

# Hydrocarbon potential of Upper Bahariya member in Um Baraka oil field, North Western Desert, Egypt

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## ABSTRACT

The present study deals with the hydrocarbon potential evaluation of the Upper Bahariya Member (Upper Cretaceous) in Um Baraka field, North Western Desert. The Upper Bahariya Member is characterised by sandy shale facies in the UMB-152 well, calcareous shale facies in the UMB-89 well and calcareous sand facies in the UMB-108 and UMB-130 wells, these facies reflect to fluvio-marine environment changing to shallow marine environment. The petrophysical parameters results of Upper Bahariya Member are represented laterally (Iso-parametric maps, such as effective porosity, shale content, net-pay thickness and hydrocarbon saturation variation maps) and vertically (Litho-saturation cross-plots). The Iso-parametric maps revealed that the promising hydrocarbon-bearing zones are characterised by their clay content range from 1.7% to 21.4%, effective porosity ranges from 13.2% to 19.7%, net pay thickness range from 7.5 ft to 15.5 ft, and hydrocarbon saturations range from 39.3% to 68.3%. The log analysis and petrophysical parameters results indicate that the Upper Bahariya Member is considered to be the main potential reservoir in Um Baraka field. The petrophysical parameters of the Upper Bahariya reservoir illustrated the improvement of the reservoir properties of Upper Bahariya Member towards the north and northwest and northeast directions, due to increasing of total porosity, effective porosity and hydrocarbon saturation.

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## 1. Introduction

The area under investigation is located in the northern part of the Western Desert of Egypt, about 450 Km west of Alexandria city. It has an area of about 12 km<sup>2</sup> bounded by latitudes 25° 21' 24" – 25° 18' 26" N and longitudes 31° 21' 31"– 31° 17' 31" E (Figure 1).

The recent geophysical and well data acquired by oil companies exploring the Western Desert have indicated that NE-SW and ENE-WSW trending Middle Jurassic to Cretaceous basins are present in different parts of the north Western Desert. The tectonic regimes that affected in northern Egypt are responsible for the formation of basins and sub-basins. Shushan basin is one of these basins which is greatly affected by such tectonic regimes and is considered as Middle Jurassic to Cretaceous rift basin, Taha (1992).

Currently, many producing formations are present in the northern part of the Western Desert, where it is a prolific area of hydrocarbon production in Egypt. Bahariya Formation is considered as one of the most promising reservoirs in the North-Western Desert due to its highest production. The reason for scientific interest in the Bahariya Formation, in addition to its reservoir potential, it is a hydrocarbon source rock within the basin Dolson et al. (2001).

The Um Baraka field contains six oil-producing zones; in addition to the Bahariya "A" potential section

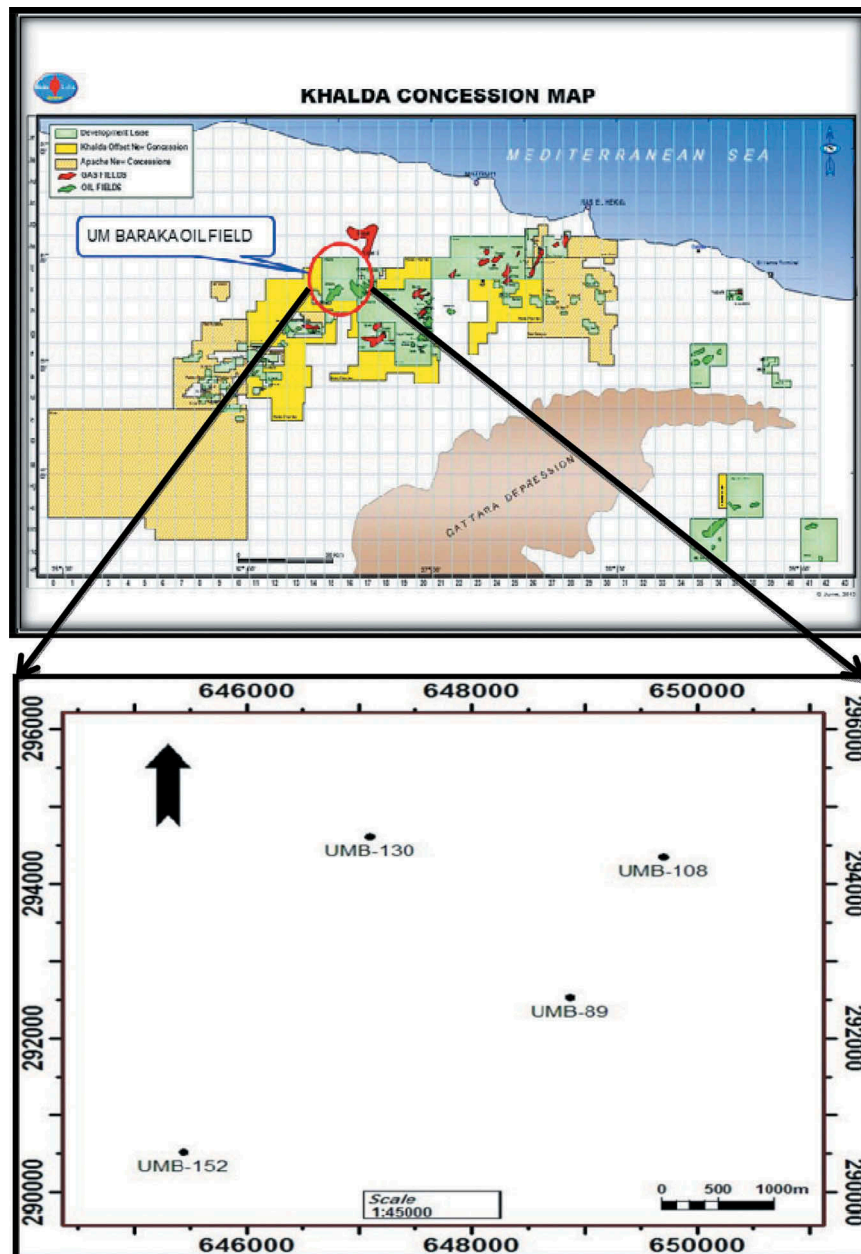
(tested oil in Um Baraka-10 well). These zones were nominated from bottom to top as, the Paleozoic 11,900 ft. sands equivalents, 11,050 ft. Sands equivalents (AEB "D5"), 10,800 ft. sands "D3", 10,700 ft. sands "D1", 10,630 ft. sands (base C3 shale), 10,000 ft. and 10,100 ft. sands (AEB C2 subunits I & I I) (Helmy and Abd El Ghaffar 1991).

The production of hydrocarbon in the Western Desert is concentrated almost in Aptian and Cenomanian-Turonian carbonate and clastic reservoirs EGPC (1992).

Petrographic investigation and petrophysical parameters results indicated that the Cretaceous clastic rock units at north Western Desert are moderate to high reservoir properties, while the Cretaceous carbonate rock units are of low reservoir properties Kassab et al. (2013).

Bahariya Formation studied by many authors, e.g. (El Sayed et al. 1998; Athmer et al. 2007; Halisch et al. 2009; El Sayed 2011), it is considered to be the most important and interesting among the Cretaceous sediments in Um Baraka area. The sand/shale sequence (Cenomanian clastics) may reach a maximum thickness of over 1000 feet in the northern flank of Shushan basin (Um Baraka area).

The Bahariya Formation in the Western Desert of Egypt was deposited under fluvio-marine to shallow



**Figure 1.** Location map of the study area showing the available wells.

marine conditions at the beginning of the Upper Cretaceous (Cenomanian) transgression (El Bassyouny 2004; Catuneanu et al. 2006).

The present study focused on the evaluation of hydrocarbon potential of the Upper Bahariya reservoir (Upper Cretaceous).

The north Western Desert was affected by two tectonic events, the Early Paleozoic and the Late Paleozoic events, Hanter (1990).

Several tectonic events affected in the north Western Desert. The Early Paleozoic (Hyrceanian) events were mild and are represented by regional uplifts of moderate magnitude producing disconformities within the Paleozoic and between the Paleozoic and Jurassic. The

presence of widely spread continental Jurassic indicates that the Late Paleozoic event could not have produced major structural or topographic irregularities. During the Jurassic, which was accompanied by major plate movements including the separation of the Apulian microplate, the newly formed Neotethys submerged many of the emergent lands of north Egypt. The end of the Jurassic witnessed a major orogenic movement, which resulted in the emergence of the land, Said (1990).

The most important tectonic event occurred during the Late Cretaceous and Early Tertiary and was probably related to the movement of the north African plate towards Europe. It resulted in the elevation and folding of major portions of the north Western Desert

along an east-northeast, west-southwest trend (Syrian arc system) and in the development of faults of considerable displacements, Meshref (1990).

In the north Western Desert, the complete stratigraphic section (Figure 2) is represented by Paleozoic to Recent sedimentary rock and overlies the Pre-Cambrian crystalline basement, Abd El Aal and

Moustafa (1988). The Pre-Cambrian crystalline basement is not reached throughout the investigated wells. The Bahariya Formation (Figure 2) deposited conformably on top of the Kharita Formation (Albian) and is located stratigraphically below the Abu Roash Formation (Cenomanian-Turonian). The Cenomanian clastics (Bahariya Formation)

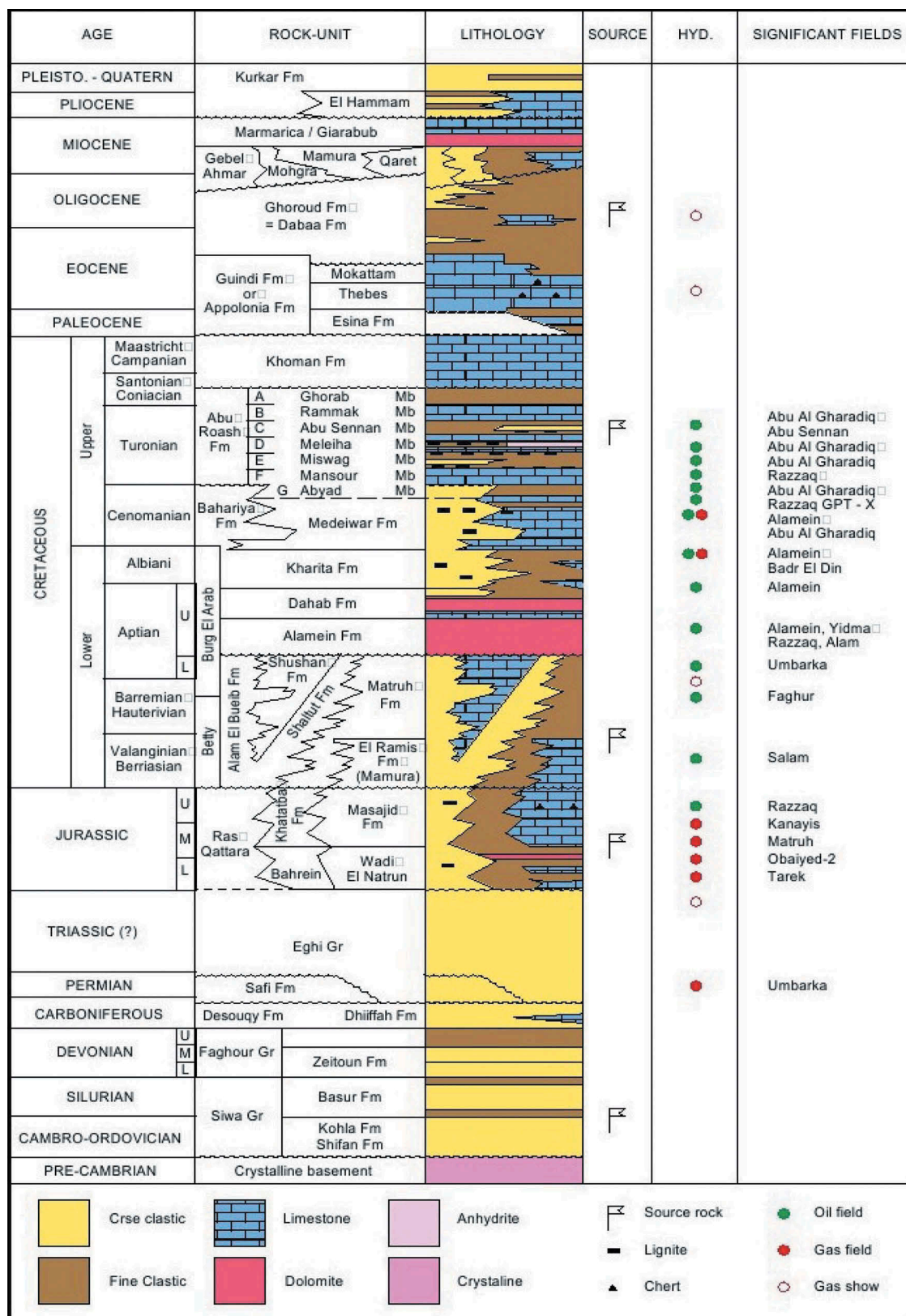


Figure 2. A generalised stratigraphic column of the North-Western Desert of Egypt (after Schlumberger 1995).

section generally represents a transgressive environment cycle between the continental Albian section and the Cenomanian – Turonian marine carbonate facies, Abdelmoaty (2015).

The depositional environment for the Bahariya Formation has been described in two fundamentally different ways (continental, braided stream and deep water marine). Recent work has indicated that the Bahariya Formation developed in a tidal flat environment with cross-cutting channel sands. The laminated sections correspond to marine siltsandshales, sediments deposited in the off-channel, tidal-flat environment. These sediments are cut by channel sands, Schlumberger (1995).

The Bahariya Formation was first assigned by Norton (1967) to describe a Lower Cenomanian fluvio-marine conditions prevailed by the beginning of the Late Cretaceous time. During this time, argillaceous sandstone sequence intercalated with some carbonate interbedded. Dominik (1985) proposed that, this formation was deposited first in dominant fluvial conditions followed by estuarine conditions and finally lagoonal conditions prevailed. The Bahariya Formation consisting of sandstone interbedded with siltstone and minor shale with some streaks from limestone, Abdelmoaty (2015).

Um Baraka area forms a part of the unstable (mobile) shelf of Egypt, where the northern part of the Western Desert forms featureless plain covered by Tertiary deposits of northerly gentle dipping with the exception of the small folded and faulted Abu Roash complex to the north of Giza Pyramids, where Cretaceous rocks are exposed, Said (1962).

The correlation of the electric logs through the Um Baraka field wells had classified the Bahariya Formation into two members, (Upper and Lower Bahariya members), where the break between the two members can be easily recognised on the log curves, where the Upper Bahariya Member characterised by low resistivity than Lower Bahariya Member.

The Upper Bahariya Member is characterised by sandy shale facies in the UMB-152 well, calcareous shale facies in the UMB-89 well and calcareous sand facies in the UMB-108 and UMB-130 wells, these facies reflect to fluvio-marine environment changing to shallow marine environment. The thickness of the Upper Bahariya Member varies from about 130 to 300 ft and consists mainly of fine glauconitic sandstone, silt, and

shale with minor limestone thin beds. The Lower Bahariya Member (400–800 ft. thickness) is relatively sand-rich succession of fine to medium-grained sandstone and shale. The Upper Bahariya Member is the main productive horizon in the Um Baraka field, Bakr (1994).

Said (1990), mentioned that the most important tectonic event occurred during the Late Cretaceous to Early Tertiary was probably related to the movement of the North African plate towards Europe. The North Western Desert was affected by this tectonic event and it led to elevation and folding of major portions of the North-Western Desert along the East–Northeast, West Southwest trend (Syrian arc system).

## 2. Materials and methods

Reservoir evaluation is the main task of well log analysis. This objective is to estimate the volume of shale, porosity, water saturation, net Pay, oil in place, permeability and rock mechanics of a reservoir. The procedures of well log analysis which performed in this study are consisting of two phases; Data gathering. Database editing task and Formation evaluation tasks.

Different wireline logging suites (Gamma ray, Neutron, Density, Resistivity, etc.), for four wells, namely, UMB-89, UMB-108, UMB-130 and UMB-152 are used in the analysis and performing the necessary calculations. The effective porosity, shale volume, and fluid saturation (water and hydrocarbon) are the most important and necessary petrophysical parameters for characterising the potential reservoirs.

In the present study, the hydrocarbon potential evaluation was done for the Cenomanian (Upper Bahariya Member) clastic reservoir rocks in the studied four wells. The open-hole log data for the studied wells are in the form of LAS files; these data were collected and digitised.

The available open-hole well logging tools for the four wells that are used in the present study are listed in Table 1.

The analysis, which has been carried out for different well logs (Gamma ray, Neutron, Density, Sonic, Resistivity, etc.), was interpreted to evaluate the hydrocarbon potentiality of Bahariya reservoir. This analysis has been carried out using *Interactive Petrophysics (IP, v3.5)* Schlumberger software.

**Table 1.** Well log tools.

NO.	Well Name	Available Logs
1	UMB-89	GR, SPDH, Caliper, BIT, RMLL, M1R3, M1R9, ZDEN, CNCF, PE.
2	UMB-108	GR, SPDH, Caliper, BIT, RMLL, M1R3, M1R9, ZDEN, CNCF, PE.
3	UMB-130	GR, SP, Caliper, BS, RMLL, M1R3, M1R9, ZDEN, CNCF, PE.
4	UMB-152	GR, SP, Caliper, BS, RMLL, M1R3, M1R9, ZDEN, CNCF, PE.

Where; GR: Gamma ray curve, SPDH: Spontaneous potential curve, BS: Bit Size curve, RMLL: Microspherical resistivity curve, M1R3: Shallow resistivity curve, M1R9: Deep resistivity curve, ZDEN: Density curve, CNCF: Neutron curve, PE: Photoelectric Effect curve.

### 3. Results and discussion

#### 3.1. Lithofacies maps evaluation

Facies maps are made for several purposes, such as; re-establish of geological history, interpretation of environmental condition, evaluation of contemporary tectonic configuration and/ or variety of economic uses, Krumbein (1952).

Table 2, concluded that the Upper Bahariya Member lithofacies calculations according to the limits accepted to characterise the lithological group, which summarises the composition of each nine lithologic groups associated with standard triangle proposed by Krumbein and Sloss (1963).

Isolith map of Upper Bahariya sandstone shows that the thickness of sandstone increases towards the north and northwest directions of the study area, where it reaches the greatest thickness of about 82.5 ft. at UMB-108 well. The sandstone attains its lowest thickness at east direction of the study area, about 46 ft., at UMB-89 well (Figure 3).

Siltstone lithofacies map of Upper Bahariya illustrates that the thickness of siltstone increases towards south and southwest directions of the study area. The largest thickness of siltstone attains 60.5 ft., at UMB-152 well, and the thickness of siltstone decreases towards north and northwest directions of the study

area. The lowest thickness of siltstone attains 36.5 ft., at UMB-130 well (Figure 4).

Shale lithofacies map of Upper Bahariya shows that shale of Upper Bahariya attains greatest thickness (45 ft.) at the southwest part at UMB 152 well (Figure 5). It decreases towards the north and north-east directions, about 23.5 ft., at UMB-108 well.

lithofacies map of Upper Bahariya Limestone (Figure 6) showed that the limestone thickness increases to the northwest direction of the study area. Greater thickness of limestone attains 37 ft., at well UMB-130, and the minimum thickness towards the southwest part, about 15.5 ft., at UMB-152 well.

Sand/Shale ratio map indicates that the ratio increases to the north and northwest around UMB-130, and decreases to southeast around UMB-89 well (Figure 7).

Clastic/Non clastic ratio map indicates the ratio increases towards south and southwest around UMB-152 well, and decrease to the northeast around UMB-130 well (Figure 8).

The facies triangle map (Figure 9) based on the standard triangle Krumbein and Sloss (1963), shows that the Upper Bahariya Member is characterised by calcareous shale facies in the UMB-89 well, calcareous sand facies in the UMB-108 and UMB-130 and sandy shale facies in the UMB-152.

Table 2. Upper Bahariya member lithofacies calculations.

Well name	Total Thick	Sandstone Thickness Ft.	Siltstone Thickness Ft.	Shale Thickness Ft.	Limestone Thickness Ft.	Clastic ratio %	Non Clastic ratio %	Clastic/ non Clastic %	Sand/ Shale %
UMB-89	154	46	56.5	27.5	24	84.4	15.6	5.41	0.55
UMB-108	175	82.5	41.5	23.5	27.5	84.2	15.8	5.32	1.26
UMB-130	181	80.5	36.5	27	37	79.6	20.4	3.89	1.27
UMB-152	189	68	60.5	45	15.5	91.8	8.2	11.2	0.64

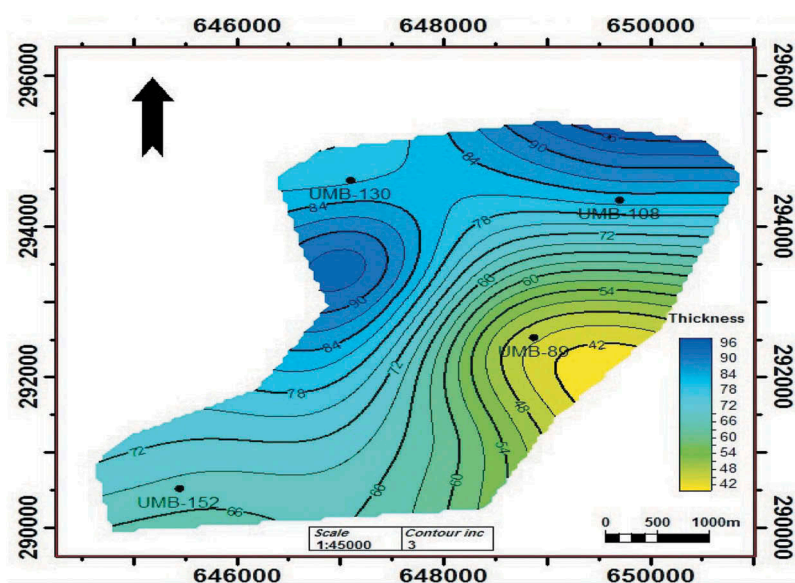


Figure 3. Sandstone isolith map of Upper Bahariya Member.

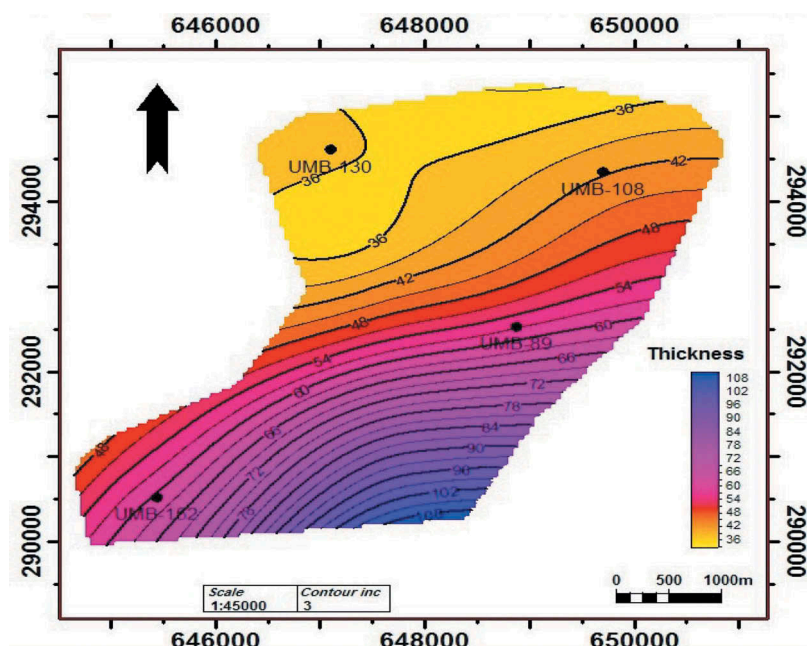


Figure 4. Siltstone isolith map of Upper Bahariya Member.

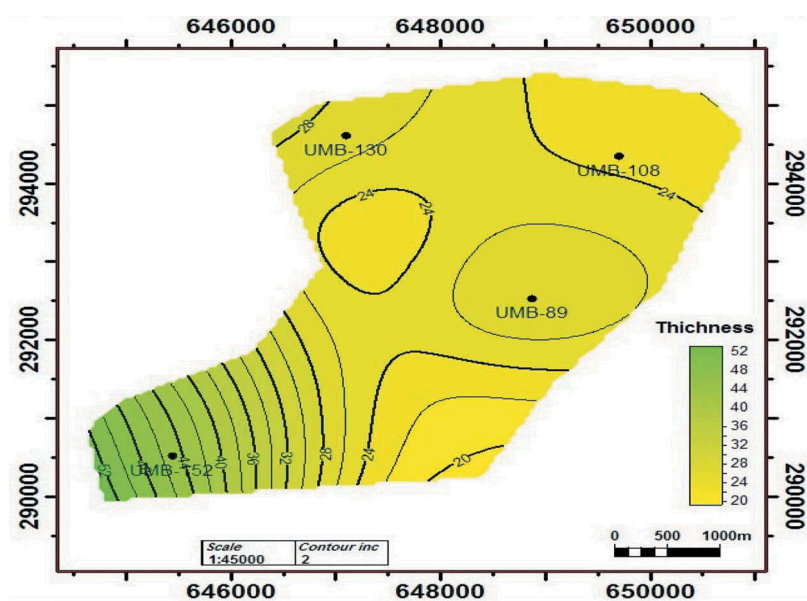


Figure 5. Shale Isolith map of Upper Bahariya Member.

### 3.2. Petrophysical evaluation

Well log analysis is the most important task for any well after drilling, to detect the reservoir rocks among the all drilled formations. Logging data is used to define physical rock characteristics (such as lithology, porosity, pore geometry, water saturation and permeability), to identify productive zones, to determine depth and thickness of zones, to distinguish between oil, gas, or water in a reservoir, and to estimate hydrocarbon reserves. Geologic maps developed from log interpretation help in determining facies relationships and drilling locations.

A set of well logs has been run in the selected four wells. These wells named (UMB-89, UMB-108, UMB-130, and UMB-152). The minimum suite of logs

consisted of gamma ray, density, neutron, and resistivity logs, all the log data are available in digital format.

#### 3.2.1. Determination of shale content ( $V_{sh}$ )

Shale content can be used as an indicator of reservoir quality. The volume of shale of the Upper Bahariya Member is determined from Neutron tool by using the following relation:

$$V_{sh} = \frac{[(\Phi N) \log - (\Phi N) \min]}{[(\Phi N)_{sh} - (\Phi N) \min]} \quad (1)$$

This can be used for determining the shale volume in case of high clay content and low effective porosities (Schlumberger 1974).

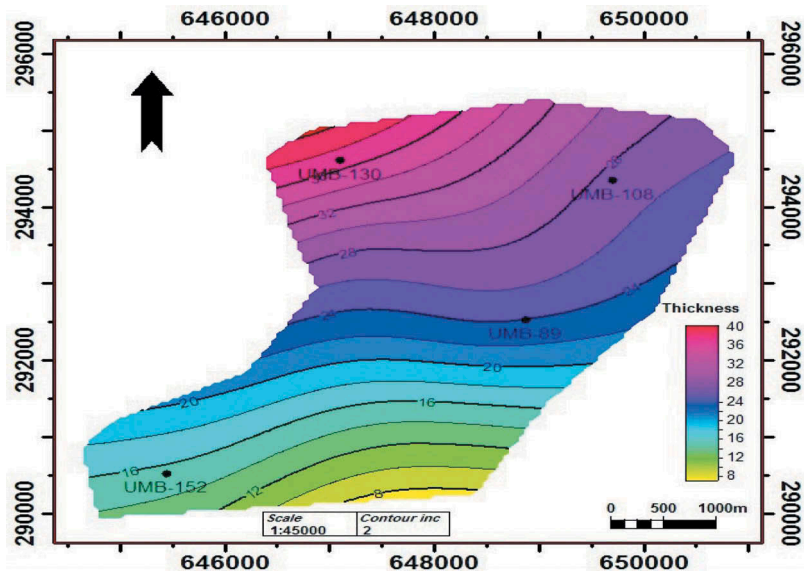


Figure 6. Limestone Isolith map of Upper Bahariya Member.

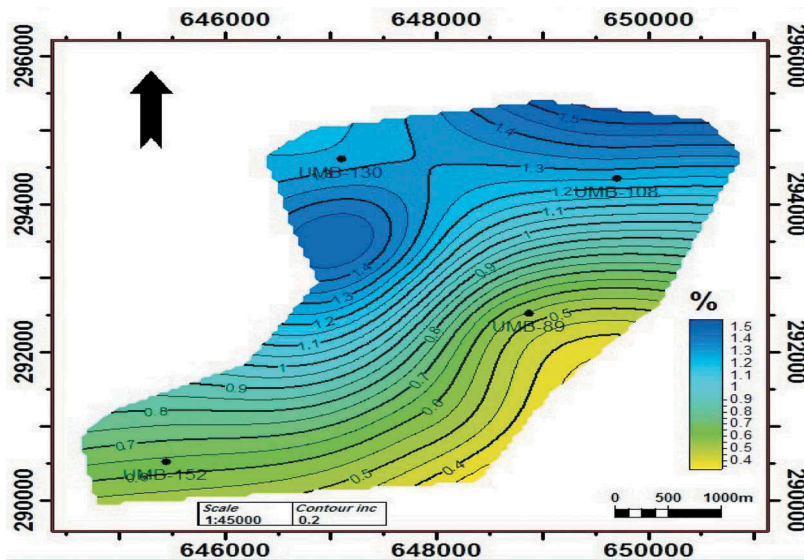


Figure 7. Sand/shale ratio map of Upper Bahariya Member.

Where:

( $\Phi_N$ ) log is the porosity of the Neutron log reading opposite zone of interest.

( $\Phi_N$ ) min is the porosity of the Neutron log reading opposite a clean sand zone.

( $\Phi_N$ ) sh is the porosity of the Neutron log reading opposite a Shale zone.

### 3.2.2. Determination of porosity from density log

The density log responds to the electron density of the material in the formation. For common formation materials, the electron density is proportional to actual density. The density log is used also as a porosity indicator. For other purposes the density log can be used in source rock evaluation, detection of gas, determination of hydrocarbon density and so on. In clean formations:

porosity ( $\Phi_D$ ) can be estimated from density log using the following equation (Wyllie 1963):-

$$\Phi_D = (\rho_{bma} - \rho_{blog}) / (\rho_{bma} - \rho_{bfl}) \quad (2)$$

Where:

$\Phi_D$  is the porosity derived from a measurement of formation density.

$\rho_{bma}$  is the Matrix density, gm/cc,

$\rho_{blog}$  is the Density log reading, gm/cc,

$\rho_{bfl}$  is the Fluid density, gm/cc,

The obtained porosity can be corrected to eliminate the Shale effect as follow:

$$(\Phi_D)_c = \Phi_D - (V_{sh} \times \Phi_{Dsh}) \quad (3)$$

Where,

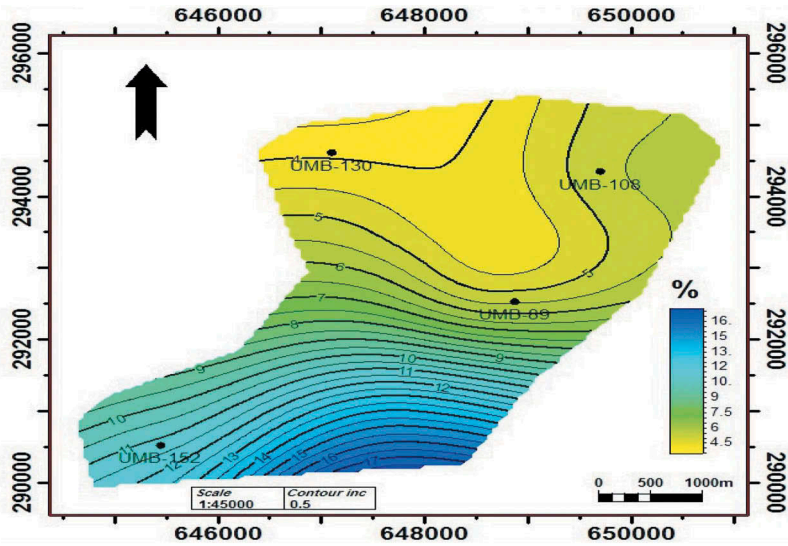


Figure 8. Clastic/non-clastic ratio map of Upper Bahariya Member.

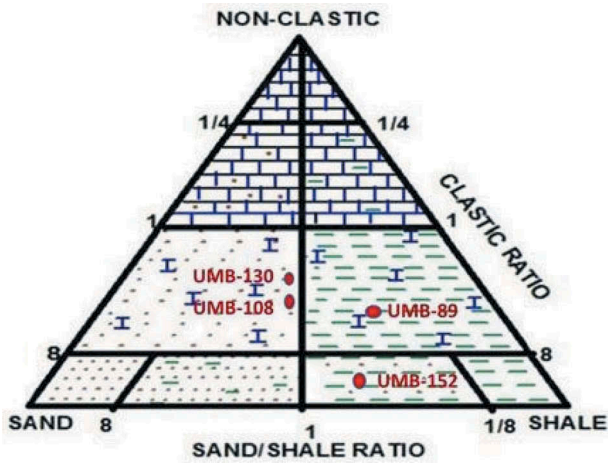


Figure 9. Triangle of lithologic groups of Upper Bahariya Member.

$$\Phi_{Dsh} = (\rho_{ma} - \rho_{sh}) / (\rho_{ma} - \rho_f) \quad (4)$$

### 3.2.3. Determination of effective porosity

The effective porosity ( $\Phi_e$ ) can be calculated by the following equation:

$$\Phi_e = \Phi_D - V_{sh}\Phi_{Dsh} \quad (5)$$

Where:

$\Phi_e$  is the effective porosity.

$\Phi_D$  is the porosity derived density log.

### 3.2.4. Determination of water saturation ( $S_w$ )

Water saturation ( $S_w$ ) is the amount of water that occupies pore space Schlumberger (1972). Indonesia equation is used to determine the water saturation:

$$\frac{1}{\sqrt{R_t}} = \left[ \frac{(V_{sh})^d}{\sqrt{R_{sh}}} + \frac{(\phi^{\frac{m}{2}})}{\sqrt{aR_w}} \right] S_w^{\frac{n}{2}} \quad (6)$$

Where:

$S_w$ : Water saturation in uninvasion zone,

$R_w$  = Formation water resistivity,

$R_t$  = Resistivity reading in uninvasion zone,

$n$  = Saturation exponent,  $a$  = Constant

$m$  = Cementation factor.

### 3.2.5. Hydrocarbon saturation ( $S_h$ )

The hydrocarbon saturation ( $S_h$ ) is the fraction of pore volume that contains hydrocarbon, it can be calculated by using the following equation:

$$S_h = 1 - S_w \quad (7)$$

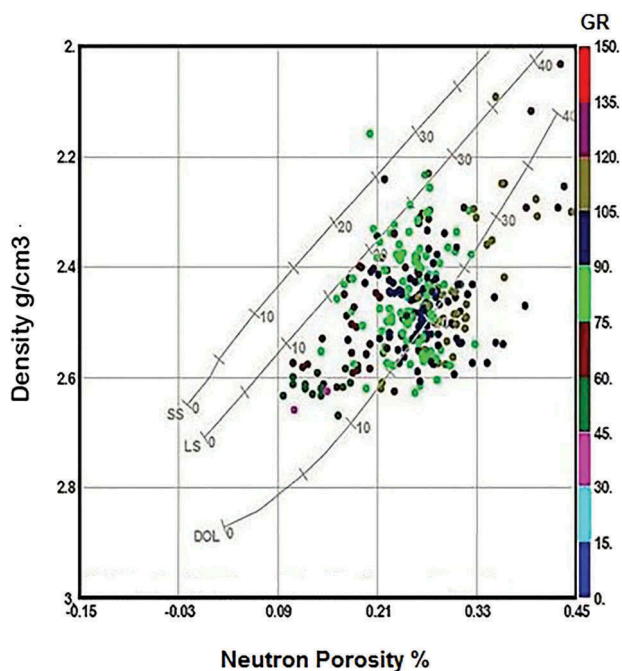
The hydrocarbons can be differentiated into residual ( $S_{hr}$ ) and movable ( $S_{hm}$ ) saturations in simple forms.

### 3.2.6. Lithological identification techniques

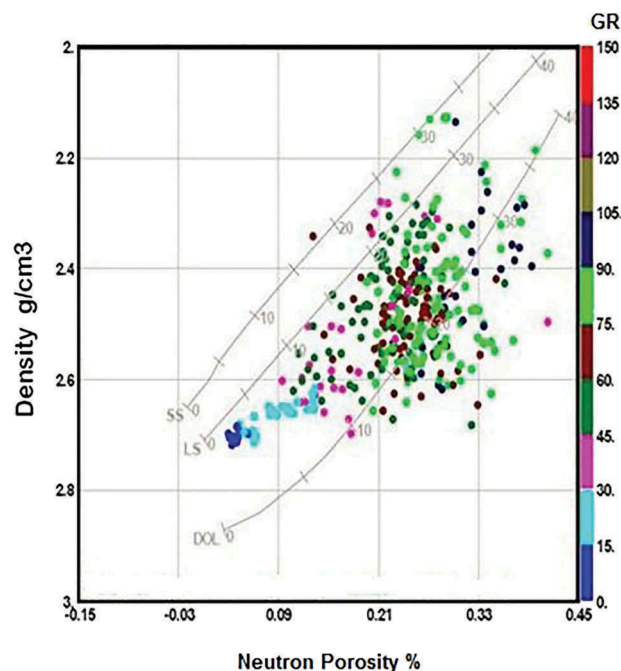
The composite log and the crossplots can be used to deduce the lithology from logs. The crossplots combinations are discussed in Poupon et al. (1970); Schlumberger (1974); Dresser (1979). The crossplot used in this study is the Neutron – Density crossplot. The shale effect can be noted on the crossplot, where the points tend to be in the southeast quadrant of the crossplot. In the present study, the Neutron – Density crossplots have been applied on the Upper Bahariya Member in the studied wells.

In UMB-89 well, the major of the plotted points (Figure 10) are scattered between limestone and dolomite lines with average porosity ranging from 15% to 25%. Some other points are shifted downward to dolomite line due to shale effect or borehole conditions. This indicates the presence of mixed lithology (sandstone, siltstone, shale and limestone).

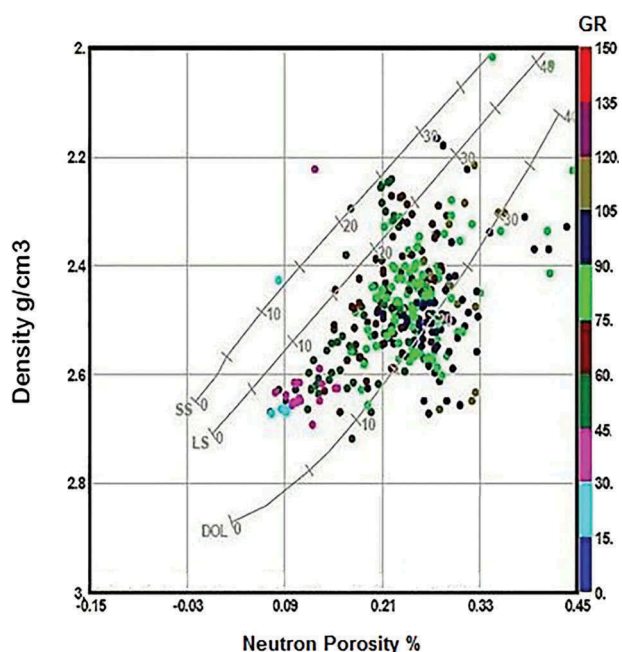
The plotted data in Figure 11 are scattered between limestone and dolomite lines with considerably porosity ranging from 13% to 25%. Some other points are shifted downward to dolomite line due to the effect of shale or borehole conditions in UMB-108



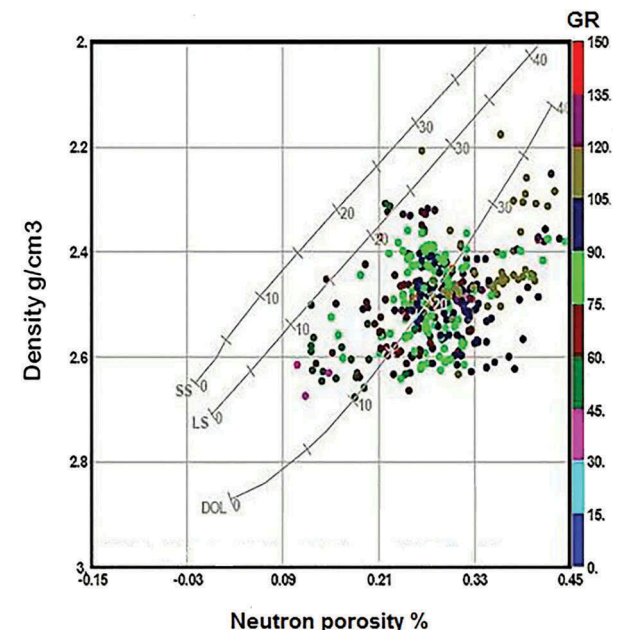
**Figure 10.** Lithological identification cross plot for Upper Bahariya Member in UMB-89 well.



**Figure 12.** Lithological identification cross plot for Upper Bahariya member in UMB-130 well.



**Figure 11.** Lithological identification cross plot for Upper Bahariya Member in UMB-108 well.



**Figure 13.** Lithological identification cross plot for Upper Bahariya member in UMB-152 well.

well, this indicates the presence of mixed lithology (sandstone and limestone with some intercalation from siltstone and shale).

Some of the plotted points (Figure 12) of UMB-130 well, are scattered between limestone and dolomite lines with porosity ranging from 15% to 25%. Some points are shifted downward to dolomite line due to the effect of shale or borehole conditions. This indicates the presence of mixed lithology (sandstone, limestone and shale). In UMB-152 well, some of the plotted points (Figure 13) are scattered between

limestone and dolomite lines with average porosity ranging from 15% to 25%. Most of the points are shifted downward to dolomite line due to shale effect or borehole conditions. This indicates the presence of mixed lithology (sandstone, limestone and shale).

The lithological cross plots (Figures 10–13) and triangle of lithologic groups of Upper Bahariya Member (Figure 9) of the studied wells illustrate that, the lithology is represented by sandstone, siltstone, shale and some streaks from limestone. The Upper Bahariya Member is characterised by sandy shale facies in the UMB-152 and calcareous shale facies in the UMB-89

well, calcareous sand facies in the UMB-108 and UMB-130 these facies reflect to fluvio-marine environment changing to shallow marine environment.

The Computer processed interpretation plots (litho-saturation cross plots) showing the vertical variation in petrophysical parameters results of Upper Bahariya Member in Um Baraka oil field.

(GR: Gamma ray curve, CALX: Caliper log curve, BS: Bit Size curve, RMLL: Microspherical resistivity log curve, M1R3: Shallow resistivity log curve, M1R9: Deep resistivity log curve, ZDEN: Density log curve, CNCF: Compensated Neutron log curve, PE: Photoelectric Effect curve, Lith-inter: Lithological Interpretation, RES.FLAG: Reservoir flag, PAYFLAG: Pay flag, SW: Water Saturation in invaded zone, SXO: Water Saturation in Flushed Zone, PHIE: Effective Porosity and BVW: Bulk volume of water)

The Computer processed interpretation plot (litho-saturation cross plot) (Figures 14–17) of the studied interval in the UMB-89 well shows that extends from 6525 to 6679 ft., the thickness of the reservoir is 7.5 ft, discriminated to six zones from depth 6522 ft. to 66,648 ft. The Neutron – Density cross plot shows mixed lithology from sandstone, siltstone, shale and some streaks from limestone, where the sandstone increases in upper part of Upper Bahariya reservoir. Porosity of net pay zones varies from 13% to 22.4%, and the mean value is 18.1%. The high gamma ray against that sand may be due to the high volume of shale in Upper Bahariya or presence of radioactive minerals and the volume of shale varies from 8.6% to 20.2%. The petrophysical analysis for

Upper Bahariya Member reflects the water saturation ranges from 43.5% to 50.2%, the average value is 50.4%. The hydrocarbon saturation increases up to 56.5%. The average value of movable hydrocarbons is 3.1%, and the average value of residual hydrocarbons is 46.5% (Figure 14).

In the UMB-108 well the computer-processed interpretation plot (litho-saturation cross plot) of the studied interval extends from 6493 to 6668 ft., the thickness of the reservoir is 15.5 ft, discriminated into five zones from depth 6517.5 ft. to 6549 ft. The Neutron – Density illustrates the mixed lithology from sandstone, siltstone, shale and some streaks from limestone. The sandstone increases in upper part of Upper Bahariya reservoir. Porosity of net pay zones varies from 13.7% to 20.9% and the mean value is 17.4%. The high gamma ray against that sand may be due to the high volume of shale in Upper Bahariya or presence of radioactive minerals and the volume of shale vary from 9.9% to 25.5%. The petrophysical analysis for Upper Bahariya unit reflects the water saturation ranges from 28.8% to 62.2%, the average value is 35.6%. The hydrocarbon saturation increases up to 71.2%. The average value of movable hydrocarbons is 9%, while the average value of residual hydrocarbons is 55.4% (Figure 15).

In the UMB-130 well the computer processed interpretation plot (litho-saturation cross plot) of the studied interval extends from 6464 to 6645 ft., the thickness of the reservoir is 14 ft, discriminated to eight zones from depth 6476.5 ft. to 6545.5 ft.

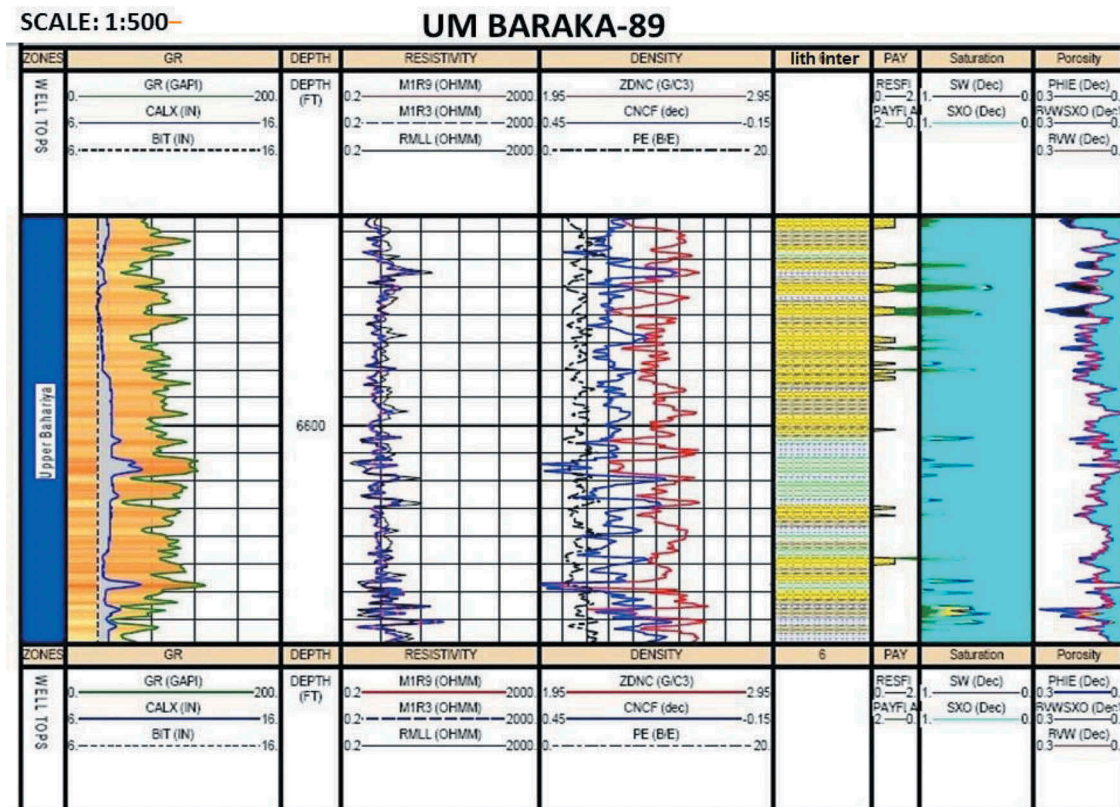


Figure 14. Computer processed interpretation (CPI) plot (Litho-saturation cross plot) for the Upper Bahariya in UMB-89 well.

SCALE: 1:500

## UM BARAKA-108

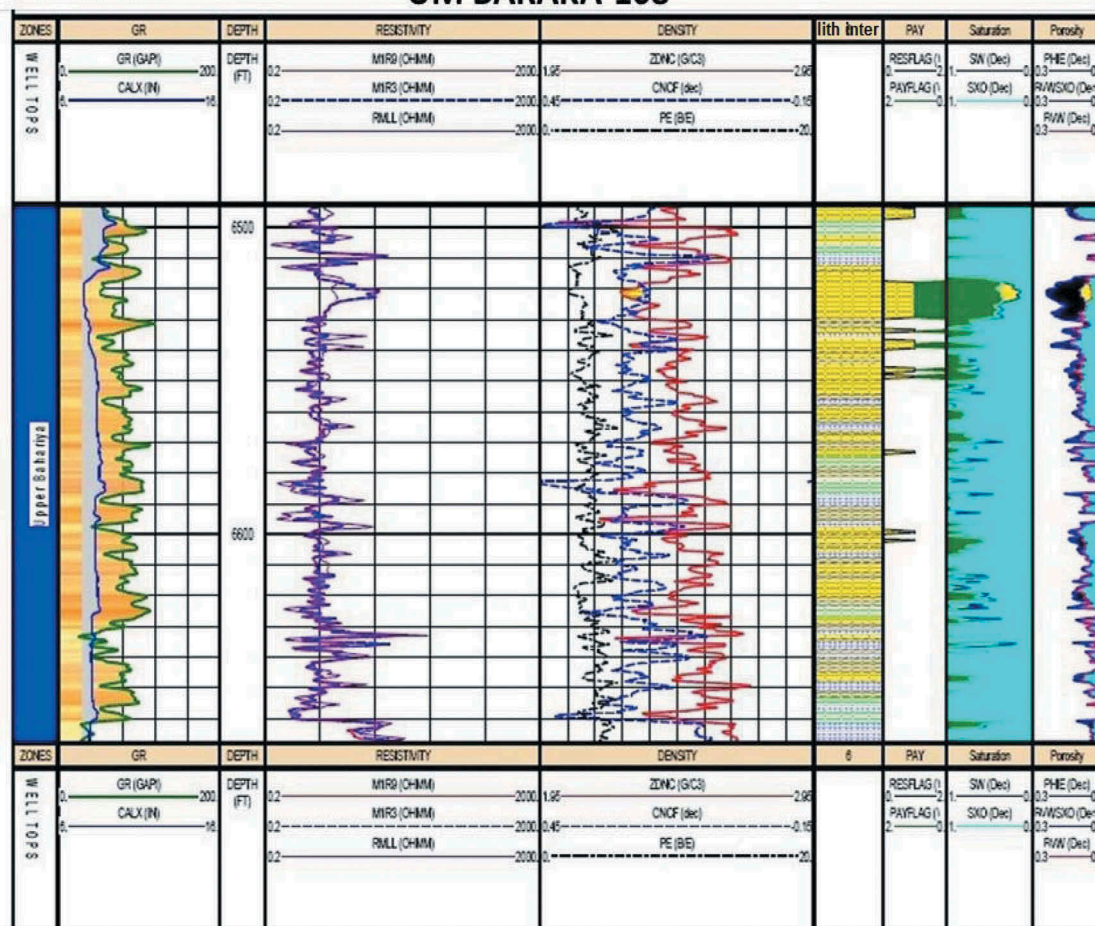


Figure 15. Computer processed interpretation (CPI) plot (Litho-saturation cross plot) for the Upper Bahariya in UMB-108 well.

SCALE: 1 : 500

## UM BARAKA - 130

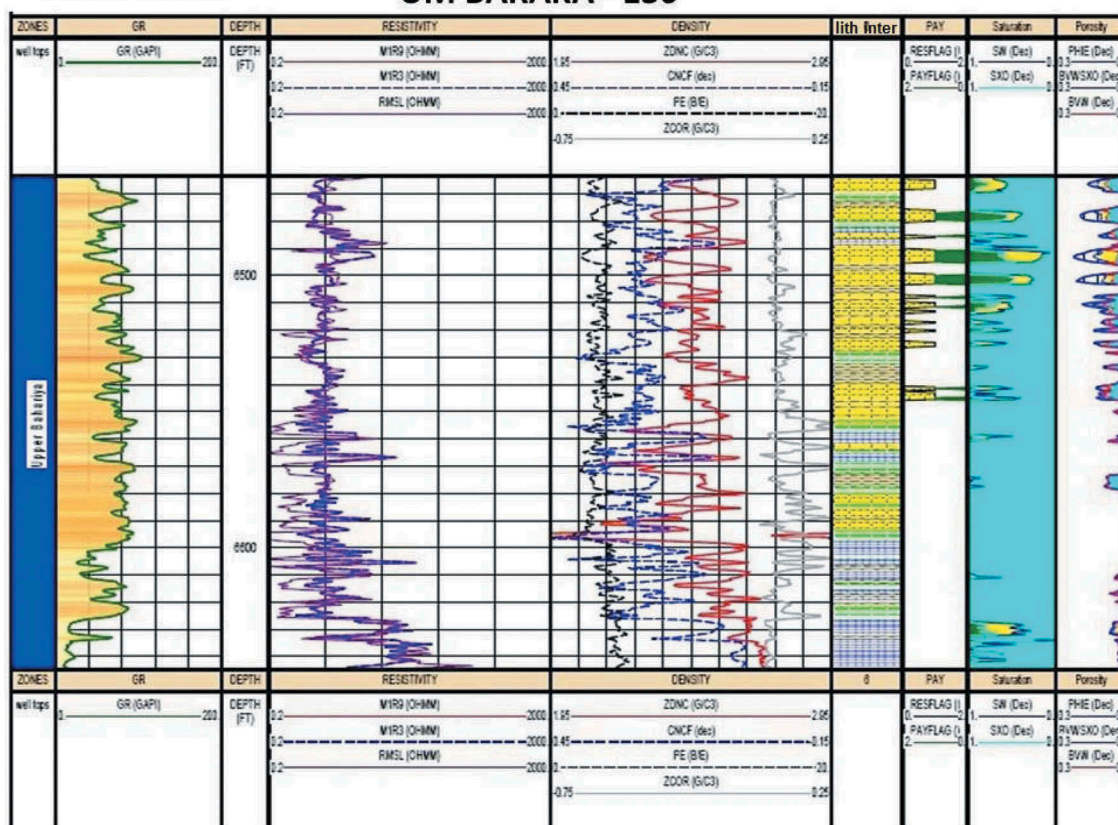
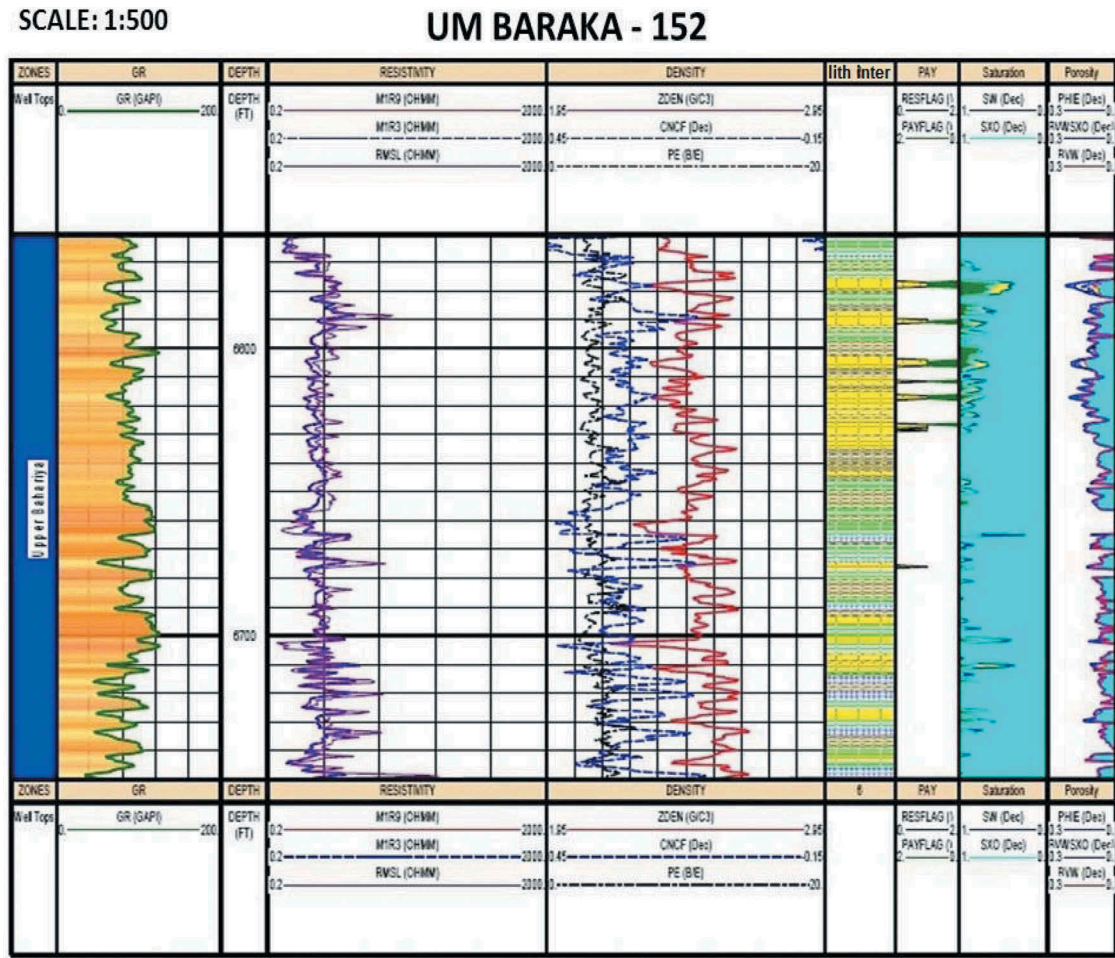


Figure 16. Computer processed interpretation (CPI) plot (Litho-saturation cross plot) for the Upper Bahariya in UMB-130 well.

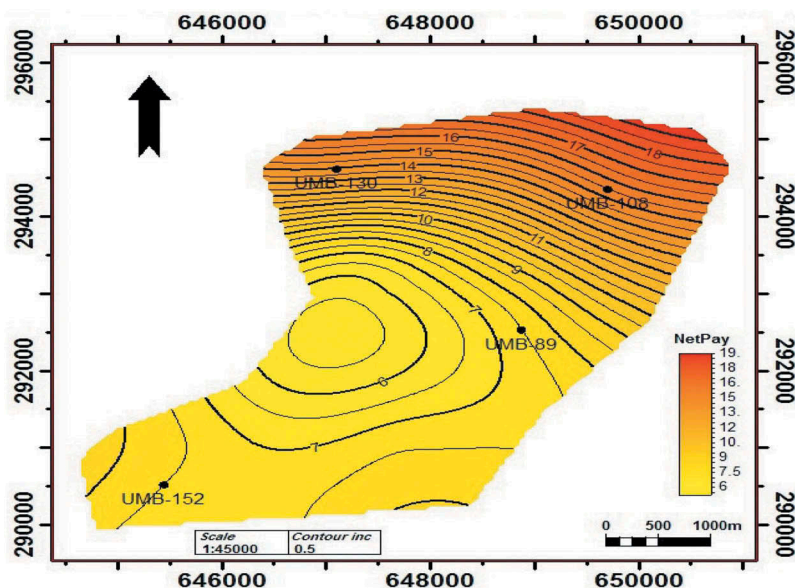
The Neutron – Density illustrates the mixed lithology from sandstone, siltstone, shale and some streaks from limestone. The sandstone increases in

upper part of Upper Bahariya reservoir. Porosity of net pay zones varies from 11.6% to 18.8% but the mean value is 14.9%. The high gamma ray against



**Figure 17.** Computer processed interpretation (CPI) plot (Litho-saturation cross plot) for the Upper Bahariya in UMB-152 well.

Where; GR: Gamma ray curve, CALX: Caliper log curve, BS: Bit Size curve, RMLL: Microspherical resistivity log curve, M1R3: Shallow resistivity log curve, M1R9: Deep resistivity log curve, ZDEN: Density log curve, CNCF: Compensated Neutron log curve, PE: Photoelectric Effect curve, Lith-inter: Lithological Interpretation, RES.FLAG: Reservoir flag, PAYFLAG: Pay flag, SW: Water Saturation in invaded zone, SXO: Water Saturation in Flushed Zone, PHIE: Effective Porosity and BVW: Bulk volume of water.



**Figure 18.** Net pay distribution map of Upper Bahariya Member.

that sand may be due to the high volume of shale in Upper Bahariya or presence of radioactive minerals and the volume of shale vary from 13.2% to 34.6%. The petrophysical analysis for Upper Bahariya unit reflects the water saturation ranges from 19.8% to 49.3% and the average value is 35.2%. The hydrocarbon saturation increases up to 80.2% and the average value of movable hydrocarbons is 26.7%, while the average value of residual hydrocarbons is 38.1% (Figure 16).

The computer processed interpretation plot (litho-saturation cross plot) of the studied interval in the UMB-152 well that extends from 6561 to 6750 ft., the thickness of the reservoir is 7.5 ft, discriminated to six zones from depth 6576.5 ft. to

6626.5 ft. The Neutron – Density shows the mixed lithology from sandstone, siltstone, shale and some streaks from limestone. The sandstone increase in upper part of Upper Bahariya reservoir. Porosity of net pay zones varies from 13.7% to 19.1% but the mean value is 16.5%. The high gamma ray reading may be due to the high volume of shale (varies from 8.4% to 27.1%) or presence of radioactive minerals in Upper Bahariya. The petrophysical analysis for Upper Bahariya unit reflects the water saturation ranges from 42.3% to 73.8% and the average value is 64.4%. The hydrocarbon saturation increases up to 57.7% and the average value of movable hydrocarbons is 15.7%, while the average value of residual hydrocarbons is 19.9% (Figure 17).

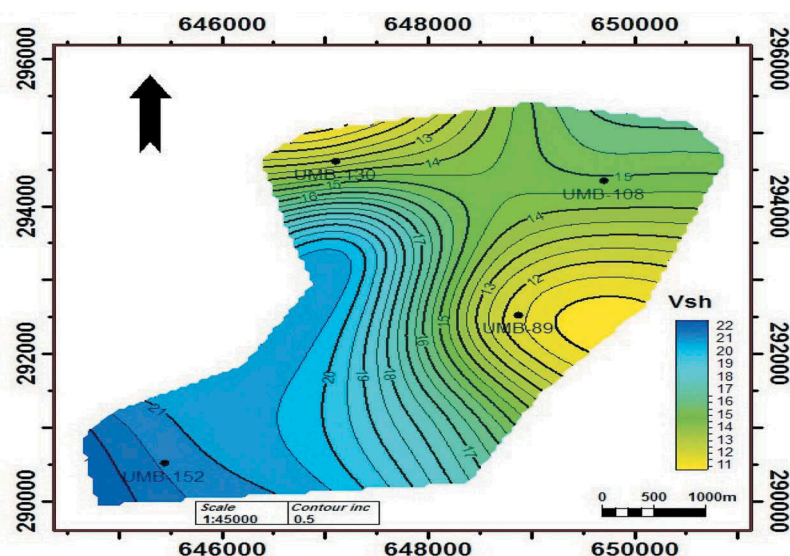


Figure 19. Shale volume distribution map of Upper Bahariya Member.

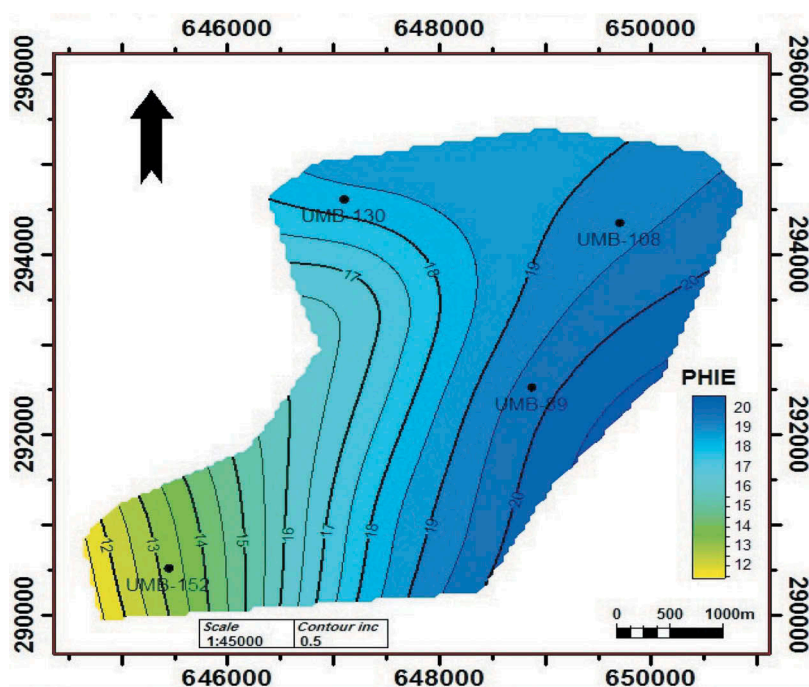


Figure 20. Effective porosity distribution map of Upper Bahariya Member.

### 3.2.7. Iso-parametric maps of Upper Bahariya

To construct the iso-parametric maps, a process of weighted averaging for each parameter was done for Upper Bahariya reservoir in the Um Baraka field. Iso-parametric maps represent the various distribution maps as cumulative presentation of the areal extension of each of the Petrophysical parameters in the study area.

**3.2.7.1. Iso-Net pay variation map.** To define the net pay intervals, you have first to set the cut-offs values (you didn't mention anything about these values) for the volume of shale, effective porosity, and water saturation by using different cross plots, then use these values

to define the pay zones (El-Din et al. 2013; Teama and Nabawy 2016). In the present study, the Cut-Offs are determined from core data as according to Khalda Petroleum Company, porosity cut-off equal 12%, volume of shale cut-off equal 35%, and water saturation cut-off equal 65% for Upper Bahariya.

The net pay of the study area (Figure 18) varies from 7.5 ft in UMB-152 well to 15.5 ft in UMB-108 well. Its value increases towards the north, northeast and north-west directions, but decreases in all other directions.

**3.2.7.2. Iso-Shale content variation map.** The shale content (Figure 19) for Upper Bahariya Member

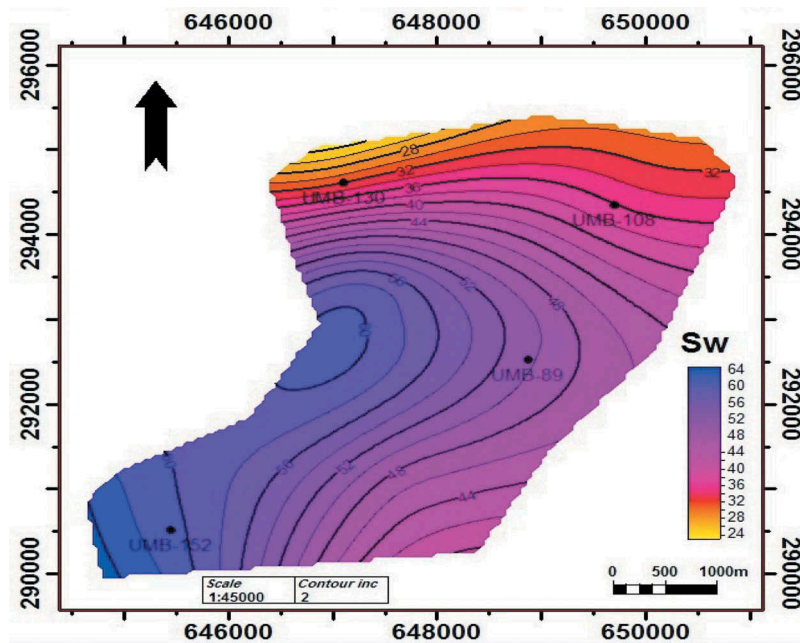


Figure 21. Water saturation distribution map of Upper Bahariya Member.

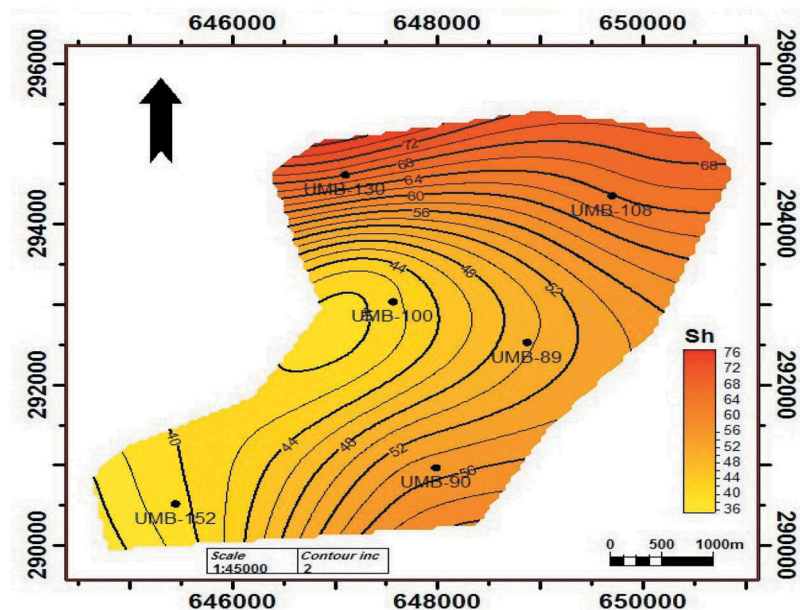


Figure 22. Hydrocarbon saturation distribution map of Upper Bahariya Member.

**Table 3.** Summarised the different petrophysical parameters calculated from the available well data.

Well name	Gross sand ft.	Net Pay ft.	Vcl %	$\Phi_e$ %	Sw %	Sh %
UMB-89	46	7.5	11.7	19.7	50.4	49.6
UMB-108	82.5	15.5	14.9	19.3	35.6	64.4
UMB-130	80.5	14	13	18.3	35.2	64.8
UMB-152	68	7.5	21.4	13.2	64.4	35.6

Where: **Vcl** is volume of clay,  **$\Phi_e$**  % is effective porosity, **Sh** is the hydrocarbon saturation, and **Sw** is the water saturation.

varies from 11.7% in UMB-89 well to 21.4% in UMB-152 well. Its value increases towards the southwest directions and decreases in all other directions.

**3.2.7.3. Iso-Effective porosity variation map.** Figure 20, illustrates that the effective porosity distribution for Upper Bahariya Member ranges from 13.2% in UMB-152 well to 19.7% in UMB-89 well. Its value increases in all directions and decreases in the southwest directions.

**3.2.7.4. Iso-Water saturation variation map.** The water saturation (Sw) distribution (Figure 21) for Upper Bahariya Member ranges from 31.7% in UMB-130 well to 60.7% in UMB-152. Its values increase towards the west and southwest directions and decreases in all other directions.

**3.2.7.5. Iso-Hydrocarbon saturation variation map.** The hydrocarbon saturation (Sh) distribution map for Upper Bahariya Member (Figure 22) ranges from 39.3% in UMB-152 well to 68.3% in UMB-130. The hydrocarbon saturation values decreases towards the west and southwest directions and increases in all other directions.

The Petrophysical parameter results of Upper Bahariya reservoir are summarised in Table 3.

## 4. Conclusion

The well log analysis results illustrated that the Upper Bahariya Member is considered of the main potential reservoir in Um Baraka field.

The petrophysical parameters of the Upper Bahariya reservoir showed that, the reservoir properties of Upper Bahariya Member is overall improving towards the north and northwest and northeast directions, this was shown by the increasing of total porosity, effective porosity and hydrocarbon saturation. In addition to increasing of net pay values towards the same directions.

Finally From the results, it can be stated that the study area is containing valuable amount of hydrocarbon accumulation, and there is a good opportunity to drill other Exploratory and development wells to enhance the productivity of the study area.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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