



# Petrophysical Properties of an Iraqi Carbonate Reservoir Using Well Log Evaluation

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## Abstract

This research was aimed to determine the petrophysical properties (porosity, permeability and fluid saturation) of a reservoir. Petrophysical properties of the Shuiaba Formation at Y field are determined from the interpretation of open hole log data of six wells. Depending on these properties, it is possible to divide the Shuiaba Formation which has thickness of a proximately 180-195m, into three lithological units: A is upper unit (thickness about 8 to 15 m) involving of moderately dolomitized limestones; B is a middle unit (thickness about 52 to 56 m) which is composed of dolomitic limestone, and C is lower unit (>110 m thick) which consists of shale-rich and dolomitic limestones. The results showed that the average formation water resistivity for the formation ( $R_w = 0.021$ ), the average resistivity of the mud filtration ( $R_{mf} = 0.57$ ), and the Archie parameters determined by the picket plot method, where m value equal to 1.94, n value equal to 2 and a value equal to 1. Porosity values and water saturation  $S_w$  were calculated along with the depth of the composition using IP V3.5 software. The interpretation of the computer process (CPI) showed that the better porous zone holds the highest amount of hydrocarbons in the second zone. From the flow zone indicator method, there are four rock types in the studied reservoir.

*Keywords: Petrophysical properties, Porosity, Permeability, Shuiaba Formation, Well log.*

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## 1- Introduction

Interpretation of well log results is one of the important processes for Engineers and geologists to identify the petrophysical properties. The log data is significant in reservoir engineering and used in the calculation, especially in the estimation of the reserve. The best interpretation for any structure of interest depends on the quality and quantity of log data available to analysts and the type of problem [1].

The interpretation of the basic logs also includes the determination of; true total porosity, effective porosity, water saturation, salinity of the formation water, mud filtrate resistivity and true resistivity for the field. Besides the porosity and the hydrocarbon saturation to calculate total reserves and predict the size of the formation containing hydrocarbon if the accumulation of hydrocarbon is commercial. For that, researchers can make interpretation for available logs that will help us to calculate the original oil in place OOIP [2].

The flow of fluid through a carbonate reservoir is a completely different process than the flows through sandstone layers. This difference is due in large part of carbonate rocks tend to have a more complex void system than sand rock. [3]. Much of the hydrocarbon reserves are found in carbonate rock. However, the characterization of the carbonate reservoir is quite complex compared to sand rock reservoirs **Error! Reference source not found.**

In the Middle East, the giant fields containing hydrocarbon are in carbonate reservoirs, which cover about 50% of the world's hydrocarbon reserves [5]. Y field is located in northeastern Iraq, and it has several pay zones, and they produce from the Tertiary and Cretaceous reservoirs which comprise the middle Lower Cretaceous Qamchuqa Group as the main reservoir system. The first well X-1 was founded in 1976 and the last well (X-33) was completed in 2008, depending on the seismic studies. [6].

## 2- Methodology

Six wells were selected in the Y oilfield for achieving the main petrophysical parameters, Table 1 and Table 2 show the well log and core data that used in this study.

The methods in this study can be summarized as follows:

In the first step, Environmental well log corrections were done, then, water formation resistivity and shale volume were calculated. Lithology was then identified in which porosity estimation was required.

The water saturation was determined by using the Indonesian equation because it gives reasonable values. Finally, water zones, movable and residual hydrocarbons were identified easily.

Table 1. Log and core data used in this study including a number of porosity and permeability measurements (data from Iraqi oil Ministry, unpublished)

well	Log data depth intervals(m)			Core sample intervals(m)	Number of plugs	Number if K and $\Phi$ measurements	Number of thin sections
	GR	Density	Neutron				
X-1	3045-3229	3045-3229	3045-3229	3128-3226.9	260	284	27
X-2	3317-3510	3317-3510	3317-3510	3348-3379.9	102	102	75
X-4	3274-3350	3274-3350	3274-3350				14
X-5	3112-3200	3112-3200	3112-3200				
X-13	3101-3165	3101-3165	3101-3165				41
X-14	3091-3288	3091-3296	3091-3296	3094-3154			18

Table 2. Depths and interval thicknesses of lithological units in the Shuaiba Formation at the studied wells in the Y oil field

Wells	interval and thickness (m)	Producing intervals (m)	Cored intervals (m)	Units	Unit intervals (m)	Unit thickness (m)
X-1	3045-3229 (184)	3045-3101	3128-3229	A	3045-3059	14
				B	3059-3115	56
				C	3115-3229	114
X-2	3317-3510 (193)		3348-3380	A	3317-3329	12
				B	3329-3384	55
				C	3384-3510	126
X-4	3274-3355 (81) penetrated			A	3274-3282	8
				B	3282-3334	52
				C	3334-3350	16
X-5	3112-3200 (88)	3120-3188		A	3112-3125	13
				B	3125-3180	55
				C	3180-3200	20
X-13	3101-3210 (109) penetrated	3150-3168		A	3101-3116	15
				B	3116-3165 logged part	49
				C	Not penetrated	
X-14	3091-3275 (186)		3094-3154.3	A	3091-3102	11
				B	3102-3160	58
				C	3160-3275	115

### 3- Results and Discussions

#### 3.1 Environmental corrections of Well Logs

Appropriate corrections (such as shale impact, opening hole conditions, invasion depth, etc.) were applied to neutron, density and gamma-ray logs were applied before the well log analysis was done. Current Schlumberger charts were used for Environmental corrections [7].

Many companies have correction models available in IP v3.5 software. The Schlumberger corrections were used to the well records specified in the Y field as shown in Table 1 because most of the records are registered by Schlumberger Company. Fig. 1 shows the environmental corrections for well X-4. The figure shows, there are no significant differences between the readings of the original records and the corresponding corrected records, except for small differences due to the washout envision effect (in some parts of the logs). Corrections are made to check true values and to obtain them.

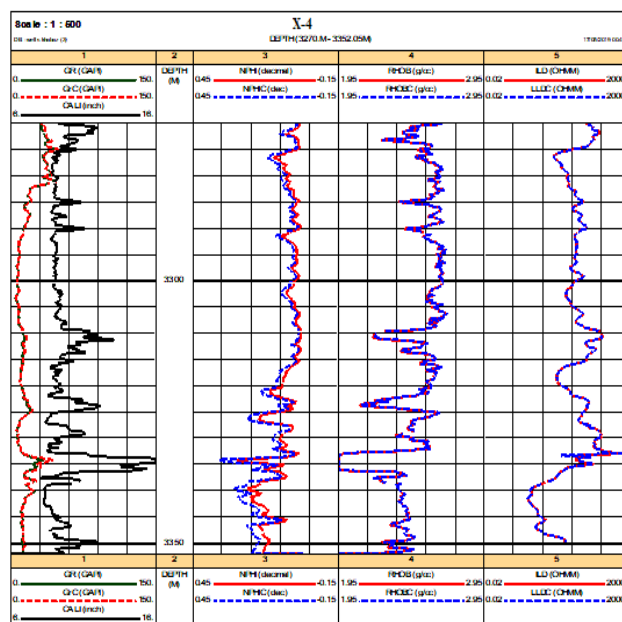


Fig. 1. Environmental correction for well X-4

### 3.2 Shale Volume Determination

The calculation of shale volume is important parameters that must be identified during any explanation because it affects the values of water saturation and porosity. The shale also controls the presence of hydrocarbons [1].

The volume of shale is determined in the Y field using gamma-ray, through the following formula [8]:

$$IGR = \frac{Gr_{log} - Gr_{min}}{Gr_{max} - Gr_{min}} \quad (1)$$

Then convert the gamma-ray index into shale content by an empirical equation for old rocks

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

Where,

IGR: gamma-ray index,

GR log: gamma-ray log reading in the zone of interest, API units,

GR min: minimum gamma-ray reading in a clean zone, API units,

GR max: maximum gamma-ray reading in shale zone, API units.

Fig. 2 shows the result of shale volume determination in well X-4 contains shale volume greater than 50% but it represents a small part from the drilled interval.

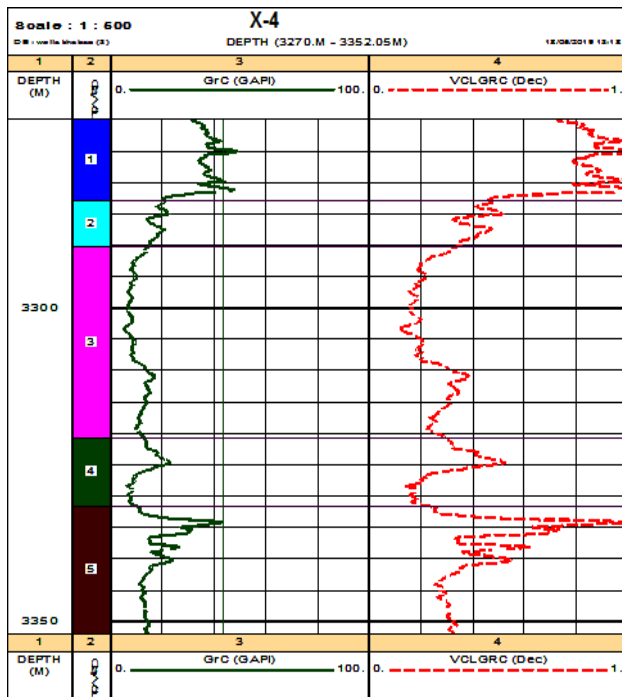


Fig. 2. Show Shale volume determination in well X-4

### 3.3. Porosity Estimation

The fluids stored in the pore spaces within the reservoir rocks could be gas, oil, and water. High porosity values indicate high capacities of the reservoir rocks to contain these fluids, while low porosity values indicate the opposite [8].

Total porosity describes the ratio of all pore volumes in a rock to the total volume containing voids, the following formula can be used to determine the density and neutron logs [9]

$$\phi_t = \frac{\phi_N + \phi_D}{2} \quad (3)$$

Where,

$\phi_D$ : Porosity from density log.

$\phi_N$ : Porosity from neutron log.

While effective porosity can be estimated by subtracting the shale volume from the total porosity as shown below [8]

$$\phi_e = \phi_t * (1 - V_{sh}) \quad (4)$$

The porosity can also be estimated depending on three types of logs that are affected by rock porosity which are neutron, sonic and density logs. In the porosity calculation process, the selection of well log type was based on the borehole conditions and the good match between the log and core porosities.

Fig. 3 shows the porosity calculated by a neutron, density and sonic logs, effective porosity and total porosity compression with core porosity in well X-2. In this paper, effective porosity (PHE) was taken because it gives a good match with core porosity.

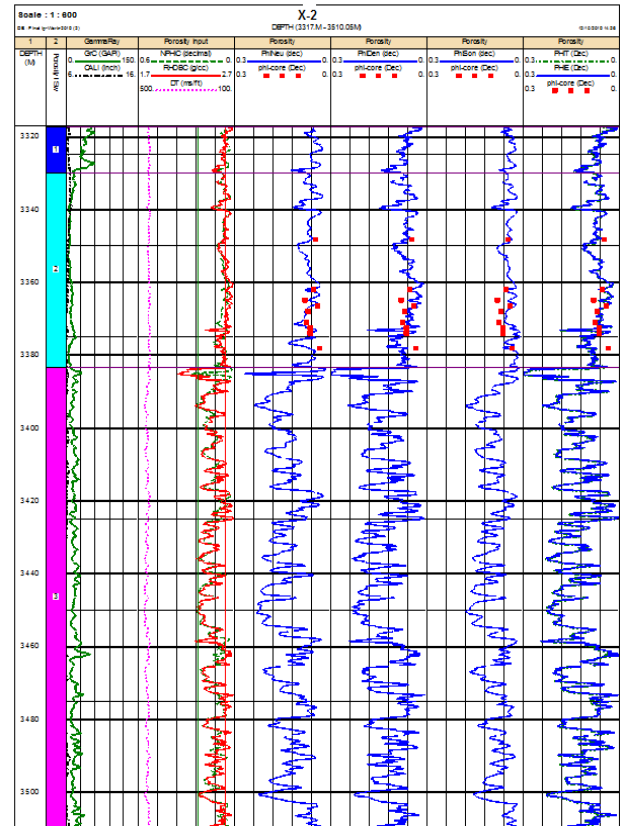


Fig. 3. Comparisons porosity analysis for well X-2

### 3.4. Fluid Saturation Determination

The most important step in interpreting the log is the determination of water saturation. Water saturation can be estimated from different equations by using IP software v3.5. There are many equations to estimate water saturation such as dual water, Archie, Simandoux, Mod sinandoux, Indonesian, Mod Indonesian, Juhaz and Waxman. Archie equation can be used to calculate fluid saturation for clean formation depending on porosity ( $\phi$ ), the resistivity of formation water ( $R_w$ ), Resistivity of formation ( $R_t$ ) as shown in equations below [10]. Archie's equation [10]:

$$S_w^n = \frac{a R_w}{\phi^m R_t} \quad (5)$$

$$S_x O^n = \frac{a R_m f}{\phi^m R_{xo}} \quad (6)$$

Indonesian and Simindox equation depended on Archie parameter ( $a$ ,  $m$ , and  $n$ ) in derivation to estimate water saturation for high percentage shale formations, where Indonesian equation depended on estimate water saturation [11].

Simindox equation [11]:

$$S_w = \sqrt[n]{\frac{a \cdot R_w}{\phi e^{m \cdot R_t}} + \left(\frac{a \cdot R_w}{\phi e^m} * \frac{V_{sh}}{2 \cdot R_{sh}}\right)^2} - \left(\frac{a \cdot R_w}{\phi e^m} * \frac{V_{sh}}{2 \cdot R_{sh}}\right) \quad (7)$$

For Indonesian [11]:

$$S_w = \left[ \frac{1}{\left[ \frac{V_{sh} \cdot (1 - V_{sh})}{R_{sh}} + \frac{m}{\phi e^2} + (a \cdot R_w) \right]^{1/n}} \right]^{2/n} \quad (8)$$

### 3.5. Bulk Volume Analyses and Computer processed interpretation (CPI)

The bulk volume of water is the unit volume of porous media occupied by water and the bulk volume of hydrocarbons is the amount of the pore volume of the hydrocarbon [12].

$$BVW = S_w * \phi \quad (9)$$

$$BVHC = S_w * \phi \quad (10)$$

CPI is a continuous result of log analyzes and interpretations in the attractive form containing porosity, fluid saturation, matrix analysis tracks.

Fluid saturation and matrix analysis tracks include bulk volume analysis of fluid and matrix. The fluids bulk volume represents a continuous distribution of the volume of fluids in the rock formation pore space [13].

Fig. 4 shows the CPI for well X-2. The CPI results show that the best porous zone with the highest percentage of movable hydrocarbon in the Shuiaba reservoir was Unit B.

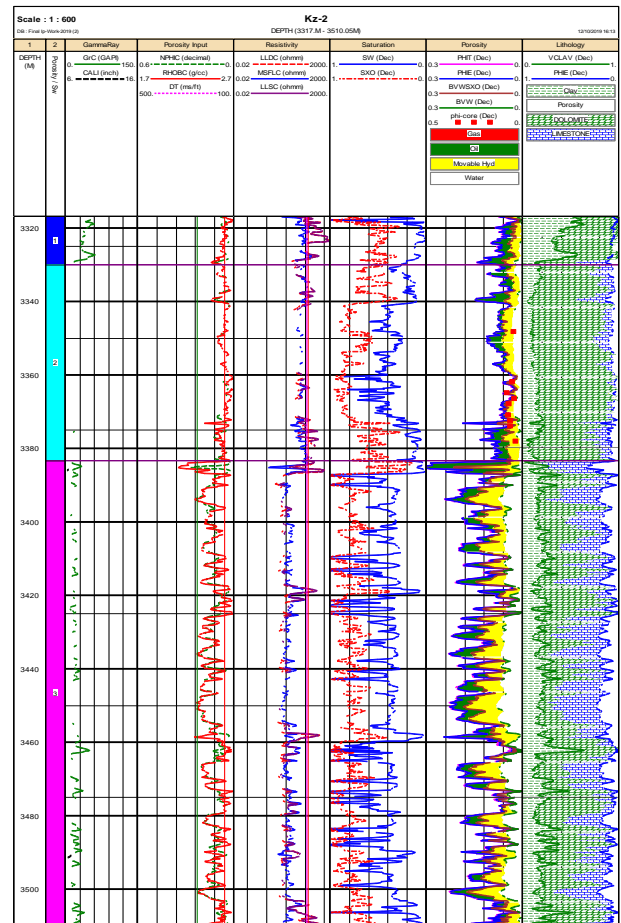


Fig. 4. Computer processed interpretation (CPI) for well X-2

### 3.6. Cut off Calculations

Cutoffs in petroleum engineering are limiting points at which the processing of flowing of fluid is stopped.

#### a. Porosity Cut Off

Elimination of the portion of the formation is low porosity and low permeability, therefore non-productive.

Typically, the cutoff of porosity for sandstones is about 8 to 10% and for limestone about 3 to 5%. Limestone's lower porosity cutoff values reflect the propensity for limestone's to be highly fractured [14].

For Shuaiba reservoir, porosity cut off estimated by using permeability porosity cross plot, by using common permeability cut off value (0.1 MD) in the cross plot for petroleum reservoir porosity cutoff identified and its value about 0.05 as shown in the Fig. 5.

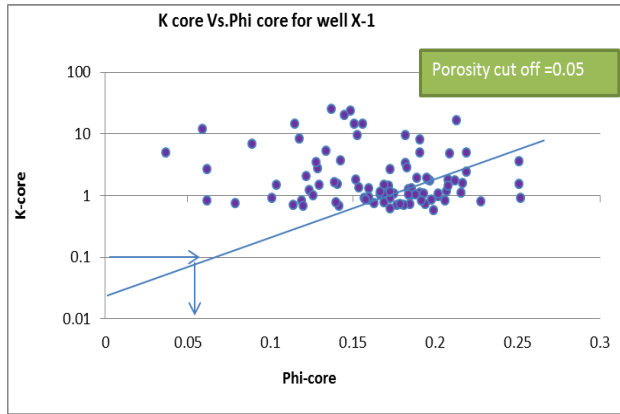


Fig. 5. Core porosity cut off the cross plot of X-1

**b. Water Saturation Cut Off**

Remove part of the formation which contains a large amount of water in the pore space. Water saturation cut off determine by using cumulative storage capacity, (phi\*so), versus water saturation and curve plot was prepared by using log analysis results. As results, water saturation cut off was 0.6 as shown in Fig. 6

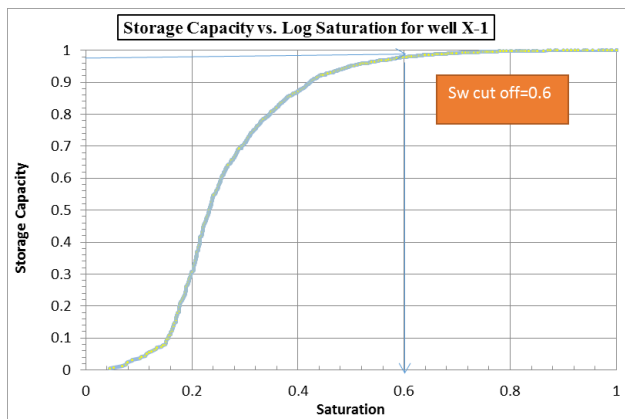


Fig. 6. Water saturation cut off of X-1

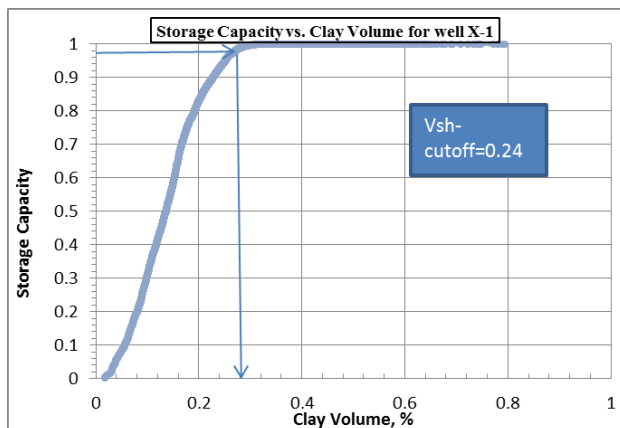


Fig. 7. Clay volume cut off of X-1

**c. Clay Volume Cut Off**

Clay volume cut off mean elimination the portion of the formation which contains large quantities of shall. Clay volume cut off determine by using, cumulative storage capacity, (phi\*so), versus clay volume and curve plot were prepared by using log analysis results. As result, clay volume cut off was 0.24 as shown in Fig. 7.

**3.7. Permeability Prediction**

Knowledge the permeability, which is the ability of rocks to transmission liquid, is important to understand the flow mechanisms in oil and gas reservoirs. Permeability is better measured in the laboratory on corded rocks taken from the reservoir. Coring is expensive and time-consuming compared to the electronic survey techniques most commonly used to obtain permeability information Error! Reference source not found.

Several methods to predict permeability are the classical method, the prediction of the statistical curve and the flow zone indicator. In this study, the flow zone indicator (FZI) was used to predict permeability, because there is no core data for the Shuiaba reservoir for that core data available for two wells are used to predict permeability in an un-cored interval.

The flow zone indicator (FZI) method used to classify core data into hydraulic units with specific FZI. This method provides accurate correlations between permeability and porosity if the FZI of reservoir rocks is known. The FZI is estimated from core data in the cored wells and is generally applied to un-cored wells by correlations with log attributes. The general approach is given inflowing equations [14]:

$$RQI = 0.0314 \times \sqrt{\frac{k}{\phi_e}} \tag{11}$$

$$\phi_z = \frac{\phi_e}{1 - \phi_e} \tag{12}$$

Kozeny equation, by substitute RQI and  $\phi_z$  with FZI, can be simplified as:

$$FZI = \frac{RQI}{\phi_z} \tag{13}$$

By taking the logarithm of both side of equation 4-6, the final approach can be written as follow,

$$\log RQI = \log \phi_z + \log \tag{14}$$

Where:

k = permeability (md),

$\phi_{eff}$  =effective porosity, (core porosity for Nhr Umr formation/Halfaya field)

FZI mean is the average flow zone indicator.

$\phi_z$  is a normalized porosity (pore volume to grain volume ratio) (fraction),



Depending on the definitions of HU obtained from the cumulative probability plot, the log-log graphs for RQI versus  $\phi Z$  were as shown in Fig. 8. The graph of log permeability (k) vs. ( $\phi$ ) Fig. 9 shows better using the FZI technique a comparison. The relationship between the porosity and permeability of each type of rock is illustrated using the power-law model; high correlation coefficients were obtained for all types of rock, so permeability can be estimated accurately from the curve equation for each type of rock.

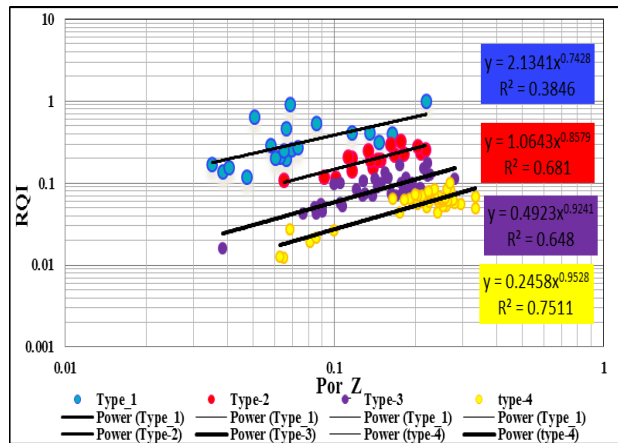


Fig. 8. RQI versus PHIZ ( $\phi Z$ ) plot

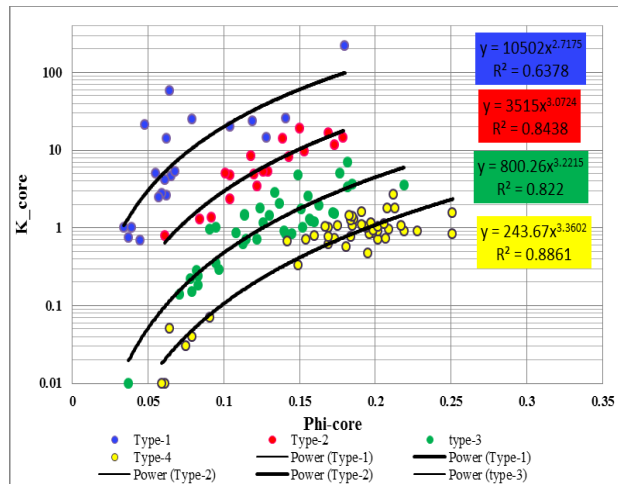


Fig. 9. Log permeability (k) versus PHIE plot

#### 4- Conclusions

This study allows the following conclusions:

- 1- Based on core data and log interpretation the shuiba carbonates can be divided into three lithological intervals: An upper unit ( thickness about 8-15 m ) consist of dolomitic limestones; B a middle unit ( thickness about 52-56m ) consist of vuggy dolostones and dolomitic limestones, and C a lower unit ( thickness about 114-126 m ) composed of shale-rich dolomitic limestones.

- 2- The range of porosity in the Shuaiba reservoir in Y field about from 1 to 24% (average 9.5%). From the plot between K-core and Phi-core, the value of cutoff porosity was determined to be 5% and this value was used to identify high-porosity zones in the reservoir.
- 3- From the neutron density plot, M-N plot and the MID plot, it was concluded that the composition of Shuiba reservoir is mainly composed of dolomite and limestone.
- 4- Due to heterogeneous carbon rocks, the Archie parameter must be correctly defined to evaluate it; incorrect values of the Archie parameter will cause unacceptable errors in the volume of water saturation and in the calculation of the initial oil in place.
- 5- The heterogeneity of carbonate reservoirs makes it somewhat difficult to apply the Archie equation when its parameters depend highly on carbonate characteristics. So that we use Indonesian method because it gives reasonable values of water saturation
- 6- Almost all wells in Iraq interpreted by various CPI methods have used constant Archie coefficients, while these parameters have different values, especially in carbonate formations that affect fluid saturation, and Archie constant values give a low saturation of hydrocarbons
- 7- From plot between RQI versus ( $\phi Z$ ) on log-log plot show there is four rock type in shuiba reservoir (wackestone, packstone, mudstone and shale).

#### Nomenclature

Symbols	Description	Unit
a, n, m	Archie's parameters	dimensionless
$\phi$	Porosity	Fraction
SW	Water saturation	Fraction
Rw	Formation water resistivity	ohm.m.
Rmf	Mud filtrate resistivity	Ohm.m.
Vsh	Shale volume	fraction
Rt	True Formation Resistivity,	Ohm.m.
Rxo	Flushed Zone Resistivity,	Ohm.m
$\phi_N$	Neutron derived porosity,	Fraction
$\phi_D$	Density derived porosity,	fraction
$\phi_e$	Effective Porosity,	Fraction
$\phi_t$	Total porosity	Fraction

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## الخواص البتروفيزيائية لمكامن الكاربونيت العراقية باستخدام تقييم سجل الآبار

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### الخلاصة

يهدف البحث إلى تحديد الخواص البتروفيزيائية (المسامية والنفاذية وتشبع السوائل) للمكامن. يتم تحديد الخواص البتروفيزيائية لتكوين الشعبية في حقل Y من تفسير بيانات السجل المفتوح لآبار (X-1 و X-2 و X-4 و X-5 و X-13 و X-14). اعتماداً على الخواص البتروفيزيائية، يمكن تقسيم تكوين الشعبية الذي يتراوح سمكه بين 180 و 195 مترًا تقريباً، إلى ثلاث وحدات ليثولوجية: وحدة عليا (أ، 8-15 م) تتكون من حجر جيرى مبلور جزئياً؛ وحدة متوسطة (ب، 52-56 م) وهي مكونة من الحجر الجيري الدولوميتي؛ والوحدة السفلية (C، > 110 متر سمكاً) التي تتكون من أحجار جيرية غنية بالصخر الزيتي والدولوميتية.. تشير النتائج إلى أن متوسط مقاومة الماء للتكوين ( $R_w = 0.021$ )، ومقاومة متوسط راسح الطين ( $R_{mf} = 0.57$ )، ومعلمات Archie تحديد من طريقة بكت بلوت ( $m = 1.94$ ،  $n = 2$ ، و  $1 = 1$ ). بينما تم حساب قيم المسامية وتشبع الماء مع عمق التكوين باستخدام برنامج تفاعل البتروفيزياء (IP V3.5). يوضح تفسير عملية الكمبيوتر (CPI) أن النتائج تشير إلى أن أفضل منطقة مسامية تحسن أعلى نسبة مئوية من الهيدروكربون المتحرك في الشعبية يركز الخزان في المنطقة الثانية.

الكلمات الدالة: الخواص البتروفيزيائية، المسامية، النفاذية، مكن الشعبية.