Petrophysical Properties and Identification of Electrofacies from Well Log Data of Nahr Umr Formation in Subba Oilfield, Southern Iraq

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Abstract
The main purpose of this study is to identify electrofacies and evaluate the petrophysical properties of the Nahr Umr Formation in four wells: A, B, C, and D in the Subba oilfield, southern Iraq. The petrophysical properties, such as shale volume, porosity, water saturation, hydrocarbon saturation, and bulk water volume, were computed and interpreted using Techlog software. According to the interpretation of density, neutron, and gamma ray sonic logs and deep resistivity logs using the IPSOM technique, four electrofacies were identified as sandstone, shaly sand, sandy shale, and shale electrofacies. The formation was divided into three parts based on well log interpretation and petrophysical analysis: the upper part, middle part, and lower part. Interpretation of formation lithology and petrophysical parameters shows that the lower part consists mainly of sandy shale with layers of sandstone and shale of high porosity and high oil saturation whereas middle part mainly consists of sandstone, alternating with thin bedded of sandy shale and shale with high porosity and medium oil saturation. The upper part consists mainly of a sandy shale alternating with shale and shaly sand with high porosity, hydrocarbon saturation, and lower water saturation.

Keywords: Nahr Umr Formation; Subba oilfield; Electrofacies; Petrophysical properties

1. Introduction
Albian-aged clastic sediments serve as reservoirs, seals, and source rocks for hydrocarbons. Major reservoirs are found in sandstone, and major seals are found in distal shale (Alsharhan, 1991, 1994). The Nahr Umr Formation is one of the most significant siliciclastic deposits and one of the most productive and promising reservoirs of the Cretaceous Sequence of Iraq's Oilfields (Al-Sudani and Salman, 2009). This formation was introduced by Glynn Jones in 1948 (Bellen Van et al., 1959) in the Y Oilfield in the south of Iraq, it is up to 360 m thick in the south of Salman and Mesopotamian zones. The formation is thickest in the south of Iraq and Kuwait around 400 m, south of Baghdad at 160 m, and northwest of Iraq (Jassim and Goff, 2006). This formation consists generally of interbedded black shale and medium- to fine-grained sandstone and siltstone, with the occurrence of thin limestone beds (Aqrawi et al., 2010; Jassim and Goff, 2006). The top of the Nahr Umr Formation in the X Oilfield appeared at a depth range between 2416.5-2494.5 m. The average thickness is about 222 m, Su-I having the biggest thickness of about 237.5 m. The upper contact surface of this formation is conformity and graded with the Mauddud Formation. The limestone at the base of the Mauddud Formation overlies the top of the black shale of the Nahr Umr Formation, and this formation is conformably bounded from

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below by the Shuaiba Formation, which corresponds when the black shale of the Nahr Umr Formation sits on the limestone of Shuaiba Formation, but this formation may be unconformable in other areas of central and southern Iraq, where the sandstone of Nahr Umr sits on the dolomitic limestone of the Shuaiba Formation (Manhi and Alsultani, 2021) as in the Dujail region in (Bellen Van et al., 1959).

Many authors have studied the Nahr Umr Formation, such as Al-Dabbas et al. (2012) recognized six distinct depositional environments in the Nahr Umr Formations in central and southern Iraq, including prodelta, distal bar, distributary mouth bar, distributary channel, over bank, and tidal channel. This study showed that the upper part of the formation is influenced by the shoreline environment, while the middle and upper parts are influenced by the fluvial and delta environments.

Al-Baldawi (2016), who identified the electrofacies of the Nahr Umr Formation in the Z Oilfield using the IPSOM technique, showed the formation consisted of sandstone interlaminated with siltstone and shale.

Al-Saad (2016) Studied the formation in W Oilfield by using reflection data and well log, this study gave a highlight to the deposition environment of Nhr Umr Formation.

According to study of Zaibel (2017), the Nahr Umr Formation in X OilField is divided into three parts based on lithology types and well log interpretation. The lower part of the formation that has a thickness between (1-13.5) m consists of small sand bodies intertwined with shale, silt, and thin beds of carbonate, and it is represented the shallow marine deposits. The middle part of the formation represents the sandy rock unit where the high marine regressive and predominance of clastic river deposits. The thickness of this part is estimated between 110.5–148.5 m consisted of more than one sandy sedimentary cycle with well-rounded and sorting sand as well as containing a large amount of quartz arenite. The size of the grains increases upwards with the presence of the cross-bedding structures and the traces of the plants at the top of each sedimentary cycle.

By studying the geological modeling of the formation in the X Oilfield, Menshed and Al-Mozan (2021) conclude the Nahr Umr Formation in X Oilfield consists of two domes separated by a saddle. The small dome is located in the north, while the large dome is located in the south.

The main purpose of this study is to make use of all the available sets of well log data acquired from A, B, C, and D wells in the X Oilfield lithological properties and to determine the petrophysical for each part of the Nahr Umr Formation. The study includes two steps, the first is the recognize the lithology prediction and identification of electrofacies of formation by the IPSOM technique using gamma ray, density, neutron, sonic, and deep resistivity logs. The second is an interpretation of well logs to determine petrophysical properties. The main purpose of this study is to make use of all the available sets of well log data acquired from A, B, C, and D wells in the W lithological properties and oilfield to determine the petrophysical for each part of the Nahr Umr Formation. The study includes two steps, the first is the recognize the lithology prediction and identification of electrofacies of formation by the IPSOM technique using gamma ray, density, neutron, sonic, and deep resistivity logs. The second is an interpretation of well logs to determine petrophysical properties.

2. Location of the Study Area

X Oilfield is situated in the southern part of Iraq, 110 km northwest of Basra City, 70 km south-east of Nasiriya City, and 30 km northwest of Z Oilfield as well as 40 km northwest of Z Oilfield.
field located between 661°833.8–667°800 Longitude and 3365°720.5–3398°663.5 Latitude. (Fig 1A and B). Table 1, shows the coordinate of wells and tops of the Nahr Umr Formation in the study area.

![Figure 1A](image1.png)  
**Figure 1A.** Location map shows the W Oilfield after (Al-Ameri et al., 2009) :B. A structural contour map of the top of the Nahr Umr Formation shows the locations of the wells in the study area.

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Top (m)</th>
<th>Bottom (m)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2460</td>
<td>2692</td>
<td>232</td>
</tr>
<tr>
<td>B</td>
<td>2457</td>
<td>2678</td>
<td>221</td>
</tr>
<tr>
<td>C</td>
<td>2458</td>
<td>2675</td>
<td>217</td>
</tr>
<tr>
<td>D</td>
<td>2442</td>
<td>2662</td>
<td>220</td>
</tr>
</tbody>
</table>

**Table 1.** The coordinates of wells and tops of the formation in study area

3. Materials and Methods

Lithology prediction of the formation was carried out using the IPSOM technique in Techlog software from gamma ray logs, density, neutron, sonic, and deep resistivity. The Ipsom modules (the intelligent classifier to sharpen Facies modeling) provide automatic classification solutions with both supervised and unsupervised methods. These methods are based on neural network technology (The Kohonen algorithm). Ipsom is designed for use in the geological interpretation of well log data and facies prediction.

In this study, four electrofacies of the Nahr Umr Formation in the W Oilfield were identified sandstone, shaly sand, sandy shale, and shale (Tables 2, 3, Fig.2).
Table 2. Inputs properties of Ipsom module

<table>
<thead>
<tr>
<th>Variable</th>
<th>Transformation</th>
<th>Unit</th>
<th>color</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR</td>
<td>Linear</td>
<td>API</td>
<td></td>
</tr>
<tr>
<td>RHOB</td>
<td>Linear</td>
<td>g/cm³</td>
<td></td>
</tr>
<tr>
<td>DT</td>
<td>Linear</td>
<td>Us/ft</td>
<td></td>
</tr>
<tr>
<td>NPHI</td>
<td>Linear</td>
<td>v/v</td>
<td></td>
</tr>
<tr>
<td>ILD</td>
<td>Logarithmic</td>
<td>Ohm.m</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Self-organizing map of IPSOM module

Petrophysical Parameters, for determining the reservoir characterization of the Nahr Umr Formation, petrophysical parameters must be obtained and evaluated. These parameters include:

Shale volume (Vsh): To derive Vsh from gamma ray (GR Log), it is imperative that the gamma ray index (IGR), determined by using the equation of (Schlumberger, 1974):

\[ IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \tag{1} \]

Where: GRlog = gamma ray reading of formation, GRmin = minimum gamma ray reading (sandstone), GRmax = maximum gamma ray reading (shale).

The shale volume was calculated by using the following (Dresser, 1979) formula:

\[ Vsh = \frac{(2^{2-IGR})-1}{3} \tag{2} \]

Where: Vsh= Volume of shale.
Porosity: Total porosity within the Nahr Umr Formation was determined from a combination of Neutron – Density derived porosities. The effective porosity from neutron log for clean beds if shale volume <10% is equal to the neutron porosity log, while in dirty or shaly beds it is calculated from the following formula:

$$\phi_{n,e} = \phi_n \times (1 - V_{sh})$$  \hspace{1cm} (3)

Where $\phi_{n,e}$ Neutron effective porosity (v/v). Density porosity is derived from the bulk density of clean liquid filled formations when the matrix density ($\rho_{ma}$) and the density of the saturating fluids ($\rho_f$) are known, using (Wyllie et al., 1958) equation:

$$\rho_D = \frac{\rho_{ma} - \rho_f}{\rho_{ma} - \rho_b}$$  \hspace{1cm} (4)

The density effective porosity for clean beds if shale volume <10% is equal to the density total porosity, while in dirty or shaly beds it is calculated from the following formula:

$$\phi_{d,e} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \times (1 - V_{sh})$$  \hspace{1cm} (5)

where: $\phi_{d,e}$ = density effective porosity (v/v). The total and effective porosity from neutron and density log was calculated from the following formulas:

$$\phi_{n,d} = \frac{\phi_n + \phi_d}{2}$$  \hspace{1cm} (for clean zone)  \hspace{1cm} (6)

$$\phi_{n,d,e} = \frac{\phi_{n,e} + \phi_{d,e}}{2}$$  \hspace{1cm} (for shaly or dirty zone)  \hspace{1cm} (7)

The porosity from sonic log measure form modified (Wyllie et al., 1958) equation:

$$\phi_{sonic} = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$  \hspace{1cm} (8)

where: $\phi_{sonic}$ = porosity from sonic log. $\Delta t_{log}$ = log reading (µs/ft), $\Delta t_{ma}$ = the matrix travel time (55 µs/ft for Sandstone), $\Delta t_f$ = the fluid travel time (189 µs/ft for fresh-water mud, 185 µs/ft for saline-water mud). The effective primary porosity for clean beds if shale volume <10% is equal to the primary total porosity, while in dirty or shaly beds it is calculated from the following formula:

$$\phi_{sonic,e} = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \times (1 - V_{sh})$$  \hspace{1cm} (9)

The secondary porosity was calculated using (Schlumberger, 1997) formula:

Table 3. Statistics of group

<table>
<thead>
<tr>
<th>No.</th>
<th>Electrofacies</th>
<th>Value</th>
<th>GR(API)</th>
<th>RHOB(g/cm3)</th>
<th>NPHI (%)</th>
<th>DT (ms/ft)</th>
<th>Rt (Ω.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone</td>
<td>Minimum</td>
<td>5.20</td>
<td>2.38</td>
<td>9.30</td>
<td>67.17</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>25.88</td>
<td>2.58</td>
<td>20.25</td>
<td>75.19</td>
<td>3.03</td>
</tr>
<tr>
<td>2</td>
<td>Shaly Sand</td>
<td>Minimum</td>
<td>20.12</td>
<td>2.20</td>
<td>18.59</td>
<td>70.79</td>
<td>3.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>51.74</td>
<td>2.45</td>
<td>26.41</td>
<td>86.30</td>
<td>4.10</td>
</tr>
<tr>
<td>3</td>
<td>Sandy Shale</td>
<td>Minimum</td>
<td>51.86</td>
<td>2.30</td>
<td>27.78</td>
<td>79.68</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>70.50</td>
<td>2.48</td>
<td>38.00</td>
<td>89.37</td>
<td>3.11</td>
</tr>
<tr>
<td>4</td>
<td>Shale</td>
<td>Minimum</td>
<td>70.00</td>
<td>2.20</td>
<td>33.75</td>
<td>90.00</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>maximum</td>
<td>116.19</td>
<td>2.29</td>
<td>42.86</td>
<td>106.36</td>
<td>4.51</td>
</tr>
</tbody>
</table>
**SPI** = (\(\text{ond} - \phi_{\text{s}}\)) \hspace{1cm} (10)

Where: SPI = Secondary Porosity Index (v/v).

Water and hydrocarbon saturation: Water saturation for the uninvaded zone was calculated according to (Archie, 1942):

\[S_{\text{W}} = \sqrt[\phi]{\frac{Fr \times Rw}{Rt}} \hspace{1cm} (11)\]

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

\[S_{\text{XO}} = \sqrt[\phi]{\frac{Fr \times Rmf}{Rxo}} \hspace{1cm} (12)\]

Where: Rw = Resistivity of water formation that is previously determined from SP log using (Bateman and Konen, 1978) \(a\) = tortuosity factor; \(m\) = cementation factor; \(n\) = saturation exponent. The hydrocarbon saturation was calculated using the following formula:

\[S_{\text{H}} = (1 - S_{\text{W}}) \hspace{1cm} (13)\]

**Bulk volume of hydrocarbon:** Includes moveable hydrocarbon saturation and residual hydrocarbon saturation. It can be calculated by the following formula (Asquith et al., 2004):

\[B_{\text{Vo}} = S_{\text{o}} \times \phi \hspace{1cm} (14)\]

Where: \(B_{\text{Vo}}\) = Bulk volume of hydrocarbon, \(S_{\text{o}}\) = Oil saturation, \(\phi\) = Total porosity. Moveable hydrocarbon saturation can be calculated from the following formula (Spain, 1992):

\[MOS = S_{\text{XO}} - S_{\text{W}} \hspace{1cm} (15)\]

Where: \(MOS\) = Moveable hydrocarbon saturation. While Residual hydrocarbon saturation can be calculated from the following formula (Schlumberger, 1987):

\[ROS = 1 - S_{\text{XO}} \hspace{1cm} (16)\]

Where \(ROS\) = Residual hydrocarbon saturation. The bulk volume of water (BVw) which is the product of a formation's water saturation (Sw) and its porosity (\(\phi\)) (Asquith and Gibson, 1982), On the other hand, the bulk volume of water can be calculated in the flushed zone and the uninvaded zone using the following formula (Schlumberger, 1984):

\[B_{\text{VW}} = Sw \times \phi \hspace{1cm} (For \text{non-invaded zone}) \hspace{1cm} (17)\]

\[B_{\text{VXO}} = Sw \times Xo \times \phi \hspace{1cm} (For \text{flushed zone}) \hspace{1cm} (18)\]

Where: \(B_{\text{VW}}\) = bulk volume water of uninvaded zone. \(B_{\text{VXO}}\) = bulk volume water of invaded zone. \(\phi\) = total porosity.

4. Results and Discussion

Electrofacies of Nahr Umr Formation detected by IPSOM technique as illustrated in Figs. 3 to 6. The computer processing interpretation (CPI) and petrophysical properties of the Nahr Umr Formation were presented in Figs 7 to 10. The net pay of the Nahr Umr Formation was selected based on the values of shale volume, effective porosity, and water saturation as shown in Tables 3 and 4. These Figures showed the Nahr Umr Formation was divided into three parts; the upper parts, the lower parts, and the middle parts. Each one of these zones is characterized by different petrophysical and lithological properties, which were summarized to the lower part consisting mainly of sandy shale with layers of sandstone and shale. This part shows low shale volume in A in the south of the field with high porosity, oil saturation, and low water saturation. The middle part with a sand-dominated unit, alternating with thin beds of sandy shale and shale. This part shows low shale volume and high sand volume. the
hydrocarbon show increase in the well A in the south of the field and a decrease in C north of the field. The upper part consists mainly of a sandy shale layer alternating with shale and shaly sand. The shale volume shows the decrease in the well A in the south of the field and increases in the well Su-12 in the north of the field. The hydrocarbon saturation was increasing in these parts, especially in B. The total porosity and effective total porosity were increased in A in the south of the field.

Fig. 3. Electrofacies in A
**Fig. 4.** Electrofacies in B
Fig. 5. Electrofacies in C
Fig. 6. Electrofacies in D
**Fig. 7.** Petrophysical properties in A
Fig. 8. Petrophysical properties in B
Fig. 9. Petrophysical properties in C
**Fig. 10.** Petrophysical properties in D
Table 4. The results of petrophysical properties in wells of the study area

<table>
<thead>
<tr>
<th>Well NO.</th>
<th>Parts</th>
<th>Top (m)</th>
<th>Bottom (m)</th>
<th>Thickness (m)</th>
<th>PAY NET Thickness (m)</th>
<th>Vsh Average (v/v)</th>
<th>PHIE-ND Average (v/v)</th>
<th>Sw Average (v/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Upper</td>
<td>2460</td>
<td>2556</td>
<td>96</td>
<td>26.52</td>
<td>0.29</td>
<td>0.29</td>
<td>0.47</td>
</tr>
<tr>
<td>A</td>
<td>Middle</td>
<td>2556</td>
<td>2675</td>
<td>119</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>A</td>
<td>Lower</td>
<td>2675</td>
<td>2692</td>
<td>17</td>
<td>0.77</td>
<td>0.26</td>
<td>0.17</td>
<td>0.37</td>
</tr>
<tr>
<td>A</td>
<td>Upper</td>
<td>2457</td>
<td>2571.5</td>
<td>114.5</td>
<td>15.41</td>
<td>0.42</td>
<td>0.16</td>
<td>0.24</td>
</tr>
<tr>
<td>B</td>
<td>Middle</td>
<td>2571.5</td>
<td>2671</td>
<td>100</td>
<td>0.61</td>
<td>0.37</td>
<td>0.12</td>
<td>0.39</td>
</tr>
<tr>
<td>B</td>
<td>Lower</td>
<td>2671</td>
<td>2678</td>
<td>7</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>B</td>
<td>Upper</td>
<td>2458.5</td>
<td>2549.5</td>
<td>91</td>
<td>18.29</td>
<td>0.41</td>
<td>0.13</td>
<td>0.30</td>
</tr>
<tr>
<td>C</td>
<td>Middle</td>
<td>2549.5</td>
<td>2667</td>
<td>117.5</td>
<td>2.00</td>
<td>0.33</td>
<td>0.10</td>
<td>0.38</td>
</tr>
<tr>
<td>C</td>
<td>Lower</td>
<td>2667</td>
<td>2675</td>
<td>8</td>
<td>2.52</td>
<td>0.36</td>
<td>0.16</td>
<td>0.32</td>
</tr>
<tr>
<td>C</td>
<td>Upper</td>
<td>2442</td>
<td>2549.5</td>
<td>107.5</td>
<td>7.77</td>
<td>0.32</td>
<td>0.2</td>
<td>0.53</td>
</tr>
<tr>
<td>D</td>
<td>Middle</td>
<td>2549.5</td>
<td>2648.5</td>
<td>99</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
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<tr>
<td>D</td>
<td>Lower</td>
<td>2648.5</td>
<td>2662</td>
<td>13.5</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

5. Conclusions

• The calculation and interpretation of petrophysical properties of wells A, B, C, and D has been deduced using Techlog software in which the porosity, water saturation, and shale volume were calculated. The interpretation shows that the Nahr Umr Formation can be divided into three parts: lower part, middle part, and upper part which are characterized by different petrophysical properties.

• Water resistivity has been calculated from SP log with value equal to 0.018.

• The interpretation shows that middle part has the highest thickness, porosity, and highest water saturation.

• The petrophysical properties of Nahr Umr Formation developed toward the south of the field.

• Four electrofacies in Nahr Umr formation were identified by applying IPSOM technique using gamma ray, density, neutron, sonic, and deep resistivity logs represented by sandstone electrofacies, shaly sand electrofacies, sandy shale electrofacies, and shale electrofacies.

References


Schlumberger, 1974. Log Interpretation . II.


