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Research Article

Integrated Petrophysical Evaluation of a Heterogeneous Shaly-sand Reservoir: A Case Study in Nahr Umr Formation-subba Giant Oil Field, Iraq

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Abstract: This study presents an integrated petrophysical evaluation for Nahr Umr reservoir by highlighting a practical trustworthy approach petrophysical model for Nahr Umr reservoir in Subba oil field depending on available data. The available data include core analysis conducted on seven core samples taken from seven wells in Subba oil field and well set logs which include gamma ray, static spontaneous, neutron, sonic, density and resistivity logs. Subba oil field is a giant oil field located in southern part of Iraq about 110 km Northwest Basra. Nahr Umr formation in Subba oil field is a heterogeneous clastic reservoir. It was considered one of the most important producing clastic reservoir in southern Iraqi oil fields. The conventional petrophysical models, by using neutron-density cross-plot for lithology and porosity and Archie's equation for water saturation, can be adequate for evaluating clean sands. Usually the shaly sand formations are adhere to bad hole in shale section. Facies identification was achieved depending on core analysis data, core description data and wire line log measurements. The calculations of permeability was based on rock types identification and using available core data measurements. The generated permeability models can be used to calculate permeability for uncored intervals in all wells corresponding to each facies. Porosity was calculated using Neutron-density porosity model and Sonic model for bad hole section. Saturation model was built by utilizing the Indonesia Equation model, this model has proved its efficiency to be applied successfully for clastic Iraqi reservoirs. The petrophysical parameters were determined on a well-by-well basis. The formation resistivity factors (a, m) and water saturation exponent (n) have been derived from Pickett plot and formation water salinity. Reservoir quality calculations or net pay values are based on cut-offs values for porosity, saturation and shale volume.

Keywords: Heterogeneous shaly-sand reservoir, integrated petrophysical evaluation, nahr umr formation/subba oil field, permeability, petrophysical parameters calculations

INTRODUCTION

Nahr Umr formation is one of the promising reservoir in southern of Iraq. The formation characteristic is almost the same in all southern Iraqi oil fields. Nahr Umr formation characterized by complex lithology, high scatter dense in permeability and porosity and high water salinity (approximately 200000 ppm). The available data generally are old and based on traditional measurements, the majority of logs are old 1970's vintage (Well Logs for Nahr Umr Formation-Subba Oil Field, 1973-1980). Nahr Umr reservoir in Subba oil field need to be developed by conducting and preparing a new efficient development plan. The development plan of this reservoir is based on assessment of the hydrocarbon in-place, which depend mostly on formation evaluation and petrophysics. The absence of an accurate petrophysical model will lead for untrustworthy predictions of the reservoir performance. Well logs interpretation, well tests, core data and core analysis consider the most common petrophysical tools used to evaluate and assess the reservoir. Standard set of logs such as gamma ray, static spontaneous, resistivity, density, neutron and sonic have been almost acquired in every well across Nahr Umr formation. Usually log analysis can provide parameters such as porosity and water saturation, these parameters can be used to assess the hydrocarbon included in the formation. The integration of well tests and core data is helpful for improving the formation evaluation results and the log analysis results. Total porosity is determined from density, neutron and sonic logs. Shale volume can be estimated by gamma-ray, density, spontaneous potential, neutron and resistivity logs. Yet the most common useful is to use gamma ray to determine shale volume. The effective porosity can be determined by subtracting the pore space associated with shale from total porosity (Saleh and Hilal, 2004). Water saturation can be estimated by utilizing many models such as Waxman Smiths, Dual Water, Indonesia models, etc. The core porosity can be used to calibrate log derived porosity. All the petrophysical analysis

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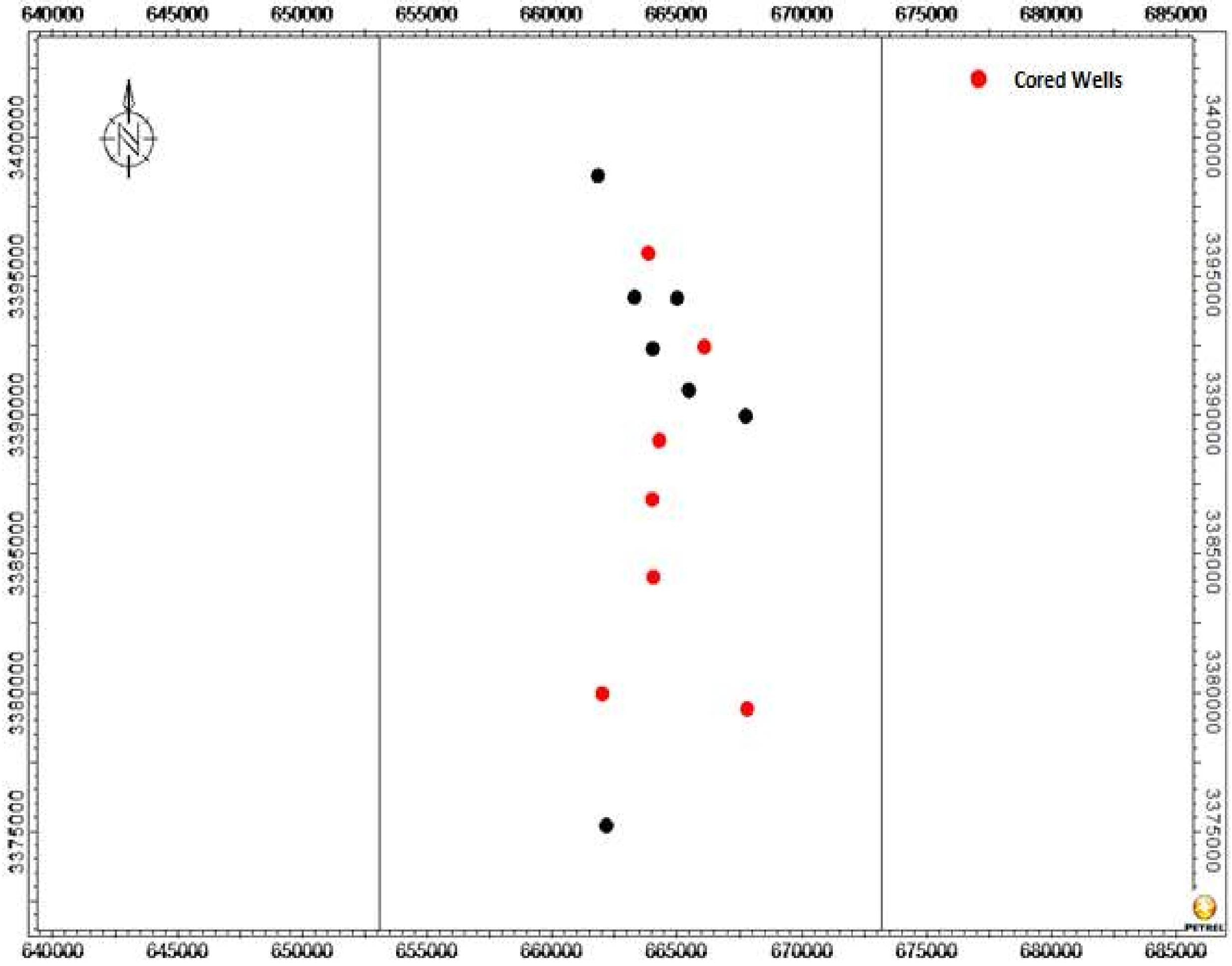

Fig. 1: Well locations for subba oil field

have been done by utilizing Schlumberger's Interactive Petrophysics (IP) Software. This study describe a practical approach for generating a worthy trust integrated petrophysical model for a heterogeneous shaly sand reservoirs depending on available old data.

The description of nahr umr formation in the subba oil field: Subba oil field is located in the southern of Iraq, (110 km) to the northwest Basra and (12 km) northwest of Luhais field (Geological and Evaluation Study for Subba Oil Field, 1979). It include 15 wells drilled in Subba oil field and penetrated Nahr Umr formation as shown in Fig. 1. The dimensions of Subba oil field are about (30 km) long and (7 km) wide. Nahr Umr formation is considered as one of the main productive reservoirs in southern Iraqi fields that comprises an important place into the stratigraphic column of the Lower Cretaceous Albian Nahr Umr as shown in Fig. 2. Nahr Umr formation has a double dome separated with shallow saddle, the larger one located in the south of the field and the smaller one in the north field (Geological and Evaluation Study for Subba Oil Field, 1979; Geological Study for Subba Oil Field, 2001). Strarigraphically Nahr Umr formation was divided into 4-layers, (A, B, C and D) (Geological Study for Subba Oil Field, 2001), these layers consist mainly of sandstone, shale and low ratio of siltstone (Geological and Evaluation Study for Subba Oil Field, 1979; Geological Study for Subba Oil Field, 2001). Siltstone in this reservoir consider non reservoir. There are two types of sandstone, fluvial sand and Tidal sand. The formation has a heterogeneous permeability profile, including very high permeability sandstone facies and very low permeability for shale facies.

METHODOLOGY

Petrophysical parameters: Petrophysical parameters were determined on a well-by-well basis, but typically for Nahr Umr reservoir the averages are as follows:

- Matrix density, (Rhoma) = 2.65 gm/c
- Hydrocarbon density, (RhoHc) = 0.877 gm/c
- Reservoir temperature, (T) = 180°F

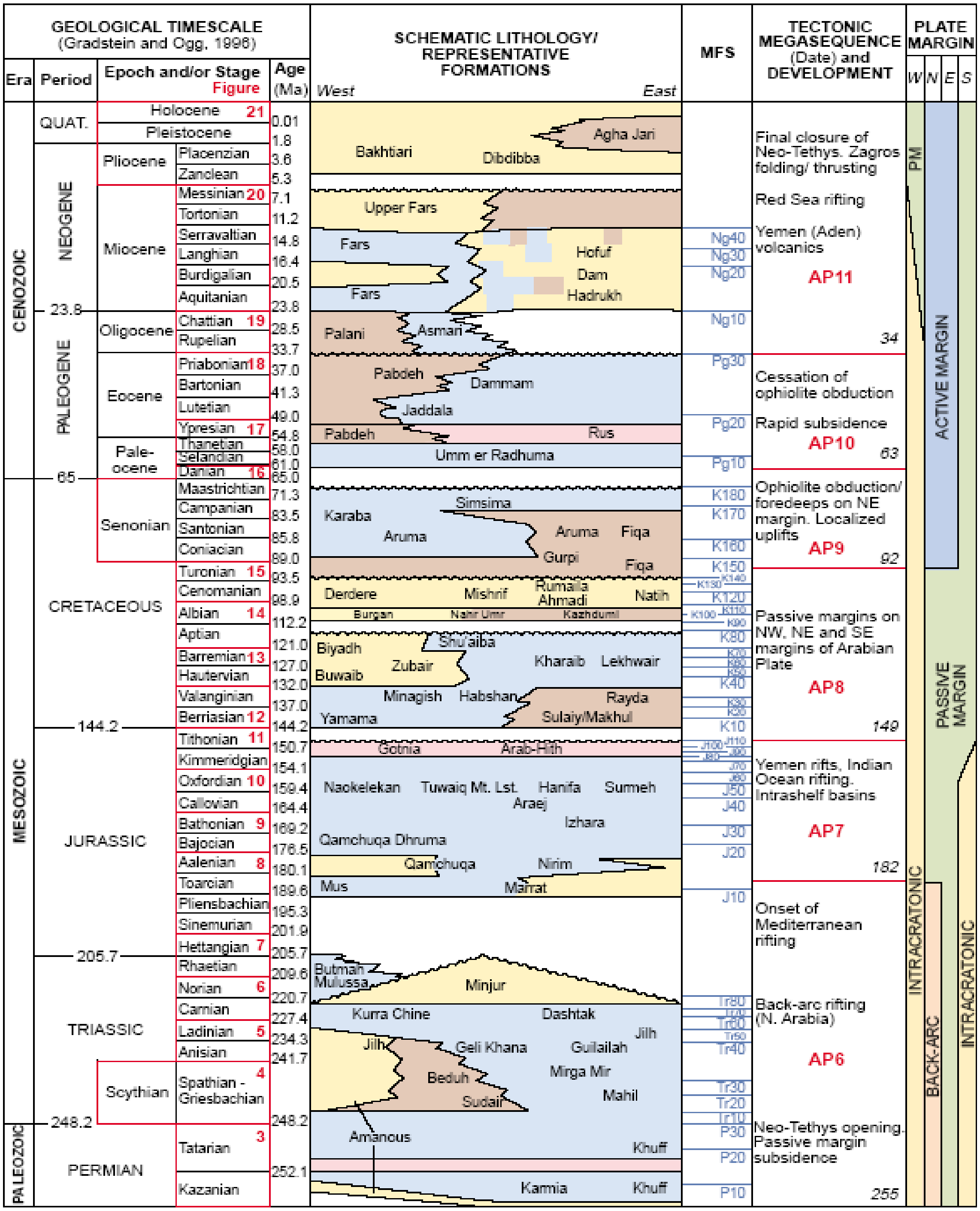

Fig. 2: Stratigraphic column for Iraq (modified from Ziegler (2001))

Core grain densities, formation resistivity or Archie's equation factors (a, m) and saturation exponent (n) data are not available for Nahr Umr formation. Therefore the key water saturation parameters have been derived from Pickett plot and formation water salinity as follow:

- Tourtuosity factor, (a) = 0.62
- Cementation exponent, (m) = (1.85-2.1)
- Saturation exponent, (n) = 2.0
- Formation water salinity = 200000 ppm NaCl

Water Resistivity (Rw) was calculated from resistivity of NaCl solutions standard Schlumberger chart at reservoir temperature (180°F) and formation water salinity, which found equal to 0.019 (ohm.m) (Geological Study for Subba Oil Field, 2001). The

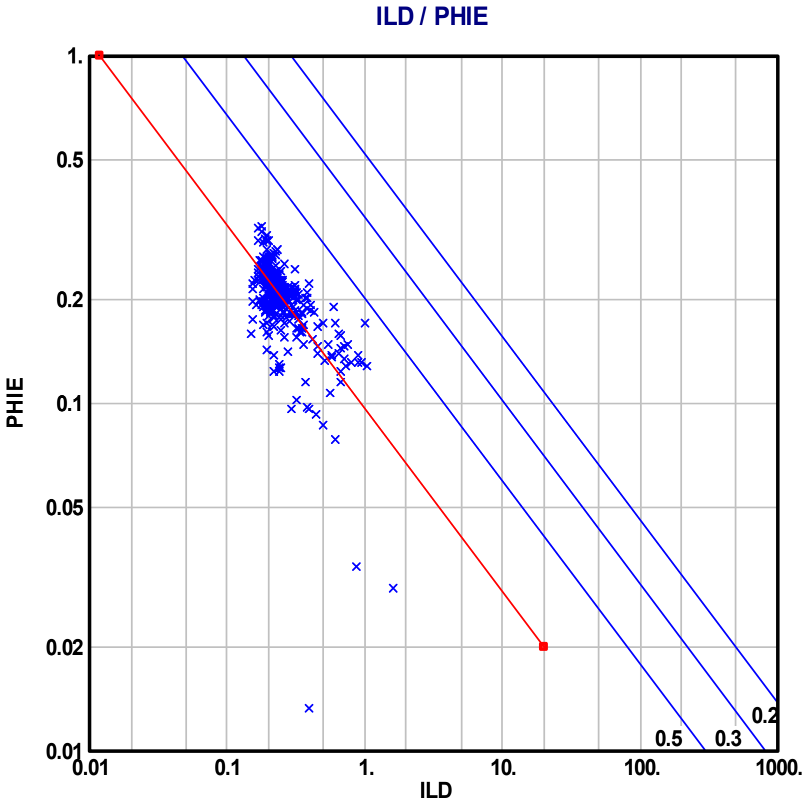

Fig. 3: Pickett plot for well x-3

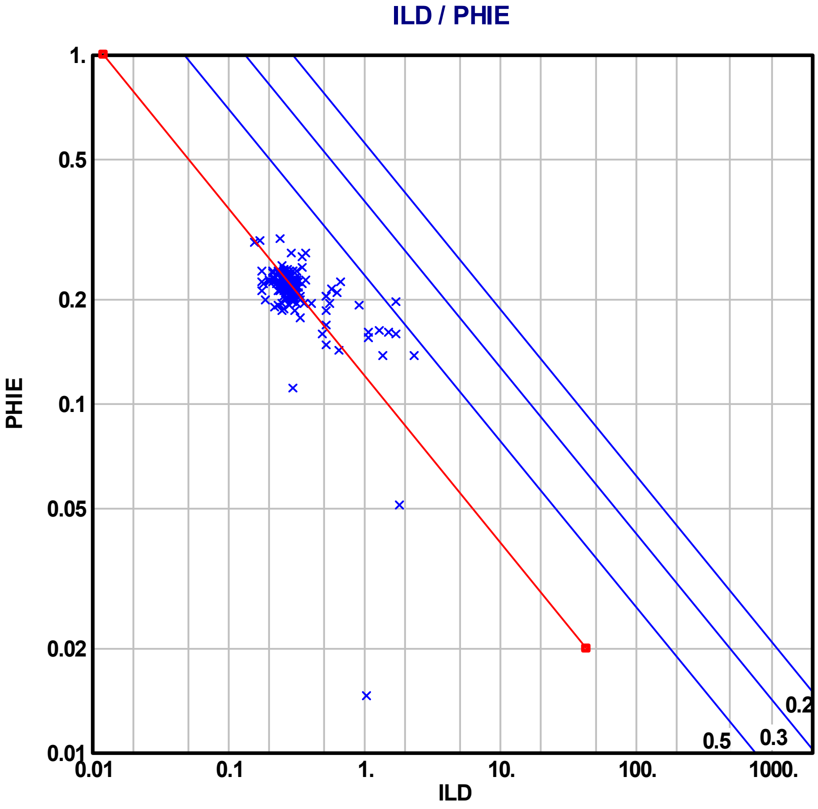

Fig. 4: Pickett plot for well X-4

tourtuosity factor (a), cementation exponent (m), saturation exponent (n) and the salinity value of 200000 ppm NaCl were tested and matched using the Pickett plot for each well as shown in Fig. 3 to 14.

Logs interpretations:

Clay volume: The clay volume was determined depending on the Gamma Ray (GR) method. The value of GR clean ranged between (2-12) API and GR clay ranged between (35- 120) API.

Porosity: Four methods were utilized to compute porosity, Sonic-Raymer porosity model, Density porosity model, Neutron porosity model, Neutron-Density porosity model. The results are compared prior to selecting a suitable porosity technique. Additionally, the computed porosities were compared to core porosities. The computed porosity from all aforementioned methods was compared with core porosity and finally Neutron-Density method was selected to generate porosity as it gave realistic results. In the bad hole section the calculated porosity from density log become invalid and hence the sonic log has been used instead of Neutron-Density log to calculate porosity.

Water saturation: Once porosity has been determined, the water saturation can determined. The Indonesia Equation was utilized to calculate Sw and Sxo corrected for the effects of clay volume. This method was used successfully and widely in petrophysical studies for shaly sand reservoir in the Iraqi oil fields, as more satisfactory results obtained with this formula. The Indonesia equation for water saturation is as follow (Andre and Jacques, 1971):

$$\frac{1}{\sqrt{Rt}} = \left[\sqrt{\frac{\emptyset^{m}}{a \times Rw}} + \frac{V_{cl}^{\,(1-(V_{cl}/2))}}{\sqrt{R_{cl}}}\right] \times Sw^{n/2} \qquad (1)$$

where,

Sw = The water saturation, fraction

Sxo = The flushed zone saturation

Rt = The true resistivity at 100% water saturation, ohm

Rw = The water resistivity, ohm

R_{cl} = The clay resistivity, ohm

Values for shale resistivity (R_{cl}) was handpicked from the logs for each well Fig. 15 and 16 show samples of the logs interpretations results for two wells.

Reservoir quality: Depending on the results of logs interpretations for 13 wells, the net values were based

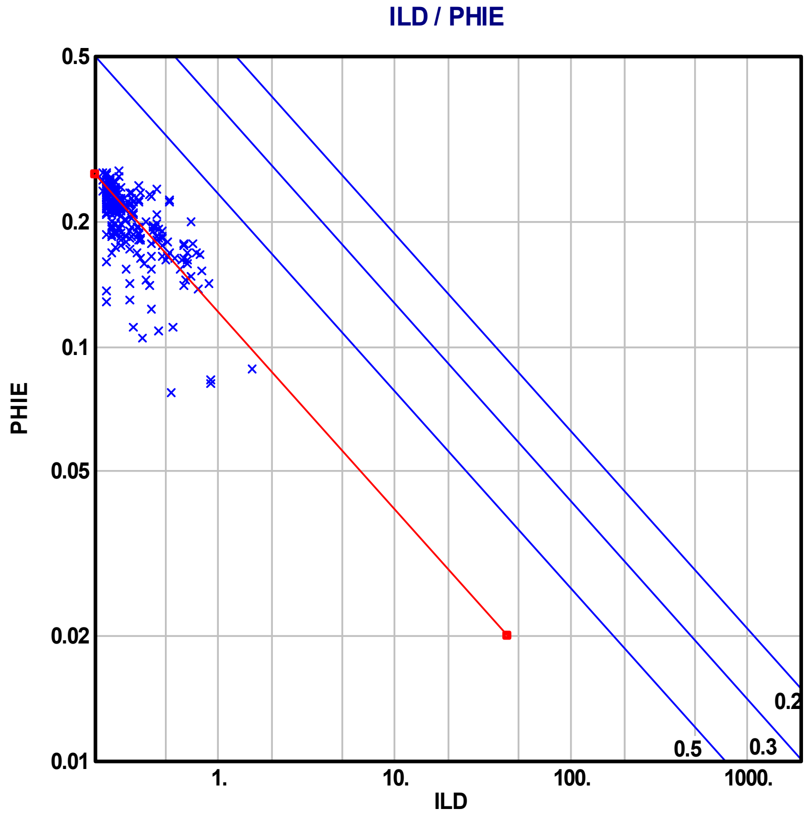

Fig. 5: Pickett plot for well X-5

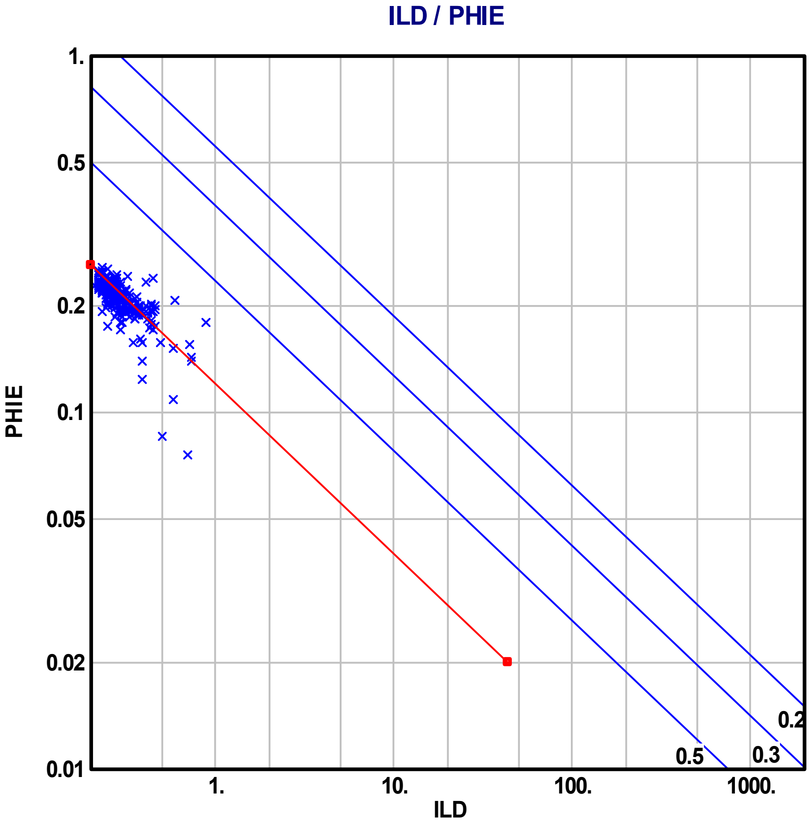

Fig. 6: Pickett plot for well X-6

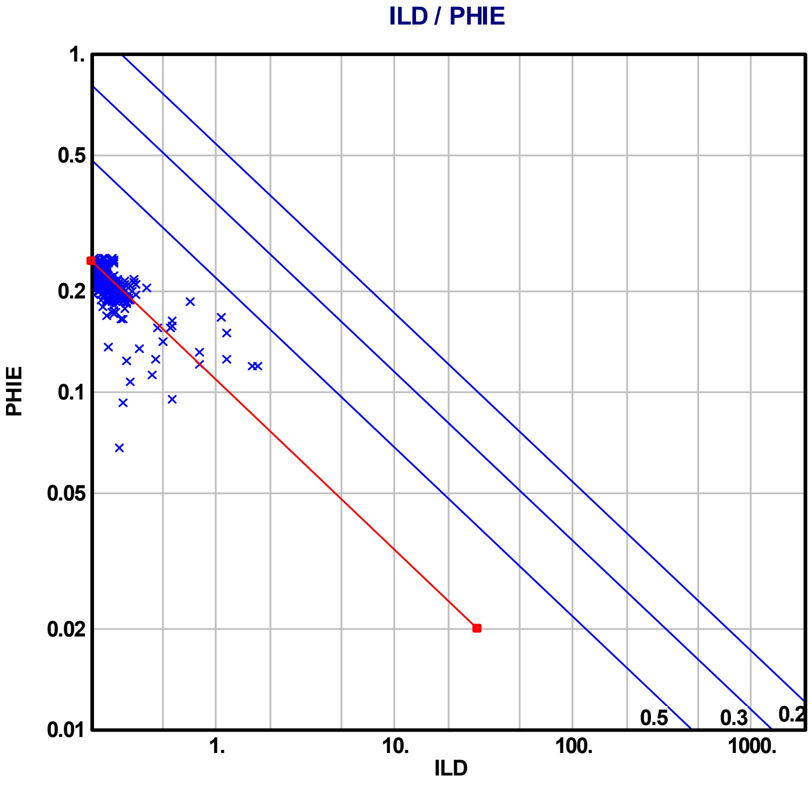

Fig. 7: Pickett plot for well X-7

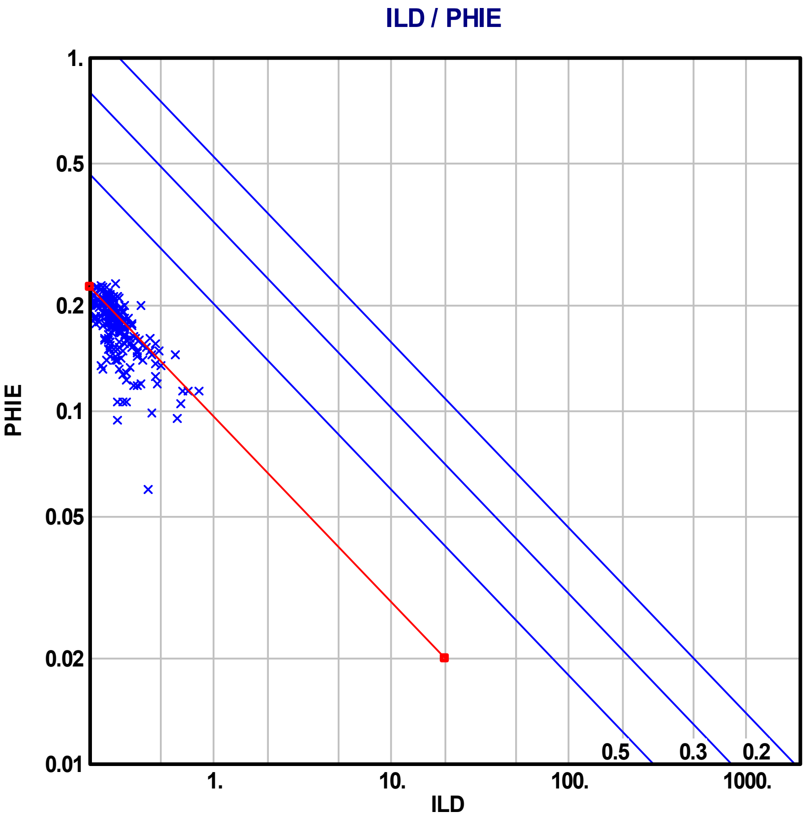

Fig. 8: Pickett plot for well X-8

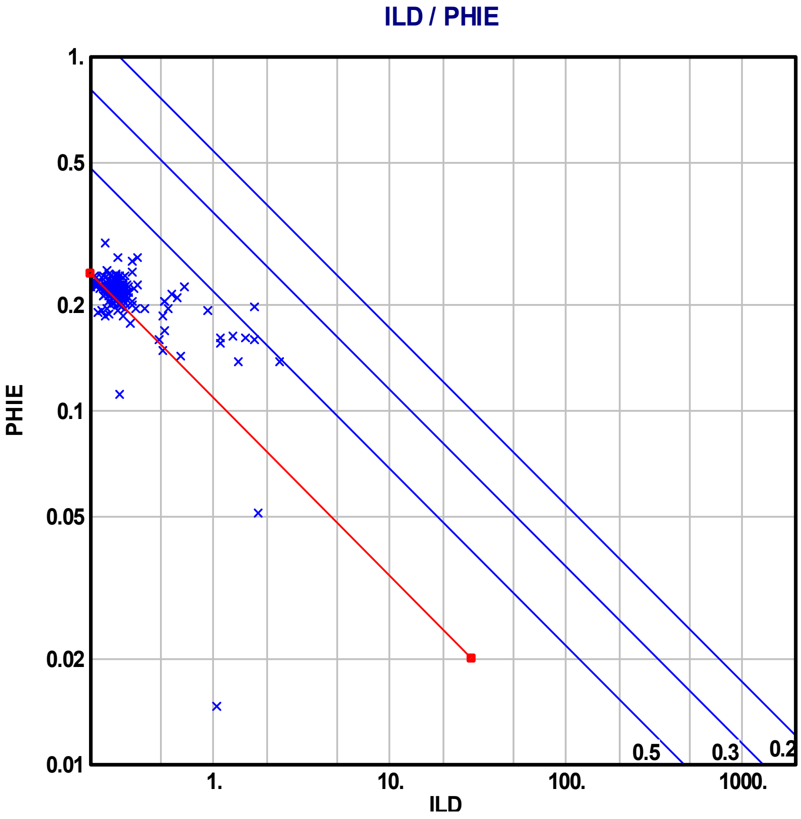

Fig. 9: Pickett plot for well X-9

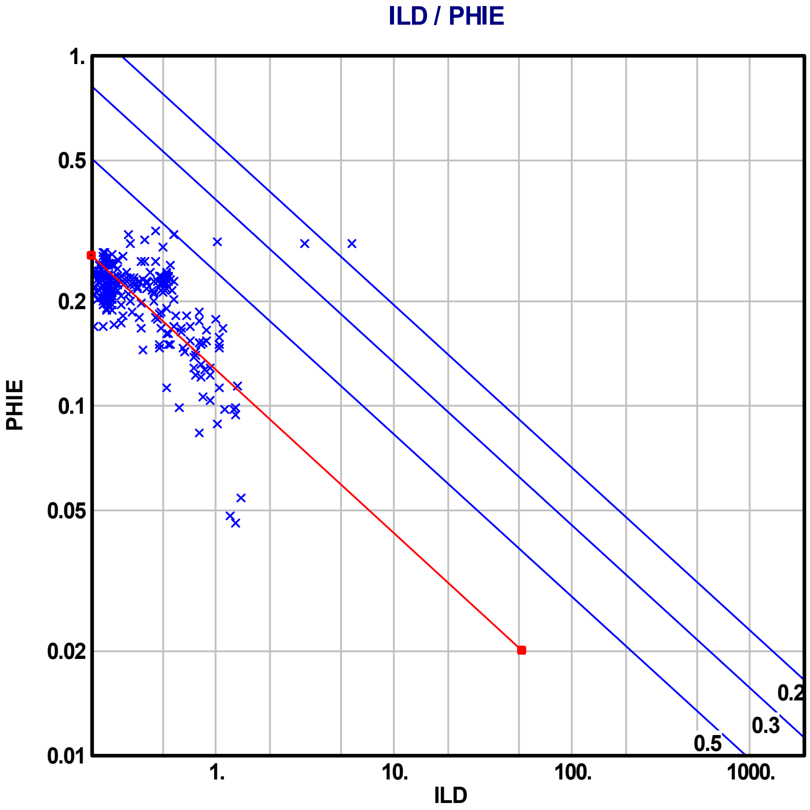

Fig. 10: Pickett plot for well X-10

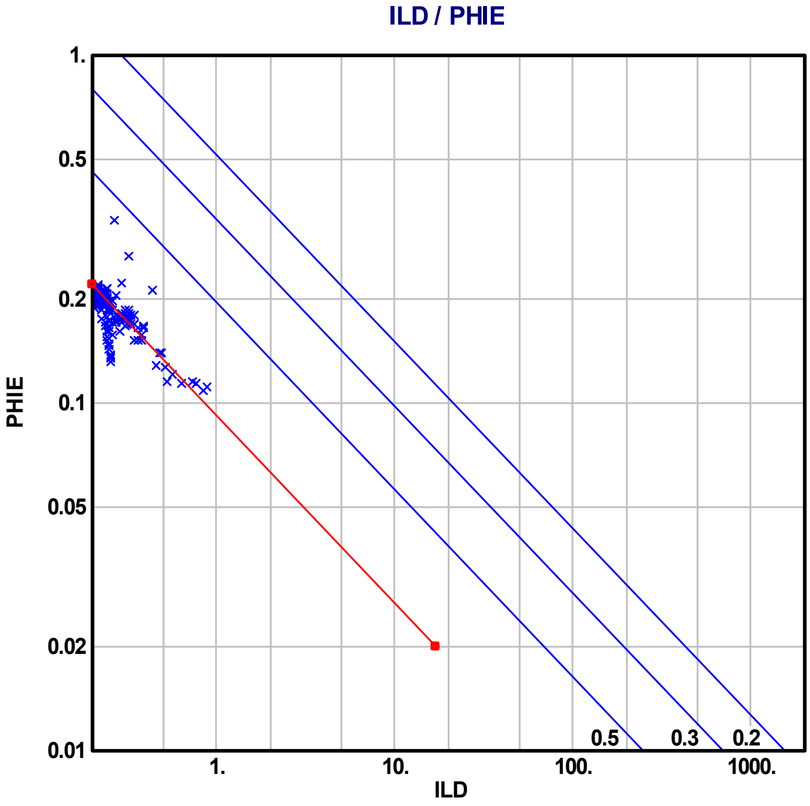

Fig. 11: Pickett plot for well X-11

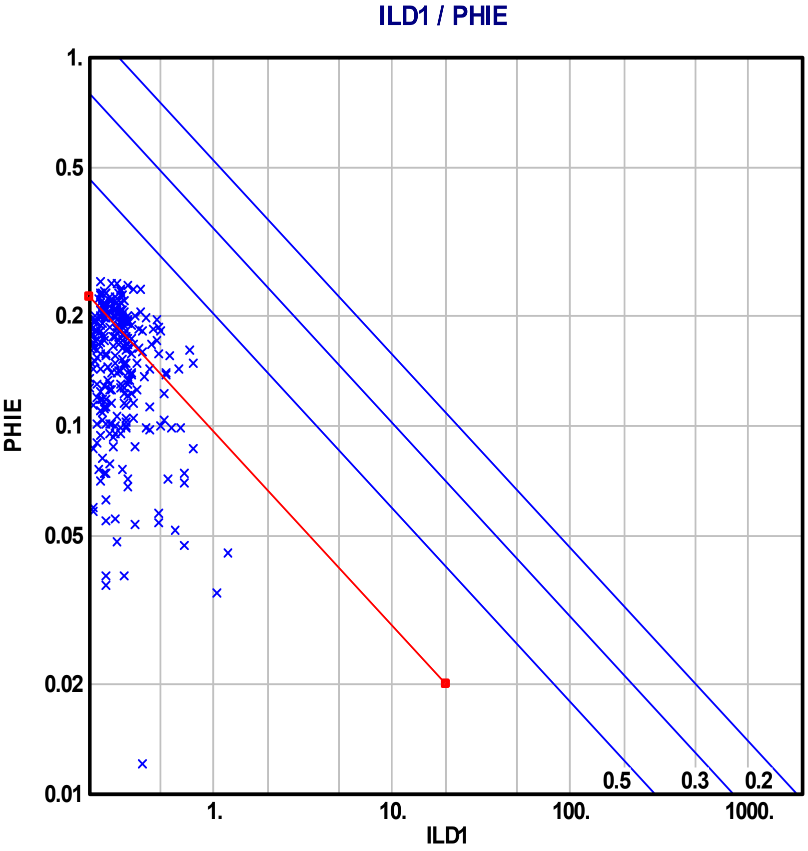

Fig. 12: Pickett plot for well X-12

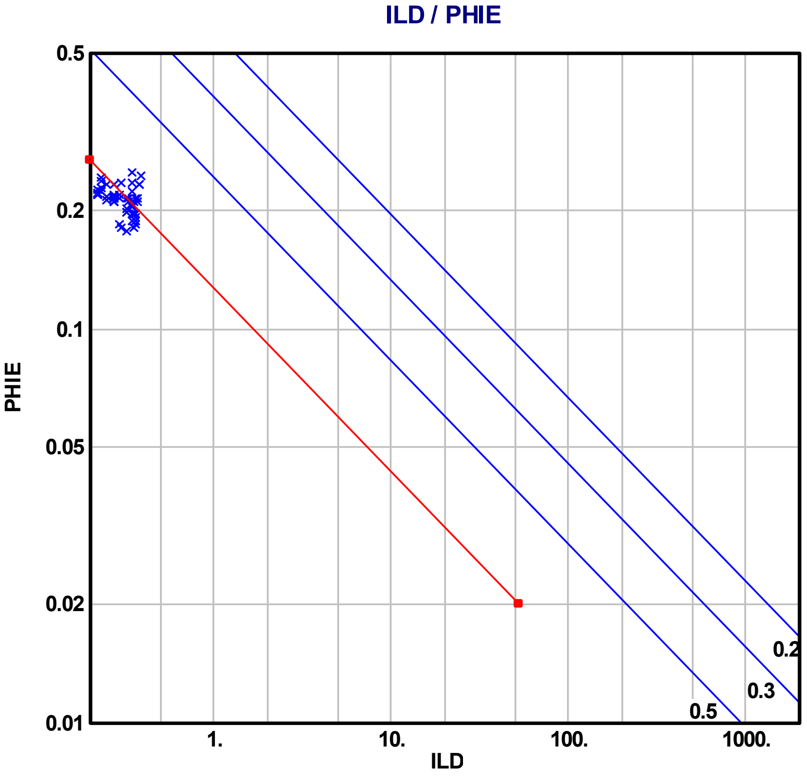

Fig. 13: Pickett plot for well X-13

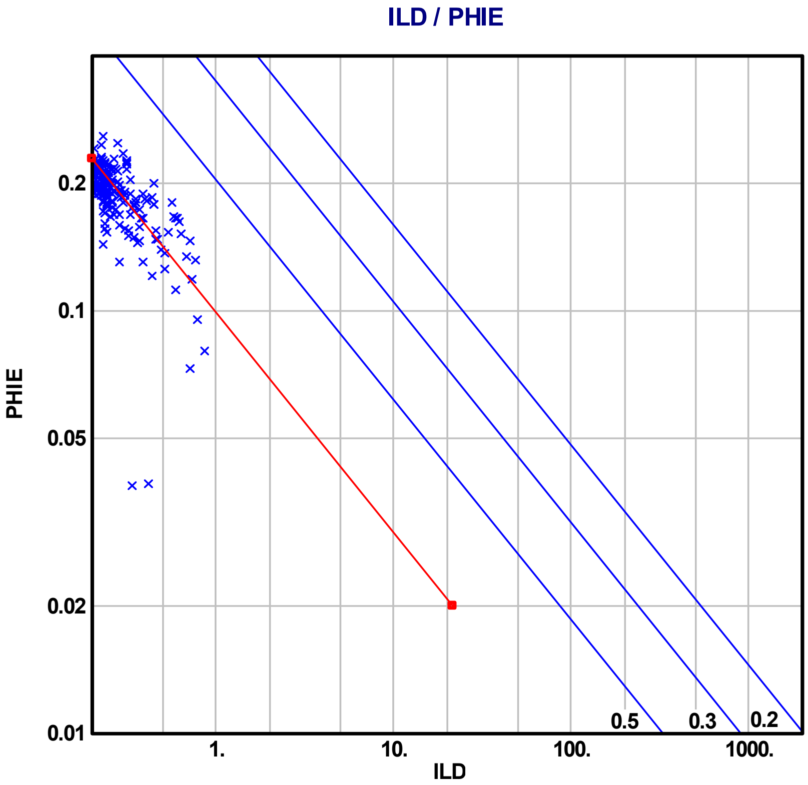

Fig. 14: Pickett plot for well X-14

on an effective porosity cut-off of >5%, *Sw* limit of < = 70% and *Vsh*<0.35. The storage capacity cut-off method was used to determine the porosity cut off, but this method doesn't work on saturation and shale calculation cut-offs. The equivalent oil column also applied for all wells and also they didn't work on saturation calculation cut-offs. Therefore, cut-offs values of saturation and shale volume have been derived from petrophysical studies done on Nahr Umr reservoir in other Iraqi oil fields and from field experiences. The storage capacity method include plot the storage capacity against porosity as shown in the following equation:

$$Storage\ capacity = \frac{\emptyset \times sw}{\sum \emptyset \times sw} \tag{2}$$

Figure 17, show storage capacity plot for six wells. The porosity cut-off calculated at storage capacity equal approximately (98%), which equal (5%).

Rock types prediction: Rock types or facies prediction is often the most crucial element when constructing a geological model. The information available from final well geological reports indicated that Nahr Umr formation in Subba oil field include mainly four facies, which are fluvial sand, tidal sand, siltstone and shale. The number of rock types has confirmed by using hydraulic flow units (Amaefule *et al*., 1993; Al-Ajmi and Holditch, 2000; Guo *et al*., 2005). The hydraulic flow unit for Nahr Umr formation identified depending on performing core analyses for seven core samples taken from seven wells spread along the field as shown in Fig. 1. The results of these core measurements which include porosity and permeability measurement are subsequently analyzed using Rock Quality Index (RQI), Flow Zone Indicator (FZI) and Discrete Rock Typing (DRT) techniques. A range of FZI for each rock type was identified.

Table 1: Rock types and corresponding DRT

Rock code	Rock type	DRT-range
0	Fluvial sand	15.8-14.5
1	Tidal sand	14.4-13
2	Siltstone	12.9-10
3	Shale	<10

The rock types quality has been identified depending on DRT criteria as follow (Table 1).

The RQI/FZI/DRT equations can be written as follow (Amaefule *et al*., 1993; Al-Ajmi and Holditch, 2000; Guo *et al*., 2005; Gunter *et al*., 1997):

$$RQI = 0.0314\sqrt{\frac{k}{\emptyset_e}} \tag{3}$$

$$\emptyset_z = \left[\frac{\emptyset_e}{1-\emptyset_e}\right] \tag{4}$$

$$FZI = \left[\frac{RQI}{\emptyset_e}\right] \tag{5}$$

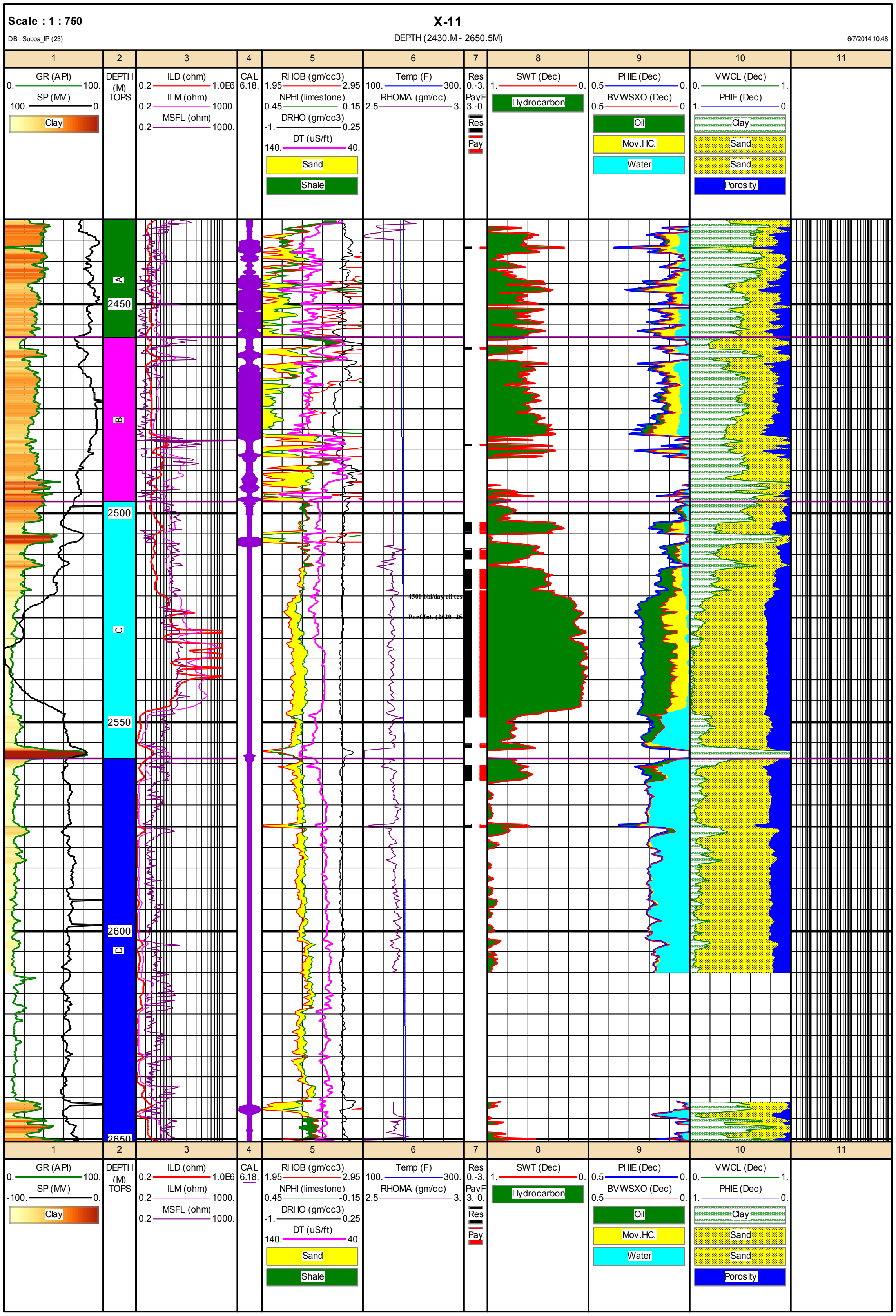

Fig. 15: Logs interpretation for well X-11

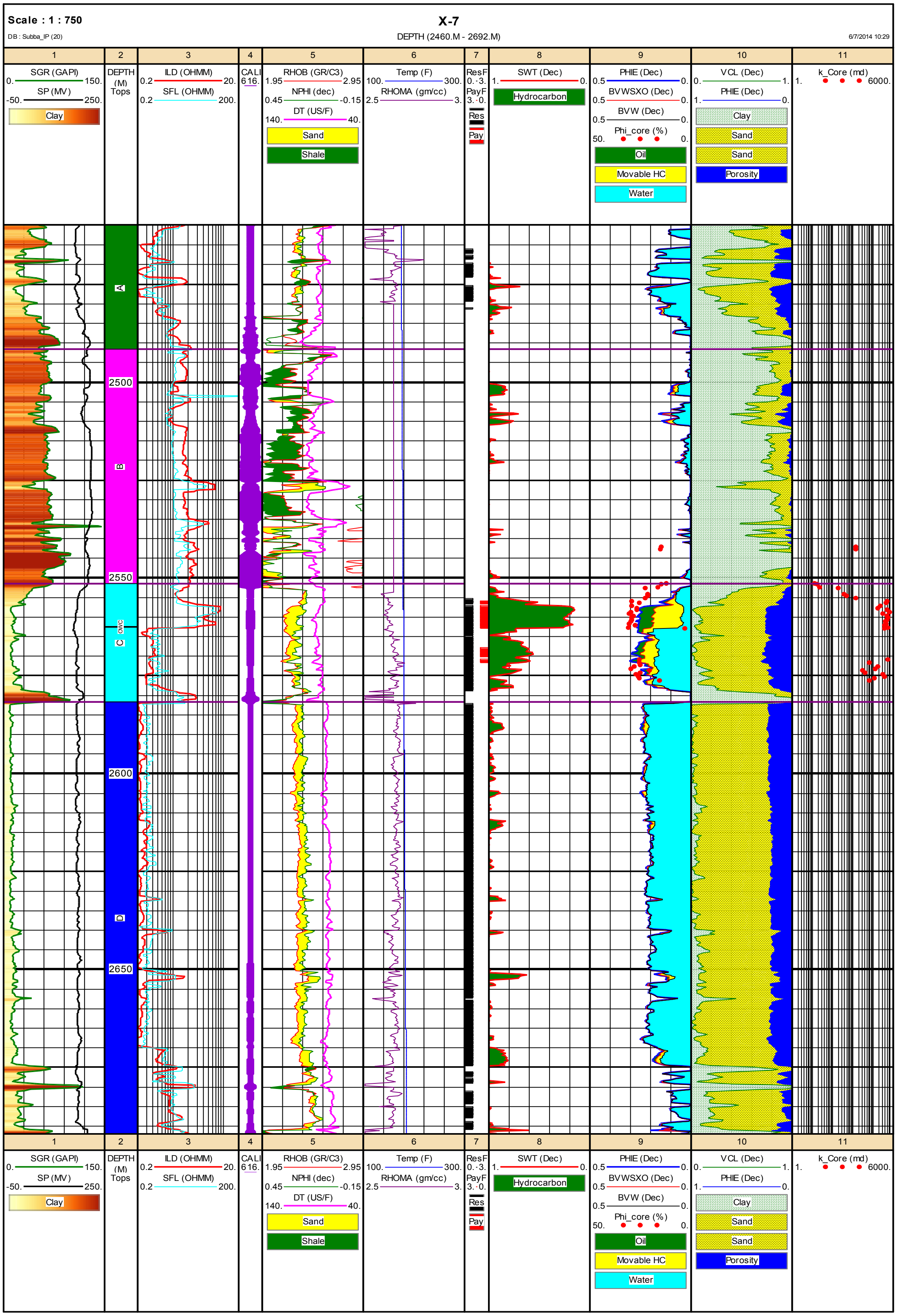

Fig. 16: Logs interpretation for well X-7

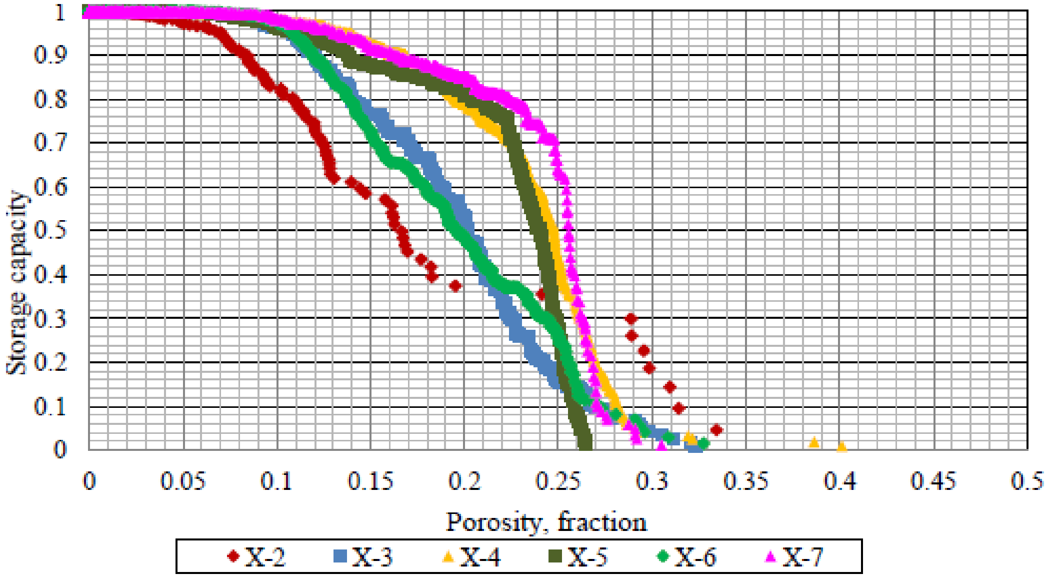

Fig. 17: Storage capacity against porosity

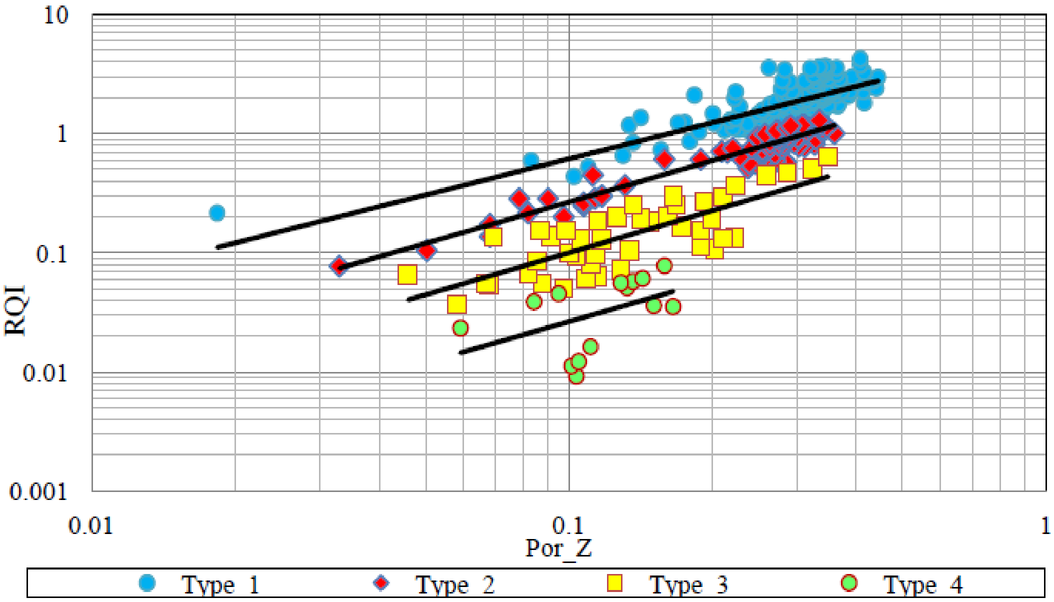

Fig. 18: RQI vs. normalized porosity relationship

$$DRT = Round\ (2ln(FZI) + 10.6) \tag{6}$$

where,

k = Permeability, md

$\emptyset_e$ = Effective porosity

$\emptyset_z$ = Normalized porosity index

RQI = Rock quality index

FZI = Flow zone indicator, µm

The core samples of the same rock type will have similar *FZI* values. Furthermore, on log-log plot of *RQI* versus $\emptyset_z$, samples which lie on the same straight line constitute a hydraulic unit (Amaefule *et al*., 1993) as shown on Fig. 18. It was demonstrated that this technique is applicable to both carbonate and clastic reservoirs (Amaefule *et al*., 1993). A continuous rock type variable *FZI* can be converted into a discrete one using Eq. (6) (Guo *et al*., 2005). The number of rock type were identified also by utilizing graphical method of probability plot of the FZI based on cluster analysis (Al-Ajmi and Holditch, 2000) and the range of FZI for each rock type was identified by colored lines, since four rock types were identified for Nahr Umr formation as shown in Fig. 19.

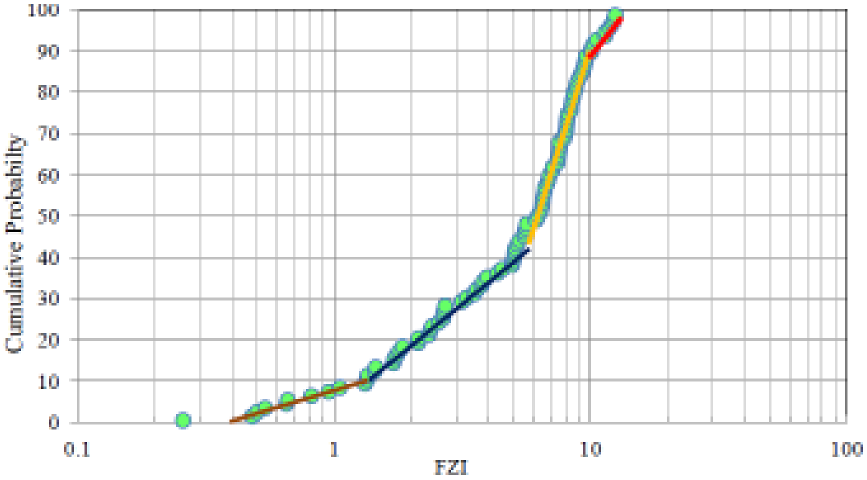

Fig. 19: Normal probability plot for FZI

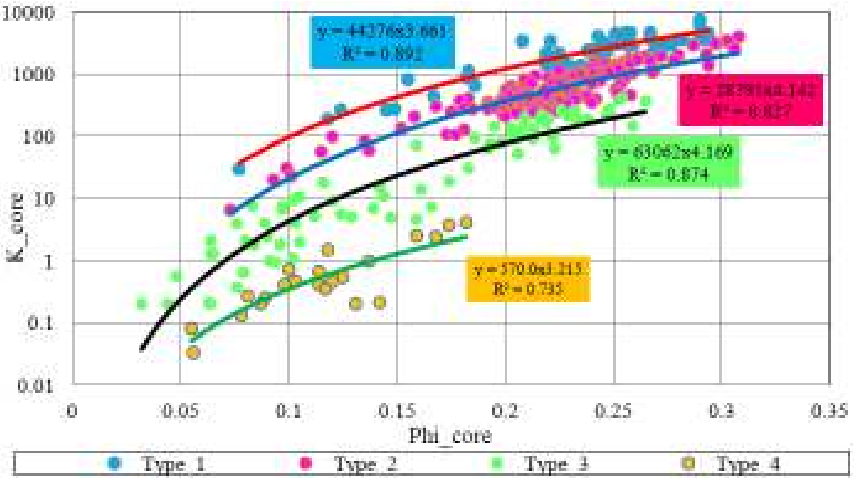

Fig. 20: Core permeability vs. core porosity for different rock types

Permeability predication: Based on the core analysis, the range of permeability values was found to be from 0 to 7500 md (All the Core Measurements Reports for Nahr Umr Formation-Subba Oil Field, 1976-1980), with an average value of 870 md. The core permeability values were used to calibrate the derived well logs permeability. The resulted equation for each rock type were indicated in Fig. 20 and shown below Eq. (7) to (10), The relation between permeability and porosity for each rock type was represented using power low model, high correlation coefficients were obtained for all rock types as shown in Fig. 19, then these equations can be used to generate permeability for fluvial sand, tidal sand, siltstone and shale rock types sequentially in geological model:

$$k = 10^{44276 \times \emptyset^{3.661}} \tag{7}$$

$$k = 10^{28795 \times \emptyset^{4.142}} \tag{8}$$

$$k = 10^{63062 \times \emptyset^{4.169}} \tag{9}$$

$$k = 10^{570 \times \emptyset^{3.215}} \tag{10}$$

RESULTS AND DISCUSSION

- Based on Pickett plot matching for 12 wells (Fig. 3 to 14), remarkable matching were obtained. This match reflected a reliable calculated (a, m, n) factors at reservoir salinity and formation water resistivity. The matching process for all wells confirmed the same calculated values for factors (a) and (n). The values of (m) were varied from well to well and ranged from (1.85-2.1). These values were used in the log interpretations for each well. The Use of incorrect values of (m, n) and (a) in water saturation model, can lead to overlooking producible zones or the completion of poor zones.
- In the porosity cut off calculations by storage capacity method shown in Fig. 15. The 5% porosity cut off was only confirmed for well X-2, the other wells reflect 7% porosity cut off. The 5% porosity cut off was consider in the reservoir

quality identification process, to ensure that all regions in the field have 5% porosity were consider in the potential calculations process. While the 7% cut off lead to neglect portion of reservoir potential in some reservoir regions.

- Based on well log interpretations for 13 wells as shown in results samples (Fig. 15 and 16), The upper part of Nahr Umr reservoir consists mainly of shale and represent barrier along the field, as well as bad hole caving mainly was inherent in this part of the reservoir.
- Oil pays was identified from water zones by Deep Induction Log (ILD). The log response characteristics of oil-bearing zones is higher that of water zones. Generally the values of ILD is less than 1 (ohm.m) for Nahr Umr reservoir in water zone. The difference between deep and short resistivity logs is also a useful tool to distinguish oil-bearing zones from water zones. In oil zones, there should be positive separation between two log curves and the separation is greater in more permeable zones than in the tight zones.
- The main oil potential is occurred in layer C, then layer A.
- The lower part of Nahr Umr reservoir (Layer D) in all wells mainly consists of clean Fluvial sandstone with very low Gamma Ray response, generally less than 12 API. As well as this part show very low Induction Log (ILD) values, generally less than 1 (ohm.m) confirming the bottom aquifer support.

CONCLUSION

- The derived water saturation exponent (n) and formation resistivity factors (a, m) from Pickett plot and formation water salinity had proved the reliability of the reflected petrophysical results.
- The computed porosity by Neutron-Density model was proved as more reliable model for the calculation of porosity for heterogeneous shaly sand reservoir. The Sonic-Raymer porosity model, was alternated in the bad hole section.
- The Indonesia model was used successfully to calculate water saturation for heterogeneous shaly sand reservoirs. This method was used successfully and widely in petrophysical studies for the shaly sand reservoir in the Iraqi oil fields. Because it gave more realistic water saturation values in the shalier sections.
- This case study demonstrated that rock typing using the RQI/FZI/DRT approach can be an effective tool in constructing consistent and reliable permeability models which are very necessary for reservoir simulation modeling. When properly classified from conventional core measurements and reasonably predicted in uncored intervals and uncored wells.
- Generally, petrophysical properties are better in lower part than upper part of Nahr Umr formation in Subba oil field. Because content less shale ratio and high fluvial sandstone.

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