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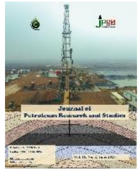

Lithology and Reservoir Characteristics of the Euphrates Formation in the Y Oil Field of Northern Iraq

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Abstract

This research studies the lithology and reservoir characteristics of the Euphrates Formation in the Y Oilfield, which is located in the low fold's zone 80 km southeast of Kirkuk City and 10 km north of Salah Al-Din City. The research focuses on the Euphrates Formation, which belongs to the sedimentary cycle of early Miocene.

The objective of this research is to analyze the lithological section of the Euphrates Formation, which has been divided into three reservoir units (Euph.1, Euph.2, and Euph.3), using well logs and cross-plot techniques. The study focuses on three selected wells (Well-A, Well-B, Well-C), employing Gamma Ray, Neutron, Density, Sonic, and Resistivity log data, which were processed using Techlog software. The aim is to calculate essential petrophysical properties such as effective porosity, permeability, and water saturation. These properties are then used to evaluate the reservoir characteristics and identify the most suitable reservoir units for hydrocarbon exploitation.

The results of the research showed a two type of lithological facies in the Euphrates Formation, consisting mainly of limestone and dolomite. The analyses show that the Well-C shows the best reservoir characteristics, with a range effective porosity of 11-26%, oil saturation between 81-89%, and permeability of 55 mD, making it more suitable for hydrocarbon exploitation. while the Well-B showed less efficient reservoir properties due to the presence of anhydrite bed, which reduce the permeability of formation. In addition, the Well-C has a net pay thickness of 74.92 m, which enhances production capabilities.

This research emphasizes the importance of using well logs to analyze reservoir characteristics, which contributes to improving resource exploitation plans and directing exploration efforts towards the most productive areas, and highlights the role of facies analysis, porosity and permeability in determining the reservoir characteristics of geological formations.

Keywords: Euphrates Formation, Reservoir characteristics, Lithology, Y Field.

الخصائص الصخرية والمكمنية لتكوين الفرات في حقل Y شمالي العراق

الخلاصة:

يتناول هذا البحث دراسة الخصائص الصخرية والمكمنية لتكوين الفرات في حقل Y النفطي، الذي يقع في نطاق الطيات الواطئة على بعد 80 كم جنوب شرق مدينة كركوك و10 كم شمال مدينة صلاح الدين. يركز البحث على تكوين فرات، الذي ينتمي إلى الدورة الرسوبية للمايوسين المبكر. يعتبر تكوين فرات مهمًا بسبب خصائصه الجيولوجية التي تجعل منه مكمنًا مناسبًا لتجمع وتدفق الهيدروكربونات.

هدف البحث هو استخدام المجسات البئرية لغرض تقسيم الصخور إلى وحدات مكمنية (Euph.1، Euph.2، Euph.3) بالإضافة إلى ذلك لتحليل الخصائص المكمنية في ثلاثة آبار مختارة (Well-A, Well-B, Well-C) داخل الحقل. استخدمت بيانات مجسات أشعة كاما، النيوترون، الكثافة، الصوتي، و مجسات المقاومية، وتمت معالجتها باستخدام برنامج Techlog، لتحديد خصائص مثل المسامية الفعالة والنفاذية وتشبع السوائل. اعتمادًا على هذه الخصائص يتم تحديد أفضل المناطق لأنتاج الهيدروكربونات.

بينت نتائج البحث عن وجود نوعان من السحنات الصخرية في تكوين فرات، حيث تتألف بشكل رئيسي من الحجر الجيري والدولومايت. أبرزت التحليلات أن البئر Well-C يظهر أفضل الخصائص المكمنية، يتروا ح مسامية فعالة بين 11-26%، تشبع نفطي بين 81-89%، ونفاذية تصل إلى 55 ملي دارسي، مما يجعله أكثر ملاءمة لاستغلال الهيدروكربونات. بالمقابل، أظهر البئر Well-B خصائص مكمنية أقل كفاءة بسبب تواجد طبقات الأنهيدرايت، التي تقلل من نفاذية التكوين. بالإضافة إلى ذلك، يتمتع البئر Well-C بسمك عطاء صافي للمكمن يصل إلى 74.92 متر، مما يعزز إمكانيات الإنتاج.

يؤكد هذا البحث على أهمية استخدام المجسات البئرية لتحليل الخصائص المكمنية، مما يساهم في تحسين خطط استغلال الموارد وتوجيه جهود التنقيب نحو المناطق الأكثر إنتاجية، كما تبرز دور تحليل السحنات والمسامية والنفاذية في تحديد الخصائص المكمنية للتكوينات الجيولوجية.

1. Introduction

Reservoir rocks are essential elements in the study of petroleum geology, as they contribute to the understanding of the properties and distribution of hydrocarbons in geological formations. This research deals with the petrophysic characteristics of the Euphrates Formation as one of the important Tertiary reservoirs belong to the early Miocene sedimentary cycle [1]. The Euphrates Formation shows diverse porosity and permeability properties, making it an important research topic.The Euphrates Formations are considered to have low to moderate porosity (avg. 2.7–20.5%) and low matrix permeability (avg. 0.87–15mD).[2]. The effective porosity values for the Jeribe, Dhiban, and Euphrates formations are determined as 15.41%, 4.65%, and 9.85%, respectively, with lithology predominantly consisting of dolomite rock interspersed with limestone slices and anhydrite nodules.[3]

This research focuses on the lithology and reservoir characteristics of the Euphrates Formation, which is characterized by widespread. The Euphrates Formation in some locations shows high porosity ranging between 20% and 30% and permeabilities ranging between 8 and 500 mD [4].

The Euphrates Formation in the Qaiyarah Oilfield consists mainly of dolomite, limestone and shale, where more than 90% of formation thickness is reservoir in some wells, while 50% in other wells [5]. The formation is considered a main reservoir unit with a thickness of up to 47.7 m. in Khabbaz Oilfield [6]. The aim of this research is to analyze the reservoir properties of the Euphrates Formation in the Y Oilfield using well logs such as Gamma Ray, Neutron, Density, Sonic, and Resistivity logs in the selected wells (Well-A, Well-B, and Well-C), utilizing Techlog software. The research aims to fill the knowledge gap in understanding reservoir rock properties by providing a detailed analysis of characteristics such as porosity, permeability, water saturation, and shale content. This will contribute to improving hydrocarbon exploitation strategies and identifying high productivity zones.

1.1. Location and Geology of the Study area

The Y Oilfield is located within the foothill zone on the southwestern border of the low folded zone in the unstable shelf zone according to the tectonic division of Iraq [1], about 80 km southeast of the Kirkuk City. The Y Oilfield is one of the most important oil fields in northern Iraq. It is represented by a convex asymmetrical fold with two wings whose axis extends from northwest to southeast with a length of more than 101 km, and a width ranging from 4 to 7 km, consisting of three domes belong to The Y Oilfield (from northwest to southeast) Albu Fadoul, Khan Nakhila and Alas (Figure. 1).

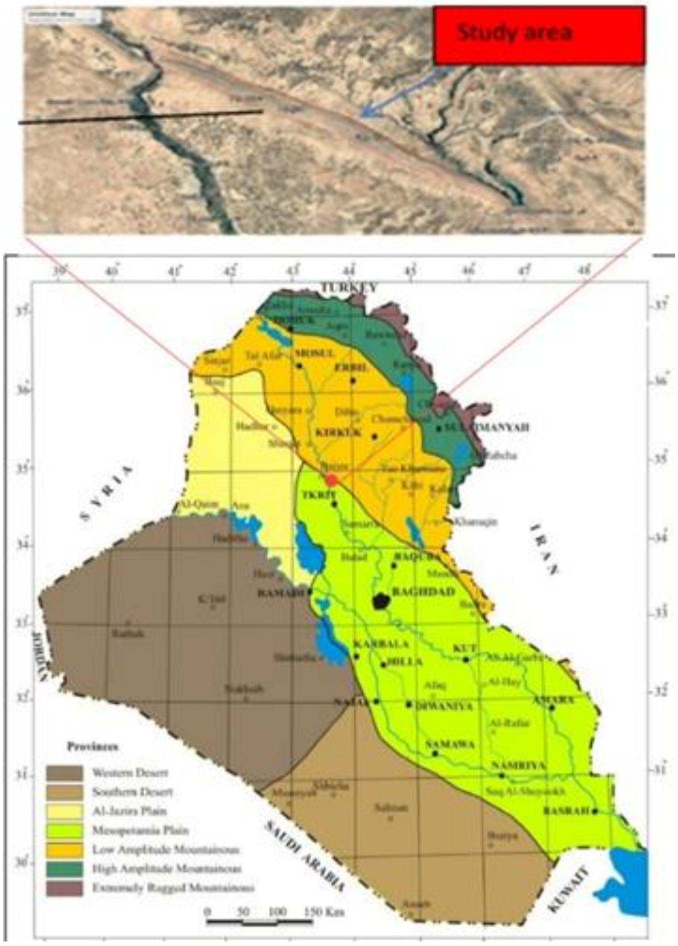

Fig. (1): Location map of the study area with the well locations marked.

2. Material and methods

This study utilized well log data from wells Well-A, Well-B, and Well-C, including Gamma Ray, Neutron, Density, Sonic, and Resistivity log data, to analyze key formation properties such as porosity, lithology, and shale content. Additionally, reservoir properties such as effective porosity, permeability, and fluid saturation (water and hydrocarbon) were evaluated. [7&8&9]

The information analysis involved the interpretation of well logs to identify lithological facies and porosity distribution. Based on gamma ray log data, the formations were classified into shaly and clean zones. Porosity and permeability were calculated for each lithological unit, and the hydrocarbon potential of the formations was assessed using data from the Euph.1, Euph.2, and Euph.3 units.

The hydrocarbon movement index was determined by calculating the ratio of water saturation in the flushed zone to that in the non-invaded zone. Net to gross thicknesses of the reservoir units were also calculated to estimate the production capacity.

3. Results

3.1. Lithology and Reservoir Properties Analysis (cross-plot diagrams)

The lithological facies of the Euphrates Formation were determined through cross-plot diagrams of Neutron (NPHI) and Density (RHOB) logs. These diagrams highlight the variations in lithology and reservoir characteristics across wells Well-A, Well-B, and Well-C, providing insights into the hydrocarbon potential of each well. Figure (2) illustrates the distribution of data across lithology lines, aiding in characterizing the lithofacies and evaluating the reservoir potential of the Euphrates Formation.

Well-A: The cross-plot data for Well-A exhibit clustering around Limestone and dolomite can be good reservoirs formations in some cases.

Well-B:

- The cross-plot for Well-B reveals a distinct concentration of data in the **anhydrite zone** at the formation's top.
- Anhydrite, characterized by low porosity and high density, diminishes the reservoir quality in this well compared to Well-A.

Well-C:

- The Well-C cross-plot data show a distribution along **limestone and dolomite lines**, similar to Well-A.

- High neutron values in the limestone zones suggest favorable porosity and reservoir characteristics, with potential for fluid storage and flow.

The cross-plot analyses confirm the diversity in lithology facies and reservoir properties among the wells, directly influencing their productivity and hydrocarbon potential.

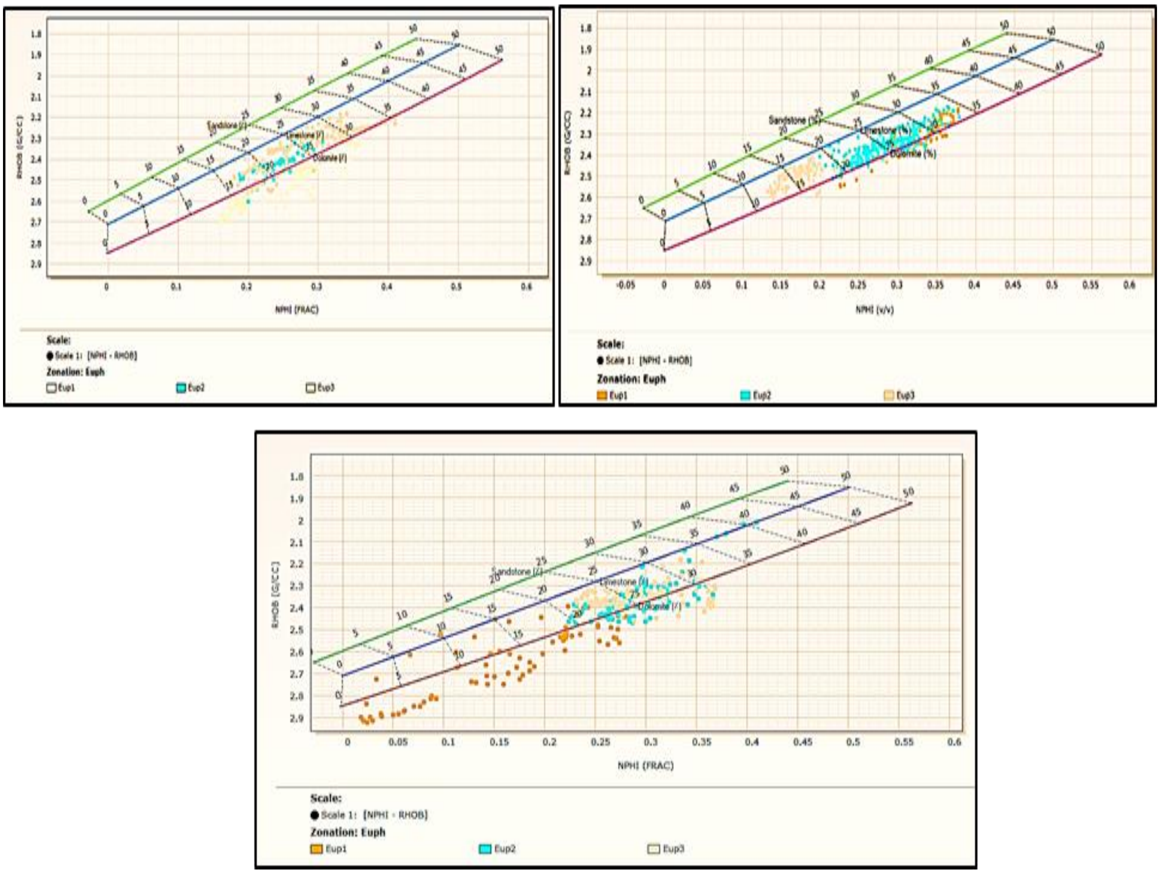

Fig. (2): Intersecting diagram between NPHI and RHOB logs to determine Lithology of the Euphrates Formation (upper left Well-A, upper right Well-Cand the down left Well-B**).**

3.2. Shale Content Analysis

Shale volume was calculated using Gamma Ray (GR) logs, which are highly effective for evaluating shale content in subsurface formations. The calculated shale contents are shown in Figures (3) to (8). The shale content was calculated using the equation below.

$$I_{GR} = GRlog - GRmin \div GRmax - GRmin \ldots\ldots \text{(Eq. 1) [10]}$$

I_{GR} = Gamma Ray Index. **GRlog** = Gamma Ray reading of the wellbore at a specific depth or formation zone (measured in API units). **GRmin** = Minimum Gamma Ray reading recorded for clean formations (such as sandstones) within the well. **GRmax** = Maximum Gamma Ray reading recorded for shale formations within the well.

3.2.1. Well-A and Well-B

- Shale content is generally less than 20% in most sections, except for narrow zones where it reaches up to 50%.
- Exhibit superior reservoir properties, particularly in Euph.2 and Euph.3 units, where shale content is minimal and conditions for porosity are optimal.

3.2.2. Well-C:

- Shale values remain below 20% across most of the formation.
- Displays high shale content in Euph.1, negatively affecting reservoir quality. However, Euph.2 offers some potential due to its relatively lower shale content.

3.3. Porosity Analysis

Porosity is a fundamental property of reservoir rocks, representing the percentage of pore space within the total rock volume. It is categorized into total porosity and effective porosity, with the latter being critical for evaluating reservoir characteristics as it excludes the pore space occupied by non-reservoir materials like shale. Figures (3, 4, 5, 6, 7, and 8**)**

Total Porosity Calculation: Total porosity was determined using Neutron and Density logs, applying the equation in the reference [11].

- **Effective Porosity Calculation**: Effective porosity was calculated by first assessing the shale volume using Gamma Ray logs to account for and exclude the shale effect. This refinement provides a more accurate measure of the porosity contributing to fluid storage and flow in the reservoir.

$$\Phi N\text{-}D=\sqrt{(\Phi N)2} + (\Phi D)2\backslash 2 \text{ ………(Eq.2)}$$

Secondary Porosity: Secondary porosity, an additional factor influencing reservoir quality, was computed for the Well-B from the equation below However, it was not calculated for Well-A and Well-C due to the absence of Sonic log data necessary for the calculation. Figures (5 and 6).

$$SPI=\Phi N\text{-}D\text{-}\Phi S\text{……(Eq.3) [12]}$$

Where: SPI= Secondary porosity.

3.4. Permeability Analysis

Permeability, a key parameter for evaluating reservoir quality, was calculated using Techlog software Figures (3, 4, 5, 6, 7, and 8**)** utilizing total and effective porosity values as input parameters [13].

- **Calculation Method**: The permeability was determined using Equation (1):

$$K= 62.5 *(PHIE^6/SWi^2) \text{ ……...(Eq.4). [13]}$$

Where: **PHIE** = Effective porosity; **SWi** = Irreducible water saturation (assumed to be 0.2 if not available or missing).

- **Well-A**: Permeability values ranged from 11 to 30 mD.
- **Well-B**: Permeability values varied from 5 to 31 mD.
- **Well-C**: The highest permeability values were observed in this well, ranging from 5 to 55 mD.

3.5. Water Saturation Analysis

Water saturation (Sw) is critical for estimating hydrocarbon saturation (Sh), as rocks containing hydrocarbons exhibit higher electrical resistivity compared to those saturated with reservoir water [15]. Water saturation (Sw) was determined using **Archie's Law** [14] a widely recognized method for evaluating water content in reservoir rocks. This calculation was performed for both invaded and non-invaded zones, utilizing log data including deep resistivity, effective porosity, and water resistivity. Hydrocarbon saturation (Sh) was calculated by subtracting water saturation from one, using the formula:

$$Sh=1-Sw \text{ …………………(Eq.5)}$$

This approach highlights the relationship between resistivity measurements and fluid distribution in the reservoir. The calculated Sw and Sh values provide understandings into the hydrocarbon potential of the Euphrates Formation.

3.6. Reservoir and Lithology Units Analysis

The petrophysical and lithological characteristics of the Euphrates Formation were assessed to identify three distinct reservoir units (Euph.1, Euph.2, and Euph.3) across wells Well-A, Well-B, and Well-C. These units were differentiated based on variations in porosity, permeability, shale content, and lithofacies. The effective porosity was calculated using (Eq.2), while permeability was determined based on (Eq.4). Water saturation was calculated using **Archie's Law**. The results derived from these equations are presented in Table (1).

- **Euph.1 Unit**: Depths range from 460–477 m RTKB in Well-A, 473–585 m RTKB in Well-B, and 476–489 m RTKB in Well-C. These depth variations reflect changes in lithofacies due to sedimentary environmental conditions.

- **Shale Ratio (Vsh)**: Well-C has the lowest shale ratio (0.08), offering the best reservoir conditions. Higher values in Well-B (0.14) and Well-A (0.13) reflect reduced quality
- **Effective Porosity (PHIE_ND)**: Well-C exhibits the highest porosity (0.26), indicating superior fluid storage capacity, while Well-A (0.16) and Well-B (0.10) show lower porosity values, indicating reduced reservoir potential.
- **Water Saturation (Sw) and Hydrocarbon Saturation (Sh)**: Well-C shows the lowest water saturation (0.11) and the highest hydrocarbon saturation (88.61%), making it the most favorable reservoir. In comparison, Well-A (Sw = 0.19) and Well-B (Sw = 0.33) exhibit higher water content, reducing hydrocarbon potential.
- **Permeability**: Well-C demonstrates the highest permeability (55.58 mD), enhancing reservoir quality. Well-A (11.79 mD) and Well-B (5.01 mD) exhibit significantly lower permeability.

- **Euph.2 Unit**: Depths range from 477–485 m in Well-A, 585–601 m in Well-B, and 489–530 m in Well-C, indicating depositional variability.

- **Shale Ratio (Vsh)**: Well-C has the lowest shale ratio (0.07), offering the best reservoir conditions. Higher values in Well-A (0.19) and Well-B (0.12) reflect reduced quality.
- **Effective Porosity (PHIE_ND)**: Well-B (0.22) and Well-C (0.23) show high porosity values, suggesting good reservoir potential, while Well-A (0.16) is less favorable.
- **Water Saturation (Sw) and Hydrocarbon Saturation (Sh)**: Well-C and Well-B have excellent hydrocarbon saturation (89.35% and 88%, respectively) and low water saturation (Sw = 0.11 and 0.12, respectively), indicating strong reservoir properties. Well-A has higher water saturation (0.18), reducing its hydrocarbon potential.
- **Permeability**: Well-B (29.63 mD) demonstrates the best permeability, followed by Well-C (18.29 mD) and Well-A (11.35 mD).

- **Euph.3 Unit**: Depths range from 485–511 m in Well-A, 601–619 m in Well-B, and 530–552 m in Well-C, highlighting depositional variability influenced by sedimentary processes.

- **Shale Ratio (Vsh)**: Well-C records the lowest shale ratio (0.08), enhancing reservoir quality, compared to Well-A (0.16) and Well-B (0.14).
- **Effective Porosity (PHIE_ND)**: Well-A and Well-B have higher porosity values (0.22), indicating better reservoir potential compared to Well-C (0.13).
- **Water Saturation (Sw) and Hydrocarbon Saturation (Sh)**: Well-A and Well-B exhibit favorable hydrocarbon saturation (78% and 80%, respectively) and low water saturation, making them good reservoirs. Well-C has lower water saturation (0.18), affecting reservoir quality.
- **Permeability**: Well-A (29.84 mD) and Well-B (31.13 mD) exhibit excellent permeability, while Well-C (4.58 mD) shows significantly lower values, reducing its reservoir quality.

Based on the above, it can be concluded that:

- **Well-C** performs best in the Euph.1 and Euph.2 units, with low shale content, high porosity, and excellent hydrocarbon saturation.
- **Well-A and Well-B** show stronger reservoir properties in the Euph.3 unit, particularly due to better permeability and hydrocarbon saturation. This analysis highlights the lithological variability across the Euphrates Formation and its impact on reservoir quality.

Table (1): Reservoir properties of Euphrates Formation in Y Field

Units	The properties	Well-A	Well-B	Well-C
Euph.1	Interval	460-477	473-585	476-489
	vsh c	0.13	0.14	0.08
	PHIE_ND	0.16	0.10	0.26
	Sw	0.19	0.33	0.119
	Sh	0.81	0.67	0.881
	Permeability	11.79	5.01	55.58
Euph.2	Interval	477-485	585-601	489-530
	vsh c	0.19	0.12	0.07
	PHIE_ND	0.16	0.22	0.23
	Sw	0.18	0.12	0.11
	Sh	0.82	0.88	0.89
	Permeability	11.35	29.63	18.29
Euph.3	Interval	485-511	601-619	530-552
	vsh c	0.16	0.14	0.08
	PHIE_ND	0.22	0.22	0.13
	Sw	0.22	0.20	0.18
	Sh	0.78	0.80	0.82
	Permeability	29.84	31.13	4.58

3.7. Movable Hydrocarbon Index (MHI) Analysis

The Movable Hydrocarbon Index (MHI) is a vital parameter for assessing the mobility of hydrocarbons within geological formations. This index is calculated as the ratio of water saturation in the flushed (invaded) zone (Sxo) to water saturation in the non-invaded zone. Hydrocarbon mobility occurs when the water saturation in the flushed zone exceeds that in the non-invaded zone, Figures (3) to (8).

- **MHI Thresholds**: According to [16], MHI value of 1 or greater indicates no hydrocarbon movement, irrespective of hydrocarbon presence within the formation. Conversely, MHI values below 0.7 for sandstone and below 0.6 for limestone signify hydrocarbon mobility. Specifically, an MHI value below 0.6 reflects the presence of hydrocarbons with sufficient permeability to facilitate movement during the drilling fluid invasion process [17].
- **Analysis and Results**: The MHI values were calculated and plotted on curves (Figures 3 to 8), with a boundary line at 0.6 marking the distinction between zones with movable and immovable hydrocarbons.
- **Well-A**: Most formation zones fall within the movable hydrocarbon range, particularly in Units Euph.2 and Euph.3, where effective porosity and permeability are high. Narrow intervals in Units Euph.1 and Euph.2 exhibit reduced porosity and permeability, occasionally reaching negligible values, indicating limited hydrocarbon mobility.
- **Well-B**: MHI values hover near or above 0.6, especially in Units Euph.1 and Euph.2, where reduced porosity and permeability limit hydrocarbon movement. Unit Euph.3 shows better reservoir properties, with lower MHI values and increased potential for hydrocarbon mobility.
- **Well-C**: All formation zones exhibit MHI values below 0.6, confirming hydrocarbon mobility throughout the well. This highlights superior reservoir properties compared to the other wells.
- **Reservoir Implications:** Unit Euph.3 in WELL-A and Well-B stands out as the most promising for hydrocarbon mobility due to higher porosity and permeability. WELL-C exhibits the best overall reservoir properties, with all units showing evidence of hydrocarbon movement. Other units in WELL-A and WELL-B demonstrate reduced reservoir quality, with immobile hydrocarbons dominating in specific intervals.

3.8. Reservoir Quality and Flow Range

The Flow Zone Indicator (FZI) is a key parameter for estimating the flow characteristics within a reservoir. It reveals the relationship between petrophysical properties on both small and large scales. According to [18,19], the FZI provides valuable insight into the flow capacity of the reservoir but does not offer direct information about the nature of the flowing fluids (whether water or hydrocarbons). To enhance the prediction of reservoir productivity, the FZI and Movable Hydrocarbon Index (MHI) were correlated using a curve, which helps identify the best zones for potential hydrocarbon extraction, Figures (3 to 8**)**.

3.9. Equations for FZI and RQI Calculation

The following equations were used to calculate the Flow Zone Indicator (FZI) and Reservoir Quality Index (RQI), as described by [19]

FZI Calculation: $FZI = RQI / \Phi z$................ (Eq.6)

Normalized Porosity Index (Φz) Calculation: $\Phi z = \Phi e / (1-Øe)$ ... (Eq.7)

Reservoir Quality Index (RQI) Calculation: $RQI = 0.0314 (K / \Phi e)^{½}$......... (Eq.8)

Where : Index; K = Permeability (in mD); Φe = Effective Porosity (in fraction).

This methodology allows for a better understanding of reservoir quality and flow behavior within the formation, providing a basis for identifying zones with optimal productivity potential, as demonstrated by the results of the calculated FZI in Figures (3) and (8).

3.10. Determination of Net Pay Thickness and Reservoir Quality Assessment for Wells WELL-A, WELL-B, and WELL-C

Gross thickness refers to the total thickness of the hydrocarbon-bearing reservoir unit, but not all of the gross thickness necessarily represents productive reservoir zones. Therefore, gross thickness is distinguished from net pay thickness, which is the sum of the thicknesses of the hydrocarbon-bearing zones within the reservoir unit. To determine the net pay thickness in the formation, three criteria were applied. The shale cutoff was set at 35%, and the porosity cutoff values were derived from the relationship between porosity and permeability for the studied wells. The porosity cutoff values were as follows: Well-A at 10%, Well-B at 11%, and Well-C at 11%. Additionally, the water saturation cutoff was approximately 35% for wells Well-A and Well-B, while it was 25% for Well-C. These values were obtained from the relationship between water saturation and porosity. At North Oil Company, a porosity cutoff of 8% and a water saturation cutoff of 80% are commonly used. When these values are applied, the net pay thickness values change as shown in the Tables (2 to 7), Figures (3 to 8). It is noteworthy that when using the porosity and water saturation cutoffs derived in the current study, through cross-plots, the determination of net pay thickness becomes more accurate in identifying the necessary perforation zones for production.

The tables provided a detailed overview of the net pay thickness and flow indicators within the studied formations. Notably, all units in the Well-C exhibit superior reservoir characteristics compared to the other wells, with the thickness of the various units having a significant impact on the production capacity of the reservoir. By utilizing the cutoff porosity and water saturation values derived from the research, it is evident that determining the net pay thickness enhances the accuracy of identifying the perforation zones necessary for production. Furthermore, the results show that Euph.3 in both Well-A and Well-B represent the best reservoir units in terms of movable hydrocarbons, characterized by significantly higher porosity and permeability.

Table (2): Net pay when cutoff porosity =10% & cutoff water saturation = 35% in Well-A

Zones	Flag Name	Top	Bottom	Gross	Net	Net to Gross	BVW	Av_vsh	Av.Phi	Av-SW
Eup1	RES	460.00	476.93	16.93	15.47	0.91	0.02	0.11	0.16	0.16
Eup1	PAY	460.00	476.93	16.93	14.63	0.86	0.02	0.11	0.17	0.15
Eup2	RES	476.93	485.29	8.36	7.14	0.85	0.02	0.15	0.17	0.15
Eup2	PAY	476.93	485.29	8.36	7.06	0.85	0.02	0.15	0.17	0.15
Eup3	RES	485.29	512.01	26.72	25.34	0.95	0.04	0.15	0.22	0.21
Eup3	PAY	485.29	512.01	26.72	24.74	0.93	0.04	0.15	0.22	0.21

Table (3): Net pay when cutoff porosity =8% & cutoff water saturation = 35% in Well-A

Zones	Flag Name	Top	Bottom	Gross	Net	Net to Gross	BVW	Av-vsh	Av -phie	Av_sw
Eup1	RES	460.00	476.93	16.93	14.63	0.86	0.02	0.11	0.17	0.16
Eup1	PAY	460.00	476.93	16.93	14.63	0.86	0.02	0.11	0.17	0.16
Eup2	RES	476.93	485.29	8.36	7.06	0.85	0.02	0.15	0.17	0.15
Eup2	PAY	476.93	485.29	8.36	7.06	0.85	0.02	0.15	0.17	0.15
Eup3	RES	485.29	512.01	26.72	25.34	0.95	0.04	0.15	0.22	0.21
Eup3	PAY	485.29	512.01	26.72	25.34	0.95	0.04	0.15	0.22	0.21

Table (4): Net pay when cutoff porosity =11% & cutoff water saturation = 25% in Well-B

Zones	Flag Name	Top	Botto m	Gross	Net	Net to Gross	BVW	Av_vs h	Av phie	Av_s w
Eup1	RES	573.10	585.54	12.44	5.36	0.43	0.02	0.16	0.17	0.12
Eup1	PAY	573.10	585.54	12.44	5.36	0.43	0.02	0.16	0.17	0.12
Eup2	RES	585.54	601.52	15.98	15.52	0.97	0.02	0.11	0.22	0.11
Eup2	PAY	585.54	601.52	15.98	15.52	0.97	0.02	0.11	0.22	0.11
Eup3	RES	601.52	619.44	17.92	16.92	0.94	0.04	0.12	0.23	0.19
Eup3	PAY	601.52	619.44	17.92	16.92	0.94	0.04	0.12	0.23	0.19

Table (5): Net pay when cutoff porosity =8% & cutoff water saturation = 80% in Well-B

Zones	Flag Name	Top	Bottom	Gross	Net	Net to Gross	BVW	Av-vsh	Av-phie	Av-sw
Eup1	RES	573.10	585.54	12.44	6.88	0.55	0.01	0.15	0.15	0.12
Eup1	PAY	573.10	585.54	12.44	6.88	0.55	0.01	0.15	0.15	0.12
Eup2	RES	585.54	601.52	15.98	15.52	0.97	0.02	0.11	0.22	0.11
Eup2	PAY	585.54	601.52	15.98	15.52	0.97	0.02	0.11	0.22	0.11
Eup3	RES	601.52	619.44	17.92	16.92	0.94	0.04	0.12	0.23	0.19
Eup3	PAY	601.52	619.44	17.92	16.92	0.94	0.04	0.12	0.23	0.19

Table (6): Net pay when cutoff porosity =11% & cutoff water saturation = 35% in Well-C

Zones	Flag Name	Top	Bottom	Gross	Net	Net to Gross	BVW	Av-vsh	Av-phie	Av-sw
Eup1	RES	476.67	489.25	12.57	12.54	1.00	0.03	0.08	0.28	0.11
Eup1	PAY	476.67	489.25	12.57	12.54	1.00	0.03	0.08	0.28	0.11
Eup2	RES	489.25	530.63	41.38	41.38	1.00	0.02	0.08	0.25	0.11
Eup2	PAY	489.25	530.63	41.38	41.38	1.00	0.02	0.08	0.25	0.11
Eup3	RES	530.63	552.01	21.38	19.23	0.90	0.02	0.07	0.16	0.18
Eup3	PAY	530.63	552.01	21.38	10.70	0.50	0.02	0.09	0.17	0.15

Table (7): Net pay when cutoff porosity =8% & cutoff water saturation = 80% in Well-C

Zones	Flag Name	Top	Bottom	Gross	Net	Net to Gross	BVW	Av-vsh	Av-phie	Av-sw
Eup1	RES	476.67	489.25	12.57	12.54	1.00	0.03	0.08	0.28	0.11
Eup1	PAY	476.67	489.25	12.57	12.54	1.00	0.03	0.08	0.28	0.11
Eup2	RES	489.25	530.63	41.38	41.38	1.00	0.02	0.08	0.25	0.11
Eup2	PAY	489.25	530.63	41.38	41.38	1.00	0.02	0.08	0.25	0.11
Eup3	RES	530.63	552.01	21.38	21.06	0.99	0.02	0.08	0.15	0.18
Eup3	PAY	530.63	552.01	21.38	21.06	0.99	0.02	0.08	0.15	0.18

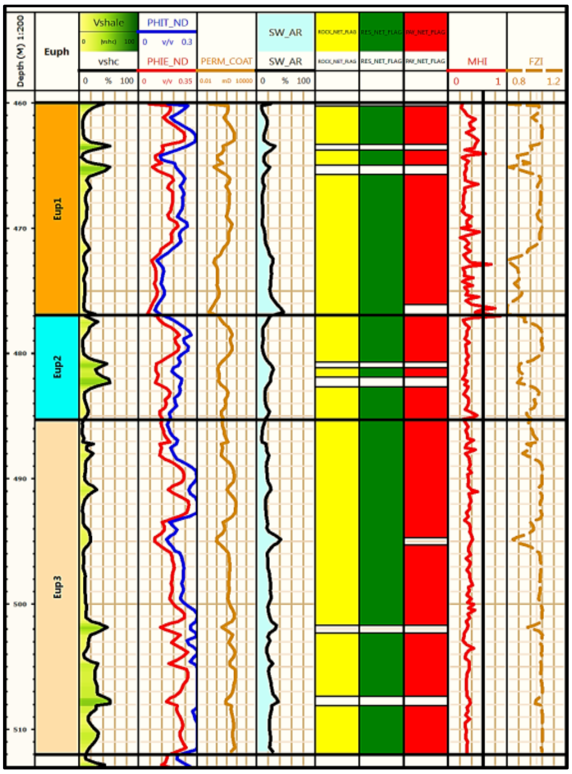

Fig. (3): Net pay when cutoff porosity =10% & cutoff water saturation = 35% in well-A

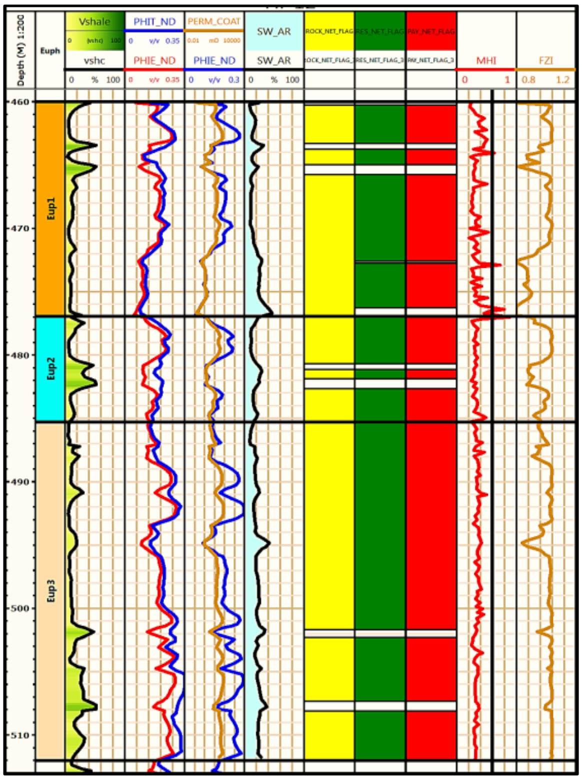

Fig. (4): Net pay when cutoff porosity =8% & cutoff water saturation = 80% in well-A

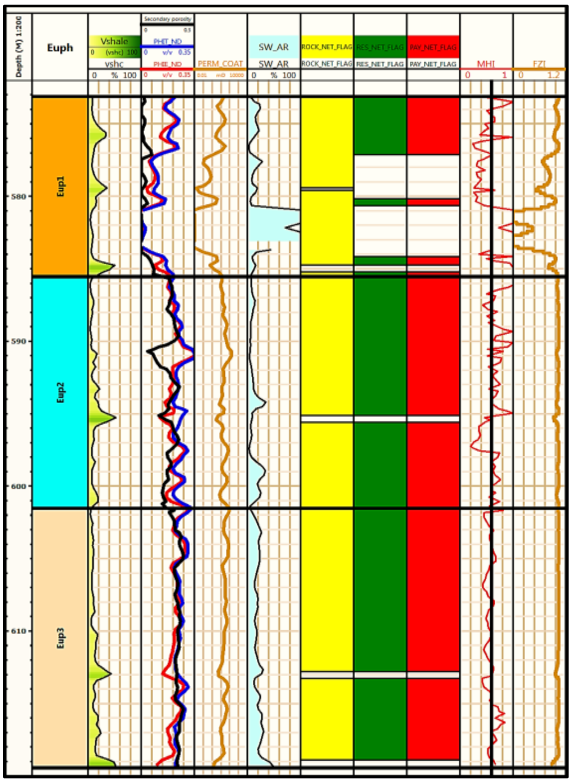

Fig. (5): Net pay when cutoff porosity =11% & cutoff water saturation = 35% in well-B

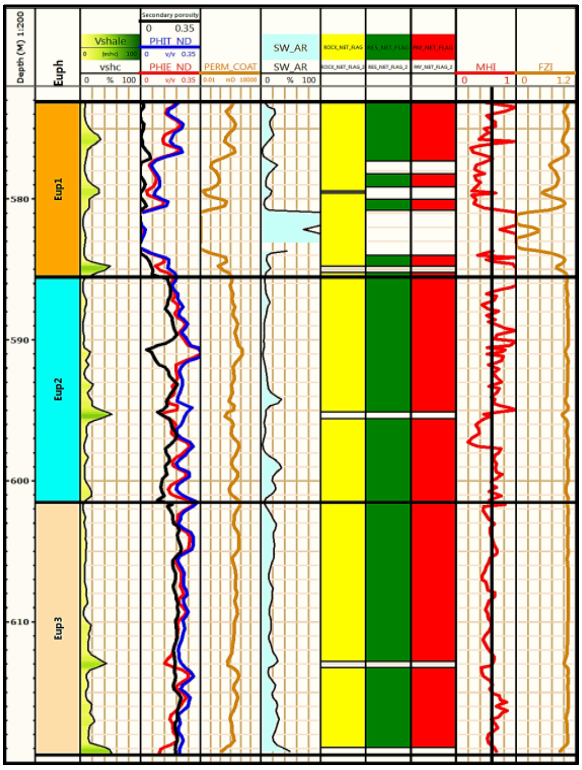

Fig. (6): Net pay when cutoff porosity =8% & cutoff water saturation = 80% in well-B

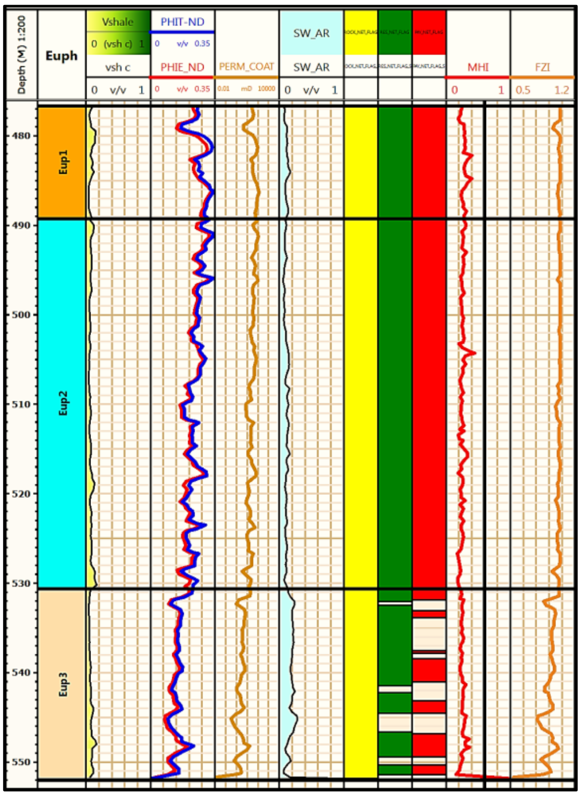

Fig. (7): Net pay when cutoff porosity =11% & cutoff water saturation = 25% in well-C

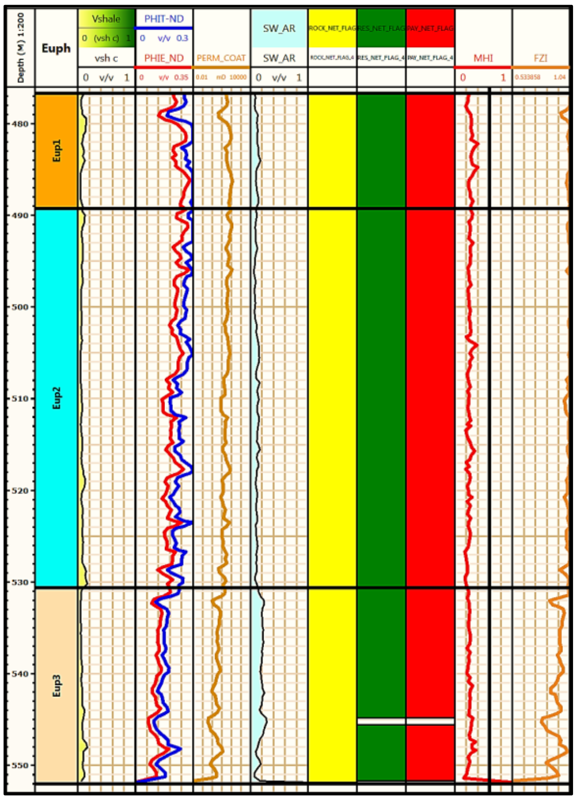

Fig. (8): Net pay when cutoff porosity =8% & cutoff water saturation = 80% in well-C

4. Discussions

The analysis of the Euphrates formation's reservoir properties in wells WELL-A, WELL-B, and WELL-C provides critical insights into the hydrocarbon production potential across the formation. The key findings from this study are outlined below:

4.1. Reservoir Characteristics:

WELL-C consistently exhibits the best overall reservoir quality compared to the other studied wells. This well has higher porosity and permeability, which means it has a greater ability to store and transmit hydrocarbons within the rock matrix. High porosity indicates more pore spaces available for hydrocarbon accumulation, while high permeability facilitates the movement of hydrocarbons through the reservoir to the production zones. Additionally, the first unit in WELL-C has a low Hydrocarbon Movability Index (MHI), suggesting that hydrocarbons can migrate freely within the pore spaces, making it the most favorable section for hydrocarbon recovery. This indicates a higher potential for production and oil recovery compared to the other wells. While WELL-A and WELL-B also contain productive intervals such as Euph.3, the overall reservoir quality of these wells is inferior to WELL-C. These wells may have lower porosity or limited permeability in certain sections, which would hinder the flow of hydrocarbons and thus limit their overall production capacity.

4.2. Lithology and Shale Content:

Lithology plays a crucial role in determining the hydrocarbon storage and flow capacity within a reservoir. In WELL-C, the formation is characterized by high porosity and good permeability, with a relatively low shale content, providing an ideal environment for hydrocarbon accumulation and movement. In contrast, WELL-B contains non-reservoir layers such as anhydrite between (581-584)m, which act as a barrier to fluid flow due to their low permeability. The presence of anhydrite reduces the formation's storage capacity, thereby negatively impacting recovery efficiency. WELL-A also exhibits favorable lithological characteristics, but the presence of higher shale content in certain intervals could restrict hydrocarbon flow, affecting the productivity of some zones. The shale content is calculated using the Gamma Ray log, and the low shale content in both WELL-A and WELL-C is advantageous for hydrocarbon retention within the reservoir.

4.3. Reservoir Unit Properties:

Three distinct reservoir units have been identified across the wells. Euph.3 in WELL-A stands out for its superior reservoir characteristics, including optimal porosity and permeability, indicating efficient hydrocarbon storage and flow. In WELL-B, the second and third units exhibit significant reservoir properties, but the presence of anhydrite may interfere with their ability to transmit hydrocarbons in certain intervals. WELL-C's first unit has the best reservoir properties among the three, with optimal porosity and permeability, making it the most promising section for hydrocarbon production. This highlights the higher potential for recovery in WELL-C compared to other units in the same well.

4.4. Water Saturation:

Water saturation is a key parameter in determining the hydrocarbon saturation within the reservoir. Water saturation was computed using the Archie equation. WELL-C shows the lowest water saturation, indicating that the reservoir has more pore space available for hydrocarbons, suggesting a higher potential for hydrocarbon production. In contrast, WELL-A and WELL-B exhibit slightly higher water saturation, meaning certain intervals may contain more water, which reduces the effective reservoir volume for hydrocarbons and impacts recovery efficiency.

4.5 Movable Hydrocarbon Index (MHI):

The Movable Hydrocarbon Index (MHI) is a critical measure of hydrocarbon mobility within the reservoir. Low MHI values indicate the presence of mobile hydrocarbons that can easily flow through the reservoir. In WELL-A, the majority of the formation falls within the range of movable hydrocarbons, although certain intervals may have restricted mobility due to rock heterogeneity. WELL-B exhibits moderate MHI values near 0.6, suggesting moderate hydrocarbon mobility. The presence of non-reservoir lithologies such as anhydrite may limit the movement of hydrocarbons in certain zones of this well. WELL-C, however, is entirely within the range of movable hydrocarbons, reflecting a high degree of fluid mobility across all units, which supports its excellent potential for hydrocarbon recovery.

4.6. Flow Zone Indicator (FZI):

The Flow Zone Indicator (FZI) is an important parameter for evaluating the flow potential of hydrocarbons within the formation. FZI analysis indicates that WELL-C has superior flow characteristics compared to WELL-A and WELL-B. This suggests that WELL-C has higher flow efficiency and thus greater potential for hydrocarbon production. The combined analysis of MHI and FZI further indicates that hydrocarbons will migrate more easily through WELL-C, supporting its higher efficiency in hydrocarbon production.

Based on the comprehensive petrophysical analysis of reservoir characteristics and production indicators across the studied wells, WELL-C emerges as the most favorable reservoir unit with the highest hydrocarbon production potential. This makes WELL-C the optimal target for future hydrocarbon recovery optimization in the formation.

5. Conclusions

The results highlight the petrophysical variations between wells and the crucial role of borehole logging in evaluating reservoir characteristics and determining the hydrocarbon production potential of different formations, which aids in optimizing hydrocarbon resource exploitation strategies and directing efforts toward high-production zones. Based on the analysis of the Euphrates Formation in the selected wells, the following conclusions were drawn:

1. **Stratigraphic Diversity in the Euphrates Formation:** The formation consists of limestone and dolomite, with a significant increase in the dolomite content in the upper part (especially in well-A), while the dolomite content decreases in the middle and lower parts.

2. **Reservoir Properties:** Well-C exhibits the best reservoir characteristics, with effective porosity ranging from 11-26%, shale content between 7-8%, oil saturation between 81-89%, and permeability ranging from 4 to 55 (mD). In contrast, well-B contains non-porous anhydrite layers, which negatively affect the reservoir properties, with effective porosity between 10-22%, shale content between 12-14%, oil saturation between 67-88%, and permeability ranging from 5 to 31 mD.

3. **Hydrocarbon Mobility Index:** Well-C demonstrates a movable hydrocarbon range across all sections of the formation, whereas wells Well-A and Well-B contain intervals outside the movable range, indicating variability in hydrocarbon mobility between the wells.

4. **Net Pay Thickness:** The net pay thickness in well-C is approximately 74.92 meters, compared to 47.03 meters in well-A and 40.78 meters in well-B.

Comparison of the conclusions drawn from this study with a previous study conducted in the Ajil Oilfield [4], which relied on core data to estimate the reservoir properties of the Euphrates Formation: In that study, the researchers concluded that the porosity of the Euphrates Formation is 9%, with shale content at 10%. They also determined a cut-off porosity of 10% and a water saturation of 65%.

In contrast, this study relied on borehole logging data to determine these reservoir properties, leading to different conclusions. The borehole log data showed that the porosity in some wells ranges between 11-26%, while the shale content is between 7-14%, and the oil saturation ranges from 67-89% across the various wells. Additionally, borehole logging revealed variability in permeability between the wells, with permeability ranging from 4-55 mD in well-C, compared to 5-31 mD in well-B.

A precise evaluation of the reservoir properties of the Euphrates Formation can be achieved by integrating core data and borehole log data. Core data provides in-depth insights into rock properties in specific samples, while borehole logs offer reliable estimates of reservoir properties across different depths. Combining both methods enhances the accuracy of the evaluation and provides better results for porosity, shale content, and water saturation.

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References

[1] S. Z. Jassim and T. Buday, "Latest Eocene–Recent Megasequence AP11," in *Geology of Iraq*, S. Z. Jassim and J. C. Goff, Eds. Prague, Czech Republic: Dolin and Moravian Museum, Brno, pp. 228–253, 2006.

[2] A. A. M. Aqrawi, J. C. Goff, A. D. Horbury, and F. N. Sadooni, *The Petroleum Geology of Iraq*. Beaconsfield, U.K.: Scientific Press, 2010.

[3] R. K. Akram, S. F. Naqshabandi, and G. Sherwani, "Integration of petrophysical and geochemical approaches for lower Miocene Euphrates and Jeribe Formations in selected wells in Tawke Oil Field, Northwestern Iraq, Zagros-fold belt," *Journal of African Earth Sciences*, vol. 205, Art. no. 105000, 2023, doi: https://doi.org/10.1016/j.jafrearsci.2023.105000.

[4] V. M. Ahmed and A. A. Al-Haleem, "Petrophysical properties estimation by using well log and core data interpretation for tertiary reservoir in Ajeel Oil Field," *Iraqi Geological Journal*, vol. 57, no. 2B, pp. 117–136, 2024, doi: https://doi.org/10.46717/igj.57.2B.8ms-2024-8-18.

[5] M. H. A. Al-Majid, "Petrophysical properties estimation of Euphrates reservoir in Qayyarah Oil Field using core and well log data," *Iraqi Geological Journal*, vol. 54, no. 2E, pp. 186–197, 2021, doi: https://doi.org/10.46717/igj.54.2E.13Ms-2021-11-29.

[6] D. H. Baban and H. S. Hussein, "Characterization of the Tertiary reservoir in Khabbaz Oil Field, Kirkuk area, Northern Iraq," *Arabian Journal of Geosciences*, vol. 9, no. 3, Art. no. 237, 2016, doi: https://doi.org/10.1007/s12517-015-2272-y.

[7] North Oil Company (NOC), *Final Report of Well-A*. Kirkuk, Iraq: North Oil Company, 1983, unpublished report.

[8] North Oil Company (NOC), *Final Report of Well-B*. Kirkuk, Iraq: North Oil Company, 1985, unpublished report.

[9] North Oil Company (NOC), *Final Report of Well-C*. Kirkuk, Iraq: North Oil Company, 1990, unpublished report.

[10] Schlumberger, *Log Interpretation, Vol. II: Applications*. New York, NY, USA: Schlumberger Ltd., 1974, 116 pp.

[11] G. B. Asquith and C. R. Gibson, *Basic Well Log Analysis for Geologists*. Tulsa, OK, USA: American Association of Petroleum Geologists, 1982, 216 pp.

[12] Schlumberger, *Log Interpretation Charts*. Houston, TX, USA: Schlumberger Wireline & Testing, 1997.

[13] A. Timur, "An investigation of permeability, porosity, and residual water saturation relationships for sandstone reservoirs," *The Log Analyst*, vol. 9, no. 4, pp. 8–17, 1968.

[14] G. E. Archie, "The electrical resistivity log as an aid in determining some reservoir characteristics," *Transactions of the AIME*, vol. 146, no. 1, pp. 54–62, 1942, doi: https://doi.org/10.2118/942054-G.

[15] D. Tiab and E. C. Donaldson, *Petrophysics: Theory and Practice of Measuring Reservoir Rock and*

Fluid Transport Properties, 2nd ed. Burlington, MA, USA: Gulf Professional Publishing, 2004, doi: https://doi.org/10.1016/B978-0-7506-7711-0.X5000-2.

[16] Schlumberger Limited, *Log Interpretation, Volume I—Principles*. New York, NY, USA: Schlumberger Limited, 1972, 112 pp.

[17] G. B. Asquith, *Handbook of Log Evaluation Techniques for Carbonate Reservoirs*, 2nd ed., Methods in Exploration, no. 5. Tulsa, OK, USA: American Association of Petroleum Geologists, 1985, 47 pp.

[18] R. Chatterjee, K. Manoharan, and M. Mukhopadhyay, "Petrophysical and mechanical properties of Cretaceous sedimentary rocks of Cauvery Basin, Eastern Continental Margin of India," *Journal of Indian Geophysical Union*, vol. 17, no. 4, pp. 349–359, 2013.

[19] M. A. Ibrahim and D. K. Potter, "Prediction of residual water saturation using genetically focused neural nets," in *SPE Asia Pacific Oil and Gas Conference and Exhibition*, Perth, Australia, Oct. 18–20, 2004, SPE-88457-MS. doi: https://doi.org/10.2118/88457-MS.