Well log NMR T2 factor analysis integrated with core analysis for reservoir quality and saturation estimation in a low-resistivity reservoir, offshore Vietnam

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Summary

Saturation estimation in low-resistivity low-contrast (LRLC) reservoirs can be highly uncertain if the resistivity log's representativeness of true formation resistivity is questionable. Additionally, LRLC reservoirs may have highly heterogeneous lithology and reservoir quality. To solve these two challenges in a LRLC siliciclastic oil reservoir in offshore Vietnam, this paper presents an advanced well log analysis workflow, based on the concept of NMR T2 factor analysis, coupled with a robust core analysis program.

Theory and Methods

Low-resistivity low-contrast reservoirs typically have deep resistivity values less than 5 ohm.m in hydrocarbon-bearing intervals, which reduces the resistivity contrast relative to adjacent shale or water-bearing zones (Worthington, 1997). This can often lead to uncertain saturation estimations and bypassed pay intervals. Conductive minerals, thin beds, and high irreducible water saturations are typical mechanisms causing LRLC and each was evaluated here.

An integrated workflow, involving core analysis, conventional well log analysis, and well log NMR T2 factor analysis, was employed (Fig. 1; Knapp et al., 2021). The objectives were to define rock properties, evaluate mechanisms causing low resistivity, determine the controls on fluid saturation, and quantify reservoir heterogeneity and fluid saturation throughout the interval of interest.

After data QC, the NMR T2 factor analysis workflow used exploratory data analytics to identify the unique unimodal components (factors) that comprise the total NMR T2 signal throughout the full interval of interest (Jain et al., 2013). The origins (i.e. pore size and fluid type) of each factor were interpreted through T2 modeling, and K-means clustering of the factors was used to create classes which represent lithofacies. Pseudo-capillary pressure analysis was used to convert T2 into Pc and determine rock quality and flow capacity of each class, which was used to evaluate fluid saturation and producibility in the analyzed interval (Hassoun et al., 1997; Ramamoorthy et al., 2000). Core Pc and NMR analyses provided critical calibration data.

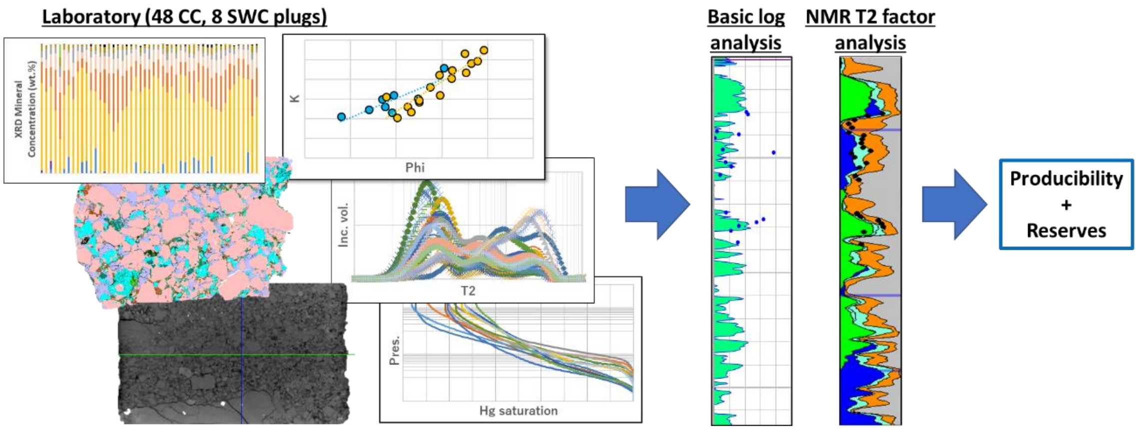

Figure 1. An overview of the integrated core and well log analysis for the LRLC reservoir.

Results and Conclusions

High water saturation was found to be the main driver of low resistivity. Illite, smectite, and chlorite drive high clay-bound water (CBW) saturations. Some high-porosity sands, with low CBW, have high capillary-bound water saturations, partially associated with kaolinite, among other factors. Integration of core NMR T2 and centrifuge experiments revealed that the bound/free-fluid T2 cut-off was significantly lower than the sandstone default of 33 ms.

Factor analysis identified 7 unique factors in the well log NMR T2 data. T2 modeling revealed that factor 7 was residual oil while factors 1-6 represented water or water-based mud filtrate in various pore size groups. After K-means clustering and pseudo-Pc analysis, the reservoir quality and fluid saturation was shown to be highly heterogeneous, with zones of high free-water risk distributed throughout the interval. Calibration to core data suggested that an appropriate free/bound-fluid T2 cut-off is 11 ms for this interval, while the default 33 ms cut-off underestimates free water risk.

Results from this workflow confirm high free-water saturations in a previously perforated and tested interval that produced oil with a 60% water cut. Several future perforation intervals have been evaluated, some of which are predicted to produce oil with lower water cut as most of the water is bound.

Novel/Additive Information

This study provides a work-around for saturation estimation which can be employed when resistivity logs are suspected not to represent true reservoir resistivity. Additionally, even for non-LRLC reservoirs, the workflow provides critical insights into reservoir quality and heterogeneity above the capabilities of a traditional well log analysis.

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