



Petrophysical Evaluation of the Oligocene Succession in Khabbaz Oil Field, Northern Iraq.

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ABSTRACT

The Oligocene succession is considered a significant reservoir interval in the Khabbaz oilfield. The current study deals with the characterization of petrophysical properties of the Oligocene formations (Anah, Azkand, Ibrahim and Palani) in the Khabbaz oilfield using a suite of open hole logs. Shale content, lithology, mineralogy, and porosity were the main petrophysical properties that were estimated in the current study. The identified lithology from Neutron-Density cross plot indicates domination of limestone, dolomitic limestone, and dolomites, as well as a few readings may be indicated sand material as a matrix in Anah Formation. The gamma ray log has been used to calculate the volume of shale along the studied formations. In general Ibrahim Formation is characterized by higher shale content with an average of about 23%, while Azkand Formation in KZ-43 is characterized by lower shale content with an average of about 8%. Based on effective porosity and shale volume values, the Oligocene formations in the studied wells were divided into nine potential reservoir units in Kz-4 and four potential reservoir units in Kz-43. The upper unit of the Azkand Formation (unit B1) and middle unit of the Ibrahim Formation (C2) in Kz-4 well have the highest potential reservoir properties among the other formations units in the studied wells. They represent the clean to slightly shaly with good effective porosity units.

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1. INTRODUCTION

Petrophysics can be defined as the study of the physical and chemical properties of rocks and their relationship with solutions and gases [1]. The study of well logs has greatly contributed in studying the petrophysical properties of rocks and determining the locations of oil reservoirs. The reservoir properties including porosity, permeability, water, hydrocarbon saturation and shale volume play vital roles in reservoir production [2].

Tertiary age formations are important from a reservoir perspective, especially what is known as the main limestone, due to its high permeability and porosity, which made it a distinctive reservoir within the oilfields of Iraq. The term "main limestones" is an informal description used to identify the first main oil-pay zone within the Kirkuk structure. Due to the importance of the Kirkuk group, the stratigraphy of the Kirkuk group was studied in detail, and the first studied the stratigraphy of Oligocene sequences are [3, 4, 5], and then, studies and research continued by foreign companies, employees of the North Oil Company and a many of researchers.

Carbonate reservoirs composed most of the Oligocene succession, which is an important reservoir interval in the Khabbaz oilfield. The Khabbaz oilfield is one of Iraq's main and essential oil fields, with multiple reservoir zones similar to most northern Iraqi oil fields. The Tertiary reservoir in Khabbaz oilfield includes the upper Oligocene Anah, Azkand, Ibrahim, and Palani formations. This study aims to interpret the well logs data

and quantitatively evaluate the petrophysical properties to identify the volume of shale, lithology, and types of porosity.

2. Geologic Setting

Khabaz Oil Field is situated in the Kirkuk Governorate, parallel to Kirkuk Oilfield (about 23 km SW of Baba Dome of Kirkuk Field), and between Bai Hassan and Jambour oil fields, around 20 km SW of Kirkuk city. It lies within the Foot Hill Zone (Hamrin–Makhul Subzone) that belongs to the Folded Zone of the Unstable Shelf Unit (Figure 1). [6].

The Oligocene Sequence is characterized by unconformable contact on both lower and upper boundaries. [7] divided the Oligocene succession into nine formations which are represented by three sequences of assumed Early, Middle, and Late Oligocene age (based on the stratigraphic position rather than fossils age diagnostic). These sequences show variations in lateral facies change from basal to reef facies and back-reef facies. According to [8], it is located in the first succession of Arabian Plate Mega-sequence (AP11). The successions exhibited lateral alterations in facies, ranging from basinal to reef and back-reef association facies. Based on lithologic variations and well-logging correlation, [9] modified Bellen's divisions into only two sections (sequences) rather than three parts; they organized the Oligocene formations into two successions: a lower succession consisting of the Shurau, Sheikh Alas, Palani, and Tarjil formations, and an upper succession consisting of the Anah, Ibrahim, Azkand, Baba, and Bajawan formations.

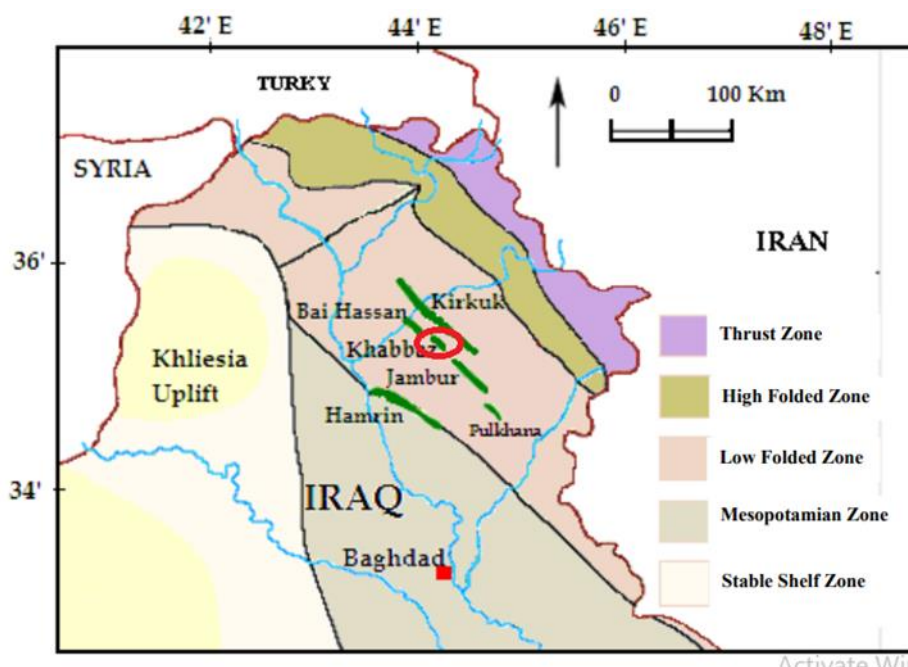


Figure 1. Location of the study area

3. Materials and Methods

To calculate the petrophysical properties of Oligocene formations in Khabbaz oil field, two wells (Kz-4 and Kz-43) that penetrate Oligocene formations were selected. The used logs in the current study, which were provided as LAS digit formats by North Oil Company (NOC) include Gamma Ray (GR), Density log (RHOB), Neutron log (NPHI), Sonic log (DT) and Caliber log (CALI). Prior to the petrophysical analysis, the data quality was checked, and environmental corrections were applied to reduce the effect of borehole conditions on log reading. The interpretation of the log results was performed utilizing the Interactive Petrophysics software (IP V3.5, 2009). The thicknesses and depth intervals of the studied formations in wells Kz-4 and Kz-34 are illustrated in Table 1.

Table 1. Thickness and Depth interval of the studied formations in the studied wells.

Well No.	Formation	Depth interval(m)	Thickness (m)
Kz-4	Anah	2247- 2281	34
	Azkand	2281- 2348	67
	Ibrahim	2348- 2388	40
	Palani	2388- 2460	72
Kz-43	Anah	2240- 2261.5	21.5
	Azkand	2261.5 - 2348.5	87

4. Calculated petrophysical properties

The study of petrophysical properties is one of the most important methods for determining the properties of subsurface rocks. In this study Shale volume and porosity are the main petrophysical properties that have been calculated and described the Lithology of the Oligocene succession in Khabbaz oil field.

4.1. Shale Volume (Vsh) Determination

The calculation of shale volume is important for understanding its impact on various petrophysical characteristics. Shale volume has a significant effect on two important parameters, such as porosity (both total and effective) and permeability, in the studied reservoir rocks [10].

Gamma ray log is frequently used as an indicator for identifying the volume of shale, because of its sensitivity to radioactive materials which highly concentrated in shale. In this study, the shale volume was determined using the flowing equation for younger rocks because the Oligocene formations is of Tertiary age.

$$V_{sh} = 0.083[2^{3.7 * IGR} - 1] \quad (1)$$

Where: Vsh: Shale volume, IGR: Gamma ray index which was acquired using the following equation

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (2)$$

Where : GRlog: gamma ray reading by log (API)., GRmin: minimum gamma ray reading (clean sand zone)., GRmax: maximum gamma ray reading (shale zone).

4.2. Identification of Lithology and Mineralogy

Identification of the various lithologies in the reservoir is one of the most essential requirements for reservoir characterization due to it is evident that facies directly affect all petrophysical and fluid parameters (such as porosity and permeability) [12]. In this study, the lithology of the Oligocene formations across the studied wells was identified by using Density-Neutron cross plot and M-N cross plot.

4.2.1. Neutron- Density cross plot

The density-neutron cross plot is one of the earliest techniques for quantitative interpretation. because it provides high lithological resolution for quartz, calcite, and dolomite as well as good resolution of porosity, this is important and widely utilized [13]. The variations in matrix density among these three typical rock types, as well as the neutron lithology effect, indicate the high degree of accuracy for dolomite, limestone, and quartz [14].

4.2.2. M-N cross plot

Data from all porosity logs are combined in the M-N cross plot to provide lithology-related parameters, represented by the letters M and N. The M and N values correspond to the slopes of the lithology lines on the sonic-density and density-neutron cross plot charts. The cross plot is a useful tool for lithology identification because it is inherently independent of porosity [15].

$$M = \frac{\Delta t_f - \Delta t}{\rho_b - \rho_f} \times 0.01 \quad (3)$$

$$N = \frac{\Phi_{nf} - \Phi_n}{\rho_b - \rho_f} \quad (4)$$

Where:

Δt_f : Transit Time of fluid within formation, (salt water mud = 185 μ sec/ft, fresh water mud = 189 μ sec/ft).

Δt : Transit time of formation (from log), μ sec/ft., ρ_b : Bulk density from density log.

ρ_f : Fluid density (salt water = 1 gm/cm³ and fresh water = 1.1 gm/cm³).

Φ_{nf} : Neutron porosity of fluid Formation (usually 1.0)., Φ_n : Neutron derived porosity.

4.3 Porosity Determination

4.3.1 Total porosity

To determine porosity for the evaluation of the formations, the neutron log is utilized combined with the density log. This combination is named the total porosity (Φ_t) which is the total amount of voids in the rock volume ([16]; [17]). The total-porosity is calculated from the density log and neutron log, by using the bellow equation ([18]; [19]).

$$\Phi_{N.D} = \frac{\Phi_N + \Phi_D}{2} \quad (5)$$

Where:

$\Phi_{N.D}$: neutron and density porosities combination (total porosity)., Φ_N : neutron porosity.

Φ_D : density porosity.

4.3.2 Secondary porosity

Secondary porosity (vuggy, molds, channels, and fractures) is created by geological processes like diagenetic processes after sedimentation and buried [20]. The secondary porosity index (SPI) was computed by the differences between the calculated porosity (total-porosity) from density and neutron log and calculated porosity (primary porosity from sonic log (DT)) using the following equation [19, 21].

$$SPI = (\Phi_t - \Phi_s) \quad (6)$$

Where

SPI = Secondary porosity index., Φ_t = Total porosity (Neutron-Density log).

Φ_s = Porosity derived from sonic log (Primary porosity).

4.3.3 Effective porosity

Effective porosity is the ratio of the volume of interconnected voids to the total volume of a reservoir [22]. It is defined as the total porosity less the water that is held as porosity inside the clays and the water that is linked to the clay [23]. The following formula is used to calculate effective porosity [15].

$$\Phi_e = \Phi_t \times (1 - V_{sh}) \quad (7)$$

Where:

Φ_e : effective porosity.,

Φ_t : total porosity ($\Phi_{N.D}$). V_{sh} : volume of shale.

5. Results and discussion

The following briefly summarizes the main results of this study:

5.1 Shale Volume

Based on the standard values limits of shale volume, and the results of the calculated volume of shale as shown in Table 2, the majority of Azkand and Anah formations in the studied wells are regarded as clean zones, except the lower section of Azkand formation and upper section of Anah formation which characterized by higher shale content (Figure 2).

The other shale zones which were supported by high gamma ray readings, were recognized in Kz-4 at the top and bottom of the Ibrahim formation and as a thin layer in some depth intervals in the middle of the Palani Formation. In general Ibrahim formation is characterized by higher shale content with an average of about 23%, while Azkand Formation in KZ-43 characterized by lower shale content with an average of about 8%.

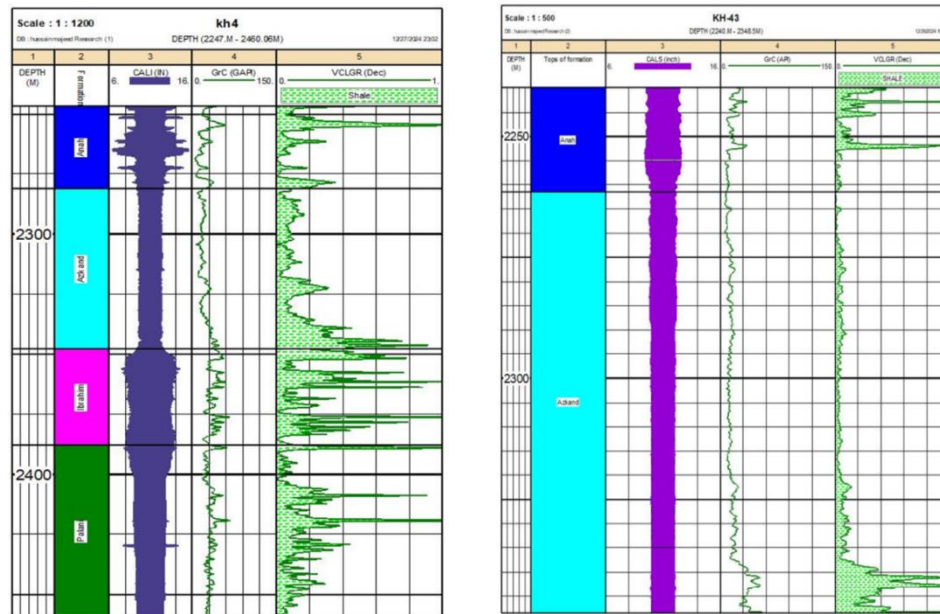


Figure 2. Shale volume of the Oligocene formations in Kz-4(left) and Kz-43(right).

5.2 Lithology Identification

The neutron-density cross plot readings for the studied wells are used to discern the lithologies of the Oligocene formations (Figure 3). The lithology of the Anah Formation mostly exhibits limestone composition, with some shale and dolomite in certain areas. Both logs (density and neutron porosity) have low values, indicating the presence of a zone of possibly sandy nature (fine brittle sandy limestone) in the Kz-4. The carbonate composition of the Azkand Formation is represented by dolomitic limestone, with some scattered outliers indicating shale material or maybe bioclastic content in both wells. Limestone is the dominant lithology of Ibrahim and Palani formations due to the concentration of most points on the limestone curve, except some points of Ibrahim formation scattered outliers indicate the presence of shale layers.

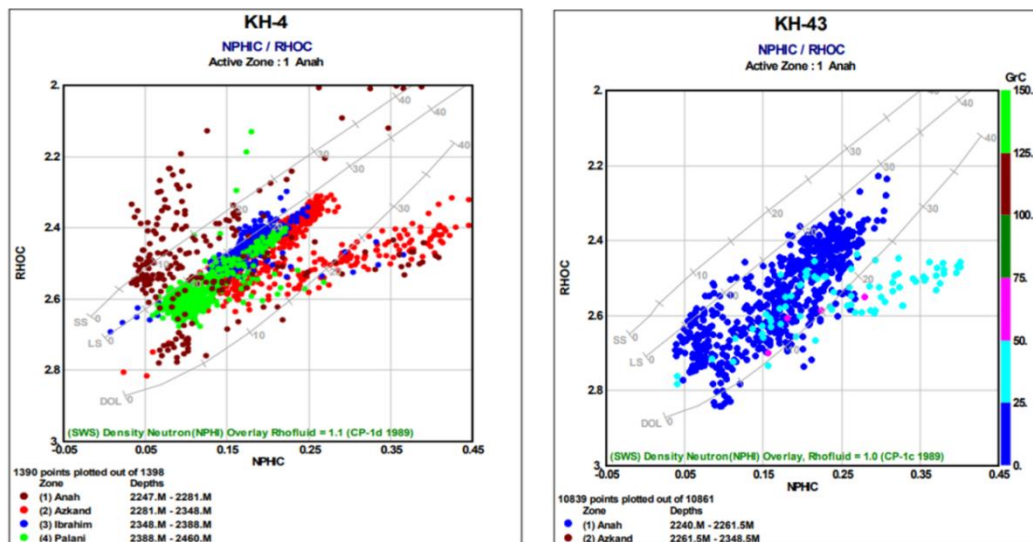


Figure 3. Neutron –Density cross plot for lithology identification of the studied wells.

Figure 4 shows that calcite is the main mineral in the Oligocene succession in both wells with some dolomite especially in Azkand Formation in both wells. This dolomite resulted from dolomitization processes and formed secondary porosity.

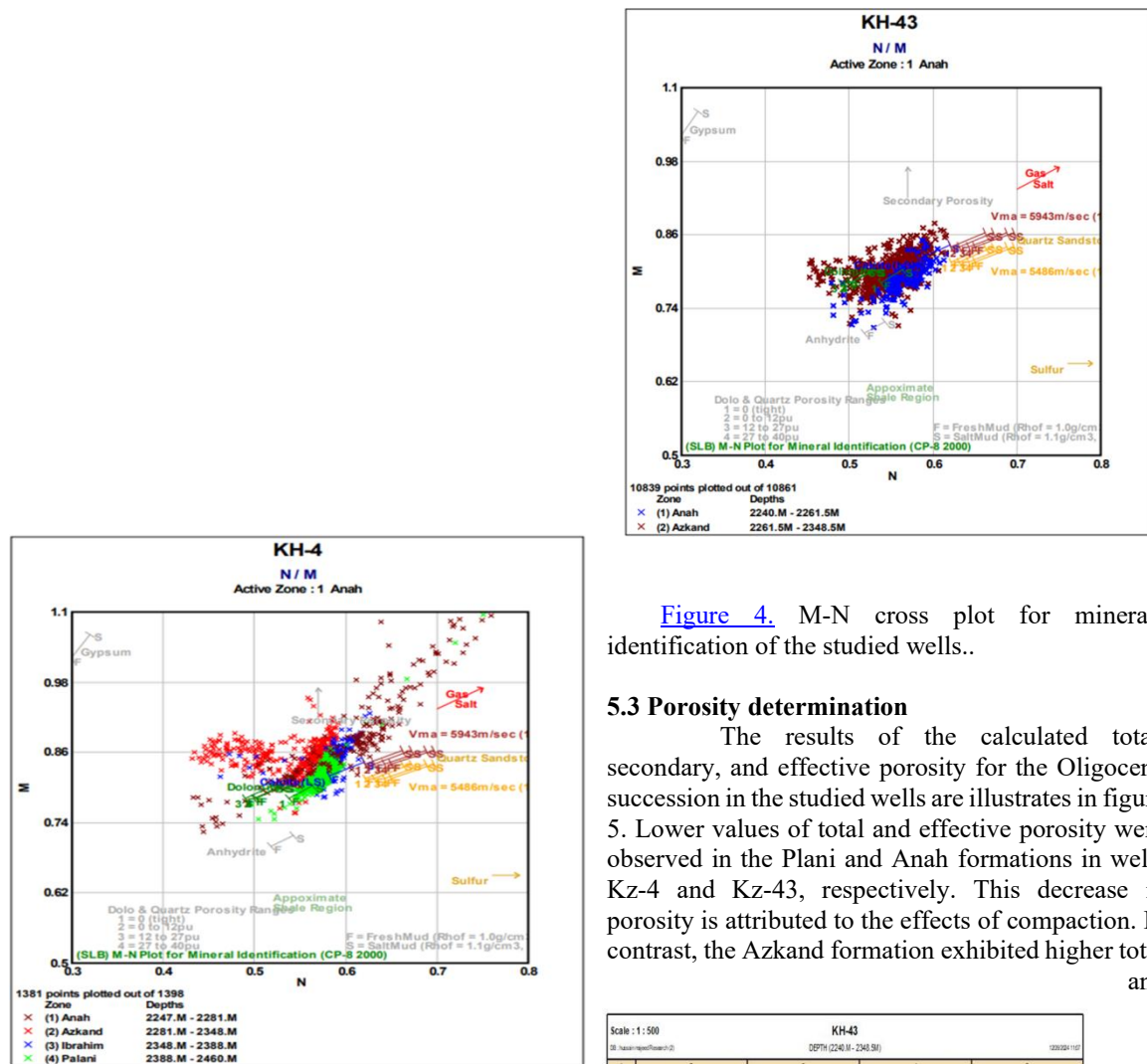
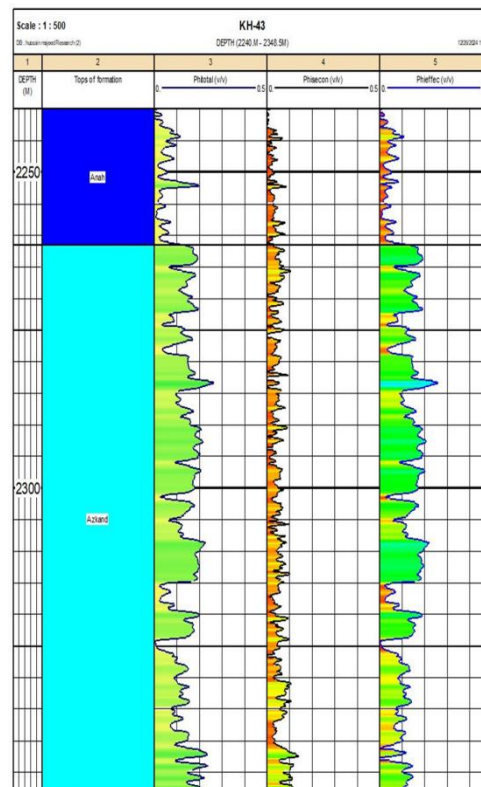


Figure 4. M-N cross plot for minerals identification of the studied wells..

5.3 Porosity determination

The results of the calculated total, secondary, and effective porosity for the Oligocene succession in the studied wells are illustrates in figure 5. Lower values of total and effective porosity were observed in the Plani and Anah formations in wells Kz-4 and Kz-43, respectively. This decrease in porosity is attributed to the effects of compaction. In contrast, the Azkand formation exhibited higher total and

effective porosity values in both wells. The secondary porosity, which reflects the influence of diagenetic processes, was found to be higher in the Anah and Azkand Formations in well Kz-4. However, it showed minimal effects in the formations of well Kz-43. The increase in secondary porosity indicates that the Anah Azkand formations in well Kz-4 are more influenced diagenetic processes, such as dissolution, dolomitization, or/and fracturing, compared to the formations in well Kz-43



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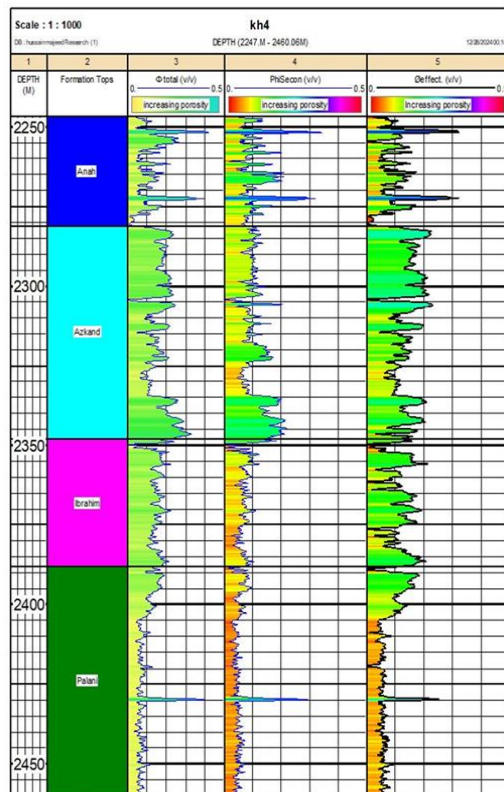


Figure 5. Total, Secondary and Effective porosities, of the studied wells.

5.4 Reservoir units

Since shale volume and effective porosity are the primary parameters that can be utilized to differentiate between reservoir potentiality intervals (as reservoir units), the formations of the studied wells were divided based on effective porosity and shale volume into nine potential reservoir units in Kz-4 and four potential reservoir units in Kz-43. To describe the porosities of the examined formations, the standard classification for evaluation porosities proposed by [24] has been used (Table 3). Figure (6) shows the divisions of formations as potential reservoir units, and the evaluation of these reservoir units is explained as follows: -

Table 2. porosity classification according to [24].

Porosity type	Percentage (%)	Porosity Type	Percentage (%)
Negligible	0-5	Good	15-20
Poor	5-10	Very Good	20-25
Fair	10-15	Perfect	>25

5.4.1. Reservoir unit A

The Anah Formation in the examined wells exhibited almost similar reservoir properties, hence, the whole formation is marked as reservoir unit A. The average shale volume in this unit was relatively consistent at around 14% in the two examined wells, whereas the lowest average effective porosity was approximately 3% in Kz.43 and the highest average effective porosity was about 9% in Kz-4 (Fig. 6). Generally, from a porosity perspective, the Anah Formation exhibits negligible to poor porosity, likely attributable to the effects of compaction in the examined wells.

5.4.2. Reservoir units B1, B2, and B3.

Azkand Formation is subdivided into three units: B1 (upper section), B2 (middle section), and B3 (bottom section). The lowest average shale volume for unit B1 was around 4% in well Kz-43, while the highest was over 9% in well Kz-4. The effective porosity in this unit ranged from a low average of around 13% in the Kz-43 well to a high average of about 17% in the Kz-4 well.

The Azkand Formation B2 unit exhibited relatively less effective porosity than the B1 unit.

The minimal average effective porosity for this unit was around 8% in well Kz-43, while the highest was over 12% in well Kz-4. The lowest average shale content recorded in well Kz-43 was around 5%, while the greatest average shale content in well Kz-4 was about 11% (Fig.6). The B3 unit had a greater average shale content than the other two units (B1 and B2), with average values of around 23% and 36% in wells Kz-43 and Kz-4, respectively. The minimal average effective porosity for this unit was around 8% in well Kz-43, while the highest was nearly 15% in well Kz-4.

According to the computed average values of effective porosity and shale content in the analyzed wells, unit B1 in the Kz-4 well exhibits the highest reservoir quality compared to units B1 and B2. It represents the clean unit with good effective porosity, whereas unit B2 has poor to fair effective porosity and unit B3 represents the shale unit.

5.4.3. Reservoir units C1, C2, and C3.

These units are only recognized in Kz-4 well. The calculated shale volume and effective porosity lead to distinguish three different reservoir units in the Ibrahim Formation. The upper section of the formation (C1 unit) revealed lower effective porosity, with an average of about 10% and a higher average shale content of about 32% (shale unit) in comparison with the other two units (Fig. 6).

Middle unit (C2) of the Ibrahim Formation showed higher effective porosity (15%) and lower shale content (14%) in comparison with upper and lower units. The lower section of the Ibrahim formation (C3 unit) had an average effective porosity of around 12% and an average shale content of around 20%. The upper and lower units of Ibrahim Formation have no significant porosity (poor to fair respectively), perhaps due to of the increased shale concentration in these units.

5.4.4. Reservoir units D1 and D2.

D1 unit which represents the upper section of the Plani Formation showed fair effective porosity, with an average of about 12% and clean shale content with an average of 7%, while D2 unit showed poor effective porosity with an average about 5% (Figure 6).

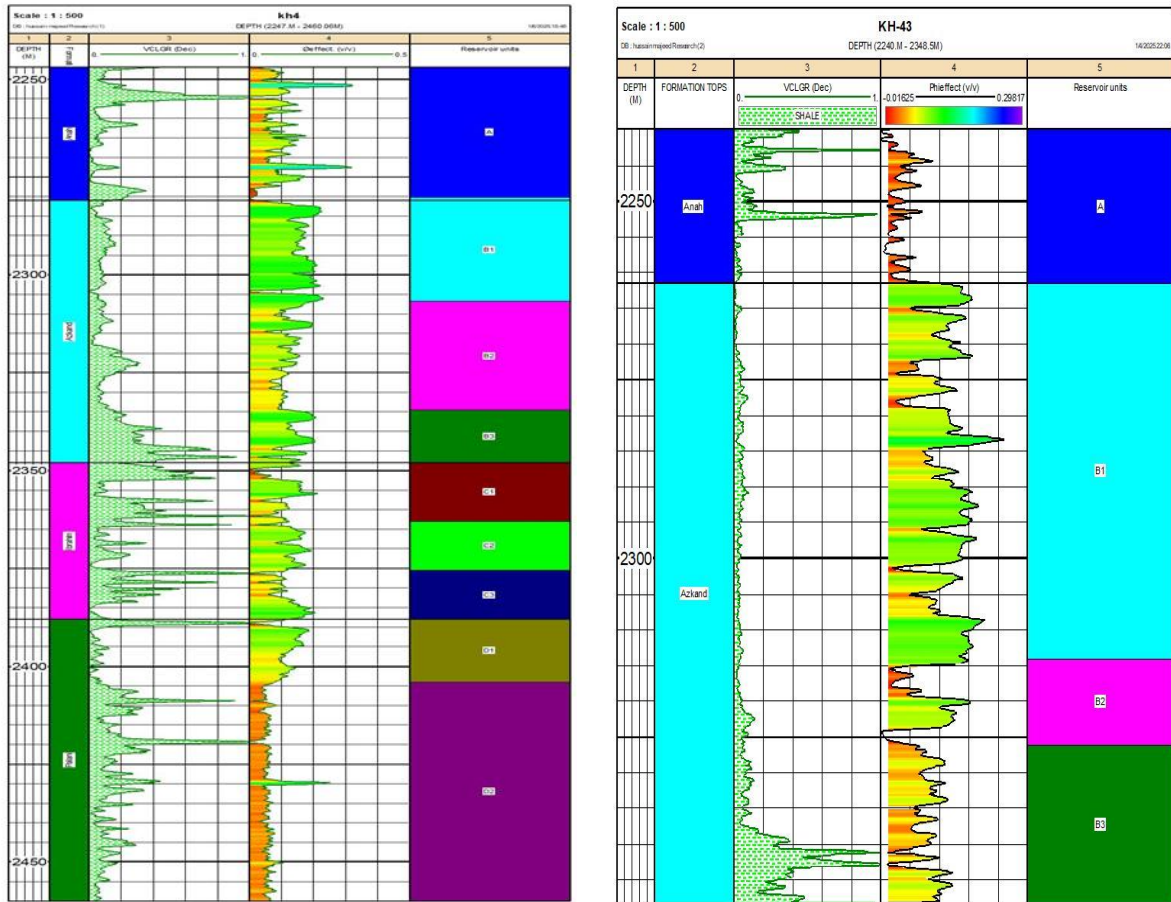


Figure 6. Reservoir units of the Oligocene succession in the studied wells

6. CONCLUSION

The open whole log data of the wells Kz-4 and Kz-43 have been used in characterizing the reservoir properties of the Oligocene formations in Khabaz oil field. From the results of calculated average values of the effective porosity and volume of shale, the upper section of the Azkend Formation (unit B1) in Kz-4 well has the highest potential reservoir properties among the other formations in the studied wells. It represents the clean unit with good effective porosity, also the middle unit of the Ibrahim Formation (C2) has good effective porosity and an average shale volume about 14%. The lower values of effective porosity in other units of the studied formations are clearly related to the effect of increasing shale volume and may be due to the effect of compaction on formation rocks.

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