



Petrophysical Properties of the Zubair Formation Units Using Well Logs of X Well, North Rumaila Oilfield, Southern Iraq

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ABSTRACT

The Zubair Formation represents the main pay of the Rumaila oil field. The determination and calculation of petrophysical properties are essential for improving our understanding of the reservoir, identifying potential economic opportunities, and reducing uncertainty in the reservoir model to optimise all field operations. The interpretation of the petrophysical properties of the Zubair Formation in the Rumaila oil field is done using the well logging data of X well. The well logs data are digitised using Neuralog software. The calculations and data representation are done using Interactive Petrophysics (IP). The main lithology of the Zubair Formation was identified as a sandstone with thick and thin shale layers based on the mud logging report, Neutron-Density, and M-N cross plots. The volume of shale is estimated as (25.35%) in X well. The interpretation of well logs data showed excellent effective porosity and is very close to total porosity. The average reservoir permeability in the X well is (416.8 mD). The saturation calculations show that the Zubair Formation has good accumulations of hydrocarbons, with an average oil saturation is 52.5%.

الخصائص البتروفيزيائية لوحداث تكوين الزبير باستخدام سجلات الآبار للبئر X ، حقل الرميطة الشمالي النفطي، جنوب العراق

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معلومات الارشفة	الملخص
تاريخ الارشفة: تاريخ الاستلام: سبتمبر 18، 2024 تاريخ المراجعة: يونيو 16، 2025 تاريخ القبول: يونيو 24، 2025 تاريخ النشر الإلكتروني: يوليو 1، 2025	يمثل تكوين الزبير الطبقة الخازنة الرئيسة لحقل الرميطة النفطي . تُعد عملية تحديد وحساب الخصائص البتروفيزيائية أمراً بالغ الأهمية لفهم الخزان بصورة أفضل، واستكشاف الفرص الاقتصادية المحتملة، وتقليل درجة عدم اليقين في نماذج المكمن بهدف تحسين كافة العمليات التشغيلية في الحقل. تم تفسير الخصائص البتروفيزيائية لتكوين الزبير في حقل الرميطة النفطي باستخدام بيانات تسجيل الآبار للبئر X ، حيث جرى رقمنة بيانات سجلات الآبار باستخدام برنامج Neuralog، في حين أُجريت الحسابات وتحليل البيانات باستخدام برنامج Interactive Petrophysics (IP). تم تحديد الصخور الرئيسة لتكوين الزبير على أنها حجر رملي يتخلله طبقات سجيلية رقيقة وسميكة، وذلك بناءً على تقرير تسجيل الطين (Mud Logging) ومخططات تقاطع مجسي النيوترون والكثافة و M-N. قُدر حجم الطين (Volume of Shale) في البئر X بنسبة (25.35%). أظهرت نتائج تفسير بيانات سجلات الآبار وجود مسامية فعالة ممتازة تقترب قيمتها بشكل كبير من المسامية الكلية. وقد بلغ متوسط نفاذية المكمن للبئر X حوالي 416.8 ملي دارسي (mD). كما أظهرت حسابات التشبع وجود تراكعات جيدة للهيدروكربونات في تكوين الزبير، إذ بلغ متوسط تشبع النفط نحو 52.5%.
الكلمات المفتاحية: الخصائص الممكنية تقييم التكاوين الخصائص البتروفيزيائية تكوين الزبير حقل الرميطة النفطي	
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Introduction

The Zubair Formation is the most crucial in Iraq's Lower Cretaceous sequences (Al-Sayyab, 1989). It was first introduced in the Zubair oil field by Glynn Jones in 1948, and then it was modified by Nasr and Hudson in 1953 (Bellen et al., 1959). It is widely prevalent in Iran, Syria, and the Arabian Gulf region (Buday, 1980). Lithologically, Dark grey shale, siltstone, and alternating course to fine-grained sandstone make up the Zubair Formation in central and southern Iraq (Bellen et al., 1959). From the Tikrit-East Baghdad field in central Iraq, the formation stretches southward toward the Iraqi-Kuwaiti border and continues through the Arabian Gulf in the southern region of the Mesopotamian zone of Iraq. It may be as high as 500 meters in the part south of Baghdad, and it is thinning in both directions—eastward into the Zagros Fold Belt and westward toward the Euphrates River. Based on fossil and regional correlation, the formation's age was estimated to be Hauterivian to Early Aptian, while palynomorph evidence brought this formation back to the early Albian age (Bellen et al. 1959). In southern and central Iraq, the Zubair Formation is overlain conformably by the Aptian Shuaiba Formation (Al-Ameri and Batten, 1997). The Shuaiba Formation, which is composed of dolomitic limestone, lies on top of the Zubair Formation, while the Ratawi Formation lies under it and is composed of dark, somewhat pyretic shales interbedded with pseudo-oolitic detrital limestone (Bellen et al., 1959). According to Harris et al. (2012) and Al-Muhailan et al. (2013), the Zubair Formation is formed from the deposition of interbedded shales and sandstone in delta and fluvial settings. The Formation has been divided into five lithological components made of sand and shale in the type section. These components are upper shale (USM), upper sandstone (USSM), middle shale (MSM), lower sandstone (LSSTM), and lower shale (LSM) (Fig. 1). In the formation, the sandstone reduces to the northeast while the shale portion rapidly falls to the southwest (Jassim and Goff, 2006; Wells et al., 2019). The study by Aldouri et al. (2025) identified ten reservoir units based on porosity, permeability, and fluid types of the Tuba oil field, Basra Governorate (Aldouri et al., 2025). The Rumaila oilfield is located about 50 km to the west of Basra city, southern Iraq (Fig. 2). According to Beydoun (1988), the reserves of the Rumaila oilfield were estimated at about 17 billion barrels. The Rumaila field is represented by a gentle, slightly asymmetrical anticline about 70km long and 10km wide. The structure trends nearly north-south, and it is considered to be made up of two domes. The northern Rumaila Dome is larger and structurally lower than the southern one (Jawzi and Associates, 2005). The whole Rumaila Field produces oil from the Lower Cretaceous Zubair sandstones (35° API gravity oil with 2% sulphur) and has a heavier oil accumulation in the Cenomanian-Turonian reefal carbonates of the Mishrif Formation (Jawzi and Associates, 2005; Jassim and Goff, 2006).

Location of Study

The Rumaila oilfield is situated in Basrah, southern Iraq, and approximately 50 kilometres northeast of the North Rumaila oilfield (Fig.2). The North Rumaila oilfield is situated within the Zubair sub-zone. The presence of several longitudinal folds is what sets this sub-zone apart. According to Jasim and Goff (2006), these fold tendencies are NS and NW to SE and contain large oil reserves in the Basra area. In the Late Cretaceous, these folds were finally surrounded by a linear and narrow anticline.

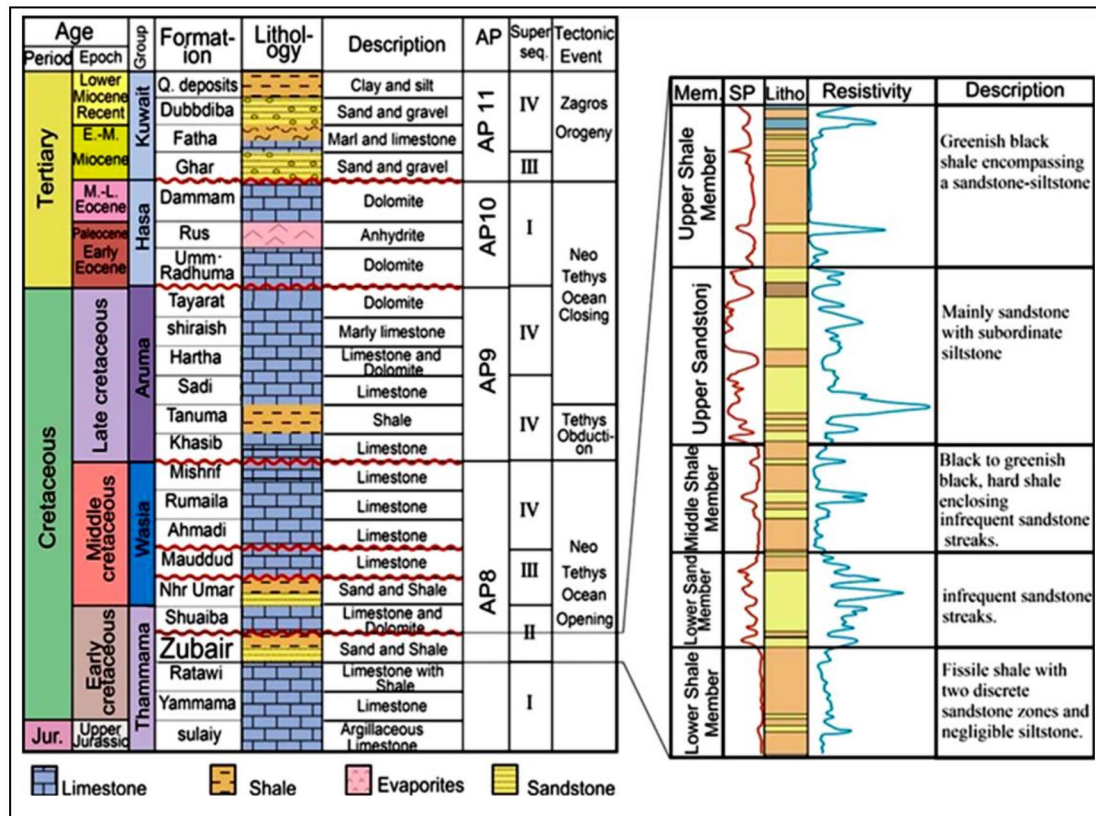


Fig. 1. Left: The stratigraphical and lithological section in southern Iraq. Right: Stratigraphic section of the Zubair Formation (Aqrawi et al., 2010).

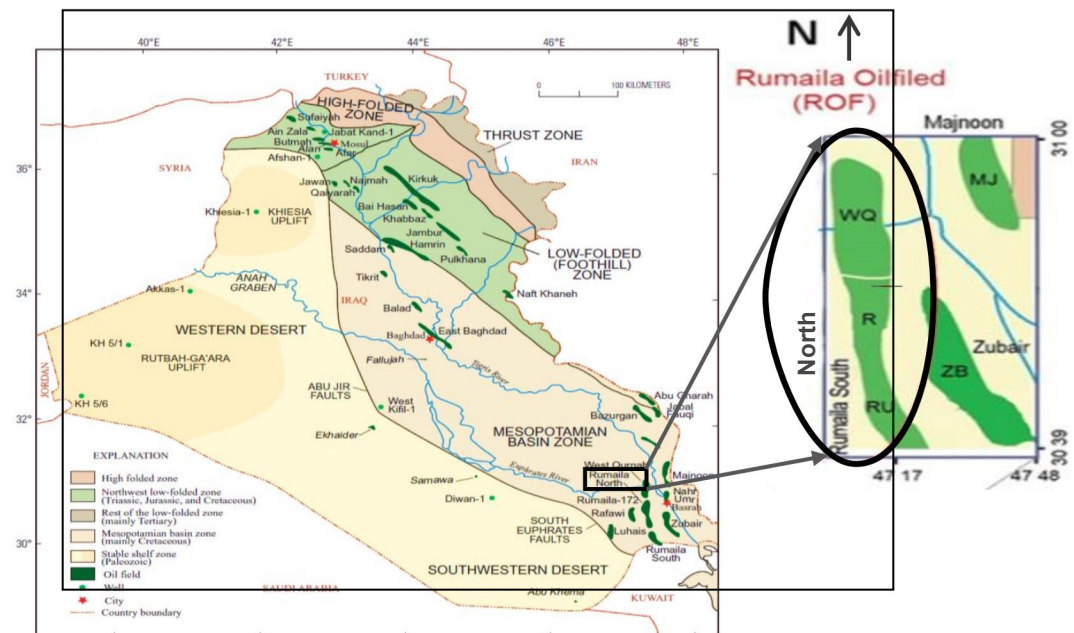


Fig. 2. Location of Study area (Fox and Ahlbrandt, 2001)

Materials and Methods

In the present study, the evaluation of the petrophysical properties of the Zubair Formation is predicated on conventional well logs. The petrophysical properties include lithology, clay volume, porosity types, permeability, water and oil saturations (movable and residual oil saturation). The Interactive Petrophysics (IP) software (V4.5) was employed for all of the following measurements and result presentation.

Environment Correction:

The used charts and correlations of well logs environment correction are based on the tool types and used to do the measurement, and on the borehole conditions.

Lithology:

In addition to the neutron and density logs, the sonic log is needed for the M-N plot. To compute the lithology-dependent variables M and N, these three logs are required. The following formulas are used to calculate M and N values (Gibson, 1982):

$$M = \{(\Delta_{tf} - \Delta_t) / (\rho_b - \rho_f)\} * 0.01 \dots \dots \dots (1)$$

$$N = (\phi_{Nf} - \phi_N) / (\rho_b - \rho_f) \dots \dots \dots (2)$$

Where: Δ_{tf} = interval transit time of fluid (189 μ sec/ft for fresh mud and 185 μ sec/f for salt mud), Δ_t = interval transit time from the sonic log in μ sec/ft, ρ_f = density of fluid (1.1 gm/cc for salt mud and 1.0 gm/cc for fresh mud), ρ_b = bulk density of formation (gm/cc), ϕ_N = the formation's neutron porosity as measured by the neutron porosity log, ϕ_{Nf} = fluid's neutron porosity (use 1.0).

Volume of Shale (V_{sh}):

Shale volume is linearly proportional to the gamma-ray log (GR) value; therefore, in theory, the shale volume may be obtained from GR value using the following formula:

$$I_{GR} = (GR_{log} - GR_{min}) / (GR_{max} - GR_{min}) \dots \dots \dots (3)$$

Where: GR_{log} the formation's gamma-ray reading (API), GR_{min} the minimal reading for gamma rays (carbonate or clean sand)

(API), GR_{max} = maximum computed gamma ray reading (API).

For older (Cretaceous) rocks, the formula was used to determine the shale volume in the Zubair Formation (Larionov, 1969):

$$V_{sh} = 0.33 * [2^{(2 * I_{GR})} - 1] \dots \dots \dots (4)$$

Where: V_{sh} is the Shale Volume and I_{GR} is the Gamma Ray Index

Porosity:

Because it indicates the possible volume of hydrocarbon storage, porosity is a significant feature of rocks. The ratio of the pore space or void volume to the total volume is known as porosity. The term “effective porosity” or “connected” pore space is widely used to signify porosity that is most available for fluid movement (Asquith and Krygowski, 2004).

1. Density Porosity ØD Calculation:

The following formula was used to calculate porosity based on the density log data (Schlumberger, 1972):

$$\text{ØD} = (\rho_{\text{ma}} - \rho_{\text{b}}) / (\rho_{\text{ma}} - \rho_{\text{fl}}) \dots\dots\dots (5)$$

Where: ØD is the porosity from density log, ρ_{ma} = matrix density (2.65 gm/cc for sandstone), ρ_{b} = bulk density of formation, ρ_{f} = density of fluid (1.0 gm /cc for fresh water)

2. Neutron Porosity ØN Calculation:

The neutron log porosity measurements are accurate if the formation is limestone, the porosity is filled with liquid (not gas), and the formation is clean (no shale). Shale raises a formation's total porosity but doesn't change the formation's effective porosity. When Vsh is above 5%, the shale value must be subtracted from the total porosity measurement using the following calculation (Johnson and Pile, 2006):

$$\text{Ø}_{\text{Nc}} = \text{ØN} - (V_{\text{sh}} \times \text{ØN}_{\text{sh}}) \dots\dots\dots (6)$$

Where: Ø_{Nc} = corrected porosity from neutron log, ØN = apparent neutron porosity read from the neutron log, V_{sh} = shale volume, ØN_{sh} = apparent porosity from neutron at the shale zone.

3. Sonic Porosity ØS Calculation:

The following formula was used to calculate primary porosity (matrix porosity) using sonic log (Willie et al. 1958):

$$\text{Øs} = (\Delta t_{\text{log}} - \Delta t_{\text{ma}}) / (\Delta t_{\text{f}} - \Delta t_{\text{ma}}) \dots\dots\dots (7)$$

Where: Øs = porosity estimated from sonic log, Δt_{ma} = interval transit time of the matrix in (µsec/ft), Δt_{log} = interval transit time for the formation, Δt_{f} = interval transit time in the fluid in (µsec/ft).

4. Total Porosity Calculation:

The following formula can be used to determine total porosity (Asquith and Krygowski, 2004):

$$\text{Øt} = (\text{ØN} + \text{ØD}) / 2 \dots\dots\dots (8)$$

5. Effective Porosity Øe Calculation:

Effective porosity represents the amount of interconnected pores (Asquith and Gibson, 1982). It can be calculated from the following formula (Schlumberger, 1998):

$$\text{Øef} = \text{Øt} * (1 - V_{\text{sh}}) \dots\dots\dots (9)$$

Where: Øt = Total Porosity, Øef = Effective Porosity, Vsh Volume of Shale.

6. Secondary Porosity SPI Calculation:

The term "secondary porosity" refers to the pore space sediment that forms after deposition as a result of diagenetic processes (Bowen, 2003). The following formula (Schlumberger, 1997) can be used to determine the secondary porosity index (SPI):

$$\text{SPI} = (\text{Øt} - \text{Øs}) \dots\dots\dots (10)$$

Where: ϕ_{corr} = Corrected porosity calculated from sonic.

Permeability Calculation:

Permeability is a crucial feature of rocks because it influences the rate at which hydrocarbons can be recovered. From less than 0.01 millidarcy (md) to well over 1 Darcy, values vary widely. For oil production, a permeability of 0.1 md is typically regarded as the minimum (Al-Sudani, 2018). In order to calculate the permeability from porosity logs, the traditional method involved correlating core permeability and porosity data and using the resulting porosity-permeability transform. The absolute permeability can be determined using porosity logs (ϕ) and irreducible water saturation using the Schlumberger chart (K3) (Schlumberger, 1984).

$$k = 10000 * \phi_e^{4.5} / S_{wi}^2 \dots\dots\dots (11)$$

Where: k = permeability, ϕ_e = effective porosity, S_{wi} = irreducible water saturation

Fluid Saturation:

1. Water Saturation:

Water saturation for the uninvaded zone was calculated according to the following formula:

$$S_w = [(a * R_w) / (R_t * \phi^m)]^{1/2} \dots\dots\dots (12)$$

Where: R_w = Resistivity of water formation that is determined from SP log, R_t = True resistivity (resistivity reading from uninvaded zone), m = cementation factor, a = tortuosity factor (Archie, 1942).

Water saturation in the invaded zone (S_{xo}) can be simply calculated from the following equation:

$$S_{xo} = [(a * R_{mf}) / (R_{xo} * \phi^m)]^{1/n} \dots\dots\dots (13)$$

Where: R_{mf} = resistivity of mud filtrate, R_{xo} = the invaded zone's measured resistivity.

2. Hydrocarbon Saturation:

The following formula can be used to calculate the hydrocarbon saturation (Archie, 1942).

$$S_h = (1 - S_w) \dots\dots\dots (14)$$

3. Movable Oil Saturation:

MOS is computed using (Schlumberger (1998) equation:

$$MOS = (S_{xo} - S_w) \dots\dots\dots (15)$$

4. Residual Oil Saturation:

The following equation can be used to calculate residual oil saturation (Schlumberger, 1987):

$$ROS = (1 - S_{xo}) \dots\dots\dots (16)$$

Bulk Volume Water:

Water saturation of the uninvaded zone (SW) and porosity are two crucial factors that affect the bulk volume water calculation. This is demonstrated by the following equation:

$$Bvw = S_w * \varnothing \dots\dots\dots (17)$$

Results

The Shale Volume (V_{sh}):

The volume of shale is the percentage of shale to the total matrix at the well, which is important to determine. It was calculated based on Eq. (4) and the average volume of shale in the Zubair formation was 25.35% at well X. The results of the current study show that the formation contains four shale zones (Fig. 4).

Lithology and Zonation:

Based on the mud logging report, MN and RHOB - NPHI cross-plots, it was determined that the basic lithology of the Zubair formation is sandstone with thick and thin layers of shale. The zonation of the formation in the study was divided based on the lithology and the volume of shale, as shown in (Fig. 4). The Zubair Formation was divided into five members, including (upper shale, upper Sandstone, middle shale, lower Sandstone and lower shale member). Three main pay units comprised the upper sandstone member: AB, DJ, and LN, split by the C and K units of insulating shale. The upper shale has a pay unit of sandstone. The X well is penetrated by the first three members and stop at the middle shale member because of the high water saturation in the lower sandstone member and lower shale member.

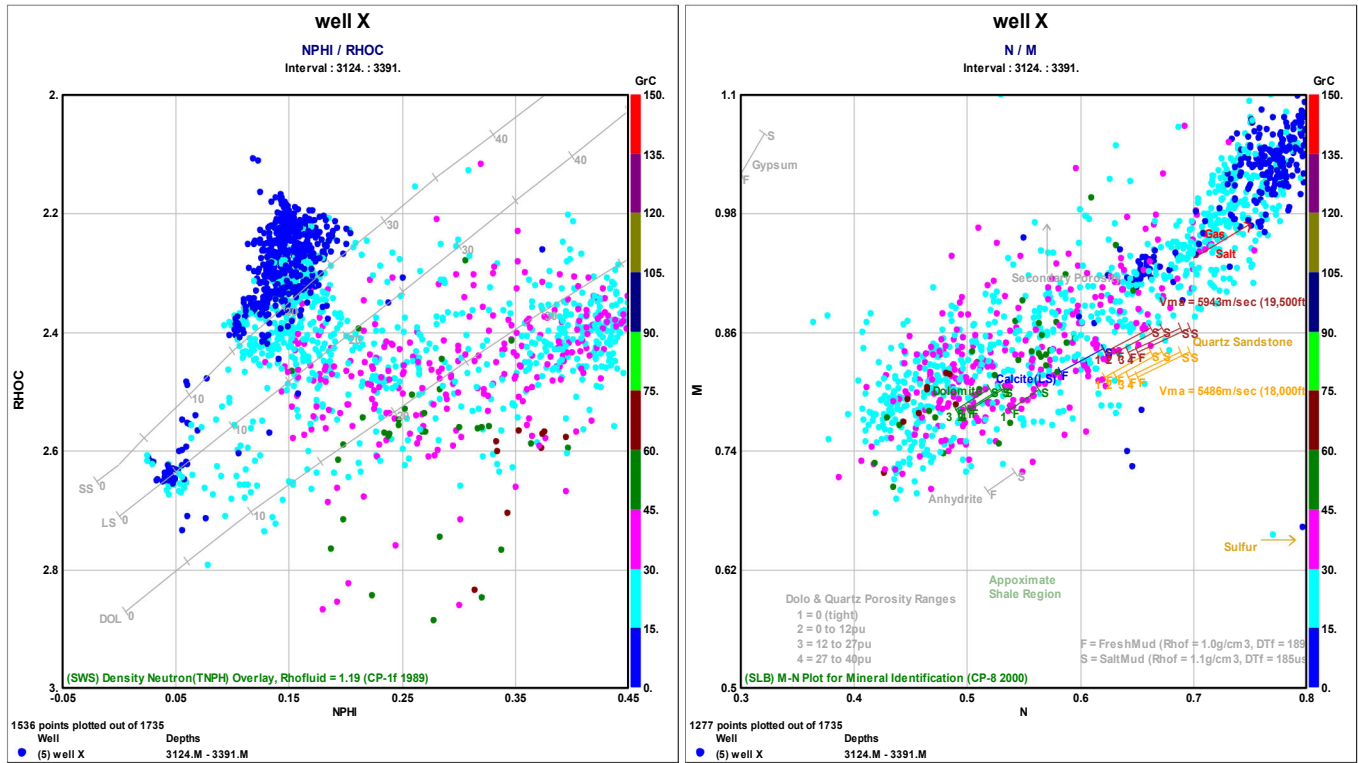


Fig. 3. The M-N RHOB-NPHI cross plots of the Zubair formation

Porosity:

1. Density Porosity (Φ_D):

The average density porosity of the Zubair Formation, after applying volume of shale correction, is 16.91% at X well.

2. Neutron Porosity (Φ_N):

Neutron porosity estimation shows a high value compared with the density porosity average. Neutron porosity of the Zubair formation is 19.72%.

3. Sonic Porosity Φ_S (Primary Porosity):

Based on (Eq.7) with the volume of shale equation for correction, the primary porosity was determined. Primary porosity forms the largest and essential part of the porosity of the sandstone rocks. The average, maximum and minimum for two wells are shown in (Table 1).

4. Total Porosity Φ_t :

Accordingng to (Eq. 8), the total porosity results show good porosity in the Zubair Formation with an average is 17.73% as shown in (Table 1) and (Fig.4).

5. Effective Porosity Φ_e :

The effective porosity result of the current study was close to total porosity at the sandstone unit, which indicates clean sandstone which reflects the quality of the reservoir. Effective porosity is considered the channel for fluid flow that significantly influences the formation's permeability. The Zubair Formation has good effective porosity with an average value of about 13.9% in X well.

6. Secondary Porosity SPI:

The secondary porosity describes the porosity that formed after the depositional process due to diagenesis and/or tectonic activity, but it is usually rare in sandstone rocks. Secondary porosity is estimated using (Eq. 10) after determining total porosity values. The average secondary porosity in the Zubair formation was 2.97% at X well.

Table 1. porosity results of the Zubair formation in X well

Value	Total porosity	Effective porosity	Primary porosity	Secondary porosity	Density porosity	Neutron porosity
Min	0.0001523	1.19E-05	0.0012	-0.25253	0.000146	0.46342
Max	0.35039	0.29625	0.46871	0.22091	0.38966	0.001040
Average	0.17726	0.13901	0.14664	0.029859	0.16914	0.19726

Saturation:

1. Water Saturation:

After applying the Archie equation, the average water saturation in the Zubair Formation is (56.2%) in X well. The shale zone has a high trapped water saturation, particularly in the upper part of the formation. Generally, the matured fields that are supported by an aquifer show an increase in water saturation and produced water.

2. Hydrocarbon Saturation:

The Zubair Formation has a hydrocarbon saturation with an average of 52.5% in X well. The hydrocarbon saturation is considered good with high economic quantities. The average movable oil saturation in the formation was 18.71, while the average saturation of residual oil was 34.6%.

Permeability:

The permeability of Zubair Formation was calculated using IP software based on the Schlumberger (K3) chart equation. The average of the permeability in the Zubair Formation at X well is 416.8 mD). The formation in the Rumaila oil field is considered the main pay because of a high productivity rate with good and excellent permeability,

although the permeability measurement using conventional well log is often unsatisfactory. The Zubair units have heterogeneity of organic matter content that eventually affects permeability (Alsultan et al, 2021).

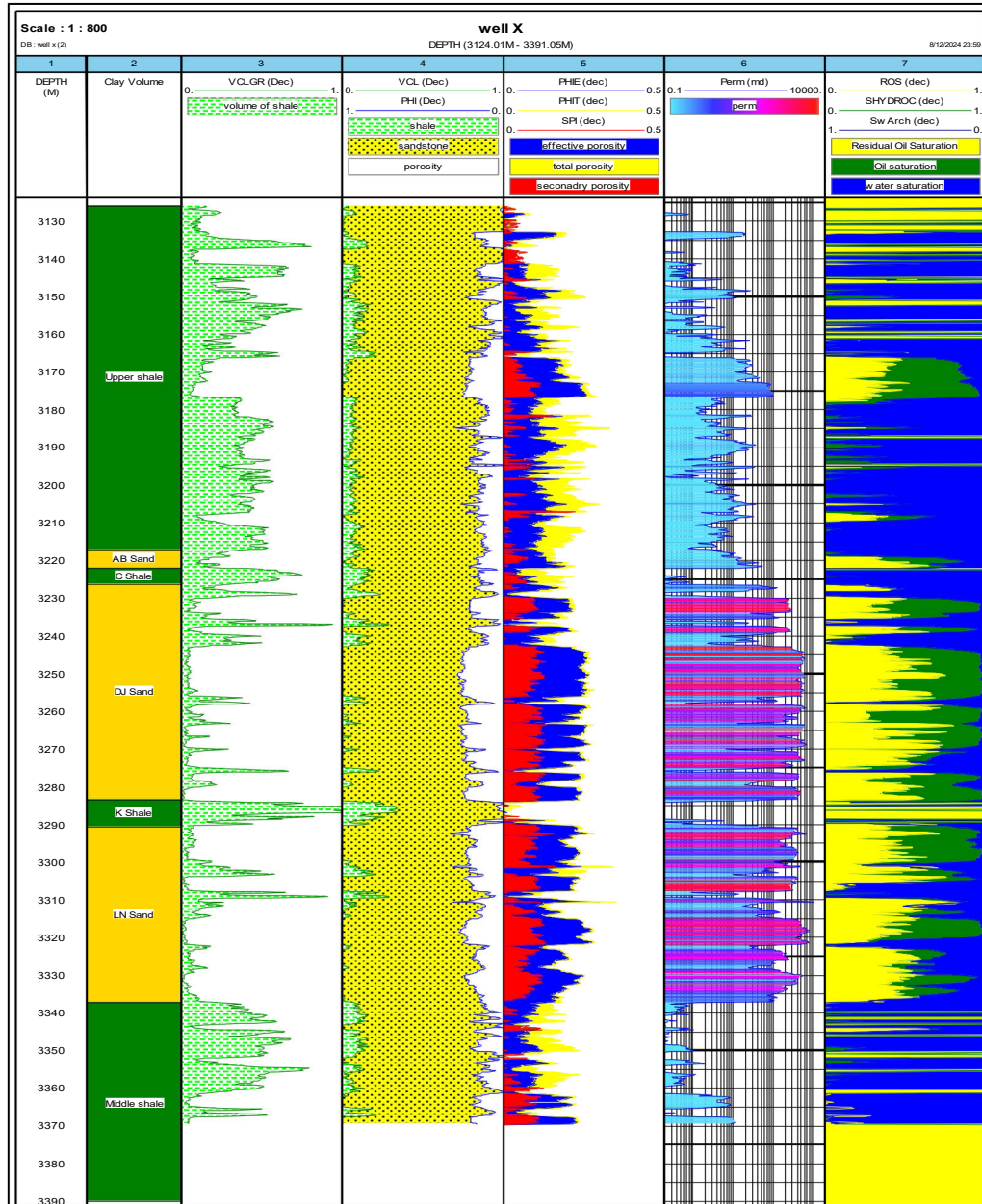


Fig. 4. The results of well logs analysis of Zubair formation in X well

Conclusion

The Zubair Formation represents the main source of oil in the Rumaila oil field, which is the largest oilfield in Iraq, because it has good petrophysical properties. The formation contains five main members of sandstone and shale that include upper shale, upper sandstone, middle shale, lower sandstone and lower shale members. The X well penetrates only the upper shale, upper sandstone and middle shale member based on the mud logging report. Based on the Neutron-Density and M-N cross-plots, the main lithology of the Zubair Formation is sandstone

with both thick and thin shale layers. The average volume of shale in the formation is 25.35%. According to the results of the current study, the total porosity of the Zubair formation is considered good, with an average is about 17.73%. The fluid saturation calculation showed high water saturation at shale units with average water saturation (56.2% in X well. The Zubair Formation has a hydrocarbon saturation with an average of 52.5%. The permeability result of the Zubair formation has a high variation between the shale and sand members (Fig.4), with an average is 416.8 mD.

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