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Predicting Reservoir or Non-Reservoir Formations by Calculating Permeability and Porosity in an Iraqi Oil Field

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ABSTRACT

This study is focused on identifying the formations, whether are they reservoir formations or not. The effective porosity and permeability evaluating of the oil reservoir is the most important methods to recognize the formations. In this study, the effective porosity and permeability of the Yamama formation in an oil field of southern Iraq can be calculated by applying, the neutron-density and the sonic logs. The calculated effective porosity of the formation ranged between (6%-17%), and the porosity in the joints was less than (0.04). The permeability in Yamama Formation calculated by three methods: Timur, Morris Biggs oil, and Schlumberger methods. By comparing the values of the permeability calculated by these methods, it was found that the methods of Timor and Schlumberger gave the same results, and also when the permeability calculated by these methods compared with the permeability of the cores, the method of Timur and Schlumberger closer than the results of the cores. So, the Schlumberger and Timor method is the one used in calculating the permeability. The permeability values for most of Yamama formation range from: 0.1 -10 md, and the permeability in the joints was less than 0.001 md.

Introduction

The importance of calculating the effective porosity and permeability of reservoir formations is not hidden from the reservoir engineering specialist, and the danger of error in calculating the porosity and permeability of the formation is not hidden from the reservoir engineering specialist, as calculating the amount of hydrocarbons in the formation depends on calculating the porosity and permeability, and also calculating the oil reserve is greatly affected by the porosity values. Effectiveness and permeability, as there is inaccuracy in calculating them; It will give wrong values for the oil reserves in the formation, and thus the decision will be affected by whether the oil in the formation is economic or uneconomic, and thus the decision will be affected by whether to start drilling production wells in this formation or to

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stop.Considerable efforts have been paid toward determination of the effective porosity and permeability in any formation [1]; This is due to the importance of the effective porosity and permeability of the formation to identify the type of rocks. Finding the hydrocarbons in reservoir rocks points out these rocks have good effective porosity and good permeability [2]. However, hydrocarbons can be presented in the pores and move through good permeability [3]. One most important fator that greatly affect the values of effective porosity and permeability is the volume of the shale [4]. When the percentage of oil shale in the reservoir rocks is low, the effective porosity and permeability of these rocks are good, and vice versa [5]. It is also important to know the type of lithology, as the type of lithology is very important in reservoir studies and through it it is possible to predict whether the rocks have porosity and permeability that allow fluids to pass through them or not [6]. The values of porosity and permeability are varied according to the lithology of the formation whether it is sandstone, limestone, or dolomite [7].

The concerned porosity for the reservoir engineer is the effective porosity [1]; in which the voids inside the rocks are classified into two types [8] connected and unconnected voids . The effective porosity is the continuousvoids in which the hydrocarbons reside and move [9]. There are several methods to determine the effective porosity [10]. The first one is by cores, which is the best and most accurate method [11]. However, due to high cost of this method and the cores are taken to very few depths, It cannot be applied to determining the porosity and the permeability [11]. The second and the most important methods to calculate the porosity is the well logs [12], in which the sensor used to calculate porosity are: Neutron , Density, and Sonic logs [13]. Porosity is classified into two types: Primary porosity, which is the porosity developed during the time of deposition, such as sandstone [14]. The second type is secondary porosity that can be formed after sedimentation, as in carbonate rocks, which tend to form secondary porosity. Moreover, the porosity can be classified into total porosity and effective porosity [15]. Total porosity is the obtained porosity from all the pores (interconnected and isolated) in the rock [16]. Effective porosity can be defined as the porosity that can be obtained from the interconnected pores (without the effects of oil shale).

This porosity is concerned in study [17], in which the voids are connected within the rocks, and can produce hydrocarbons from oil formations at the good value of the porosity. This is due to the connected voids in the rocks allow hydrocarbons to pass through these rocks, which is called permeability. Permeability is directly proportional to the effective porosity [18], high values of the effective porosity leads to high permeability. Hence, the hydrocarbons will move through the rocks toward the bottom of the drilled [19]. One of the important issue that the reservoir engineer must recognize is to determine the value of the neglected effective porosity (porosity cut-off) [20] ,and the value of the good and acceptable effective porosity in oil reservoirs [21]. Porosity is an important rock property because it is a measure of the potential storage volume of hydrocarbons [22]. Porosity in carbonate reservoirs ranges from 1 to 35% and averages 10% in dolomite reservoirs and 12% in limestone reservoirs. Permeability is also important factor because it is a rock property that related to the rate in which hydrocarbons can be recovered. The values are considerably ranged from less than 0.01 millidarcy (md) to well over 1 darcy. A permeability of 0.1 md is generally considered as the minimum value for oil production. Highly productive reservoirs commonly have permeability values in the Darcy range [23]. Determining the characteristics of rocks in terms of oil shale [4], porosity, hydrocarbon saturation, lithology [6], and permeability are the most important factors that a reservoir engineer is keen to know. By defining these characteristics, the primary oil present can be calculated and the oil reserve can be calculated as well [24]. There are numerous studies that have been concerned with calculation of the effective porosity and permeability, but this study reveals only the studiereveal only the concerned studies with calculating the effective porosity and permeability in the Yamama Formation - southern Iraq. Al-Sudani et al. studied petrophysical properties estimation of Yamamah Reservoir in Nasiriyah Oilfield. this study; the calculated values of porosity were not compared with the porosity calculated from the analysis of the cores. In addition, the shapes that show the relation of the porosity with depth were not included and it also didn't explain the detailed methods of calculating the effective porosity was calculated not mentioned. the permeability values mentioned in this study were only the values obtained from the analysis of cores [23]. Handhal et al. studied Petrophysical Properties of Mishrif and Yamama Formations at selected oil fields, in south Iraq. The well log used in this study to determine rock properties, including effective porosity, but it did not compare the calculated values of the effective porosity with the effective porosity calculated from cores analysis [25]. Al-Jawad et al. studied flow units and rock type for reservoir characterization in a carbonate reservoir at the case of Yamama Reservoir in the south of Iraq (Ratawi Field) [26]. Al-Aani et al. investigated the geological model construction for Yamama Formation at Faihaa Oil Field- South of Iraq. Petrel software has been used in this study to explain the distribution of petrophysical properties (shale volume, effective porosity, and hydrocarbon saturation) by construction of 3D geological model for Yamama Formation. Several methods were used to identify and characterize the flow units and type of rocks within the main reservoir, including: Porosity– water saturation relationship, flow zone indicator (FZI) method, capillary pressure analysis, and Porosity–Permeability relationship (R35), cluster analysis method, capillary pressure curves and cluster analysis methods. Finally, Ali et al. studied petrophysical properties of the Yamama Formation in Siba Oilfield [27].

In this study, Techlog software is used without displaying the comparison of the calculated effective porosity from this study with the porosity calculated from the analysis of the cores. Also, the permeability was calculated in the FZI method, and no comparison was made between the permeability calculated in this way and the permeability calculated from the analysis of the cores. This study is distinguished from all previous studies by considering very important factors. Firstly: A study specialized in calculating the effective porosity and permeability only and only for the formation of the Yamama . Secondly, it was used to calculate the porosity by more than one method (density log, neutron log, and sonic log) and after calculating the porosity by these methods, they were compared and the effective porosity was calculated using them. The study was not limited to that only, but the effective porosity calculated by these methods was compared with the effective porosity calculated through the analysis of the core. Hence, the accuracy of these calculations can be identified through this comparison. As for calculating the permeability, this was done using methods that were not used in all previous studies. The methods used in this study to calculate the permeability are: Timur, Schlumberger, and Morris biggs oil methods. All calculated values of the permeability from each above method are compared with the permeability calculated through the analysis of the core in order to determine which methods are more accurate in terms of results to adopt it in this configuration.

Fig. 1 shows area of study location which obtained from Oil Exploration Company, Iraqi Ministry of Oil. Fig. 2 shows contour map top of Yamama – South Iraq oil field which obtained from the same company. Fig. 3 show contour map top of Yamama – South Iraq oil field [28]. Fig. 4 show sequence stratigraphy in southeastern Iraq [29].

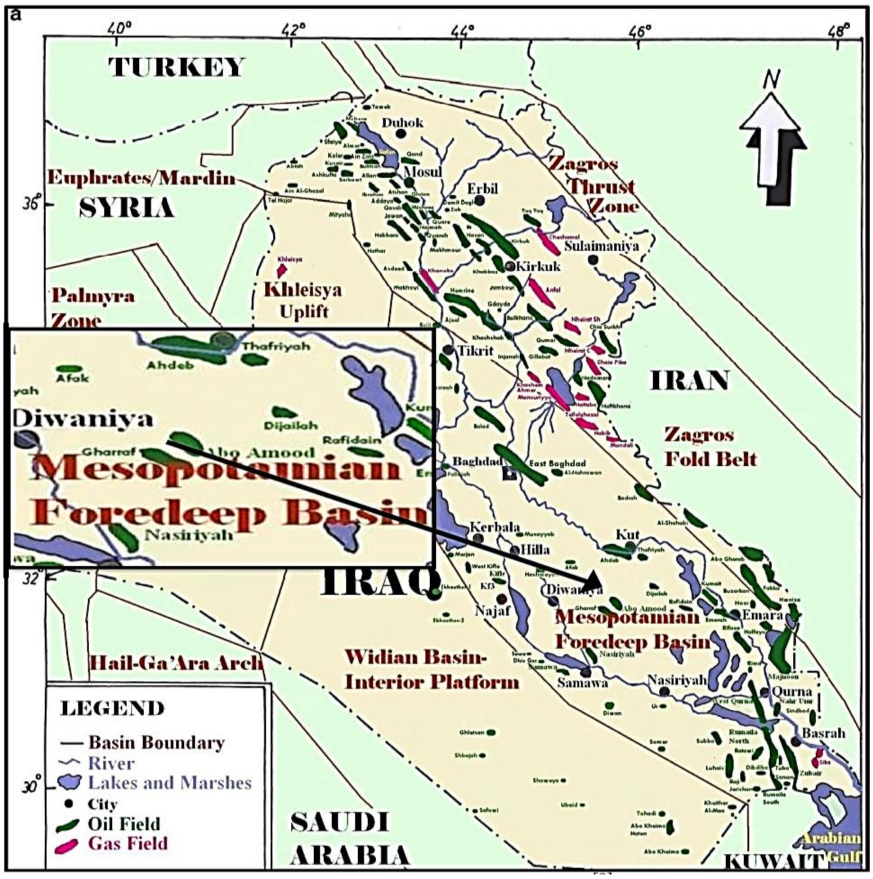

Fig. 1. Area of study location

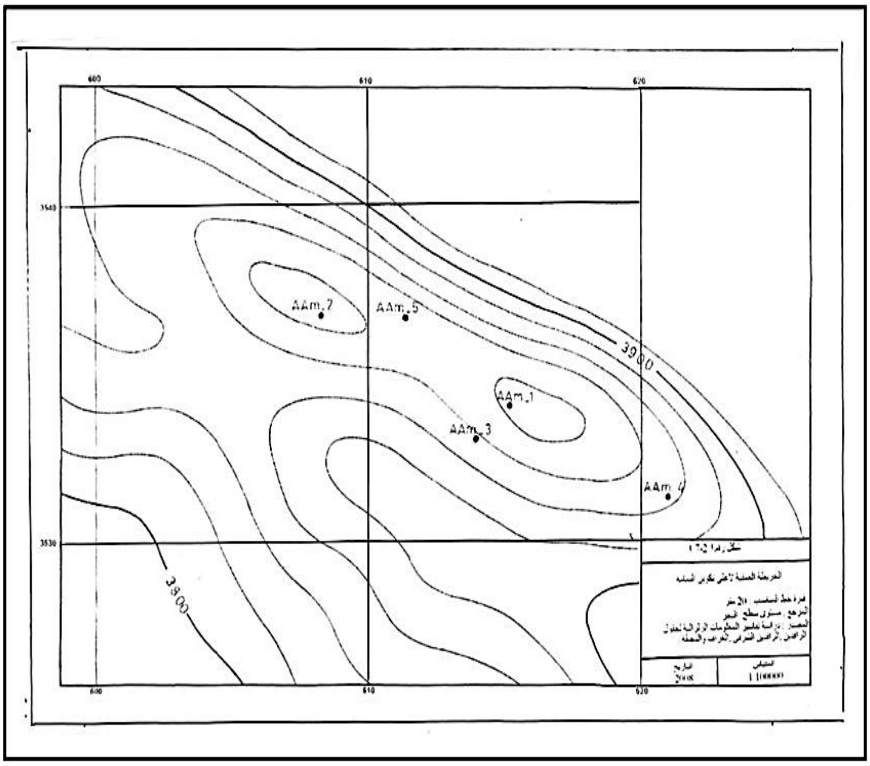

Fig. 2. Contour map top of Yamama – South Iraq oil field

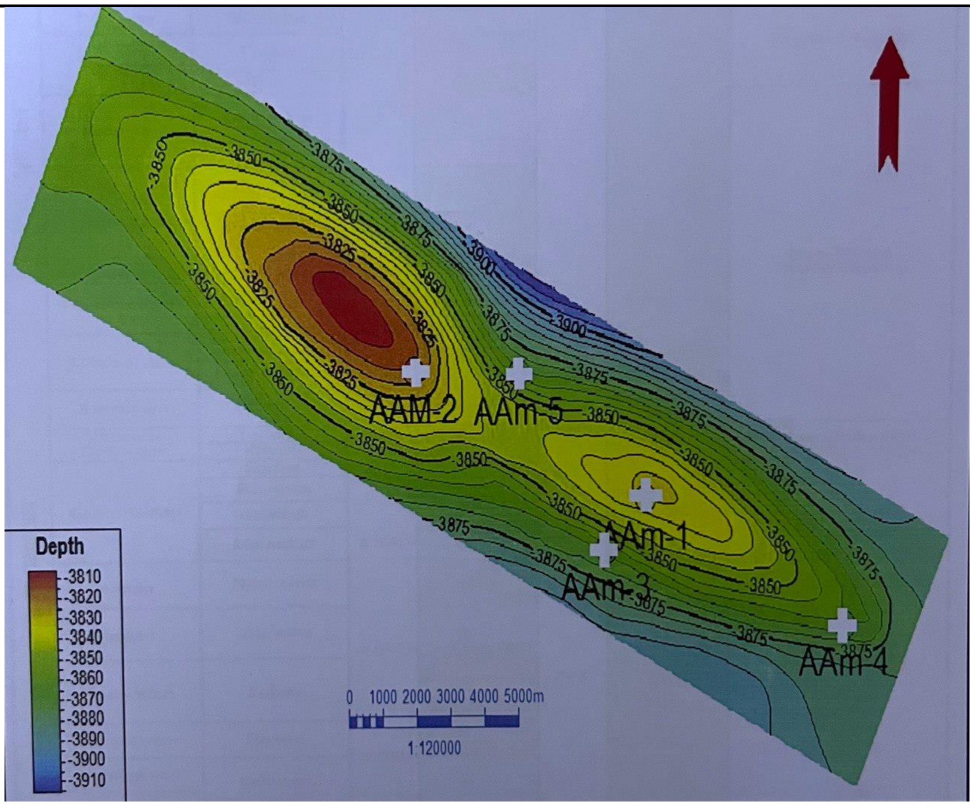

Fig. 3. Contour map top of Yamama – South Iraq oil field

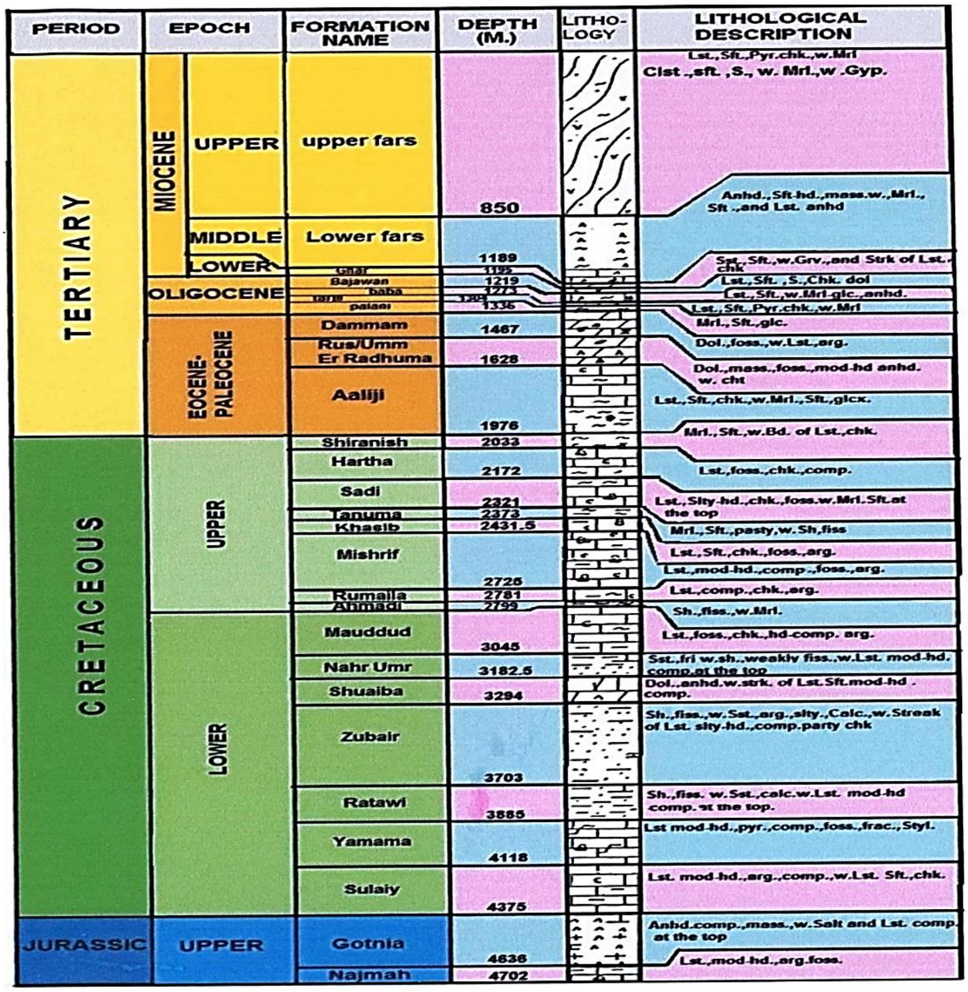

Fig. 4. Sequence stratigraphy in southeastern Iraq

Methods and Theory

Methods

The first step in this study is the digitization of the well log using Neuralog software. After that, the interactive petro physical (IP) program was applied for the petro physical study by integrating all the available data, especially the cores and the well log. Then the porosity logs were analyzed to get the porosity areas through each log and the results were compared with the base data and then the best one was selected according to the condition [30]. Then the effective porosity calculated by these methods was compared with the effective porosity calculated through cores analysis [31], and the permeability calculated in this study was also compared with the permeability calculated by cores analysis [32].

Theory

Porosity Estimation

There are numerous sensors from which the total porosity and the effective porosity may be calculated, and those sensors are Neutron log, Density Log and Sonic Log. Neutron logs reply frequently to the quantity of hydrogen with inside the formation. The neutron log shows the quantity of liquid that exists in porosity. The neutron log allows us to come across the fuel line sector which is evaluated with different porosity logs or a middle analysis. Also, neutron logs can pick out the lithology of the formation with the aid of using drawing it with any other porosity log. Accurate porosity may be acquired from the mixture of the neutrons log with different porosity logs [33].

Density Log

This log is carried out to compute the electron density of the formation that facilitates figuring out the Porosity and to identify the density of the saved hydrocarbons. Phi-Den: Calculated porosity by Density log. Assessing of sand and rock reservoirs are the main parts of this log to deal as a source of gamma radiation and these two sensors must be located one of them near and the other far. The total density of the formation is measured by the far sensor, while the density of the formation in the invaded area near the well wall is measured by the near sensor in the measuring unit of gm/cm^3. The Porosity from the Density log is calculated by Eq. 1 [1]:

$$\phi = \frac{(\rho ma - \rho b)}{(\rho ma - \rho f)} \quad (1)$$

where ρma is the matrix density, ρb is bulk density log reading, and ρf is filtrate density.

Sonic Log:

This log measures the transition interval (a transitional sound wave) across one foot of the formation, and it is the inverted velocity [34].

phi-Son:

Calculated porosity by Sonic log. To determine Porosity from the sonic log by applying Eq. 2 [35].

$$\phi = \frac{(\Delta t - \Delta tma)}{(\Delta tf - \Delta tma)} \quad (2)$$

Δt	transit time in the formation
Δtma	the acoustic transit time of the rock matrix
Δtf	the acoustic transit time of interstitial fluids

Permeability Estimation

Permeability of the porous media is maximum crucial to take the obligation of fluid transmissibility consistent with the variety and uncertainty of its prediction, many empirical techniques had been evolved to expect the fee of permeability from nicely logs, porosity statistics, and irreducible water saturation. Wyllie and Rose generate a technique to expect permeability by referring to a porous medium porosity and its irreducible water saturation, Swi, as shown in Eq. 3 [36]:

$$K = a\,\frac{\Phi^b}{Swi^c} \quad (3)$$

K: Permeability, md
Φ: Effective porosity.
Swi: Water saturation.
The value of the constant a, b, and c In the Timur method: a = 8581, b = 4.4, c=2
The value of the constant a, b, and c In Morris Bigs oil method: a = 62500, b = 6, c=2
The value of the constant a, b, and c In Schlumberger chart K3 method (41): a = 10000, b = 4.5, c=2

Results and Discussion

Fig. 5 show the average shale volume of the formation which its value less than 10% according to the gamma-ray log via plots. This is a good indication that the effective porosity values for the formation are high; because the higher the value of the shale volume, the lower the effective porosity values and the presence of the shale in high values closes the connected pores and thus prevents the movement and transfer of hydrocarbons within the rocks. Fig. 5shows that if the reading is high, it means that the volume of shale in the rocks is high, and the reading ranges from zero to one. Zero means that the volume percentage of shale in the rocks is zero, and one means that the volume percentage of shale is one hundred percent. Fig. 5 Shows Vshale-Gamma ray log in well AA-1.

Fig. 6 shows that the reading ranges from 1 to 0.5. The higher the value of the reading and approaching 0.5 indicates that the porosity of the rocks in the formation is high, and the lower the reading and approaching zero indicates that the porosity of the rocks is low. Fig. 6 shows that the effective porosity of the formation ranges between (0.06-0.17) depending on the use of density log, neutron log, and acoustic log. This is a good indication that the formation is a reservoir and the possibility of hydrocarbons gathering within it is strong. The effective porosity in which oil is present in carbonate rocks is 0.06 and above. It also gives an indication that hydrocarbons can move and move through this formation; because the movement of hydrocarbons within the formation depends on good values of effective porosity.

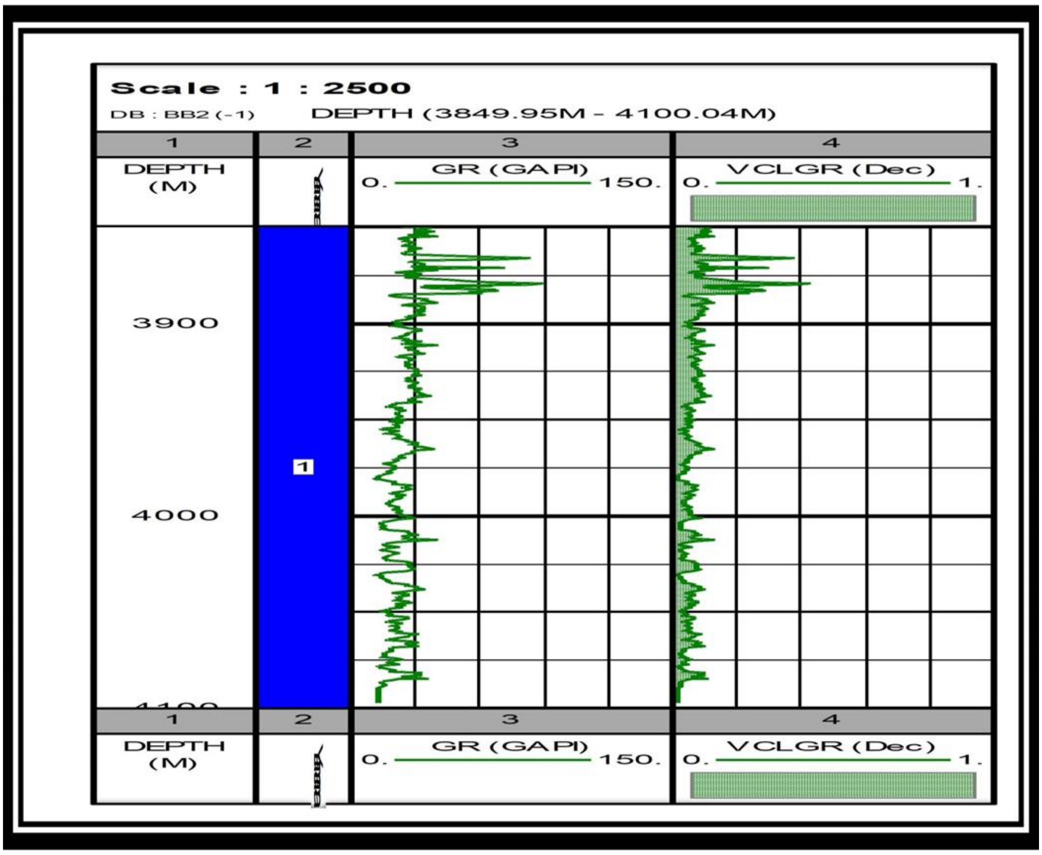

Fig. 5. Vshale-Gamma ray log in well AA-1

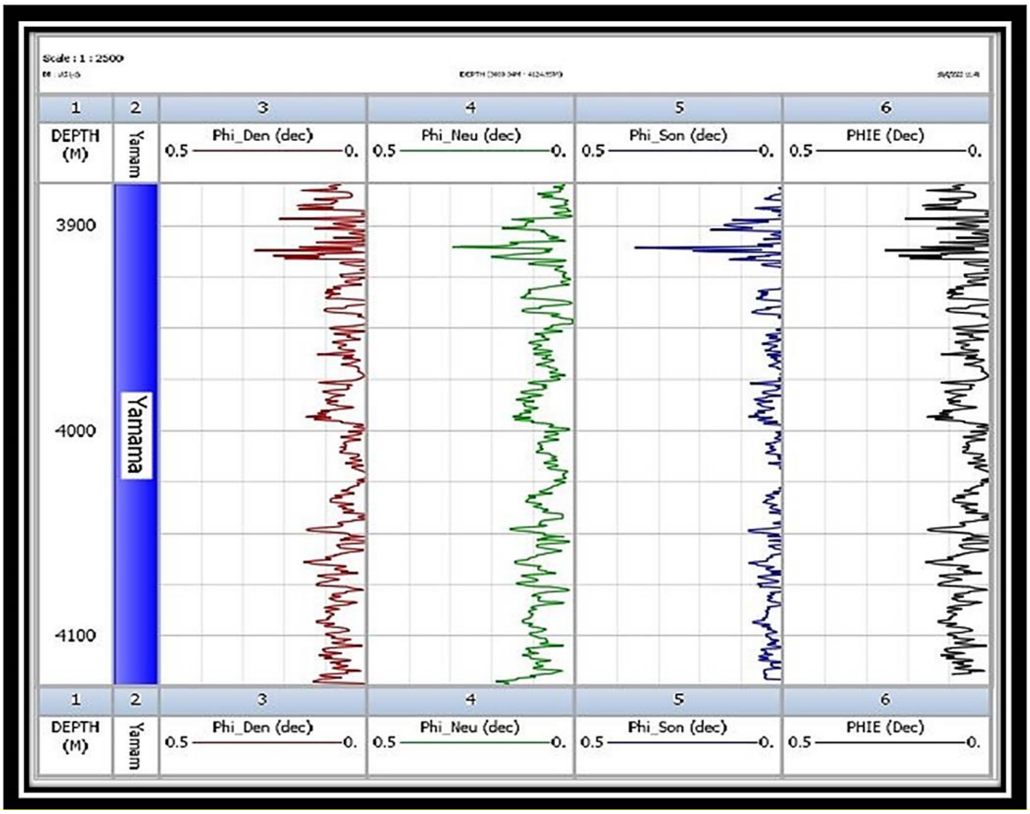

Fig. 6. phi-Den, phi-Neu, phi-Son, and PHIE in well AA-1

[Fig. 7](#) shows that the permeability of the formation ranges between (0.1-10) md according to the use of Timur, Schlumberger, and Morris Biggs oils. These calculated good values of permeability give an indication and evidence that the formation studied is a reservoir formation, and that the possibility of gathering hydrocarbons within its rocks, and the possibility of their movement and movement within the formation is possible. The type of fluids present in the pores of the formation can be determined by calculating the water saturation, oil saturation and gas saturation in the rocks through resistance sensors and applying the Archie equation.

Fig. 7 Shows K-Morris Biggs oil, K-Schlumberger, and K-Timur in well AA-1. Meanings of these symbols are Permeability calculated by Morris method, Biggs method, Schlumberger method, and K-Timur method in well AA-1. The reading ranges from 1 to 1000 milliliters. The higher reading refers to the greater the permeability of the rock, and vice versa.

Fig. 8 shows the comparison between the effective porosity calculated from the cores and the effective porosity calculated from the density log, sonic log, and neutron log. It is clear from the figure that the resolution is high which is consistent to the effective porosity values calculated by the cores. The comparison between the effective porosity values calculated by any method with the effective porosity calculated from the cores analysis is very important, as no calculations are trusted without making this comparison. The accuracy between its results and the results of the cores analysis is as high as possible.

Through this form, the accuracy of the calculations can be known. If the straight line passes through all the points, it indicates that the accuracy is one hundred percent, and if the straight line passes through most of the points but does not pass through some points, it indicates that the accuracy is high, but less than one hundred percent. The further the points are from the straight line, the lower the accuracy.

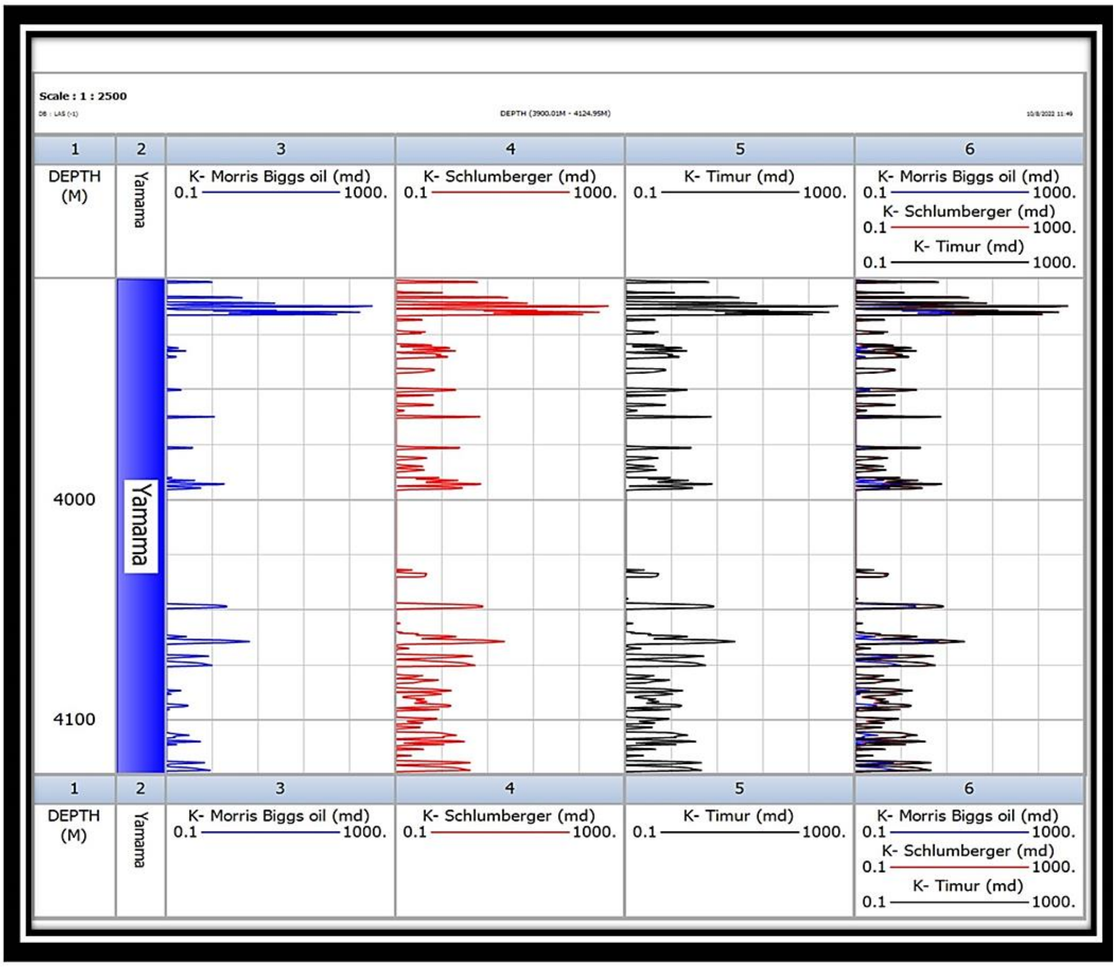

Fig. 7. Shows K-Morris Biggs oil, K-Schlumberger, and K-Timur in well AA-1

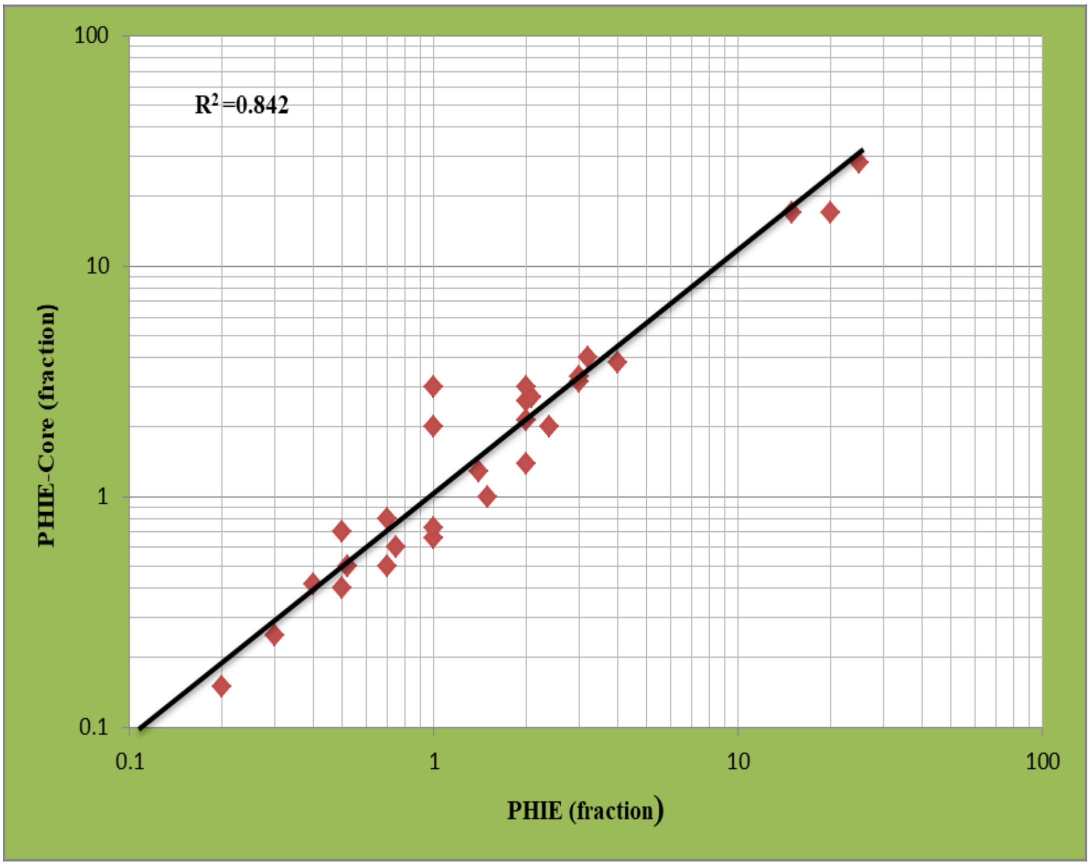

Fig. 8. Accuracy of porosity by well logging in well AA-1

Fig. 9 shows the comparison between the permeability calculated from the cores and the permeability calculated by Schlumberger method and Timor method. It appears from the figure that the accuracy ratio is high, which is consistent to the transmittance values calculated by the cores. Thus, these two methods can be chosen to calculate the transmittance in this configuration. It does not depend on the Morris Beggs oil method because the accuracy rate in the Morris Beggs oil method is low, and this means that the error rate in the calculations is large. Through this form, the accuracy of the calculations can be known. If the straight line passes through all the points, it indicates that the accuracy is one hundred percent, and if the straight line passes through most of the points but does not pass through some points, it indicates that the accuracy is high, but less than one hundred percent. The further the points are from the straight line, the lower the accuracy.

Fig. 10 shows the comparison between the permeability calculated from the cores and the permeability calculated by Morris Beggs oil method. It is clearly notice from the above figure that the accuracy ratio is low, whilst the error rate in the transmittance values calculated in this way is large; This is due to the calculated values of the transmittance can be further to the computed transmittance values from Cores analysis which means the error rate in these calculations is high. Whilst when the calculated transmittance values are consistent to the calculated transmittance values from the fundamental analysis, the calculation error rate will be low.

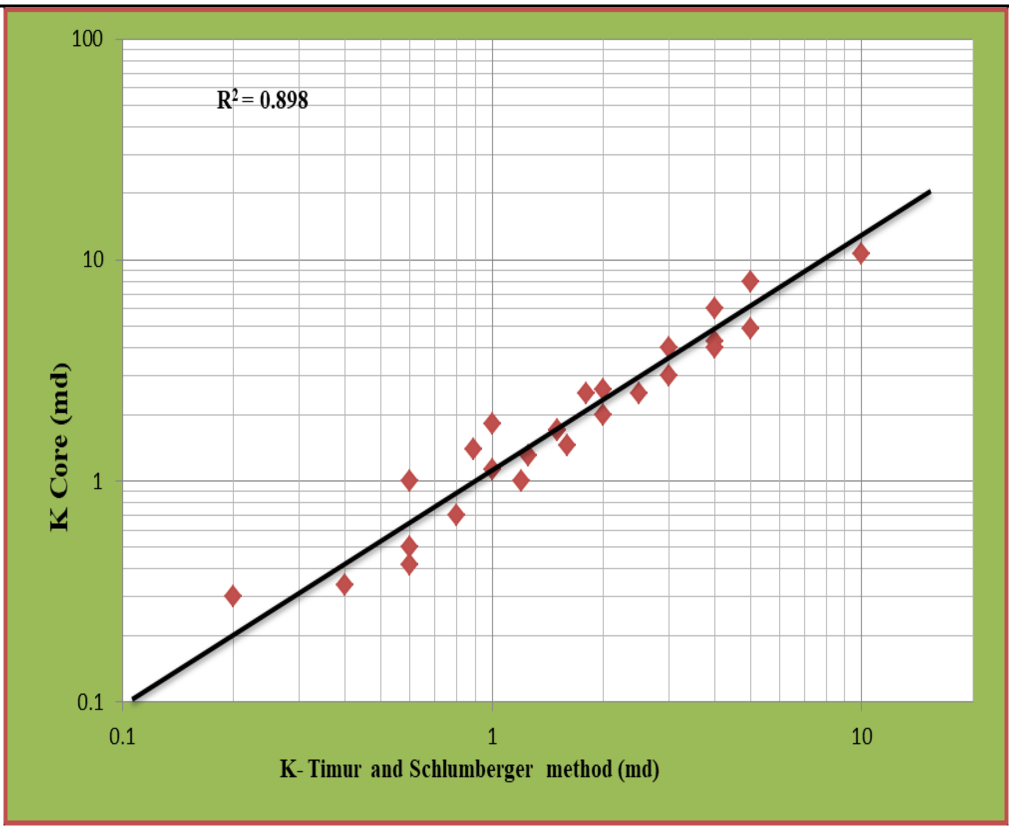

Fig. 9. Accuracy of permeability by Timur and Schlumberger method

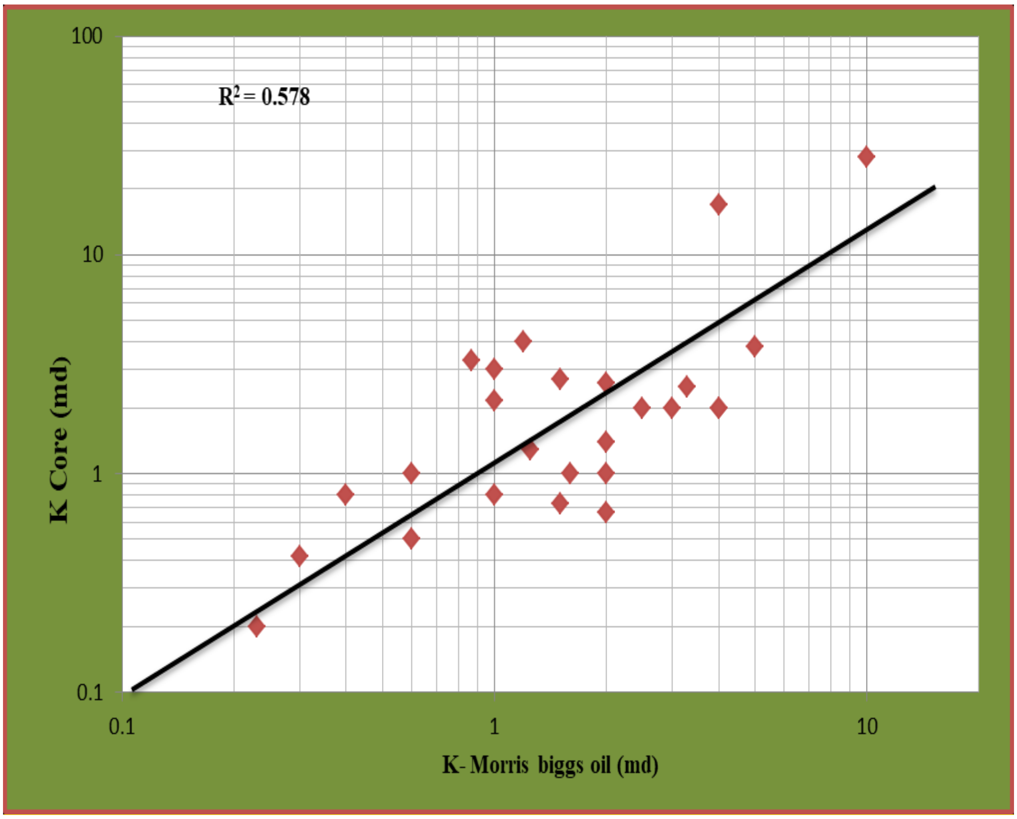

Fig. 10. Accuracy of permeability by Morris biggs oil method

The next investigation is to compare the results of this study with those of previous studies Al-Sudani which the effective porosity and permeability of the Yamama formation has been calculated in southern Iraq. The value of the effective porosity and permeability, respectively: (0.12 - 0.14 md), (2.921 - 5.639 md). These values are close to the results of this study, bearing in mind that the three-dimensional method was used. The advantage of this study is that the effective porosity was calculated using the Neutron log, Density log, and Sonic log, and the results were compared with cores analyzes and they were very close, and the permeability was calculated using the Morris biggs oil method, Timur method, and Schlumberger method. When comparing the permeability calculated by these methods with the permeability calculated by cores analyzing; The Timur and Schlumberger method was the closest to the Cores results, which gives an indication of the accuracy of calculating the permeability by this method. Handhal et al. (2019) calculated the effective porosity of Yamama formation in southern Iraq, and the value of the calculated effective porosity was: (0.06-0.14)[37]. Al-Ani et al. (2021) calculated the effective porosity of Yamama formation in southern Iraq, and the value of the calculated effective porosity was: (0.08-0.16). The effective porosity value calculated in this study ranges between (0.06-0.17) [38]. This indicates that the effective porosity results calculated from this study are very close to the effective porosity values of the previous studies.

Conclusion

The results of this study indicate that the porosity of the Yamama formation ranges between (0.06-0.17) and these results were obtained by applying the density log, neutron log, and acoustic logarithm. These effective porosity values are acceptable because when compared to the core value, it was close to it, and the error rate was very small. Also, when comparing these values calculated in this study with the values calculated in previous studies; The results were very close. This study also showed that the value of the permeability of the Yamama formation ranges between (0.1-10) md, and these values were calculated by Schlumberger and Timor method after comparing them with the permeability of the cores, and they were close to it. Considering the values of both the porosity and the permeability calculated for the formation, it is clear that the formation rocks are reservoir rocks and they are capable of saturating with hydrocarbons due to connected pores (effective porosity) and they have a good ability for fluids to pass through them (permeability) .After this study, we can predict that the Yamama formation is a reservoir formation, and in order to know the saturation of the rocks of this formation with water, oil and gas, we need to calculate the water saturation of the rocks of this formation using resistance sensors and using the Archie equation. After knowing the water saturation, it is possible to determine the saturation of the rocks with oil and gas. It is known in reservoir engineering that, in order for the formations to be oil reservoirs, they must have high permeability in order to allow the movement of oil through the formation, and from the formation to the bottom of the well. However, in gas reservoirs, the permeability in them is not required to be as high as the permeability in oil wells. Because gas can move through a permeability where oil cannot move.

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Nomenclatures

Symbol	Definition	Unit
Vshale	Shale volume.	(-)
Pma	The matrix density	gm/cc
ρ_b	bulk density log reading	gm/cc

ρ_f	filtrate density	gm/cc
Δt	transit time in the formation	µsec/ft
Δtma	the acoustic transit time of the rock matrix	µsec/ft
$\Delta t f$	the acoustic transit time of interstitial fluids	µsec/ft
well AA-1	well in the fields of southern Iraq	(-)
Phi- Den	Calculated porosity by Density log	(-)
phi-Neu	Calculated porosity by Neutron log	(-)
phi-Son	Calculated porosity by Sonic log	(-)
PHIE	Effective porosity	(-)
K-Morris Biggs oil	Permeability calculated using Morris Biggs oil method	md
K-Schlumberger	Permeability calculated using Schlumberger method	md
K-Timur	Permeability calculated using Timur method	md
K	Permeability	md
Φ	porosity	(-)
Swi	water saturation, fraction	(-)

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