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Petrophysical Evaluation of the Jeribe–Euphrates Formation Using Well Log Data, Fauqi Oil Field, Southern Iraq

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ABSTRACT

The work presented in this paper is a case study of the southeastern Iraqi Fauqi Oil Field to evaluate both the petrophysical properties and lithology of the Jeribe–Euphrates Formation. Reservoir characterization was performed using well log data, including Gamma Ray (GR), Density (RHOB), Neutron (NPHI), Sonic (DT), Spontaneous Potential (SP), and resistivity logs. Data processing, correction, and interpretation were conducted using Interactive Petrophysics (IP) software. The Gamma Ray method was used to estimate shale volume (Vsh), while porosity was calculated using various methods, with the neutron–density combination providing reliable results. To determine water saturation (Sw), the Archie equation was applied using commonly adopted parameters for carbonate reservoirs. Lithology was determined from density–neutron cross plots and M–N cross plots, which indicated that the Jeribe–Euphrates Formation are mainly composed of dolomite with minor limestone. The results show variations in reservoir quality, with certain intervals exhibiting favorable petrophysical properties and hydrocarbon potential.

1. INTRODUCTION

Petrophysical parameters are the critical parameters that are mostly used for evaluating oil or gas reservoirs, such as porosity, fluid saturation, and thickness of production intervals. These characteristics are obtained from three major sources, including core data, geophysical and well logging studies, as well as pressure tests. The basic objective of well logging studies is assessing the productivity capability of any productive rock formations encountered during drilling operations [1]. Reservoir characterization is a vital component of an oilfield development, as it provides the vertical and lateral distribution of reservoir attributes. The modern technology advancement facilitates the interpretation of different kind of well log measures utilizing sophisticated software in order to estimate petrophysical properties with high accuracy [2]. Well logging is the process of recording details of geological formations penetrated by a borehole. It represents an integrated approach to measuring reservoir properties, based on subsurface samples or physical instruments lowered into the well [3]. Interpretation of well log results is one of the most important processes for engineers and geologists to classify petrophysical properties. Log data are essential in reservoir engineering calculations, particularly in reserve estimation. The quality and quantity of log data, as well as the type of problem, strongly influence the accuracy of interpretation [[4],[5]].

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Among the derived properties, effective porosity and permeability can be regarded as the key indicators to determine reservoir quality [[6],[7]]. Lithology also plays a major role in controlling reservoir properties and fluid flow behavior, as porosity and permeability vary depending on rock type [[8],[7]]. Effective porosity represents the interconnected pore spaces that allow hydrocarbons to accumulate and move within the reservoir [[9],[7]].

Carbonate reservoirs are characterized by heterogeneity due to depositional and diagenetic processes, which influence porosity, permeability, and hydrocarbon distribution. These characteristics are critical for predicting reservoir behavior and improving reservoir models [[10],[11]]. Therefore, integrated analysis of well log data is required to accurately evaluate reservoir properties and understand reservoir performance.

Accordingly, the objective of the current study is to analyze the petrophysical properties of Jeribe-Euphrates Formation in Fauqi oil field, utilizing the well log data with special emphasis on the properties like volume of shale, porosity, water saturation, and lithology.

2. AREA OF CASE STUDY

The Fauqi oil field is located in southeastern Iraq in the Maysan Governorate, close to the border between Iraq and Iran. It is positioned about 50 km northeast of Amarah city and about 175 km north of Basra. It stretches along the eastern border and is found very close to the Buzurgan oil field, a few kilometers apart [[12],[13],[14]], see Figure 1.

Structurally, the field consists of two domes aligned in a northwest–southeast direction and separated by a depression along the fold axis. The overall structural setting is classified as an en echelon fold [15].

Oil is the mainstay of Fauqi oil field output, mainly related to the Asmari and Mishrif formations. In 1974, the first exploratory well was drilled and reached the Nahr Omar Formation at a depth of 4,683 m but hydrocarbon accumulations were only found in Tertiary reservoirs (Asmari and Mishrif formations). Production started in commercial quantities from 1979 with eight wells and rose to 24 wells by 1980 but the war interrupted operations. Production activities resumed in 1998 and have continued since then [[16],[14]]. By 2021, the number of producing wells had exceeded 65 [[13],[14]]. The Oligocene–Miocene Asmari Group represents one of the most significant hydrocarbon reservoirs in the Zagros Basin, extending from southwestern Iran to southeastern Iraq. In Iraq, it occurs in several oil fields, including Fauqi and Abu Ghirarb [[17],[15]]. Geologically, the study area lies within the unstable shelf (Hamrin–Makhul zone) according to the longitudinal tectonic division of Iraq, and within the Mesopotamian block according to the transverse division. The region is bounded by the Sirwan Fault to the north and the Takhadid–Qurnah Fault to the south [[18],[15]].

Within the Fauqi oil field, the Asmari Formation consists of four main subdivisions which include Jeribe–Euphrates Formations, Upper Kirkuk Formation, Buzurgan Member, and Middle–Lower Kirkuk Formation [[19],[15]]. Jeribe–Euphrates Formation forms the upper part of the Asmari reservoir deposits and represents Neogene deposits. These formation consist of Unit A with sub-units (A1, A2, and A3) made up mainly of dolomite rock (about 85%) and shale rocks (about 15%), with an average thickness of about 40 meters [14].

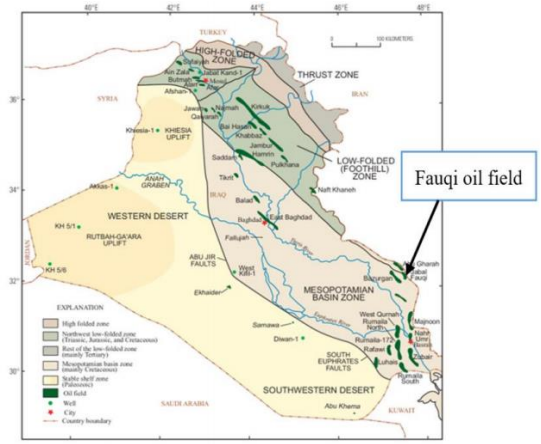

Figure 1. Iraqi Fauqi oil field location on Iraq map [14]

3. METHODOLOGY

This study initially assessed the petrophysical properties through well log data collected from a single borehole (FQ-25). There are several steps in the interpretation workflow. The data were digitized first, and then environmental corrections were applied because well log measurements are indirect measurements affected by borehole conditions (e.g., rock and drilling mud properties and circulation effects). All logs, namely GR, RHOB, DT, Resistivity, and NPHI, were acquired. The datasets from these logs were then analyzed together using Interactive Petrophysics (IP) software. This is part of formation evaluation using the data. An overview of this entire procedure is presented in Figure 2.

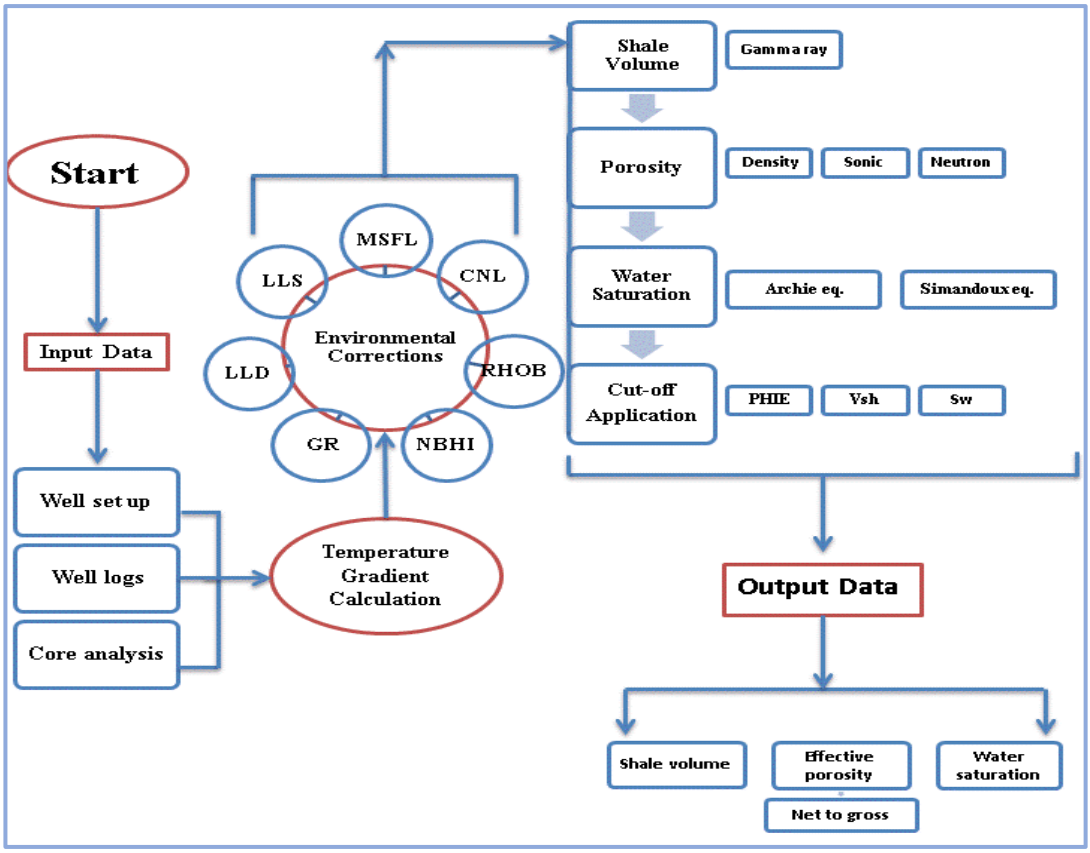

Figure 2. Diagram illustrates steps and parameters of petrophysical properties

4. RESULTS AND DISCUSSION

4.1 Corrections for Logs Measurements

Well log data and drilling parameters can be significantly affected by salinity, mud properties, filter cake, and borehole size [[20],[21]]. The Interactive Petrophysics (IP) software was employed in this study to apply these corrections using Schlumberger algorithms. In phase one, only logs impacted by borehole conditions were corrected, whilst other logs were used without correction in situations where no correction was required and when the relevant parameters needed for correction were not available. Logs were then interpreted to calculate petrophysical properties after correction. An example of these corrections for well FQ-25 is depicted in Figure 3.

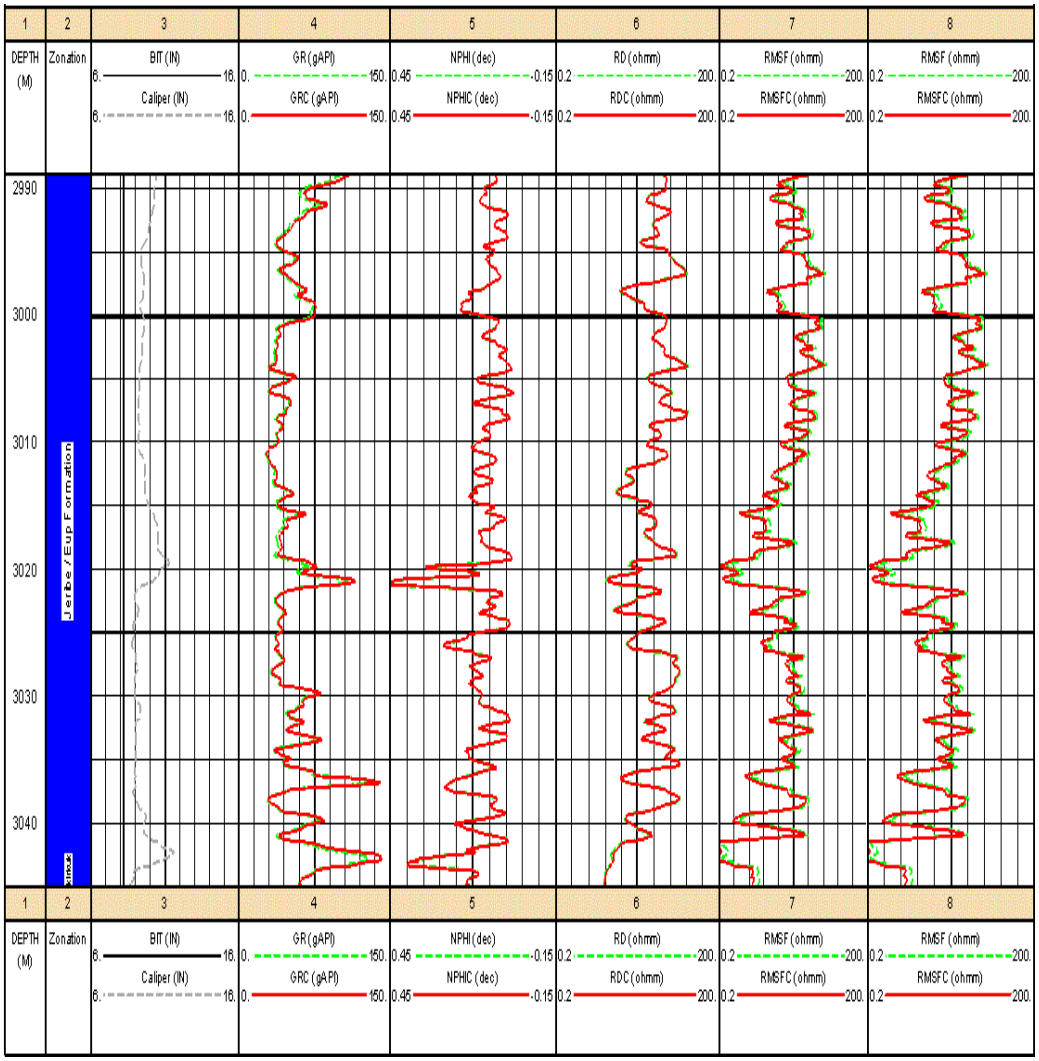

Figure 3. The environment corrections for logs in well FQ-25.

4.2 Shale Volume

In the study area, shale volume (Vsh) was estimated using gamma ray logs. The first step consisted of calculating the gamma ray index (IGR) as defined by Eq. (1) [[22],[23]]:

$$I_{GR} = \frac{GR_{log} - GR_{clean}}{GR_{shale} - GR_{clean}} \quad (1)$$

Next, shale volume was estimated according to the Larionov (1969) model for young rocks as:

$$V_{sh} = 0.083\ (2^{3.7\ X\ I_{GR}} - 1) \quad (2)$$

Figure 4(a) shows the estimated shale volume of well FQ-25. Histogram analysis of the studied well shows that the shale volume (Vsh) within the Jeribe–Euphrates Formation is around 9.5%, as illustrated in Figure 4(b).

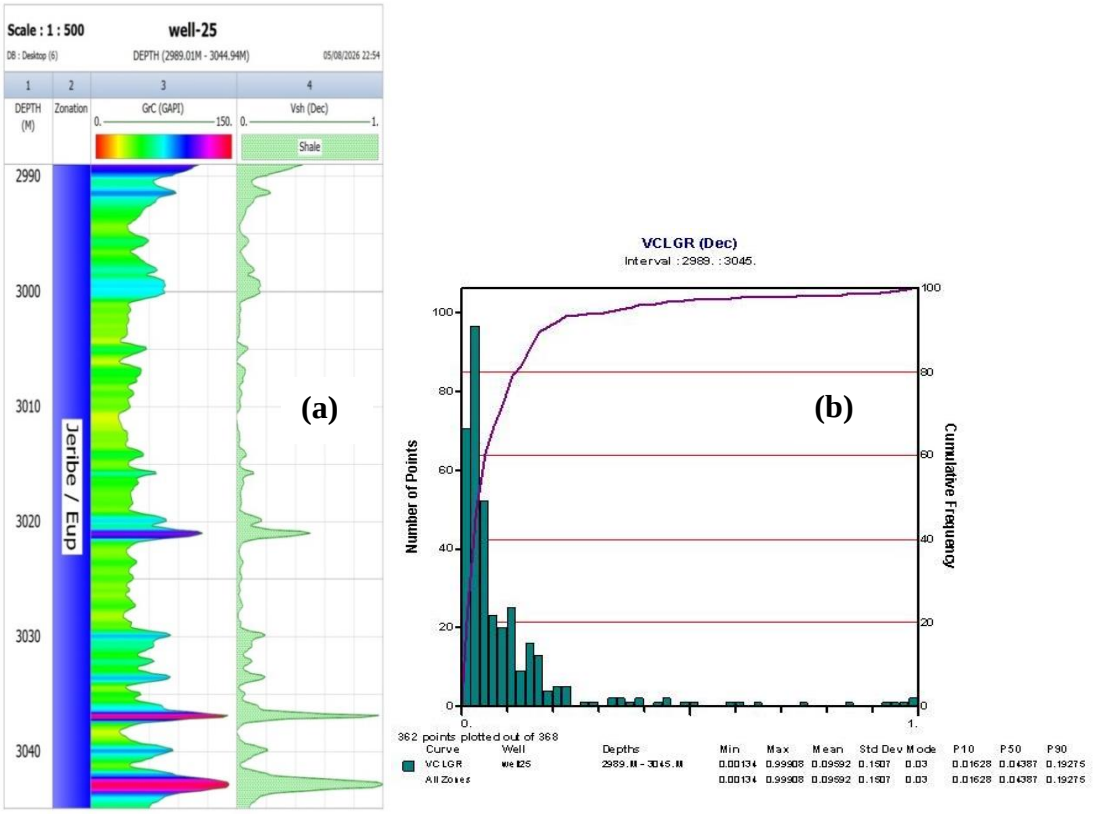

Figure 4. Shale volume for Jeribe–Euphrates Formation: (a) Well FQ-25's shale volume log (b) Shale volume histograms

4.3 Porosity Estimation

Porosity refers to the relationship between pore volume and rock volume, which is normally represented in percentages [[24],[25]]. Porosity was calculated using a variety of well logs, such as density, neutron, and sonic logs. The density and neutron log porosity combination was chosen as the best approach to represent total porosity.

4.3.1 Total Porosity

Total porosity is defined as the ratio of the total pore volume to the bulk volume of the material, regardless of whether the pores are interconnected or isolated [[26],[27]]. Schlumberger [28] proposed an equation for estimating total porosity using neutron and density logs, which can be expressed as follows [27]:

$$\emptyset_t = \frac{\emptyset_D + \emptyset_N}{2} \quad (3)$$

4.3.2 Effective Porosity

Effective porosity is defined as the ratio of the volume of interconnected pore spaces to the total volume of the reservoir rock [[26],[27]]. It can also be expressed as the total porosity minus the volume of clay-bound water and the water retained within clay-associated porosity [[29],[27]].

$$\emptyset_e = \emptyset_t \, (1 - V_{sh}) \quad (4)$$

4.3.3 Secondary Porosity

Secondary porosity is an occurrence which occurred after the deposition process in reservoirs. The secondary porosity may be identified through secondary porosity index (SPI) [[30],[31]].

$$SPI = \emptyset_t - \emptyset_s \quad (5)$$

Table 1 summarizes the effective porosity (PHIE) and Secondary Porosity Index (SPI)

values for units A1, A2, and A3 in well FQ-25, whereas the porosity logs obtained from different estimation methods are illustrated in Figure. 5.

Table 1: Estimated effective porosity (PHIE), total porosity and secondary porosity index (SPI) Values for the Jeribe–Euphrates Formations in Well FQ-25.

Well Name	Zone	A1	A2	A3
FQ-25	Interval	2989-3001	3001-3021.63	3021.63-3045
	PHIT	0.057	0.077	0.098
	PHIE	0.043	0.070	0.081
	SPI	0.029	0.041	0.026

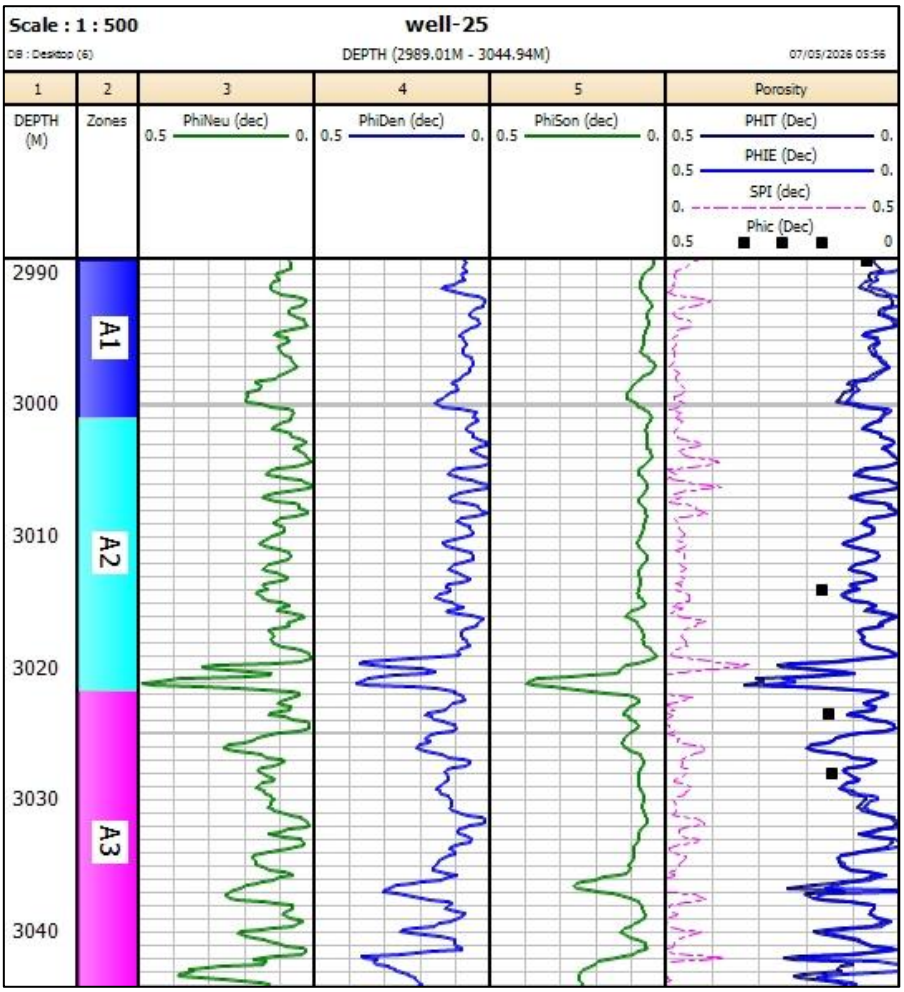

Figure 5. Estimating porosity in different methods for well FQ-25

4.4. Lithology Identification

Identification of Lithology It is important to identify the lithology of the formation in order to characterize sediment, rock, matrix and

reservoir identification, which was done using two cross plots:

4.4.1 The Neutron-Density Cross Plot for Lithology Identifications

The neutron density cross plot is an important technique in well logging used for the determination of formation porosity and lithology by relating neutron porosity to bulk density (NPHI vs. ρb). It is suitable for use on formations that are drilled with fresh water drilling muds, clean matrix rocks, and fully saturated formations. It can be used to differentiate various lithologies, including sandstone, limestone and dolomite, with good lithological discrimination, making minerals like calcite, quartz, and anhydrite identifiable [[32],[31]]. The neutron–density cross plot of well FQ-25 reveals that most data points are concentrated along the dolomite trend line, indicating dolomite as the dominant lithology, while limestone appears in minor proportions, as presented in Figure 6.

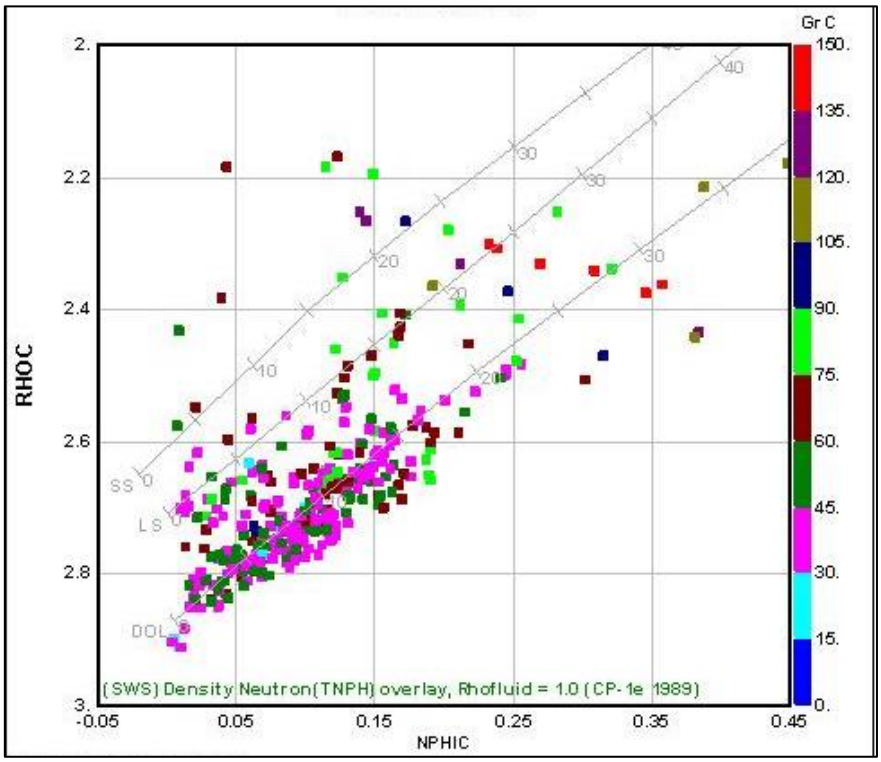

Figure 6. Density Neutron cross plot for (FQ-25).

4.4.2 The M-N Cross Plot for Mineral Identifications

The M-N cross plot is one of the most commonly used techniques in lithology interpretation and mineralogical identification [[33],[31]]. The technique utilizes all three types of porosity log readings, sonic, density, and neutron logs to determine mineral contents through the M and N parameters plotted on the graph where M and N refer to the unique slopes associated with the three logs that can be used to define various lithologies including calcite, dolomite, sandstone, gypsum sulfur, gas, and secondary porosity zones [31].

$$M = \frac{\Delta t_{fl} - \Delta t_{log}}{\rho_b - \rho_{fl}} \; X \; 0.01 \qquad (6)$$

$$N = \frac{\emptyset N_{fl} - \emptyset N}{\rho_b - \rho_{fl}} \qquad (7)$$

The M–N cross plot for Jeribe–Euphrates Formation indicates that most points are allocated mostly between the calcite and dolomite trends, showing also a clear shifting

to the secondary porosity trend area as shown in Figure 7 for well FQ-25.

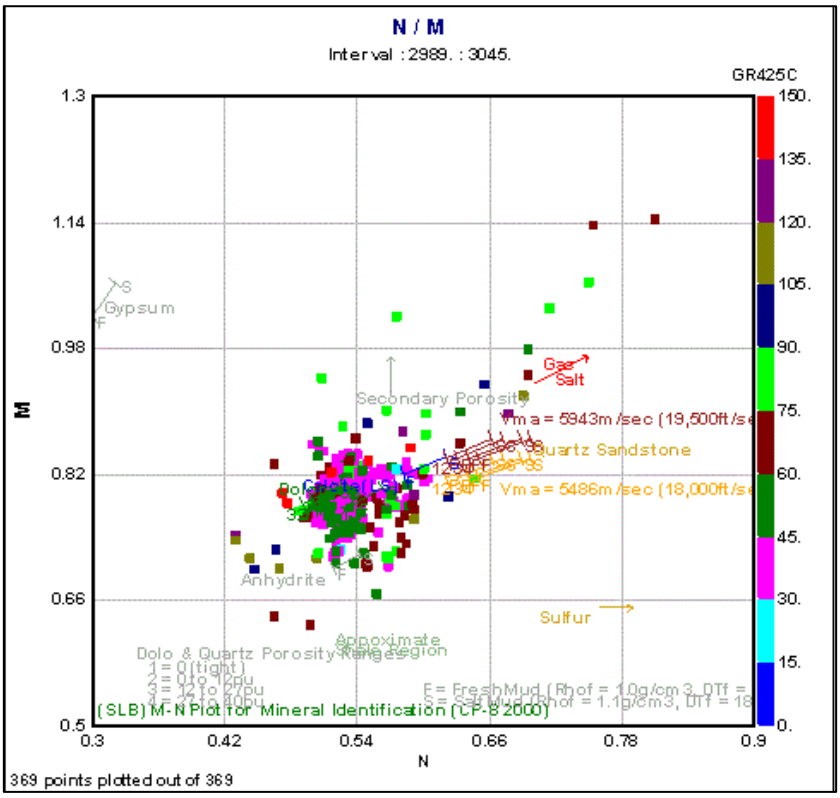

Figure 7. The M-N cross plot in (FQ-25) well.

4.5. Water Saturation

Sw was evaluated through the application of Eq. (8) and Eq. (9) by Archie and Simandoux, with the empirical constants assumed as a = 1, m = 2, and n = 2, and the formation water resistivity taken as Rw = 0.025 [34].

Since shale content significantly affects the estimation of porosity and water saturation from well logs in both sandstone and carbonate reservoirs (limestone and dolomite), Hilchie (1987) suggested that shale begins to have a noticeable effect when its volume exceeds approximately 10%. Accordingly, intervals with shale volume (Vsh) less than 0.1 were evaluated using Archie's equation, whereas intervals with Vsh ≥ 0.1 were calculated using the Simandoux equation to account for shale effects. The obtained results for well FQ-25 are illustrated in Figure 8.

$$S_w = \left(\frac{a}{\emptyset^m} X \frac{R_w}{R_t}\right)^{\frac{1}{n}} \quad (8)$$

$$S_w = \frac{aR_w}{2\,\emptyset^m}\left(\frac{a}{\emptyset^m} X \frac{R_w}{R_t}\right)^{\frac{1}{n}} \quad (9)$$

Sxo, which is the saturation of water in the flushed zone, can be obtained through the Archie [35] and Simandoux equations, as expressed in Eq. (10) & Eq. (11).

$$S_{xo} = \left(\frac{a}{\emptyset^m} X \frac{R_{mf}}{R_{xo}}\right)^{1/n} \quad (10)$$

$$S_w = \frac{aR_w}{2\,\emptyset^m}\left(\frac{a}{\emptyset^m} X \frac{R_w}{R_t}\right)^{\frac{1}{n}} \quad (11)$$

4.6. Bulk Volume Water and Hydrocarbon Movability

Bulk Volume Water (BVW) was computed in both the univaded and the invaded zones using the following two formulas [36]:

$$BVw = SW\,\emptyset N.D \quad (12)$$

$$BVxo = Sxo\,\emptyset N.D \quad (13)$$

The area between the porosity curve and the BVxo (∅ x Sxo) curve is a measure of the residual oil saturation, and the area between the BVw (∅ x SW)curve is a measure of the movable oil saturation [36].

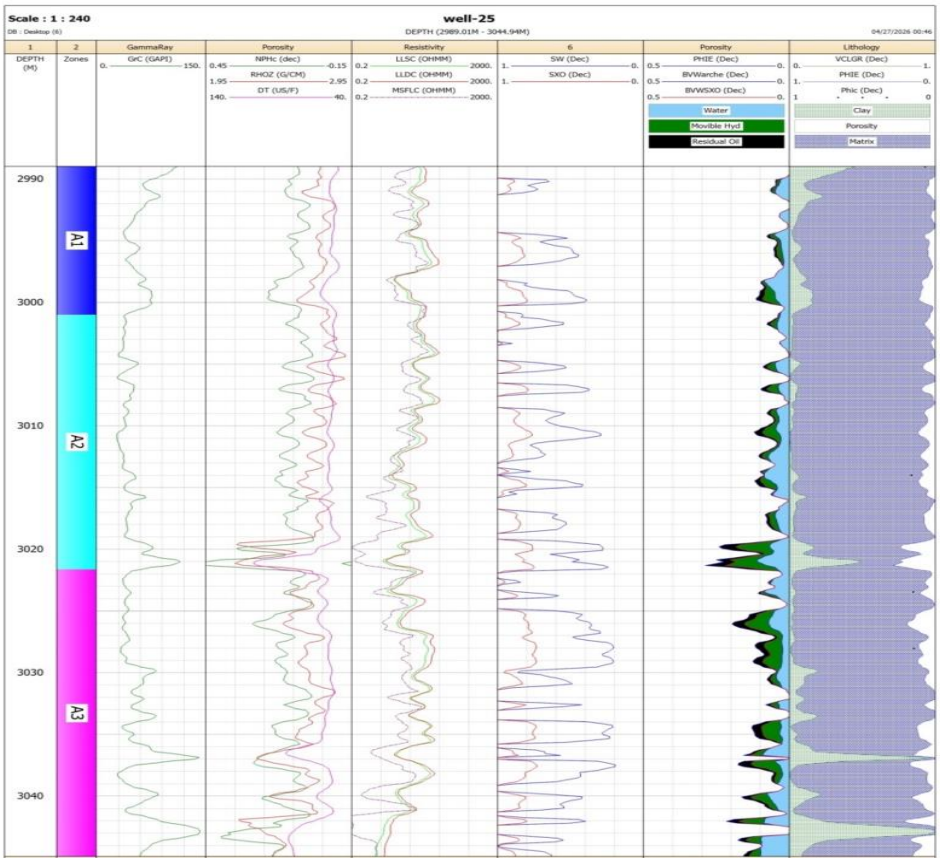

Figure 8. Water saturation log view of well FQ-25.

4.7. Hydrocarbon Pay Zone

The calculation of NTG has been made as illustrated in Figure 9 by excluding layers which are not part of the reservoir such as shale, porosity, and water saturation, with respect to the total reservoir thickness and setting the cutoffs to be 5-8% porosity, 58% water saturation, and 25% shale.

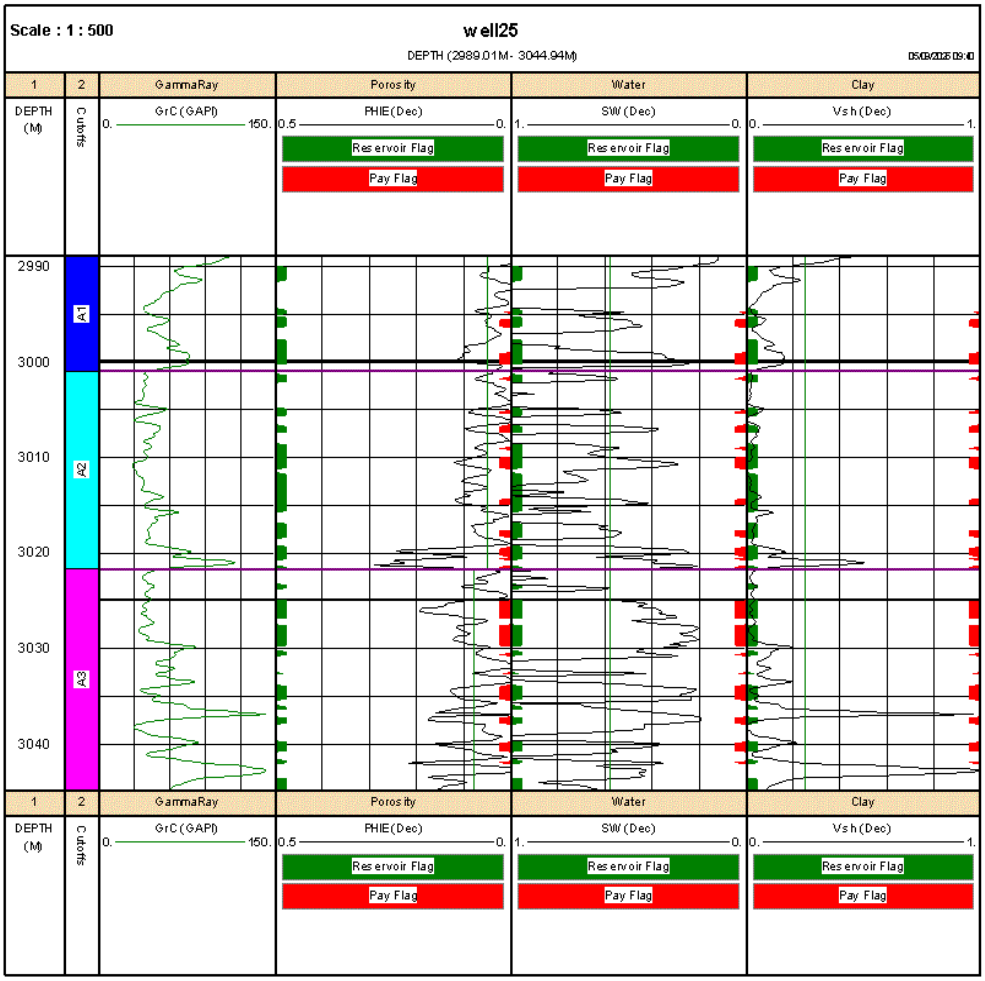

Figure 9. Water saturation log view of well FQ-25.

4. CONCLUSIONS

The petrophysical characteristics of Jeribe–Euphrates formation in the Fauqi Oil Field have led to the following results:

1. The effective porosity (ϕe) of Jeribe–Euphrates Formation ranges from 0.043 to 0.081, where Unit A3 is characterized by the highest value of effective porosity compared to the other studied intervals reflecting comparatively preferable rock reservoir quality. Total porosity (PHIT) values vary between 0.057 and 0.098
2. The Secondary Porosity Index (SPI) varies from 0.026 to 0.041 with the maximum value in Unit A2, indicating increased secondary porosity and higher storage potential in this interval. The effective porosity values are generally lower than total porosity, as the shale content influence observed in most of the data sets.
3. For the Jeribe–Euphrates Formation, shale volume (Vsh) is lower than 9.59 %, indicating a largely clean reservoir with suitable petrophysical properties.
4. Variations observed in the neutron–density cross plots indicate increased dolomitization within some reservoir intervals, which may be associated with fracture development. Furthermore, the M–N cross plots confirm the predominance of dolomite with minor calcite content and indicate the development of secondary porosity within these intervals.
5. NTG analysis reveals a significant increased proportion of moveable hydrocarbons are attributed to Unit A3,

making it the most favorable productive unit in the reservoir.

6. Oil saturation prevails in the reservoirs studied, with levels ranging from poor to fair in relation to water saturation.

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