100 ms. The NMR lab analysis also suggests better match with our inversion result. After incorporating the modified T2 cut off value for further evaluation, we have seen the enhanced free fluid porosity, increased effective thickness with overall good facies distribution in the low resistivity carbonate pay. These key parameters are well indicative towards the producibility of the reservoir.

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