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Net pay determination by artificial neural network: Case study on Iranian offshore oil fields

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ABSTRACT

Determining productive zones has always been a challenge for petrophysicists. On the other hand, Artificial Neural Networks are powerful tools in solving identification problems. In this paper, pay zone determination is defined as an identification problem, and is tried to solve it by trained Neural Networks. Proposed methodology is applied on two datasets: one belongs to carbonate reservoir of Mishrif, the other belongs to sandy Burgan reservoir. The results showed high precision in classifying productive zones in predefined classes with Classification Correctness Rate of more than 85% in both geological conditions. Applicability of proposed pay zone determination procedure in carbonate environment is a great advantage of developed methodology. Fuzzified output, being independent of core tests and verification with well tests results are of other advantages of the Neural Network-based method of pay zone detection.

1. Introduction

Carbonate reservoirs play an essential role in hydrocarbon production these days. Due to Scopus database, from the beginning of 2010 up to December 23th 2013, there are 817 scientific articles that their titles contain “carbonate reservoir”, whereas in the meantime, there are only 63 papers that contain “sandy reservoir” or “clastic reservoir” in their titles. This statistics shows high importance of researching about carbonate reservoirs in the recent years. Although there are hundreds of publications about carbonates, still there are huge ambiguities, uncertainties and imprecise interpretations, when characterizing these chemical reservoirs. One aspect of this uncertainty is in net pay evaluation. Although petrophysicists utilize the cut-off-based method for net pay determination in carbonate rocks, the results are not as satisfactory as in clastic reservoirs. The main reason is that the cut-off method is mainly developed in sandstones, and does not work properly in complex and highly heterogeneous environment of carbonates.

Chronologically, the whole story of net pay determination could be categorized in three stages. The primitive stage backs to when petroleum explorers used to identify productive zones while drilling by gas-meter, flourimetric, cased-hole wireline formation tester, drill stem test (DST), etc. (Millikan, 1925; Matthews and Russell, 1967; Cooke-Yarborqugh, 1984; Connell et al., 1986).

Following invention of logging technology, the mid-stage of net pay determination started. In this stage, petrophysicists attempted to study the whole drilled interval accurately; thereafter, distinguishing pay zones by thresholds on petrophysical values. Previous publications of cut-off net pay determination (1980–2002) are summarized in a comprehensive work, done by Worthington and Cosentino. In mentioned study, cut-off parameters of 31 articles, as well as general information of investigated datasets, lithology and hydrocarbon type are listed in a table (Worthington and Cosentino, 2005).

Following this work, very important statistical notes about cut-offs were discussed in Jensen and Menke (2006). We can call this paper as a turning point, i.e. start of the third stage in net pay studies, due to incorporating optimization techniques in the process of identifying productive zones. Later, some other optimizations were carried out on cut-off estimation by considering: production plan under the concept of dynamic cut-off (Worthington, 2008); cut-off optimization due to viscosity in Mahbaz et al. (2011), Masoudi et al. (2011); and finally, application of data-driven and fusion-based

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Nomenclature

Abbreviation	Description
AI	artificial intelligent
ANN	artificial neural network
CCAL	core analysis
CCR	classification correctness rate
Cl	classified
DST	drill stem test
F( )	activation function
F1 to F7	field number 1 to field number 7
IOOC	Iranian offshore oil company
LLD	deep laterolog resistivity
LLS	shallow laterolog resistivity
MLP	multi-layered perceptron
NPV	net pay value
RHOB	bulk density log
SCAL	special core analysis
Sum	summation
W1 to W7	well number 1 to well number 7

techniques in net pay classification (Masoudi et al., 2012a, 2012b, 2012c).

The current work is following previous data-driven approaches to identify productive zones by artificial neural network (ANN), which is a powerful tool for estimation/classification. Therefore, general geological and sedimentological aspects of reservoirs, carbonate and clastic, under study are introduced firstly. Then structure of multi-layered perceptron (MLP) and its components are discussed under methodology bullet. Finally, results are shown and compared to cut-off procedure of net determination. It is worthy to mention that well test results were used for training and validating ANNs.

2. Datasets and geologic settings

Authors selected two different environments to apply the proposed methodology on – the first one is carbonate reservoir of Mishrif; and the second reservoir is clastic reservoir of Burgan reservoir. Main reason of applying the methodology on Mishrif reservoir was to develop the proposed methodology on a carbonate rock. Of course, applicability of the proposed method on a sandy reservoir of Burgan is studied also.

Mishrif formation is equivalent to Upper Sarvak Formation with the age of Cenomanian – Early Turonian. It is a very important oil reservoir in the Middle East, deposited in a regressive cycle, i.e. starts with basinal (outer self) environment, followed by slope environment, then shoal or reefal environment, finally ends with lagoon environment (Al-Dabbas et al., 2010). Oil field of which Mishrif is investigated through (we call it First Field here) is a relatively small field in the Persian Gulf, with the trend of North–South. In this field, Mishrif formation is overlaid on Khatiyah formation, and is separated from overlaying Laffan Formation by unconformity of Upper Cretaceous. In this field, there are seven wells that Mishrif is drilled wholly, and required petrophysical data and well tests are available through.

The second dataset belongs to Sandy Burgan reservoir with the age of Middle Cretaceous (Albian era). Burgan is a Member of Kazhdumi Formation (Bashari, 2007; Mahbaz et al., 2011). Based on IOOC reports in the field of which Burgan is investigation (we call it the Second Field here), Burgan Member is deposited on unnamed clastics, after a sedimentation gap. In sequence stratigraphy of Burgan Member in an adjacent offshore field, it is revealed that Burgan consists of four sedimentation sequences that each starts from shallow sandy facies, and ends with deeper shaly facies (Honarmand and Moallemi, 2009); in another word, four progressive regime. Available dataset in the Second Field comprised of five drilled wells.

Both structures, the First and the Second Fields, are of Iranian offshore oil fields in the Persian Gulf. Utilized data in both datasets consist of calculated porosity, shale content and water saturation, as well as well test results for result verification.

3. Methodologies

Net pay determination is done by two methodologies: the conventional cut-off-based method and the ANN-based method. The former method provides a crisp output, whereas the latter ANN-based gives a fuzzified but still discrete output (Masoudi, 2013). The result of the cut-off method is considered as a benchmark for assessing the proposed method; however well test results have been used for verification.

3.1. Conventional cut-off-based methodology

Cut-off determination has been discussed several times in the literature. To be concise, enthusiastic readers are referred to Worthington (2010), Mahbaz et al. (2011)), and only a brief workflow, which is used in this study is provided below.

In order to select thresholds; firstly, shale-porosity plot is produced in each well to differentiate reservoir facies. Then, borders of

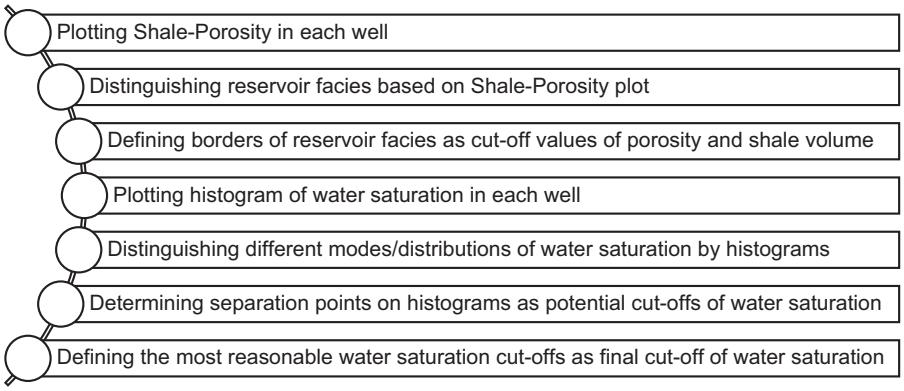

Fig. 1. Procedure of net pay determination by cut-off methodology.