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An integrated quantitative approach for determination of net reservoir cutoffs: A case study of Q oil field, Lake Albert, Uganda

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ABSTRACT

Petrophysical cutoff of net reservoir plays a very important role in reservoir characterization for the evaluation of hydrocarbons in place and the estimation of ultimate hydrocarbon recovery. There have been many approaches to quantify cutoffs, yet each of these approaches yields a different reservoir model with some amount of uncertainties due to lack of enough data, insufficiency of knowledge and the heterogeneous nature of petroleum reservoirs. Conventionally, net reservoirs cut-offs are evaluated by applying static petrophysical well-logs without consideration of dynamic performance, which results in a crisp classification of reservoir or non-reservoir zones. This paper takes Q oilfield in Albert Basin of Uganda as an example, provides a new structured quantitative approach which integrates all core, petrophysical interpretation, modular dynamics test data, reservoir fluid data and development wells pattern together to determine a reasonable net reservoir cutoffs. Three dependent variables including oil initially in place (OIIP), total oil production (FOPT) and total water production (FWPT) were selected to test the sensitivity with two independent variables, i.e. volume of clay (Vclay) and porosity. Then experiment design and response surface method were used in constructing the proxy models that are related to the dependent variable. After running 5000 realizations, probability density function (PDF) was utilized to locate P50 value on the cumulative probability curve. Finally, the cutoffs of Vclay and porosity were determined by the arithmetic mean of corresponding P50 value. The case study clearly illustrates how all available data from a reservoir should be integrated for appropriate determination of the net reservoir cutoffs.

1. Introduction

Net reservoir, a key parameter in reservoir evaluation, has sufficient reservoir quality and useful capability to store fluids and allow them to flow (Worthington, 2010; Hadi, 2017). The principal part of identification of net reservoir is to determine its cutoffs. However, although the concept of cutoff has been continuously used since the 1950s, there is no universal agreement on its definition and quantification methods yet (Worthington, 2008). In the most commonly used procedure, it is usually expressed in term of a log-derived shale volume fraction, Vclay, being less than a Vclay cutoff and the fractional porosity being greater than or equal to a porosity cutoff through a Vclay-porosity cross plot (Worthington and Cosentino, 2005). Recently, some new methods including diffusivity equation (Masoudi et al., 2011), Bayesian (Masoudi et al., 2012a), fuzzy classifier fusion (Masoudi et al., 2012b),Dempster–Shafer theory (Masoudi et al., 2014a), artificial neural network (Masoudi et al., 2014b) and NMR T2 (Testamanti and Rezaee, 2017) have been adopted to determine net zone. Meanwhile, the study context has been expended from terrestrial clastic reservoirs to carbonate (Masoudi et al., 2012c), shale-gas (Worthington and Majid, 2014) and fractured reservoir (Kolganov and Kovaleva, 2012).

If the collected data is enough to cover a broad range of parameter variation, even thin beds reservoir may obtain an accurate cutoff (Carpenter, 2014). Nevertheless, Q oilfield in Albert Basin in Uganda is in the early stage of the oilfield development (Xu et al., 2017). Cutoff determination is difficult because of lack of drilled wells and other supported data. In addition, although the reservoir cutoffs were generated and applied during the petrophysical evaluation, their impacts will be more obvious in reservoir engineering. The conventional cut-off-based methods for determining net pays are often based on static data, however Drill Stem Test and permeability data start to be used in recent studies (Worthington, 2010; Masoudi et al., 2011, 2012a; b; c; 2014a; b). That indicates not using dynamic data might increase the uncertainty of predicting reservoir production (Galley, 2016; Testamanti and Rezaee, 2017). This paper takes Q oilfield in Albert Basin of Uganda as an example, providing a new structured quantitative approach that integrates all core, petrophysical interpretation, MDT test data, reservoir fluid data and development wells pattern for determination of net reservoir cutoffs.

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Abbreviation

Vclay	fractional volume of clay
SW	saturation of water
NTG	net to pay
MDT	modular dynamics test
OIIP	oil initially in place
FOPT	field oil production total
FWPT	field water production total
MMbbls	millions barrels
Adj. R-square	Adjusted R-square
RSM	Response Surface Methodology
PDF	Probability Density Function

2. Geological setting

Lake Albert, located at the northern end of the Western branch of the EARS, stretches over a total distance of over 500 km from Rwanda in the South to Sudan in the North along Uganda's western boundary with the Democratic Republic of Congo (Karner et al., 2000), and has an average water depth of approximately 25 m (Karp et al., 2012) (Fig. 1). The geological sequence in the Albert Basin is of the Miocene–Recent age, resting on the metamorphosed Precambrian basement (Roberts et al., 2012). The penetrated sequence comprises a series of interbedding sandstones and shales, representing a mixture of Low-stand events, during which sedimentation was dominated by fluvial process and flood or high-stand events, during which lacustrine deposition predominated (Aanyu and Koehn, 2011; Zhang and Scholz, 2015).

The structure of Q oil field comprises a southwest-northeast trending 3-way dip-closed hanging wall anticline that seals against basement to the south-east along the main bounding fault of the Albert Basin (Xu et al., 2017). In this field, five wells were drilled to evaluate the oil-bearing potential zone and MDT tests were carried out to assess the reservoir connectivity. The core collected in K-3 well showed an obvious characteristic of fan delta front that flow from east bounding fault to the west deep lake (Xu et al., 2017) (Fig. 1).

3. Dataset and approach

3.1. Dataset

3.1.1. MDT data

In this study, 78 MDT points in total were collected from five wells by Schlumberger's new formation dynamics tester in Q oil field, including 44 good oil points, 26 good water points, 6 tight points and 2 sample points (Fig. 2). No data has been collected in the light blue area (Vclay: 0.35–0.48 & Porosity: 0.085–0.125) in Fig. 2 and thus it leads to the uncertainty of net reservoir cutoff. In other words, within the blue no-data area, if the cutoffs were selected conservatively, the estimation of hydrocarbon in place and recoverable reserve will be pessimistic. Otherwise, the results would be over-estimated.

3.1.2. Reservoir model

A robust static 50*50 m 3D geomodel including facies model, Vclay model, porosity model, permeability model was established for Q oil field (Fig. 3). And the NTG model was defined by Vclay model and porosity model. This grid was used to calculate hydrocarbon volume (OIIP) in static model. Then it was integrated with oil producers and water injectors to simulate the dynamic process. The total volume of Oil production (FOPT) and water production (FWPT) were obtained from dynamic simulation results.

3.2. Approach

An Integrated Quantitative Approach was utilized to determine net reservoir cutoff. Compared to the conventional methods, it took both static and dynamic indices into consideration to obtain an appropriate cutoff result. This structured approach encourages combining different sorts of data to test and verify the final net reservoir cutoff value (Fig. 4).

3.2.1. Parameter selected

Two sorts of parameters were selected in this study: independent variable and dependent variable. Two petrophysical parameters were used as independent variables including Vclay and porosity while the three dependent variables were OIIP, FOPT and FWPT. OIIP, which refers to hydrocarbon in place, was used as a static index, and FOPT and TWPT, indicating the recoverable reserve, were used as dynamic variables.

3.2.2. Experiment design and response surface

Experimental design allows finding an equation which relates the response with the variation of the input factors, and offers an evolutional model (Oguz et al., 2016). In fact, Experimental design methods are effectively distributing simulator runs within ranges of uncertainty parameters. Therefore, minimizing the numbers of runs is required to study the system. In order to seek a robust relationship between dependent variable and independent variable, a four-lever experimental design with two variables (Vclay and porosity) was conducted. The experimental design results covered the whole data range by not too many cases to avoid consuming excessive time (Moras et al., 2017).

Response Surface Methodology (RSM) is a modeling technique useful for building empirical model (Venkataraman, 2000; Rohmer and Bouc, 2010). The objective of RSM is to develop, improve and optimize

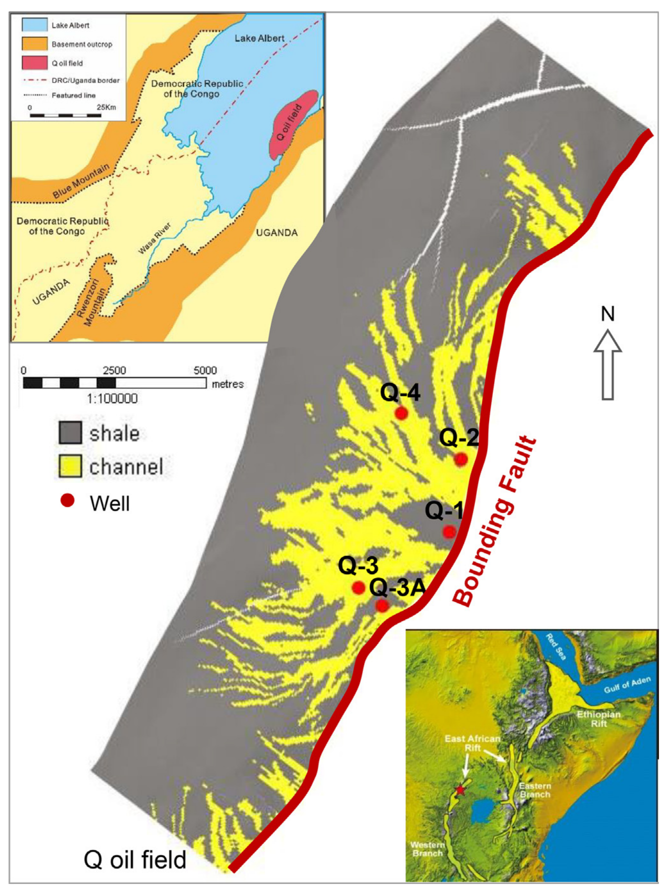

Fig. 1. Structure background and sedimentary facies of Q oilfield.