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Using Geophysical Well Logs in Studying Reservoir Properties of Zubair Formation in Luhais Oil Field, Southern Iraq

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Abstract

The characterizations of reservoir require reliable knowledge of certain fundamental reservoir properties. Log measurements can define or at least infer these properties: resistivity, porosity, shale volume, lithology, and water, oil, or gas saturation and permeability. The current study represents evaluation of petrophysical properties in well LU-12 for Zubair Formation in Luhais Oil Field, southern Iraq. The petrophysical evaluation was based on geophysical well logs data to delineate the reservoir characteristics of Zubair Formation. The available geophysical well logs such as (sonic, density, neutron, gamma ray, SP, and resistivity logs) are digitized using the Didger software. The environmental corrections and petrophysical parameters such as porosity, water saturation, hydrocarbon saturation, bulk water volume, etc. were computed and interpreted using Interactive Petrophysics program. Lithological, mineralogical and matrix identification studies were estimated using porosity combination cross plots. Petrophysical properties were determined and plotted as computer processing interpretation (CPI) using Interactive Petrophysics program. Zubair Formation in Luhais oil field is divided into three units according to petrophysical properties: Upper Zubair, Middle Zubair, and Lower Zubair. Middle Zubair is characterized by good porosity but high water saturation. Interpretation of well logs of Zubair Formation founds that Zubair Formation production in well LU-12 is noncommercial but present weak oil shows in some ranges of the formation especially in upper and lower Zubair units but middle Zubair is characterized by free oil shows .Lithological study of Zubair Formation appears that it consists mainly of interbedded sandstone, shale, and shale sandstone whereas mineralogy of Zubair Formation consists mainly of quartz sandstone and Some calcite.

Keywords: Zubair Formation, Luhais oil field, Petrophysical Properties

استخدام المجسات الجيوفيزيائية البئرية لدراسة الصفات المكمنية لتكوين الزبير في حقل اللحيس النفطي، جنوب العراق

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الخلاصة

تمثل الدراسة الحالية تقييم للخصائص البتروفيزيائية في بئر لحيس(12) تكوين الزبير في حقل لحيس النفطي–جنوب العراق.لقد اعتمد التقييم البترفيزيائي على بيانات المجسات الجيوفيزيائية للآبار لتوضيح الخصائص المكمنية لتكوين الزبير.ان المجسات البئرية المتوفرة مثل(الصوتية والكثافة والنيوترون وأشعة كاما و الجهد الذاتي و مجسات المقاومة النوعية) تم تحويلها الى قيم رقمية باستخدام برنامج (Diger). لقد اجريت

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التصحيحات البيئية كما ان المعاملات البتروفيزيائية مثل المسامية والتشبع المائي والتشبع الهيدروكاربوني وحجم الماء التراكمي الخ تم حسابها باستخدام برنامج(Interactive Petrophysics). اجريت دراسات تشخيصية للصخارية و للمعدنية ولمادة الحشوة وذلك باستخدام اسقاط التقاطع المشترك للمسامية.ورسمت الخصائص البتروفيزيائية على شكل تفسير المعالجة الحاسوبية(CPI) باستخدام برنامج(IP).قسم تكوين الزبير في حقل لحيس النفطي الى ثلاث وحدات اعتمادا على الخصائص البتروفيزيائية : الزبير الاعلى والزبير الاوسط و الزبير الاسفل.يمتاز الزبير الاوسط بمسامية عالية ولكن بتشبع مائي عالٍ.ان تفسيرات المجسات البئرية الجيوفيزيائية لتكوين الزبير اوضحت بأن الانتاج في بئر لحيس(12) غير اقتصادي ولكن توجد هنالك مشاهدات ضعيفة في بعض مديات التكوين و خاصة في وحدتي الزبير الاعلى و الاسفل. يمتاز الزبير الاوسط بمشاهدات لنفط حر.اظهرت دراسة صخارية تكوين الزبير انه يتكون بشكل رئيسي من تطبقات للحجر الرملي والطفل و الحجر الرملي الطفلي بينما تتكون معدنية تكوين الزبير بشكل رئيسي من الحجر الرملي الكوارتزي و بعض الكالسايت.

Introduction

Zubair Formation is the most important formation of the Lower Cretaceous depositional cycle in Iraq [1]. It is widespread in the Arabian Gulf region as well as in Syria and Iran [2]. Petrophysical properties are the study of rock properties and their interactions with fluids (gases, liquid hydrocarbons and aqueous solutions). Well logging is the technique of making petrophysical measurements in the subsurface earth formations through the drilled borehole in order to determine both the physical and chemical properties of rocks and the fluid they contain [3]. The objective is to locate, define, and produce hydrocarbons from a given reservoir and it is also known as formation evaluation. Due to the enormous amount of data well logging can provide, the technology plays a pivotal role in hydrocarbon exploration and production industry. These techniques can be used in all phases of hydrocarbon exploration and production process. Rapid and sophisticated development in well logging technology has revolutionized the hydrocarbon industry [4].

The main purpose of this study is to make use of all the available sets of well logs data acquired from LU-12 well of Luhais oil field to determine the petrophysical and lithological properties for each zones in Zubair Formation. This study deals with pre-interpretation and the internal properties of Zubair Formation. The study includes two steps, the pre-interpretation and the interpretation. The pre-interpretation includes the determination of effective porosity (corrected to shale effects) and all the parameters that are required in the interpretation processes. The interpretations were made using **Interactive Petrophysics Program v3.5 (**an interactive program to carry out interpretations and log corrections for borehole environment and invasion effects).

Study Area

Luhais oil field is located at about (50Km) southwest of North Rumaila oil field in the Basrah city, southern Iraq. The field lies approximately between (47º, 47 ` 14 º, 19`) Latitude and (30º, 30 ` 13 º, 24`) Longitude Figure-1. Many wells were drilled in Luhais oil field since 1973 to determine the Structural configuration and facies distribution of the reservoir rocks [5]. Morad et. al. (1989) [6] mentioned that Luhais oil field represents a gentle anticline fold and the main producing formations in this field are Zubair and Nahr Umr Formations. Zubair Formation in Luhais oil field appears at depths ranging between (2777-3227 m) and its total thickness in the type section reaches about 450 m in well LU3. It consists of interbedded sandstone, siltstone and shale, and sometimes with carbonate rocks especially in the upper part of the formation. [5]. The age of the formation, as determined on the basis of both fossils and regional correlation, is Hauterivian till Early Aptian [7], while palynomorphs evidences extended this formation up to earliest Albian age [8]. It is introduced to designate the prevalently terrigenous clastics and oil bearing sequences of the southern Iraqi fields [2].The lower and upper contacts of the Formation are mostly gradational and conformable in the central part of the basin, but towards the west in the Salman Zone, the lower boundary of the Formation is unconformable and the upper boundary with the overlying Albian sequences is unconformable [9]. The underlying formation is the Ratawi Formation which consists of dark, slightly pyritic shales interbedded with pseudo-ooliticdetrital limestone and it is overlain by Shuaiba Formation which consists of dolometic limestone [7].

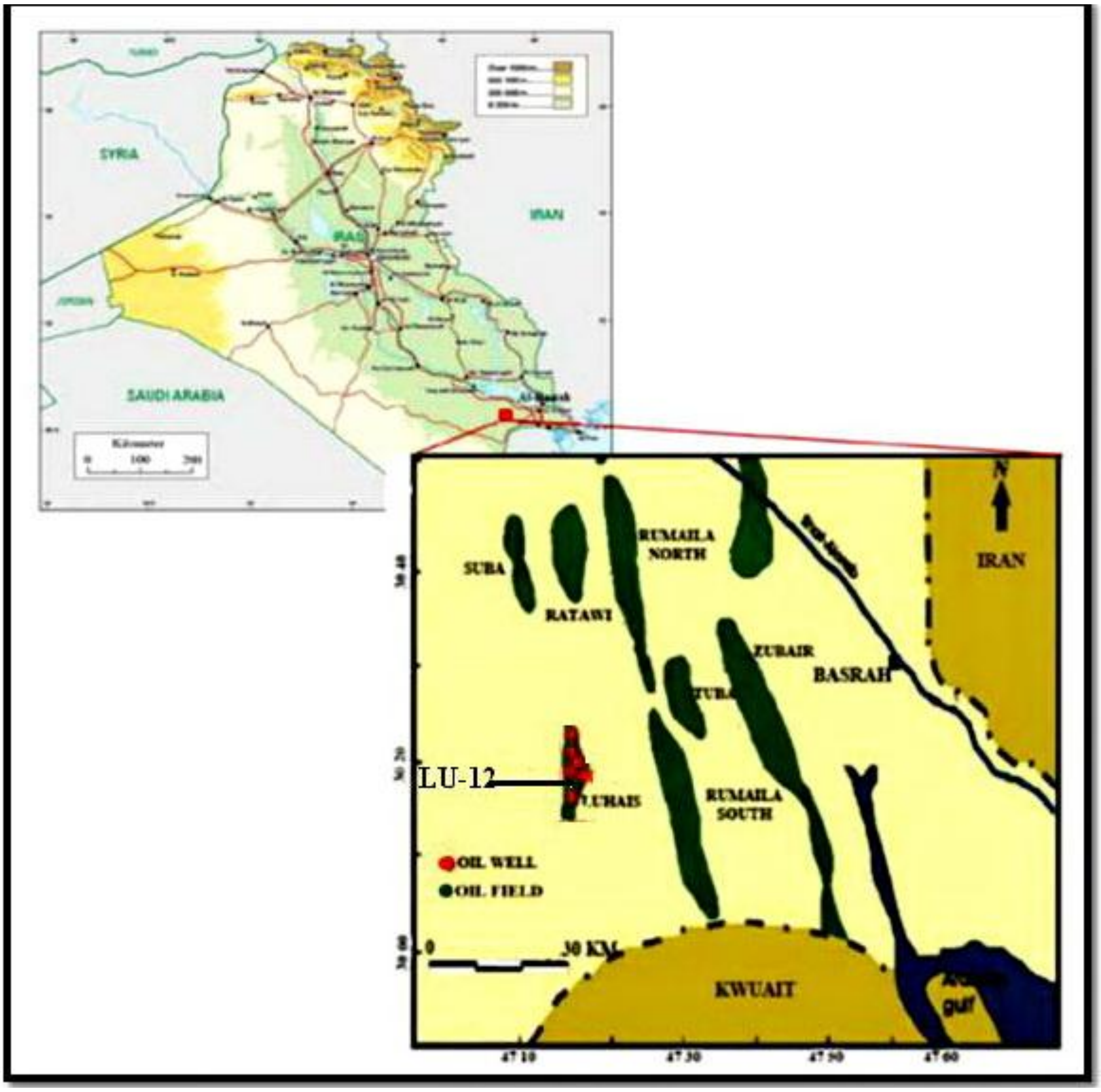

Figure 1- Location map shows the studied well within Luhais oil field [5].

Methodology

To delineate the mentioned aims of the study, data from the available open hole logs such as (Calliper log, Spontaneous Potential, Gamma Ray, Density, Sonic, Neutron and Resistivity logs) of studied wells were used. The available open hole logs data were digitized in order to be imported into the appropriate software for analysis and interpretation, Didger V.4 software was used in this very first step. One reading per 0.25m depth is selected for recording the input data measurements. The proper corrections (i.e. Shale effect, borehole conditions, depth of invasion, etc) for Gamma ray , neutron, density and resistivity log , were applied before commencing the open hole well log analysis as based on Schlumberger's well log analysis basic Corrections using **Interactive Petrophysics Program v3.5** which present in figure-2 that show corrected well logs for well LU-12. **Interactive Petrophysics Program v3.5** was used for well logs analysis and plotted to evaluate petrophysical properties of Zubair Formation in Luhais oil field.

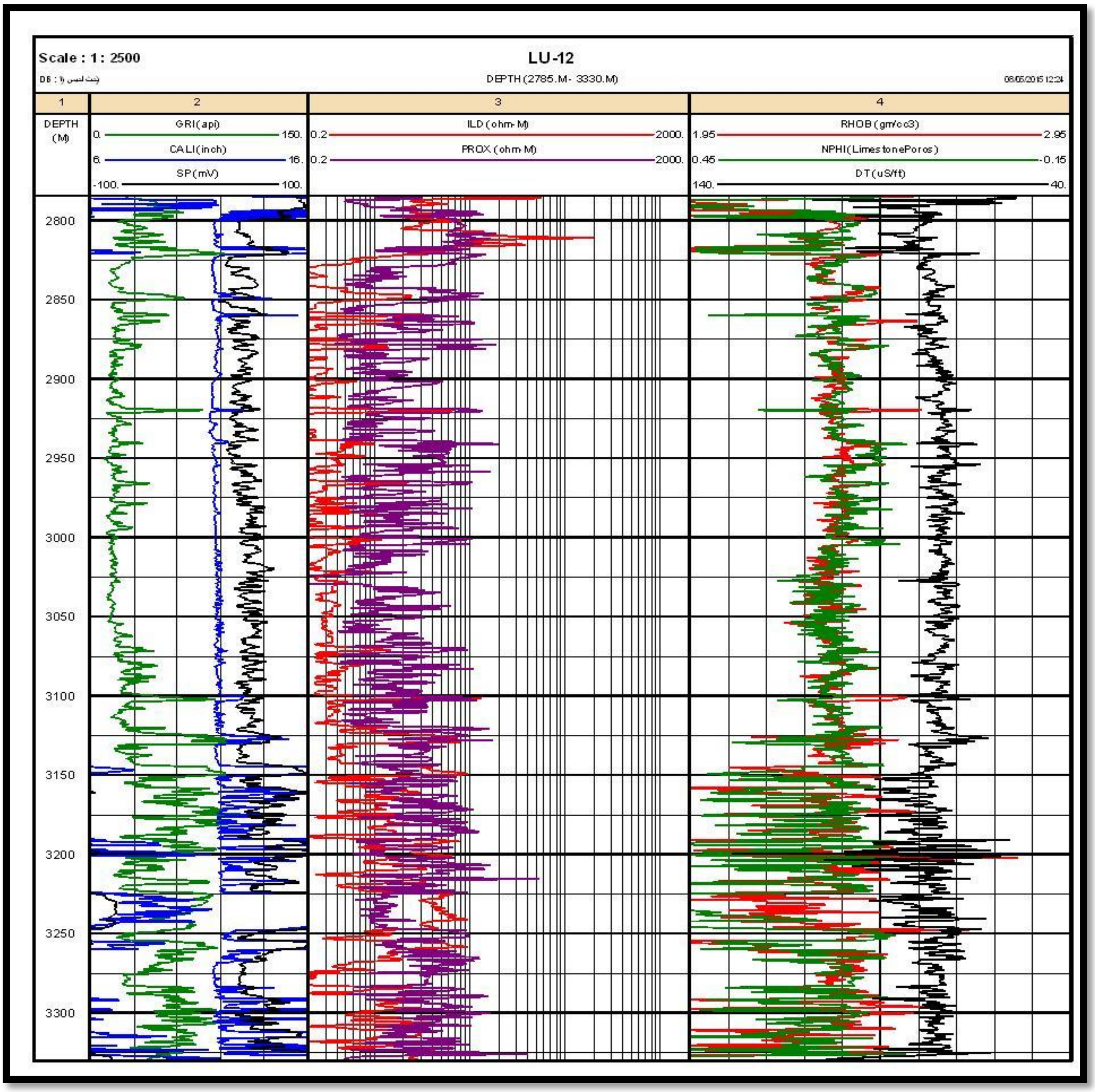

Figure 2- Corrected well logs (Density, Neutron, Sonic, Gamma Ray, and Resistivity logs) for LU-12 in Zubair Formation.

Properties of Reservoir:

For determining reservoir properties of Zubair Formation, petrophysical parameters must be obtained and evaluated. These parameters include:

A- Volume of shale (Vsh): To derive Vsh from gamma ray (GR Log), it is imperative that the gamma ray index (IGR), determined by using equation of Schlumberger (1974) [10]

$IGR = (GRlog - GRmin) / (GRmax – GRmin)$ (1)

Where: GRlog = gamma ray reading of formation; GRmin = minimum gamma ray reading (clean sand or carbonate): GRmax = maximum gamma ray reading (shale). For the purpose of this work, the formula of Dresser Atlas (1979) [11] for older rocks was used to determine the shale volume

$Vsh = 0.33 * [2 (2*IGR) – 1]$ (2)

B- Porosity: Total porosity within Asmari Formation was determined from combination of Neutron – Density derived porosities. Neutron log measure the direct porosity after corrected based on the equation of Tiab & Donaldson (1996) [12]

$ØNcorr = ØN – (Vsh * ØNsh)$ (3)

Where ØNcorr. = corrected porosity is derived from Neutron log for no clean rocks**:** ØNsh = Neutron porosity for shale. Density porosity is derived from the bulk density of clean liquid filled formations when the matrix density (ρma) and the density of the saturating fluids (ρf) are known, using Wyllie *et al.*, (1958) [13] equation

$$ØD = (\rho ma – \rho b) / (\rho ma – \rho f) \quad (4)$$

Where ρma = density of matrix (2.71 gm/cm3 for limestone, 2.87 gm / cm3 for dolomite, 2.61 gm / cm3 for sandstone), ρf = density of fluid (1 gm/ cm3 for fresh water, 1.1 gm/ cm3 for saline water).
In intervals, whose shale volume is more than 10%, we used equation (5) to remove shale effect from porosity calculation

$$ØDcorr = ØD – (Vsh * ØDsh) \quad (5)$$

Where ØDcorr. = corrected porosity is derived from Density log for no clean rocks**:** ØDsh = density porosity for shale.
Total porosity (Øt) is then calculated as follows

$$Øt = (ØN + ØD) / 2 \quad (6)$$

The effective porosity (Øe) is then calculated, using equation of Schlumberger (1998) [14] after total porosity corrected from shale volume

$$Øe = Øt * (1-Vsh) \quad (7)$$

Sonic log (Δt) based on Wyllie time- average equation (8) was used to determine primary porosity

$$ØS = (\Delta tlog - \Delta tma) / (\Delta tfl - \Delta tma) \quad (8)$$

Δt is increased due to the presence of hydrocarbon. To correct for hydrocarbon effect, Hilchie (1978) **[15]** suggested the following empirical equations:

$$Ø = ØS * 0.7 \text{ (gas)} \quad (9)$$

$$Ø = ØS * 0.9 \text{ (oil)} \quad (10)$$

Then, in order to correct sonic porosity from shale effect within formation, the following equation is used

$$ØScorr = ØS – (Vsh* ØSsh) \quad (11)$$

Where ØS = sonic derived porosity: Δtlog = interval tansit time in the formation; Δtma = interval transit time in the matrix; Δtfl = interval transit time in the fluid in the formation; ØSsh = apparent porosity of the shale; ØScorr = corrected sonic porosity.

Secondary porosity index (SPI) was computed by the difference between total porosity and the primary porosity (that is determined from sonic log) after made corrections for shaliness and hydrocarbon effect

$$SPI = (Øt – Øscorr) \quad (12)$$

C- Water and Hydrocarbon Saturation:

Water saturation for the uninvaded zone was calculated according to Archie (1942) [16]:

$$Sw = \{(a * Rw) / (Rt * \_m)\}^{1/n} \quad (13)$$

Water saturation in the invaded zone (Sxo) can be simply calculated from the same equation above by replacing Rw with Rmf (mud filtrate resistivity available from well log headers) and Rt with Rxo (measured resistivity of the invaded zone):

$$Sxo = \{(a * Rmf) / (Rxo * \_m)\}^{1/n} \quad (14)$$

Where: Rw = Resistivity of water formation that is previously determined from SP log. a = tortuosity factor; m = cementation factor; n = saturation exponent.
Than can be calculating the hydrocarbon saturation, by using the following equation:

$$Sh = 1 – Sw \quad (15)$$

Moveable hydrocarbon saturation was calculated based on Schlumberger (1998) [14] equation:

$$MOS = Sxo - Sw \quad (16)$$

Whereas residual oil saturation was calculated from Schlumberger (1987) [17] as follows equation:

$$ROS = 1 - Sxo \quad (17)$$

D- Determination of Archie's Parameters (a,m,n) Using Pickett Plot:

Archie (1942) [16] provided a path from qualitative log interpretation to quantitative log analysis through an equation that required parameters which were not available from logs, and which, in the time before calculators and computers, required some effort to solve. Aware of ability of people to recognize pattern, Pickett, (1966) [18] developed a graphical solution to Archie's equation which allowed the quick determination of water saturation by observation of the data, and without the need for numerical calculations. As calculators and computers became available, the primary function of those two methods has turned from the quick prediction of water saturation to the prediction of calculation parameters to be used in faster and more detailed interpretation methodologies [19].

In this study Pickett's plot method has been used in the determination of Archie's parameters from well log using Interactive Petrophysics software (V.3.5). It is a graphical solution to Archie equation that involves plotting true or deep resistivity (Rt) against porosit φ) oth on logarithmic scale.

Archie's coefficients (a, m, and n), which are more sensitive to pore type, should be determined for different types of carbonate rocks. Classic petrophysics holds that Archie's parameters are constant for a given sample of reservoir rocks, but an increasing number of cases are being encountered where these coefficients have been observed to vary, that's why many techniques where used to determine Archie parameters [19]

According to Pickett, (1966) [18]:

$$\mathbf{R_t} = \frac{\mathbf{a}}{\boldsymbol{\varphi}^{\mathbf{m}}} \frac{\mathbf{R_w}}{\mathbf{S_w^n}} \quad (18)$$

Where,

S_w: the water saturation (fraction),

R_w: the water resistivity (ohm-m),

R_t : formation resistivity (ohm-m), and,

a, n, and m: Archie’s parameters (dimensionless).

Rearranging the equation will produce linear arrangement of data as following:

$$\log R_t = -\, m \log\varphi + \log a\, R_w - n \log S_w \quad (19)$$

If Sw = 100% (in water bearing zones), the equation will be reduced to:

$$\log Rt = -\, m \log\varphi + \log a\, Rw \quad (20)$$

Equation (20) is an equation of a straight line on log-log plot, where m is the slope and (a.Rw) is the intercept at φ=1. As Rw is known from other sources, (a) may be easily found. There are, however, some limitations regarding the application of Archie’s formula that may be summarized as follow:The

1- The method requires the presence of water zone.

2- The values of (m) and (a) are averaged for the selected formation.

Figure-3 shows the result of Pickett plot of Luhais oil field in well (LU-12). It shows that the data give the same trend for well under study where m is the slope and (a* R) is the intercept at φ=1 and as for Rw it was calculated earlier. Values of a, m, and n have been calculated by drawing a straight line within the water zone by using Interactive Petrophysics software v.3.5.

E- Bulk Volume Analysis

Bulk volume of water (BVW) is the product of formation water saturation (Sw) and its porosity [20].

$$BVw = Sw * Ø \quad (21)$$

Also the bulk volume of water in the invaded zone is calculated as follow:

$$BVxo = Sxo * Ø \quad (22)$$

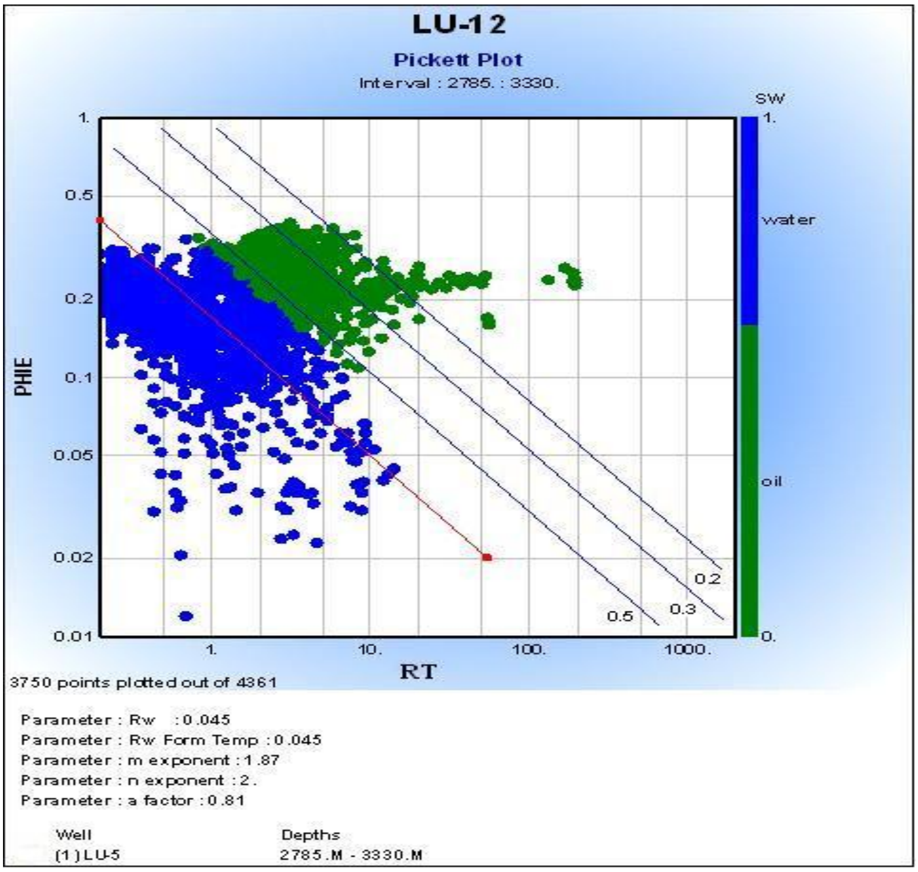

Figure 3- Pickett plot for Zubair Formation in LU-12.

Porosity Combinations Cross Plots:

The porosity combinations cross plots (Density vs. Neutron Cross Plot, M-N , and Matrix Identification (MID) Cross Plot) were used to identify main lithology, mineralogy, and matrix of Asmari Formation according to Schlumberger (2005) [21] equations:

For M-N cross plot:

$$M = (\Delta tfl - \Delta tlog) / (\rho b - \rho f) \times 0.01 \quad (23)$$

$$N = (\text{Ø}Nf - \text{Ø}N) / (\rho b - \rho f) \quad (24)$$

Where: Δtf = interval transit time in fluid =189 (m/s) for fresh water = 185 (m/s) for salt mud.

Δt = interval transit time (the log reading).

Pb = formation bulk density (the log reading).

Pf= fluid density 1 (g/cm3) for fresh water or 1.1 (g/cm3) for salt mud.

ØNf = neutron porosity for fluid =1.

ØN = neutron porosity.

For Matrix Identification (MID) Cross Plot:

$$Rhomaa = (\rho b - \text{Ø}ta\,\rho f)/(1 - \text{Ø}ta) \quad (25)$$

$$\Delta tmaa = (\Delta t \log - \text{Ø}ta\,\Delta tf)/(1 - \text{Ø}ta) \quad (26)$$

Where: Rhomaa : apparent density of matrix (gm/cc), Δtmaa : apparent transit time in rock matrix (µsec/ft), and, φta : is the apparent total porosity.

Results and Discussions:

Figure-4 represents computer processed interpretation (CPI) of well LU-12 that has been deduced using Interactive Petrophysics (IP) software. The Figure shows the full interpretation process as following:

1. The lithology track: This represents the effective porosity (PHIE), percentage of shale (Vshale), and percentage of Matrix (sandstone bed).

2. Fluid analysis track: that represents the effective porosity (PHIE), water filled porosity in the invaded zone (BVWXO), and water filled porosity in the un-invaded zone (BVW). Notice that:

- The zone between (PHIE) and (BVWXo) represents the residual hydrocarbons.
- The zone between (BVWXo) and (BVW) represents the movable hydrocarbons.

-The zone between (PHIE) and (BVW) represents the total hydrocarbons.
3. Saturation track: represents the water saturation in the flushed and un-invaded zone.
4. Porosity track: represents the total porosity and secondary porosity.
5. Hydrocarbon saturation: represents the hydrocarbon saturation in Zubair Formation.

The figure shows that Zubair Formation was divided into three members based on petrophysical properties: upper Zubair, middle Zubair, and lower Zubair. In the type section of Zubair Formation in south Iraq Zubair Formation was divided into five members: Upper shale Member, Upper sand Member, Middle shale Member, Lower sand member, and Lower shale member .In Luhais oil field,because of the absence of the middle shale member which leads to combination of the lower and upper sand members to form middle sand member [22].

Computer processed interpretation (CPI) of well under study shows that upper Zubair member has a thickness of about 41.5 m and it is characterized by shale volume ranges between (0.027- 0.725) whereas effective porosity ranges between (5%-39%) and water saturation between (5- 95%) with average value about 47% which indicates that upper Zubair member is characterized by weak oil show.

The middle Zubair member has a thickness of about 296m and it is characterized by shale volume ranges between (0 - 0.652) with average value about 6% whereas effective porosity ranges between (2%-32%) and water saturation between (26- 100%) which indicates that upper Zubair member is characterized by low shale but high porosity and water saturation without any oil show.

The lower Zubair member has a thickness of about 207m and it is characterized by shale volume ranges between (0.021-1) with average value of about 0.319 whereas effective porosity ranges between (2-37%) with average value about 18.5% and water saturation about 77% which indicates that lower Zubair member is not a good reservoir.

Figure-5 shows that the lithology of Zubair Formation in Luhais field consists mainly of sandstone, whereas Figure-6 of (M-N) crossplot shows that mineralogy of Zubair Formation consists mainly of quartz sandstone with few amounts of calcite. Figure-7 of MID crossplot shows that the matrix of Zubair Formation is consisting of calcite and quartz.

Conclusions:

According to this study and depending on the petrophysical properties of Zubair Formation in Luhais oil field, Zubair Formation is divided into three members: Upper, Middle and Lower members. The upper Zubair member has a thickness of about 41.5 m but Lowe Zubair about 207m while Middle member has the highest thickness in Zubair Formation. It is about 296m. According to Computer processed interpretation (CPI), Zubair Formation is characterized by porosity ranges from (2-39 %) whereas water saturation ranges from (5-100 %) but shale volume ranges from (0.0021-1). In general, Zubair Formation is characterized by a high porosity and water saturation. It is found that Zubair Formation in well LU-12 is not oil production but may be present weak oil shows in some ranges of the formation, especially in upper and lower Zubair units, but middle Zubair is characterized by free oil shows .Lithological study of Zubair Formation appears that it consists mainly of interbedded sandstone, shale, and shale sandstone, whereas the mineralogy of Zubair Formation consists of quartz sandstone and some calcite.

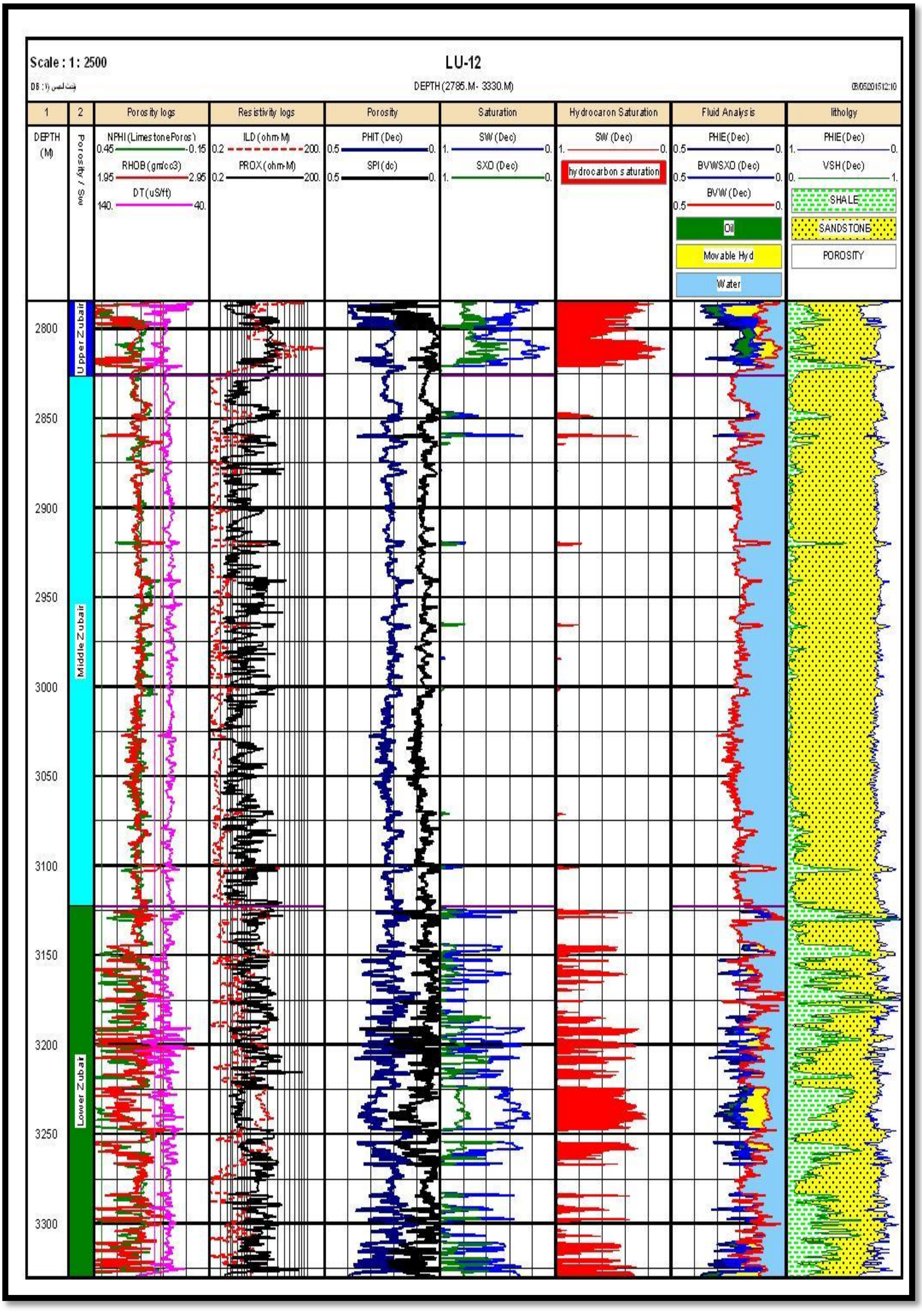

Figure 4- Computer processed interpretation (CPI) for Zubair Formation in well Lu-12.

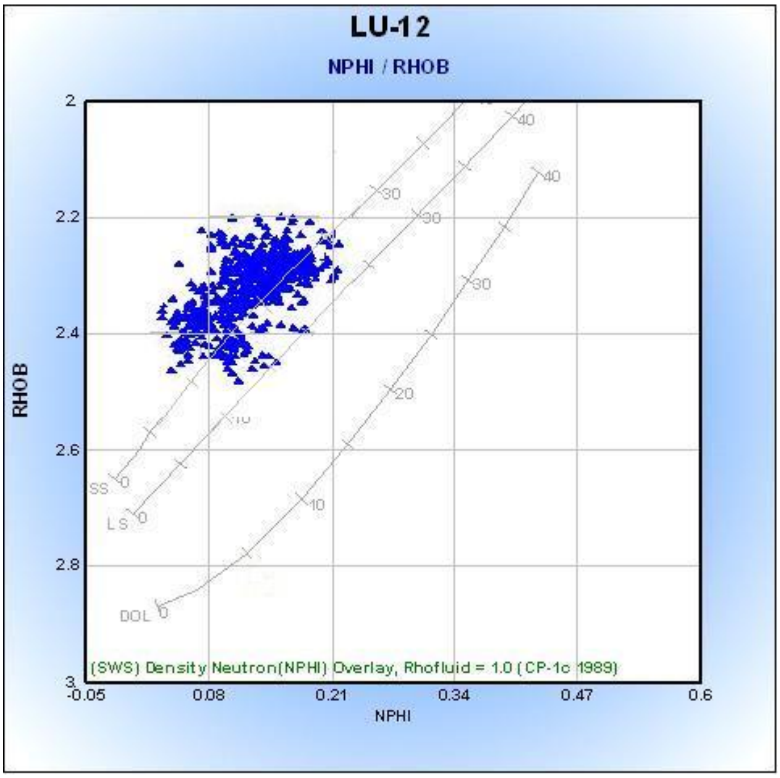

Figure 5- Neutron – Density crossplot for Zubair Formation in well LU-12.

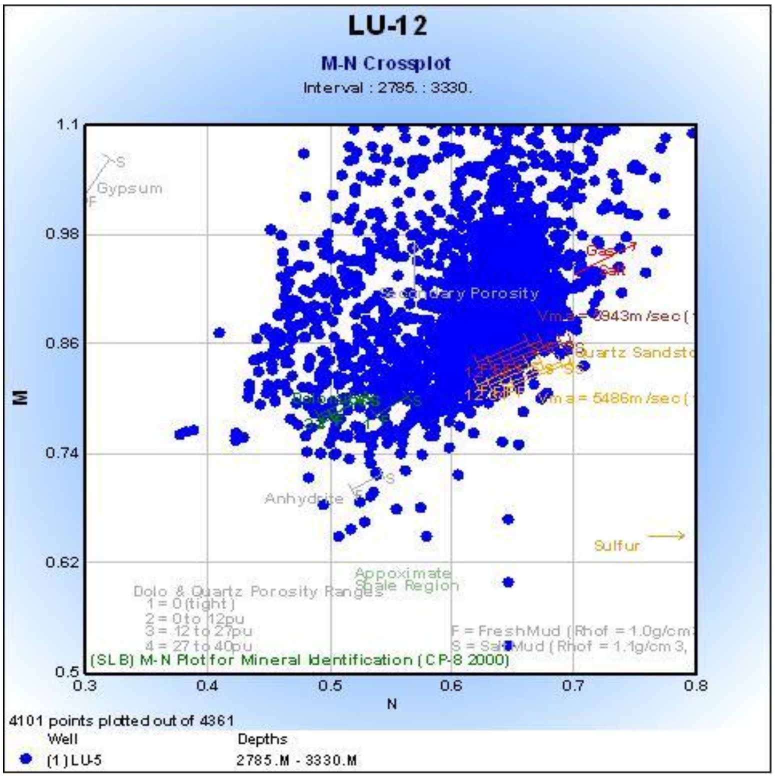

Figure 6- M-N crossplot for Zubair Formation in well LU-12.

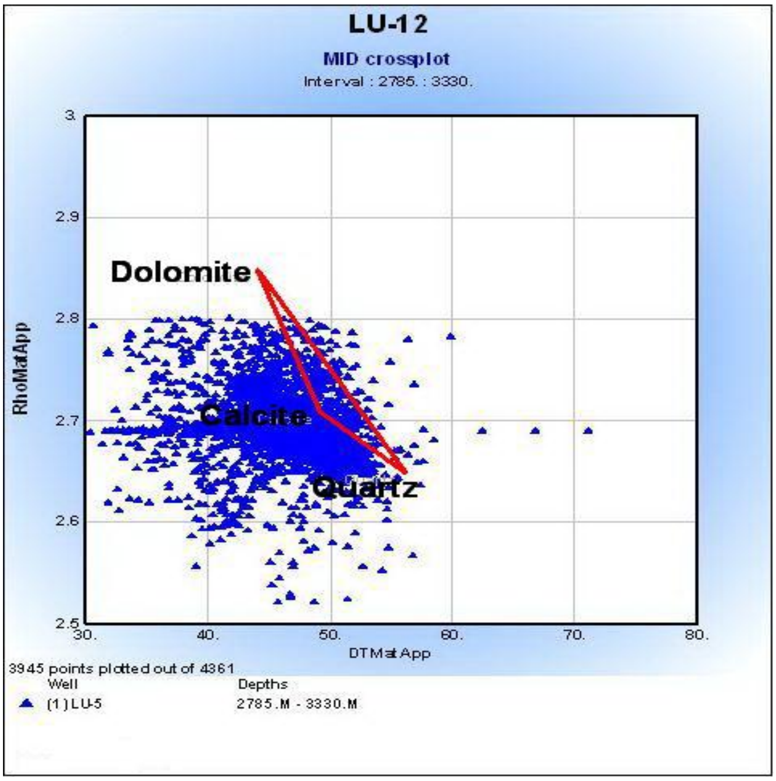

Figure 7- MID crossplot for Zubair Formation in well LU-12.

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