Determination of the Petrophysical Properties of the Khasib Reservoir, East Baghdad Oil Field, Middle Iraq

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ABSTRACT

This study aims to determine and evaluate the petrophysical characteristics of the Khasib Formation, which represents the main oil-producing reservoir in the East Baghdad oilfield. To accomplish the aim of the study, the log data for five wells have been interpreted using the Schlumberger Techlog 2015.3 software. The main lithology of the Khasib Formation has been determined as limestone based on the interpretation of neutron, density, and sonic logs and using the M-N cross plot method. The shale volume was determined based on the gamma ray log, and the results showed that the shale volume in the Khasib Formation ranges from about 15% to 27%, and this value increases toward the top of the formation. The total porosity of the Khasib Formation has been determined based on the density and neutron logs, and their values range from about 12% to 23%. The effective porosity is calculated depending on the relationship between the total porosity and shale volume, and the values of this type of porosity range from 8% to 18%. The study shows that the B and C units of the Khasib Formation represent the best hydrocarbon-bearing zones, where these units are characterized by high values of effective porosity and oil saturation. The units A, E and F of the formation are characterized by high values of shale content with low effective porosity, and these units represent cap or seal beds for the oil producing zones. The other units (G, H and I) are characterized by high values of water saturation.

تحديد الخصائص البتروفيزيائية لمكمن الخصيب، حقل شرقي بغداد النفطي، وسط العراق

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الملخص

تهدف هذه الدراسة إلى تحديد وتقييم الخصائص البتروفيزيائية لتكوين الخصيب والذي يمثل الخزان الرئيس المنتج للنفط في حقل شرقي بغداد النفطي. لتحقيق هدف الدراسة، تم تفسير بيانات المجسات لخمسة آبار باستخدام برنامج (Schlumberger Techlog 2015.3). تم تحديد اللثولوجي الرئيس لتكوين الخصيب على أنه حجر جيري بناءً على تفسير مجسات النيوترون والكثافة والمجس الصوتي، وباستخدام طريقة الرسم المتقاطع. (M-N) تم تحديد حجم الطين باستخدام مجس أشعة كاما، حيث أظهرت النتائج أن حجم الطين في تكوين الخصيب يتراوح من حوالي 15٪ إلى حوالي 27٪، وتزداد هذه القيمة باتجاه أعلى التكوين. تم تحديد المسامية الكلية لتكوين الخصيب بناءً على مجسات الكثافة والنيترون، حيث تراوحت قيمها من حوالي 12٪ إلى 23٪. تم حساب المسامية الفعالة اعتمادًا على العلاقة بين المسامية الكلية وحجم الطين، حيث تراوحت قيم هذا النوع من المسامية من 8٪ إلى 18٪. أوضحت الدراسة أن الوحدتين B وC لتكوين الخصيب تمثلان أفضل المناطق الحاملة للهيدروكربونات، حيث تتميز هذه الوحدات بقيم عالية من المسامية الفعالة ودرجة تشبع النفط. تمتاز الوحدات A، F وE بمحتوى عالٍ من الطفَل وقيم واطئة للمسامية الفعالة، وهذه الوحدات تمثل طبقات عازلة. تمتاز الوحدات الأخرى G، H وI بقيم عالية من تشبع الماء.

Introduction

Determination of the petrophysical properties of the carbonate reservoirs is more challenging compared to the sandstone reservoirs due to the heterogeneity that characterizes the carbonate rocks (Jameel et al., 2020). The well log interpretation is considered a powerful technique in the determination and evaluation of the petrophysical properties of the hydrocarbon reservoirs especially when the core data are unavailable or rare.

The Khasib Formation (Late Turonian – Early Campanian) represents one of the main Cretaceous oil reservoirs in the East Baghdad oilfield in addition to Tanuma and Zubair reservoirs. The formation contains about 14% of the total proved oil reserves in Cretaceous reservoirs in addition to the Saadi and Tanuma Formations (Sadooni, 2004). The Khasib Formation is firstly defined by Owen and Nasr (1958) in the Zubair Oilfield, Southern Iraq. In the type section, the Khasib Formation was divided into two main lithological parts. The lower part is characterized by dark shale, and argillaceous limestone, whereas the upper part consists of grey argillaceous limestone (Bellen et al., 1959). In central Iraq, the formation is composed of chalky limestone, marlstones, and marly limestone with a thickness ranging from 60 m. to 130 m. (Al-Qayim, 2010). The Khasib Formation is characterized by good reservoir zones which were developed due to the diagenetic dissolution and fracturing (Aqrawi, 1996). The formation has been divided into four reservoirs units by Total (1984).

This study aims to determine and evaluate the petrophysical properties of the Khasib Formation, which represents the main oil-producing reservoir in East Baghdad Oilfield, based on the analysis and interpretation of well log data.

Location and Geology

The East Baghdad oilfield is one of the important giant fields in Iraq, which is located about 10 km to the east of Baghdad city (Fig. 1). The field was discovered in 1974 by the Iraqi National Oil Company, and the first well (EB-1), which is located about 20 km east of the center of Baghdad city, was drilled in 1975. The East Baghdad oilfield is an asymmetrical anticline fold with an axis that extends NW-SE, and the structure has a length of about 120 km and a width of about 8 km. The field is characterized by flower structures and horst-graben-related features (Sadooni, 2004). The stratigraphic column in the East Baghdad oilfield extends from Upper Jurassic to Pliocene (Figure 2). The Khasib Formation represents one of the main oil-producing zones in the East Baghdad oilfield in addition to the Saadi and Tanuma Formations. The thickness of the formation ranges between 80 m to 120 m, and it mainly consists of limestone and marly limestone (Al-Qayim et al., 1993). Al-Temimi (2018) referred that the Khasib Formation in the East Baghdad oilfield is mainly limestone with inclusion of dolomite. The Khasib Formation was deposited in a ramp setting, and it is underlain unconformably by the Kifil Formation and overlain conformably by the Tanuma Formation (Al-Qayim, 2010). The Khasib Formation was subdivided into nine stratigraphic units (A, B, C, D, E, F, G, H, I) based on the lithological changes and recognition of depositional cycles (Iraqi National Oil Company, 1981). This subdivision of the stratigraphic units of the Khasib Formation is used in this study.
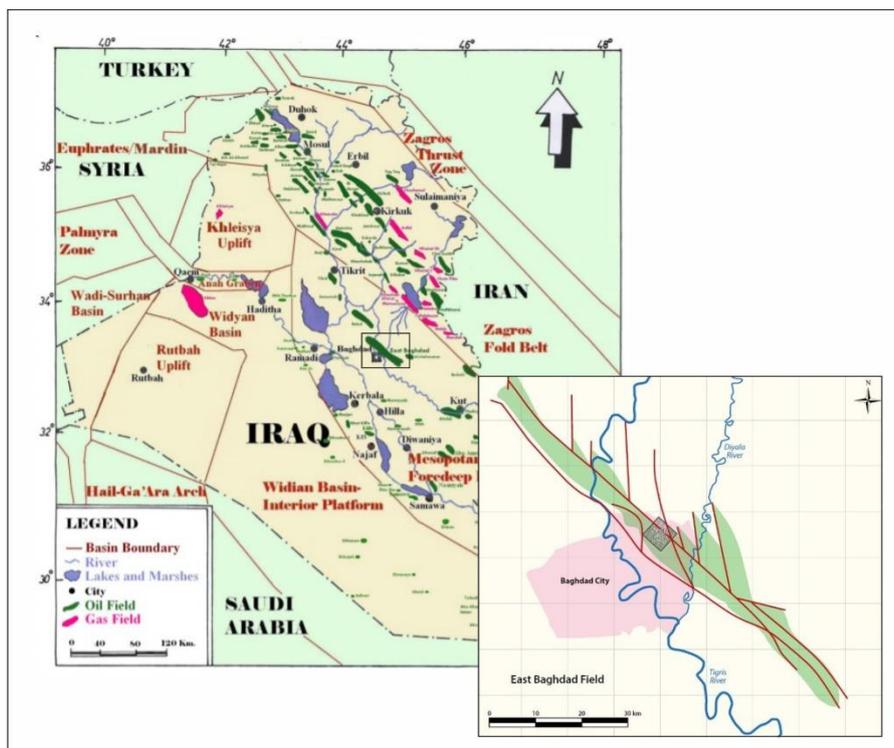
Fig. 1. Iraqi oil fields map showing the location of East Baghdad oil field (modified from Al-Ameri, 2011).

AGE	FORMATION	LITHOLOGY	DEPTH
PLIOCENE	MUQDADIA (BAKHTIARI)		
UPPER MIOCENE	INJANA (UPPER FARS)		
			1000
MIDDLE MIOCENE	FATHA (LOWER FARS)		
LOWER MIOCENE	JERIBE		
OLIGOCENE	BAJAWAN		
	TARJIL		
EOCENE	JADDALA		
PALEOCENE	ALIJI		
UPPER CRETACEOUS	SHIRANISH		
	HARTHA		2000
	SA`DI		
	TANUMA		
	KHASIB		
MIDDLE CRETACEOUS	KIFIL		
	RUMAILA		
	AHMADI		
	MAUDDUD		3000
	NAHR UMR		
LOWER CRETACEOUS	SHUAIBA		
	ZUBAIR		
	RATAWI		4000
	CHIAGARA		
JURASSIC	GOTNIA		
	NAJMAH		
	SARGELU		4700

S. STONE | MARL | LIMESTONE
SHALE | ANHYDRITE | DOLOMITE

Fig. 2. The stratigraphic column in the East Baghdad oilfield (modified from Al-Ameri, 2011).

Materials and Methods

This study is costructed on the analysis and interpretation of the available well logs data for five wells (EB-4, EB-16, EB-6, EB-30, and EB-34) in the East Baghdad oilfield. The available log data (neutron, density, sonic, gamma-ray, resistivity) have been analyzed and interpreted using Schlumberger Techlog 2015.3 software. The methodology used in this study is summarized as the follows:

1- Lithology identification:

The first step in the reservoir characterization is generally identification of the lithology because it has a direct impact on the reservoir characteristics of the formation. In this study,

the lithology of the Khasib Formation has been determined based on the neutron, density, and sonic logs, and using the M-N cross plot method.

   2- Shale volume calculation:

The shale volume is generally calculated based on the interpretation of gamma-ray log, and using the following equations (Larionov, 1969):

$$V_{sh} = 0.33*(2^{(2*IGR)} - 1) \tag{1}$$

$$IGR = (GR_{log} - GR_{min} / GR_{max} - GR_{min}) \tag{2}$$

Where V_{sh} is the shale volume, IGR is the gamma-ray index, GR_{log} is the gamma-ray reading from the log, GR_{max} is the maximum gamma-ray reading, and GR_{min} is the minimum gamma-ray reading.

   3- Porosity calculation:

The porosity is considered one of the fundamental properties of the hydrocarbon reservoirs because it represents the pore spaces where the hydrocarbons are stored. In addition, the porosity represents a significant factor in the determination of the hydrocarbon reserves, therefore, the accurate estimation of the porosity is needed in the reservoir evaluation. The porosity is classified into two main types based on the nature of pore spaces: effective porosity and non-effective porosity. Connected pores characterize the effective porosity, whereas isolated pores characterize the non-effective porosity. The total porosity represents the total volume of pores whether isolated or connected. The porosity of the Khasib Formation has been determined based on the interpretation of density log, sonic log, and neutron log. The total porosity of the formation was estimated based on the combination of neutron and density logs, and according to the following formula:

$$\emptyset_T = (\emptyset_N + \emptyset_D) / 2 \tag{3}$$

Where $\emptyset_T$ is the total porosity; $\emptyset_N$ is the neutron porosity; $\emptyset_D$ is the density porosity.

The density porosity is estimated using the following equation proposed by Gaymard and Poupon (1968):

$$\emptyset_D = \rho_{ma} - \rho_b / \rho_{ma} - \rho_f \tag{4}$$

Where ρ_{ma} is the matrix density (2.710g/cc); ρ_b is the bulk density (g/cc); ρ_f is the fluid density (1.15g/cc).

The effective porosity was calculated using the relationship between total porosity and shale volume according to the following equation (Schlumberger, 1972):

$$\emptyset_{Eff} = \emptyset_T * (1 - V_{Sh}) \tag{5}$$

Where $\emptyset_{Eff}$ is the effective porosity; $\emptyset_T$ is the total porosity; V_{sh} is the shale volume.

The secondary porosity of the Khasib Formation has been determined using the following equation:

$$\text{ØSec} = \text{ØT} - \text{ØS} \qquad (6)$$

Where ØSec is the secondary porosity; ØT is the total porosity; ØS is the sonic porosity, which represents the primary porosity.

The sonic porosity was determined using the Wyllie time-average equation (Wyllie *et al.*, 1958):

$$\text{ØS} = (\Delta\text{tlog} - \Delta\text{tma})/(\Delta\text{tf} - \Delta\text{tma}) \qquad (7)$$

Where ØS is the sonic porosity; Δtlog is the interval transit time of the formation; Δtma is the interval transit time of the matrix (45.55.5μs/ft); Δtf is the interval transit time of the fluid (189μsec/ft).

4- Water saturation calculation:

Estimation of the volume of shale is an important factor in the reservoir evaluation because the presence of shale may lead to reduce the porosity and permeability, which are considered the main characteristics of the hydrocarbon reservoirs. The water saturation has been calculated using the dual water model, which is proposed by Waxman and Smits, (1968). This method is used to estimate the water saturation in shaly formations based on the relationship between resistivity and saturation. This relationship is expressed by the following equation (Waxman and Smits, 1968):

$$1 / R_T = (S_w{}^2 / F * R_{w)} + (B * Q_v * S_w / F) \qquad (8)$$

Where R_T is the resistivity of the uninvaded zone; S_w is the water saturation in the uninvaded zone; F is the formation factor of the interconnected porosity; B is the equivalent conductance of the sodium clay-exchange cations as a function of the formation water conductivity, and Q_v is the CEC of the rock per unit pore volume.

Results and Discussion

1- Identification of lithology

The identification of lithology is considered the first step in evaluating the petrophysical properties of the hydrocarbon reservoirs because it has an impact on the reservoir's characteristics especially the porosity and permeability. In this study, the lithology of the Khasib Formation has been determined based on the interpretation of neutron, density, and sonic logs, and using the M-N cross plot method. Most of the M-N cross plot data of the Khasib Formation is concentrated in the calcite region (Fig. 3). This indicates that the main lithology of the Khasib Formation is limestone. Some points of the M-N cross plot are located in the dolomite region (Fig. 3).

2- Shale volume calculation

In this study, the shale volume of the Khasib Formation is calculated based on the gamma-ray log. The results show vertical and lateral variations in the values of shale volume of the Khasib Formation (Fig. 4). The values of the shale volume range from about 15% to about 25%, and this value increases toward the top of the formation (Fig. 4).
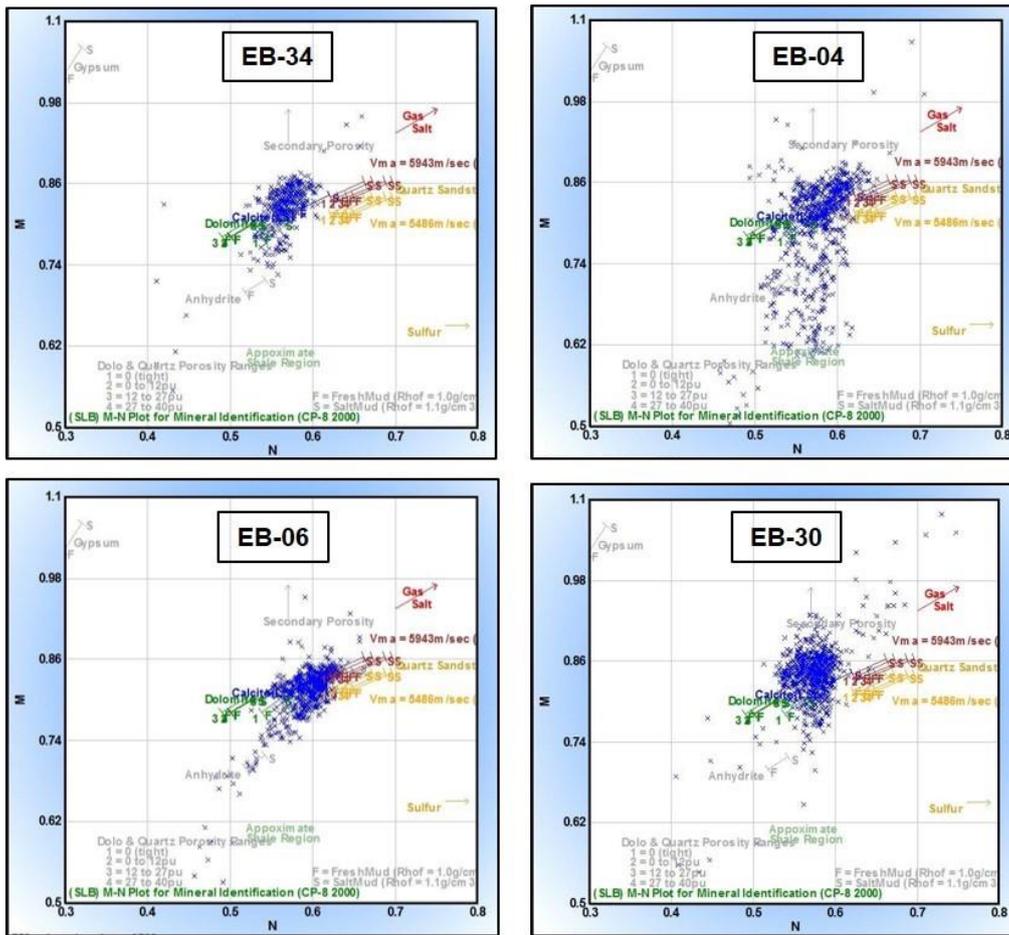
Fig. 3. M-N cross plot of the Khasib Formation in the studied wells.
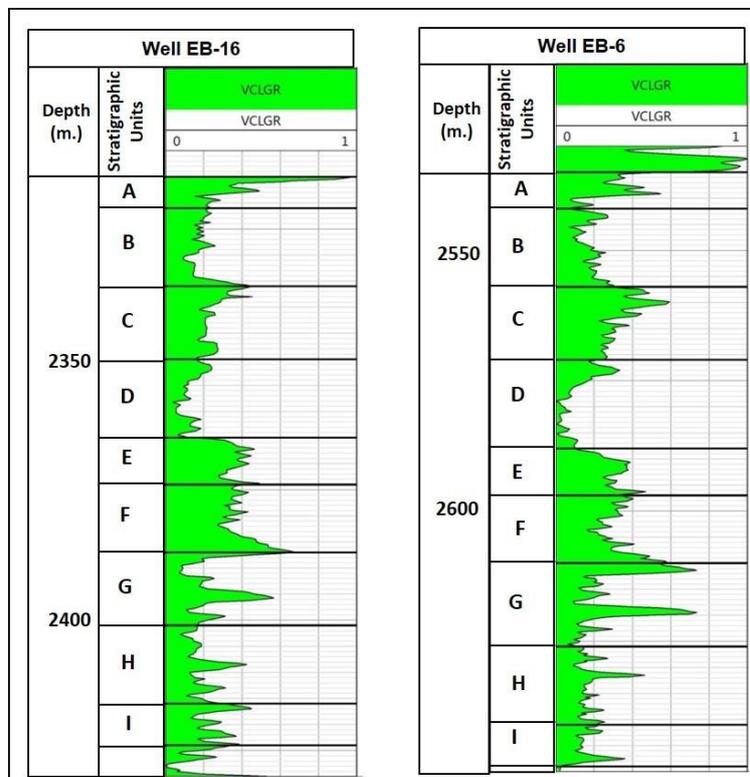
Fig. 4. A comparison of shale volume of the Khasib Formation between well EB-16 and well BE-6 in the East Baghdad oilfield.

3- Porosity Calculation

In this study, the total porosity of the Khasib reservoir has been determined firstly based on the interpretation of density and neutron logs. The effective porosity of the Khasib Formation has been determined based on the relationship between the total porosity and shale volume, which was introduced by Schlumberger (1972) mentioned previously. In addition to the total and effective porosities, the secondary porosity of the Khasib Formation has been estimated based on the difference between the total porosity and sonic porosity, where the sonic porosity represents the primary porosity. The results of the three types of porosity are illustrated in Fig. (5).
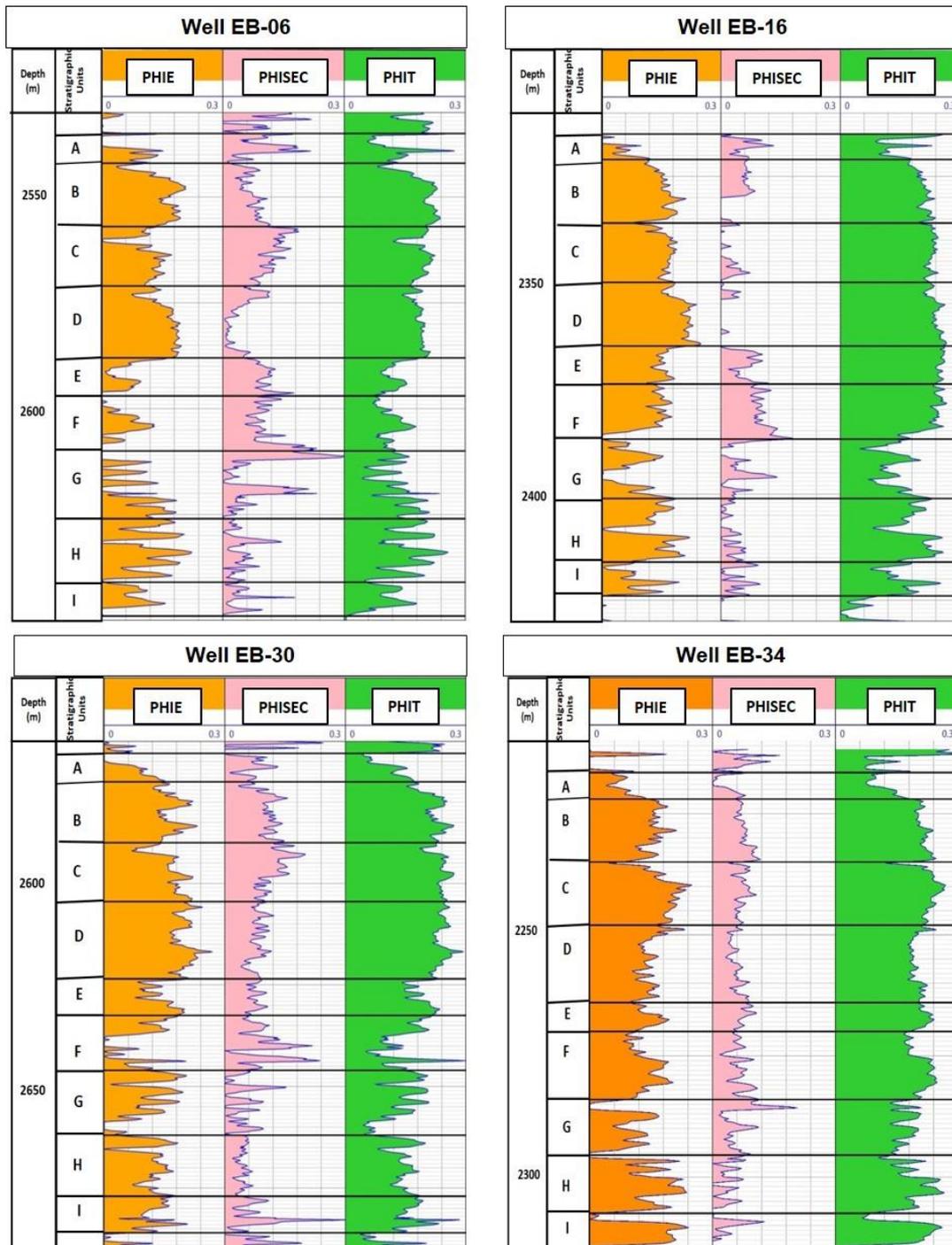
Fig. 5. The effective porosity (PHIE), secondary porosity (PHISEC), and total porosity (PHIT) of the Khasib Formation in the studied wells.

To accomplish accurate values of the effective, secondary, and total porosities, the average arithmetic values of porosities have been calculated using the following equation:

$$\text{\O} = \Sigma\text{\O}/n \tag{9}$$

Where: Ø is the porosity, and n is the number of reading (depth interval every 0.25m). The results of the mathematical averaging calculation of porosity is listed in Table (1).

The results show that the porosity of the Khasib Formation varies vertically and laterally. The total porosity of the Khasib Formation ranges from 12% to 23% (Table 1 and Fig. 5), and these values coincide with the study of Jameel, *et al.*, (2020). The effective porosity ranges from 8% to 18%, and this porosity is most dominant in the units B, C, and D of the Khasib Formation (Table 1 and Fig. 5). The secondary porosity represents the controlling type in the units A, E, and F units of the formation, and its values range between 3% to 8% (Table 1 and Fig. 5).

Table 1: The average values of porosities for the stratigraphic units of the Khasib Formation.

Stratigraphic Units	Thickness (m)	Average arithmetic total porosity	Average arithmetic effective porosity	Average arithmetic secondary porosity
A	5.5	0.122	0.082	0.043
B	13	0.206	0.152	0.079
C	13	0.228	0.18	0.07
D	16	0.199	0.15	0.057
E	6	0.218	0.143	0.078
F	14	0.209	0.15	0.065
G	11.5	0.171	0.102	0.066
H	12	0.192	0.158	0.035
I	7	0.177	0.144	0.028

4- Water and oil saturation calculation

Fluid saturation is the ratio of fluid volume within the pores of the rock to the total volume of the pores (Brock, 1986). The water saturation is a significant property in the evaluation of the hydrocarbon reservoirs because its value is used to estimate the hydrocarbon saturation. Therefore, an accurate determination of the water saturation is needed to calculate the oil in place. The oil saturation is calculated by the following equation (Brock, 1986):

$$S_o = 1 - S_w \tag{10}$$

In this study, the dual water model is used to calculate the water saturation of the Khasib Formation. The results show that the water saturation of the Khasib Formation ranges from 20% to 100% (Fig. 6). The B and C units of the Khasib reservoir represent the best oil-bearing zones where the oil saturation in these units is about (65%) (Fig. 6). The other units (A, D, E, F, G, H, I) have a low value of oil saturation (S_o) ranging between 0 to 20% (Fig. 6).
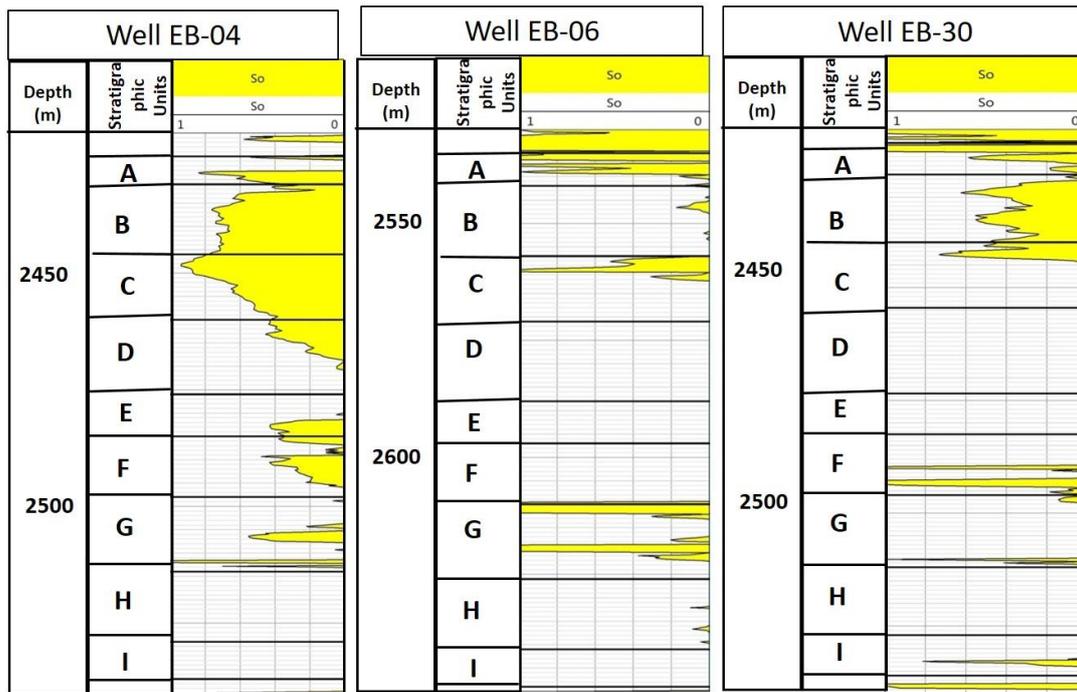
Fig. 6. Oil saturation (s$_o$) (yellow) and water saturation (s$_w$) (white) of the Khasib reservoir in the East Baghdad oil field.

Conclusions

The petrophysical characteristics of the Khasib Formation are performed based on the well log interpretation. The main lithology of the Khasib Formation has been determined as limestone based on the M-N cross plot method. The interpretation of the gamma ray log shows that the shale volume of the Khasib Formation ranges from about 15% to about 45%. The total porosity of the formation ranges between 15% and 23%. The value of the effective porosity ranges from about 8% to about 18%, and this type is most dominant in the stratigraphic units B, C, and D of the Khasib Formation. The secondary porosity is the controlling type in the stratigraphic units A, E, and F of the formation, and its value ranges from 3% to 8%. The study show also that the B and C units of the Khasib Formation represent the best hydrocarbon-bearing zones, where these units are characterized by high values of effective porosity and oil saturation.

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