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Evaluation of petrophysical Properties of Zubair formation Luhais oil field Using Well Logging Analysis and Archie Parameters

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ABSTRACT

Well log analysis is used to determine the rock properties like porosity, water saturation, and shale volume. Archie parameters in Archie equation, which sometimes considered constants greatly affect the determination of water saturation, also these parameters may be used to indicate whether the rocks are fractured or not so they should be determined. This research involves well logging analysis for Zubair formation in Luhais field which involves the determination of Archie parameters instead of using them as constant.
The log interpretation proved that the formation is hydrocarbon reservoir, as it could be concluded from Rwa (high values) and water saturation values (low values), the lithology of Zubair from cross plot is sand-stone, finally the low values of cementation exponent refer to that the formation may be vuggy or fractured or high permeability.
Keywords: well log, porosity, shale, Archie parameters, saturation, tortuosity.

تقييم الخواص البتروفيزيائية لمكمن الزبير في حقل اللحيس باستخدام تحاليل المجسات ومعاملات ارتشي

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الخلاصة

ان عمليات تحليل المجسات تستخدم لتحديد خواص الصخور مثل المسامية والتشبع المائي وحجم الطفل وكذلك تحديد التكوين الكيميائي للصخور. ان معاملات ارتشي تؤثر كثيرا على حسابات التشبع المائي وكذلك يمكن استخدام هذه المعاملات لتحديد ما اذا

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كانت الصخور متشققة او لا. يتضمن هذا البحث تحليل المجسات لتكوين الزبير في حقل اللحيس وكذلك تحديد معاملات ارتشي من علاقة المقاومة النوعية العميق مع المسامية وكذلك حساب التشبع المائي ومعاملات ارتشي وكما تضمن البحث حساب حجم الطفل.
لقد أثبت تفسير المجسات لبئر لحيس- 8 أن التكوين الزبير عبارة عن مكمن هيدروكربوني ، حيث يمكن استنتاجه من Rwa (القيم العالية) وقيم تشبع الماء (القيم المنخفضة) ، وعلم ان طبقة الزبير من الأرض المتقاطعة هو من الصخور الرملية ، وأخيراً القيم المنخفضة لمعامل التسميت تشير إلى أن التكوين قد يكون متشققا أوذو نفاذية عالية.
الكلمات الرئيسية: المسامية، عوامل ارشي ، التشبع ، التعرج .

1. INTRODUCTION

Saturations of fluid and porosity are of the most significant properties of reservoir used in the estimates of oil and gas reserve **(Pickett, 1942)**. The saturation of fluid can be determined from the measurements of the electrical conductivity and resistance of the core samples using the equation of Archie's also known as the equation of saturation. In this equation, *a* is the parameter of tortuosity, *Rw* is the reservoir water resistivity, Ø is formation porosity, *Rt* is the resistivity of uninvaded zone, Sw is water saturation, while *m is* cementation exponent, *and n* is saturation exponent. The factor *a* frequently has a value of unity, in original Archie’s equation, (**Archie, 1942)**. The values of the exponent m and n are proved to be very depending on the type of formation of petrophysical properties, specifically, depending on the characteristics of the composition and the capillary forces.

1.1 Area of Study

The Luhais oil field is located in southern Iraq, about 105 km west of Basra and 350 km southeast of Baghdad. The border to Kuwait is 35 km southeast of Luhais and to the west of Rumaila field. The distance between the southern rim of the Luhais field and the northern limit of the Subba field in the Euphrates river plain exceeds 55 km., Luhais field was discovered by Basrah Oil Company in 1961, and started production in 1977. The oil density is 32 in API units, **Fig. (1)**. Oil in lower cretaceous sandstone was discovered at Luhais in 1961. The structures are north-south elongated gentle anticlines with structural dips at their flanks in the order of one degree.
The zonation used in this paper is according to the geologic report. The available data is for Luhais- 8.

1.2 Aims and Objectives

1- The petrophysical parameters, which are called Archie parameters Porosity exponent (m), Tortuosity coefficient (a), and saturation exponent (n) are estimated. Then the demonstrating factors that influence these parameters by using diverse methods.

2- The hydrocarbon region is detected.

3- The water saturation is calculated using the Archie model; using variable petrophysical parameters in this calculation.

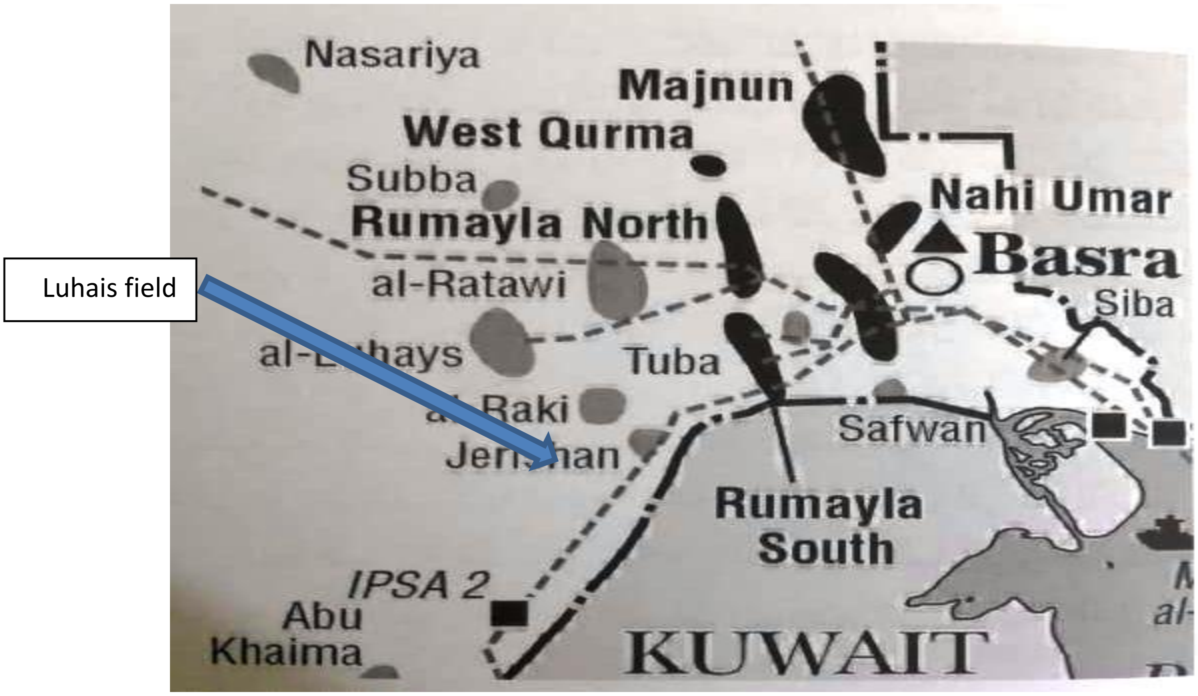

Figure 1. LUHAIS Field Location.

1.3 Background

Archie's equation was published in 1942; the exponents of fluid saturation and porosity have been fundamental factors in the determination of reservoir fluid saturation **(Watfa, 1987)**. If no enough data about the reservoir rocks are available, it is accepted to give average-constant values to *n* and *m* by comparing the texture of reservoir rock to be studied with similar rock textures described in the authoritative publications or from adjacent formations. Even when sufficient petrophysical data about the reservoir rock is available (routine core analysis, well logging records, etc.)

Most of the hydrocarbon reservoirs in Iraq are carbonates, which are characterized by high heterogeneity. Heterogeneity reflected by large variation in lithology and petrophysical parameters. The variations are caused by large variations in texture and facies of carbonate reservoirs and also by the presence of vugs and fractures in them. Thus all of these variations need to be studied in order to predict the behavior of the carbonate reservoir **(ADNAN, 2011).**

Before introducing the proposed methodology, it is prudent to consider a brief review of the exponents of Archie and existing methods to determine them. This review will include three major points. First, the experimental relationships of Archie that gave birth to the saturation exponent n, and porosity exponent (cementation exponent), m. Second, the current methodologies that are used to calculate tortuosity coefficient, a, porosity exponent, m, and saturation exponent, n. Finally, the efforts that have been done to relate Archie's exponents to rock texture and capillarity concepts are considered. The main point derived from this discussion is that the methodologies used to calculate Archie's exponents are based on average fit trend lines (**Schlumberger, 1979)**.

The following is a review of the studies concerning petrophysical properties of Iraqi reservoirs carried out in Petroleum Engineering

A petrophysical study was made for the three main hydrocarbon units, of Mishrif Formation, North Rumaila Oil Field in Sothern Iraq **(ADNAN, 2011)**.
Well logging and core analyses data were used to carry out the study. The available logging information is scanned and converted to digits by Didger program Package 3.03. The well environmental conditions are corrected and the interpreted data were achieved by Interactive Petrophysics software v3.6 and FORTRAN Programs.
Formation evaluation achieved for the Yamama reservoir of the Ratawi field depending on the logging and cores analysis data. The available logging data were digitized by using Didger program package 3.03. The log's data are gamma-ray, electric (spontaneous potential, deep and shallow lateral-log), neutron and formation density **(ZAINAB, 2012)**.
Pickett plot method is used for the determination of Archie's coefficient (tortuosity coefficient (a), exponent of saturation (n), and the cementation factor (m)) by using interactive petrophysics software.

1.3.1 Cementation Exponent, *m*
The initial determination for the porosity exponent, *m* was estimated by Archie, who did not name it "*cement exponent*" **(Coates, and Dumanoir, 1977).** Archie clarified that (m) could be used to make a relation between porosity and formation resistivity factor. This equation is valid for the quantitative analysis of resistivity logs. First, Archie established the relation between the resistivity of sand fully saturated with brine (*Ro)* and the water resistivity, *Rw*, for many of cores saturated with brine as follows:

$$Ro = F\, Rw \qquad (1)$$

Then Archie found the formation resistivity factor, *FRF*; is a function of formation type that changes with porosity. This main relation works as a technique to characterize sand type formations:

$$F = a\, Ø^{-m} \qquad (2)$$

After that Archie found the porosity exponent *m* with a magnitude of (1.3) in clean unconsolidated sand packs in a laboratory and that *m* with a range of (1.8 - 2) in the consolidated sandstones he inspected. The term cementation exponent refers to the exponent *m;* it concluded that the formation resistivity factor for any given porosity tends to be high as the sand be more cemented **(Serra, 1986)**. **(Schlumberger, 1979)** was interested in the influence of the geometry of pore and tortuosity on the rock resistivity. By taking into consideration that the resistivity is the measurement of fluids contained in the rock pore throats, they provide the tortuosity factor, *a,* to the Archie equation.

1.3.2 Saturation Exponent, *n*
The relation given in **(Eq. 2)** works for sands that are fully saturated with water, and suggested that the following **Eq. (3)**, and **(4)** was applied when pores are partially saturated with brine:

$$Rt = R0\, Sw^{-n} \qquad (3)$$
$$Rt/R_O = I_R = Sw^{-n} \qquad (4)$$

The magnitudes of n are commonly measured in the laboratory by stepwise decreasing the water saturation in a core plug and determining the resistivity at each step. A plot of water saturation versus resistivity, from **Eq. (5)** will finally give the magnitude of the saturation exponent which represents the slope of the line that joins all the calculated points.

$$Sw^n = (a\,Rw) / (Rt\,\varphi^{m}) \tag{5}$$

(Hamada, and Al-Awad, 2001) recognized that the wettability is not well determined in the laboratory and that wettability has a definite effect on the saturation factor (n) at low saturations of water.

2. METHODOLOGY

If the core is not available for the formation to be studied, the practice is to determine magnitude for the cementation and saturation factors from the good knowledge of rock porosity and general texture of rock Conventional Methodology Laboratory data in The Conventional Methodology. From core plugs are plotted on log-log plots according to the relationships expressed by **Eq. (5)** and **(6)**. Linear least-squares fits are performed on each data set to determine the saturation and porosity exponents based on the following equations:

$$Log\,(F) = log(a) - m\,log(\varphi) \tag{6}$$

$$Log\,(IR) = -n\,SW \tag{7}$$

Limitations of The Conventional Methodology: it is common, the tortuosity coefficient is usually set to $a=1$. Or the tortuosity factor is determined from the intercept of the line where porosity (φ =1.0). By following the relation for the formation resistivity factor, **Eq. (2)**, only the points of which water saturation ($Sw=1$) is used to determine the porosity exponent. At low water saturation the index of resistivity (IR) will be a function of wettability. This impact causes the data to diverge from the expected Archie's equation which is specified by **Eq. (7).**

2.3 Determination of Clay Volume Well Logging Data

Many methods are suggested to calculate clay volume (**Schlumberger, 1979)**; some of them are used as follows:

2.3.1 Single Curve Methods

The following methods are used to find clay volume (V_{clay}) from a single log as follows:

A-Gamma Ray Log Method:

$$I_{GR} = \frac{(GR_{\log} - GR_{\min})}{(GR_{\max} - GR_{\min})} \tag{8}$$

For older rocks the equation is:

$$\boldsymbol{Vsh \leq 0.33\,(2^{2\times IGR} - 1)} \tag{9}$$

For younger rock the Larionor equation is:

$$\boldsymbol{Vsh \leq 0.083\,(2^{3.7\times IGR} - 1)} \tag{10}$$

B-Resistivity Log Method

The following equation:

$$V_{clay} \leq \left[\frac{R_{clay}\left(R_{\max} - Rt\right)}{R_t\left(R_{\max} - R_{clay}\right)} \right] 1/b \tag{11}$$

R_{max}: maximum value resistivity recording in non- invaded hydrocarbon bearing zone, ohm.m

R_{clay}: resistivity in front of shale zone, ohm.m.

1 / b is computed as follow**:**

(A)- $1 / b = 1$ when $R_{clay} / Rt \leq 0.5$.

(B)- $I/ b = 0.5/ (1 - R_{clay} / Rt)$ when $R_{clay} / R_t > 0.5$.

2.4 Determination of Archie Parameter

2.4.1 Resistivity - Porosity Crossplot

This method was presented by **(Pickett, 1942)**, and was used to determine **a** and **m** from well logs by the following equation:

$$\text{Log } Rt = -m\text{log} + \text{log } aRw \tag{12}$$

Eq. (12) is a straight line on log-log paper, where (**a**.**Rw**) is the intercept at φ=1 and (**m**) is the slope; as (Rw) is determined from other sources, and (a) can easily calculated. In oil-bearing zone (no water zone) the value of m can be determined by cross-plot of ***Rt*** vs. **φ**. **Fig**. **1**, Rt versus porosity.

$$Rxo = a.Rmf/\varphi m \tag{13}$$

$$Log\ (Rxo) = -m\ log\ (\varphi) + log\ (a.Rmf) \tag{14}$$

A log-log plot of Rxo vs. φ would result in a straight line with a slope equal to (-m). ***The porosity exponent of the fractured–matrix is smaller than the porosity exponent of the matrix.*** Saturation exponent (n) is calculated by applying least-square method for the points represent irreducible water saturation as appearing in the top of Rt-φ cross plot (Pickett plot) as follows:

$$log\ (Rt) = log(Swi\ .Rtirr) + (n\text{-}m)\ log(\varphi) \tag{15}$$

The derivation of the equation is a straight line equation on a log-log scale with *Rt* on the y-axis and *φ* on the x-axis; the intercept is (Swi.Rtirr) with a slope of (n-m). Commonly the significance of this plot is to determine (n) as (m) is obtained from Pickett plot. It must be stated that the derivation of equation depends on irreducible water saturation levels.

2.4.2 F-Φ Plot Method

This procedure is laboratory-based measurements used to estimate (**m**) from core analysis in the laboratory as F can be determined for core full saturated by brine where;

$$F=Ro/Rw \qquad (16)$$

Where,

F: formation resistivity factor,

Ro: resistivity of core fully saturated with water ohm.m,

Rw: water resistivity ohm.m.

(Archie, 1944) And φ is also can be determined in the laboratory for the same core. The theoretical basis of this method is as follow:

$$F = a / \varphi^{m} \qquad (17)$$

Take the logarithms of both sides:

$$\log F = \log a + m \log \varphi \qquad (18)$$

Eq. (17) is a straight line equation on log-log paper, where **m** is the slope and **a** is the intercept at (Φ=1). The determination of m is made by assuming (**a**= l) in **Eq. (21)** so m will equal:

$$m = -\log F / \log \varphi \qquad (19)$$

The calculation of the formation factor is usually done under the special core analysis.

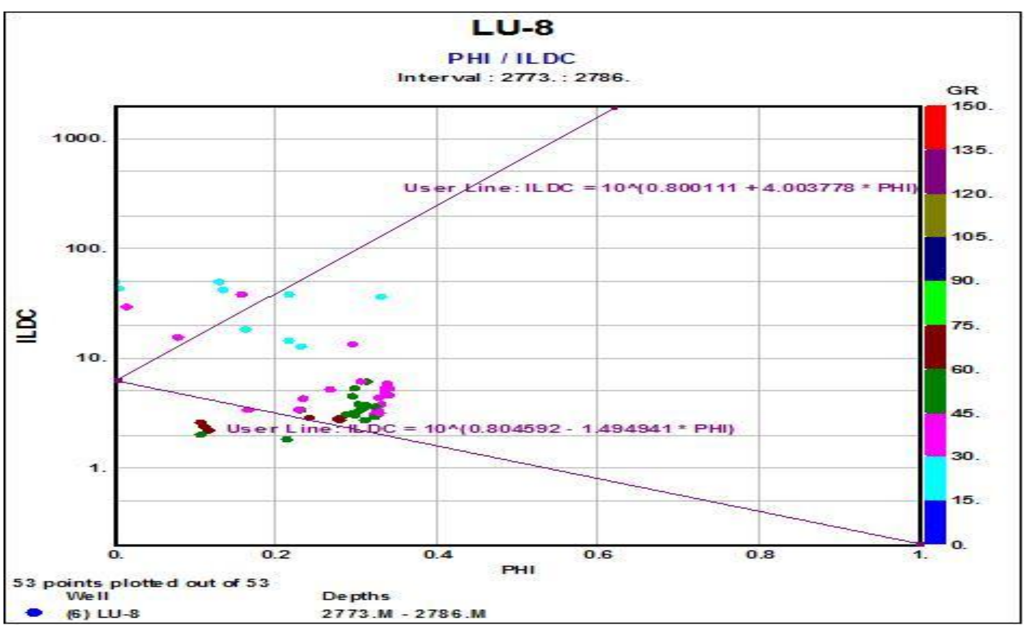

Figure 1. Rt versus porosity.

2.5 Estimation of Fluid Saturation

The evaluation of water saturation is the most significant step in log explanation as all the above work is done to obtain more accurate water and hydrocarbon saturation. Water saturation is determined by three methods in this work**.**

2.5.1 Archie Equation

Water saturation (Sw) is given by:

$$Sw^{n}=\frac{a.Rw}{\emptyset^{m}\ Rt} \qquad (20)$$

2.6 Bulk Analysis of Formation Fluid

The following equations are used:

The bulk of Free Water

$$Vwf=\varphi_e Sw \qquad (21)$$

The bulk of Hydrocarbon

$$BHC=\varphi_e\ (1\text{-}sw) \qquad (22)$$

The bulk of Moveable Hydrocarbon

$$Moveable\ hydrocarbon=\varphi_e\ (S_{xo}\text{-}S_w) \qquad (23)$$

2.7 Determination of Irreducible Water Saturation (Swi)

Swi can be determined by plotting porosity versus water saturation in a linear scale and drawing hyperbola from minimum water saturation and choose the levels that fall on this parabola that represent irreducible water saturation levels. **Fig. 2** represents computer process interpretation (**CPI**) of LUHAIS oil field.

2.8 Determination of Formation Water Resistivity *Rw* and Mud Filtrate Resistivity *Rmf:*

A precise knowledge of ***Rw*** and ***Rmf*** is essential to accurate determination of the water saturation in virgin and flushed zones. It is, therefore, important to take great care in its determination by matching and comparing the results obtained from various methods.

2.8.1 SP log

This technique is one of the more significant widely used methods to determine ***Rw*** from ***SP*** log; this technique depends on the following relation between ***Rw*** and ***SSP***:

$$SSP= -\ K \log ((Rmf)e/ (Rw)e) \qquad (24)$$

But before the method can be applied, certain prepared steps must be done:

1. The shale baseline of the ***SP*** log is defined, if necessary, by referring to the gamma-ray, neutron-density, and caliper to locate the shales in the section of interest.
2. The maximum deflection of the potential (***SSP***) opposite 'clean', thick beds are defined; the *SSP* for each formation.
3. The temperature at the point where the ***SSP*** was read is determined. Table 1 represents SSP results.

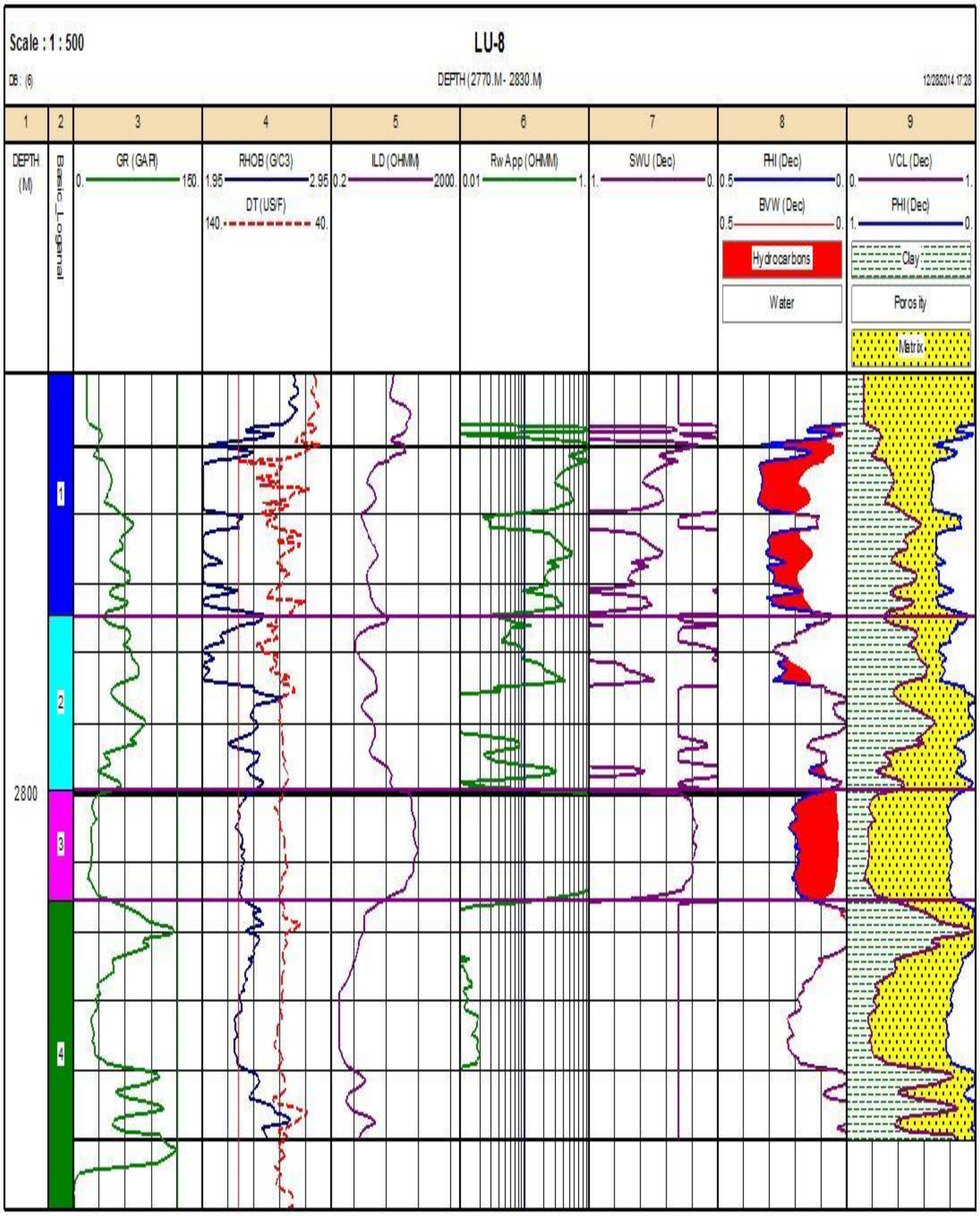

Figure 2. CPI for Zubair formation by IP.

Table 1. Rw and Rmf calculation.

Formation	***Temperature (ºF)***	***SSP***	***Rw from SP***	***Rmf (laboratory)***
Zubair	***168***	***-15***	***0.035***	***0.0742***
Formation	***Temperature (ºF)***	***SSP***	***Rw from Rwa***	***Rmf (laboratory)***
Zubair	***168***		***0.034***	***0.0742***

2.8.2 Apparent Resistivity Method (*Rwa)*:
Rwa is the apparent water resistivity of the formation determines from Archie's equation, that proposes clean water-bearing zone. ***Rwa*** is defined by the following relationship:

$$Rwa = Rt/F \tag{25}$$

In clean, water-bearing zones ***Rwa*** is at a minimum, roughly corresponding to ***Rw***, whereas in hydrocarbon-bearing zones the value is much higher (above three times ***Rw***) since in reality (***sw*** is well below unity and ***Rt*** high):

$$Rw = Rt.Sw \tag{26}$$
$$Rw = Rt.\ (Sw/F) \tag{27}$$

The value of ***Rwa*** is then plotted as a log versus depth hydrocarbon zones are characterized by high values of ***Rwa.*** **Fig. 3** represents **Rwa** results.

3. RESULTS AND DISCUSSIONS

3.1 Determination of Formation Water Resistivity *Rw* and Mud Filtrate Resistivity *Rmf:*

A precise knowledge of ***Rw*** and ***Rmf*** is essential in order to accurately determine the water saturation in virgin and flushed zones. It is, therefore important to take great care in its determination by matching and comparing the results obtained from various methods.

3.1.1 SP log

Table 1 involves the results of SP method.

3.1.2 Apparent Resistivity Method (*Rwa)*:
The value of ***Rwa*** is then plotted as a log versus depth hydrocarbon zones are characterized by high values of ***Rwa.*** **Fig. 3** represents **Rwa** results.

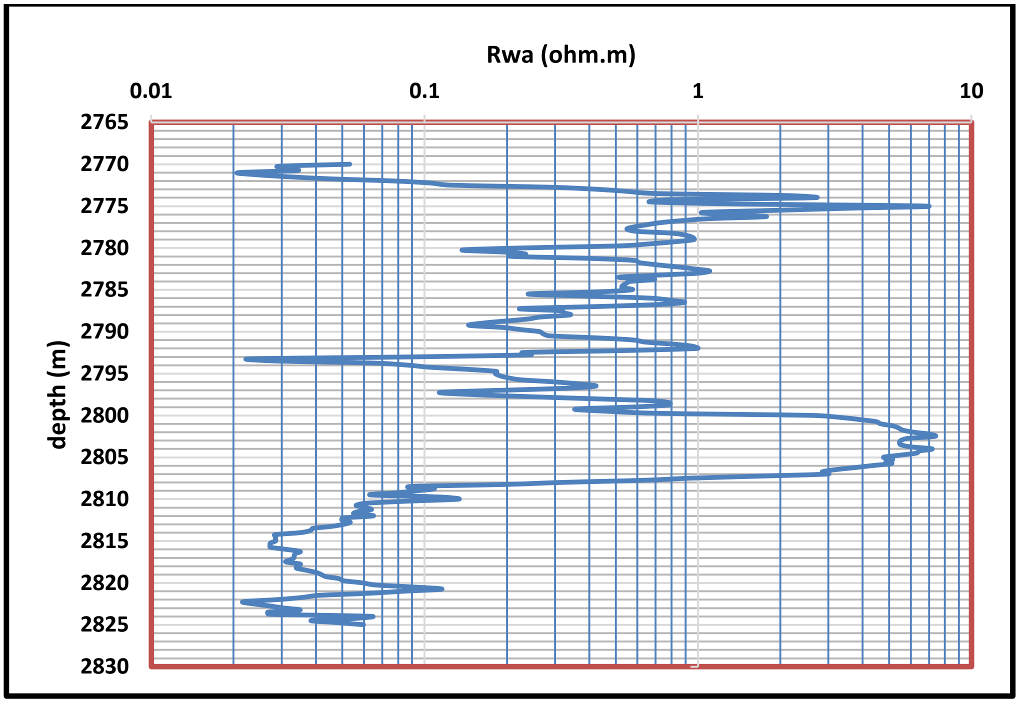

Figure 3. Rwa vs. Depth for Zubair formation in well LUHAIS.

3.2 Determination of Archie's Parameters: (Tortuosity factor, Porosity Exponent, and saturation exponent) by Crossplot Method (Pickett method):

This method is applied for each zone separately to calculate value for (m, n, and a) for each formation, As shown in **Fig. 4.** Also, **Table 2** shows the results of (a, m, and n) for all reservoir zones.

3.3 Calculation of Water Saturation:

ZONE 1: the results of water saturation for zone 1 by assuming constant and variable Archie parameters, is shown in **Fig. 5 and 6**.

4. DISCUSSION

1- The differences in Archie parameters from unit to unit and from well to well represent the heterogeneity of the investigated area.

2- From the M-N cross plot and MID plot, it was concluded that the formations in lug well consist mainly of sandstone although it is dolomitized in some places and contains little shale while in the neighboring wells the main matrix is dolomite. **Fig. 7** represents M-N plot.

3- Iraqi wells, which were analyzed by several CPI techniques have used fixed Archie coefficients, whereas these coefficients have different magnitudes especially in carbonate formations that change saturation of fluids. The fixed values of Archie factor produce low saturation of hydrocarbons in the formation studied, **Fig. 5 and 6.**

4- Variation of Saturation Exponent Due to Wettability Change: The results of the saturation exponent for all formations and give an indication of the water-wet system as the saturation exponent is near (2), **Table 2.**

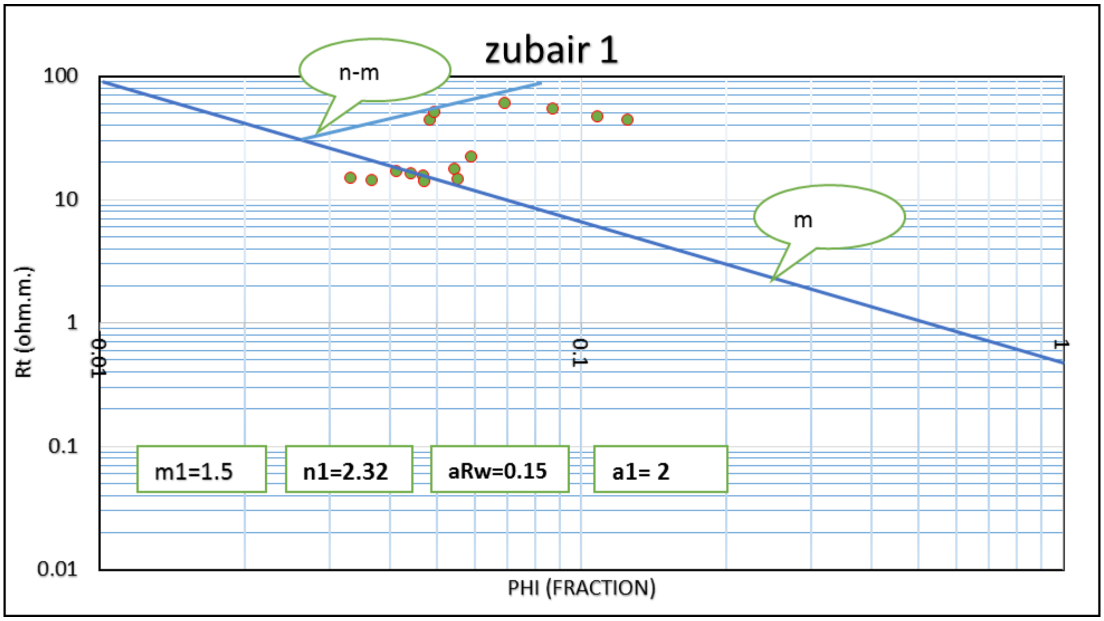

Figure 4. Calculation of (a,m,n) by Pickett plot.

Table 2. Results of the Pickett method in LUHAIS field.

Zubair formation	**m**	**n**	**A**
Zone 1	**1.5**	**2.32**	**2**
Zone 2	**1.65**	**2.42**	**2**
Zone 3	**2.52**	**2.56**	**0.61**
Zone 4	**1.97**	**1.95**	**1.23**
Zone 5	**1.65**	**1.82**	**1.22**

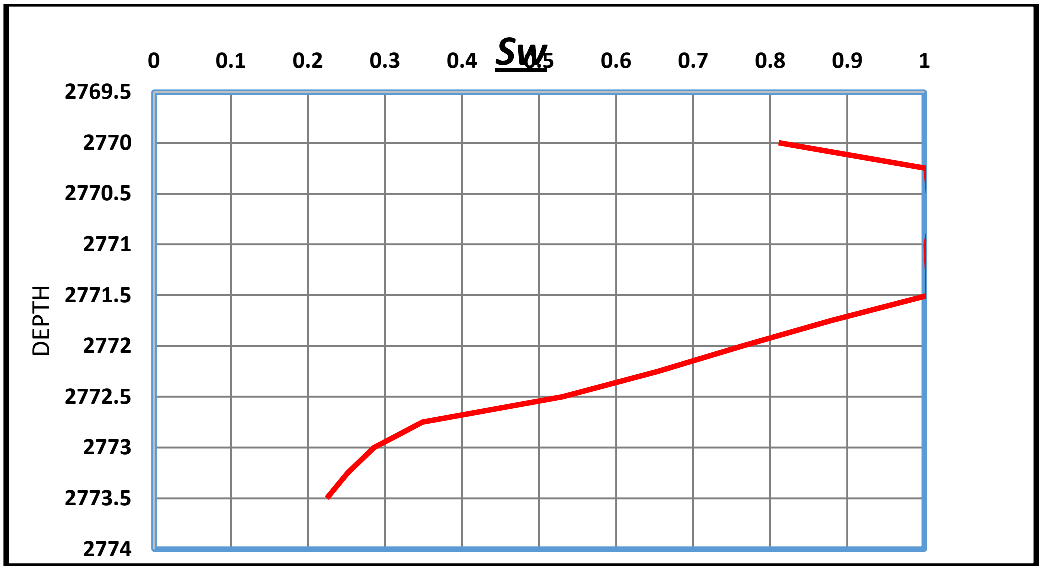

Figure 5. *Sw* vs depth for zone 1 (a=1, m=2, n=2)

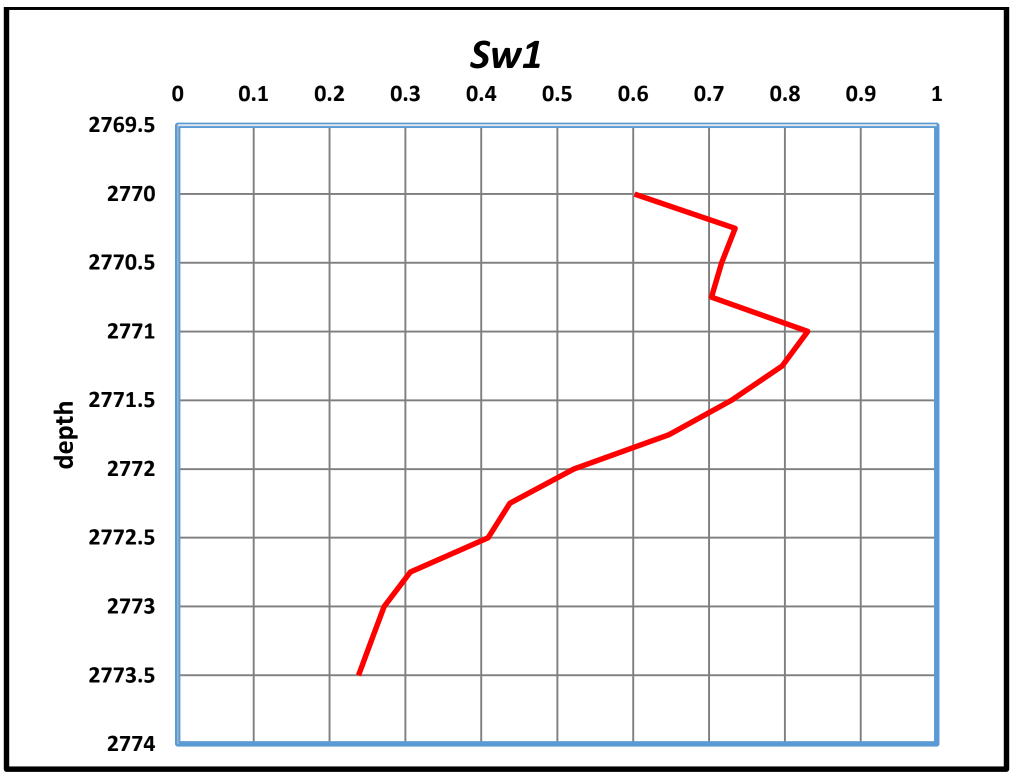

Figure 6. Sw vs depth for zone 1 (a=2, m=1.52, n=2.32).

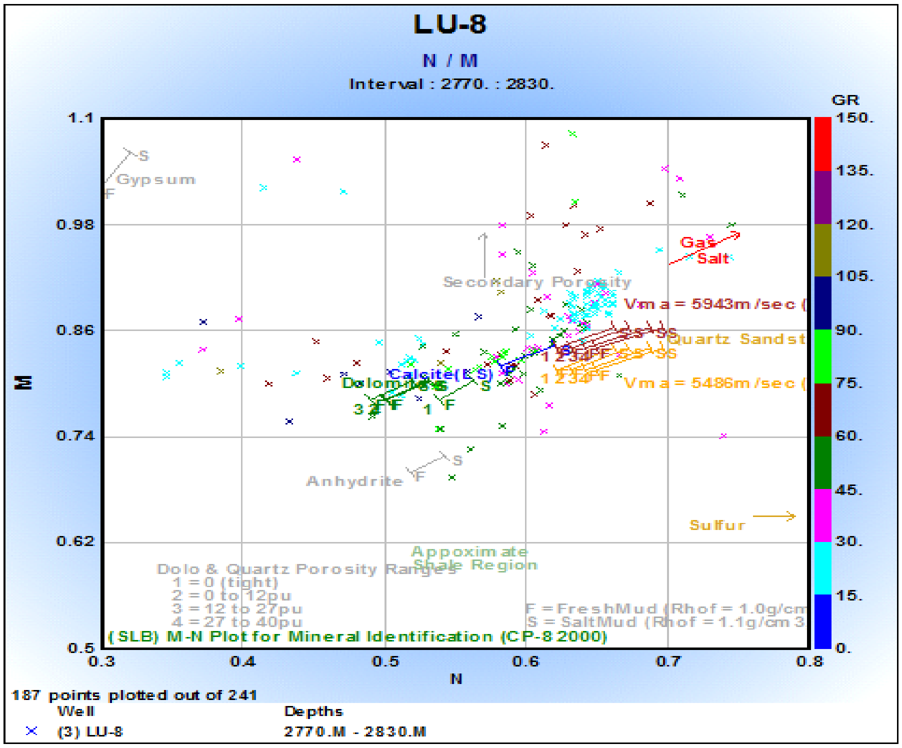

Figure 7. M-N Crossplot by IP.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Archie Parameters

1- **The values of porosity exponent (less than 2)** refer to that the Zubair formation is fractured.

2- **There are different values for porosity exponent in the same reservoir:** This phenomenon appears clearly in the reservoirs; in each zone can distinguish three intervals having different results for porosity exponent.

3- The appearance of heterogeneity porosity in rock texture for this region, which feeds these faults by fluids in reservoir this caused the ability of region to give high oil productivity.

4- Hydrocarbon and water region can be predicted by ***Rwa*** calculations; in water-bearing zones ***Rwa*** is at a minimum, roughly corresponding to Rw. Whereas in hydrocarbon-bearing zones the value is much higher (above three times ***Rw***).

5.2 Recommendations:

1. The results and findings of this study can be expanded further if lab measurements are applied.

2. The results of this study should be expanded to study how Archie's exponent Variations effect on the analysis and methods of calculation should be expanded to all Iraqi reservoirs. This could bring ranges for the water and hydrocarbon saturations that are even closer to those expected from core measurements

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