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PETROPHYSICAL EVALUATION OF THE UPPER CRETACEOUS ABU RAWASH G MEMBER AT WADI EL-RAYAN OIL FIELD, WESTERNDESERT, EGYPT

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تقييم بتروفيزيائي لعضو ابورواش'G' من العصر الطباشيري العلوي في حقل بترول وادي الريان بالصحراء الغربية، مصر

الخلاصة: يعتبر حقل وادي الريان من اهم حقول البترول في شمال الصحراء الغربية حيث ان الخزان الرئيسي للمنطقة ابو رواش”G " حيث ينتمي الي عمر " Cenomanian “و يتكون من طفلة و حجر رملي و تقاطعات كربونية صغيرة .

تم استخدام برنامج ”Tech log" الخاص بشركة شلمبرجير لتحديد الخصائص البتروفيزيائية مثل حجم الطفلة , المسامية الكلية , المسامية الفعالة، تشبع الماء، تشبع الهيروكربون و حجم الخزان و الجزء المنتج.

تم عمل التتابع الراسي للخصائص البتروفيزيائية مقابل العمق. المسامية الفعالة حوال ٢٢ % و التشبع الهيدروكربون يزيد عن ٦٠ %.

وقد تم استخدام العلاقات المختلفة لتقييم و دراسة الخصائص الصخرية و المعادن الموجودة في الخزان وتظهر هذة العلاقات ان صخور الخزان تتكون من الطفلة مع تداخلات من الحجر الرملي و الحجر الجيري . بناءً علي تفسير البيانات البتروفيزيائية ، تم تفسير صخور أبو روش "G" على أنها خزان جيد مع منطقة استكشاف واعدة تقع خاصة في الجزء الشمالي من الحقل.

ABSTRACT: *Wadi El-Rayan oil field is located in one of the most prolific basins in the northern part of theWestern Desert of Egypt. The main age of Abu Rawash G Memberreservoir is Cenomanian; it's composed of shale and sandstone intercalations with minor carbonate interbeds. The Schlumberger application ''Techlog'' was used to determine the petrophysical characteristic of such reservoir; such as shale volume, total porosity, effective porosity, water saturation, hydrocarbon saturation, flushed zone saturation, reservoir and pay flag. Litho-saturation plot of the petrophysical parameters versus depth were illustrated. The effective porosity is about 22% and hydrocarbon saturation is exceeding 60%. Moreover, the cross- plots were used to show the lithological and mineralogy components which reflect that the main lithology of Abu Rawash G is shale with intercalations of limestone and sandstone. Based on the petrophysical data log, the rock of Abu Rawash "G" member is interpreted as good reservoir with promising exploration area located specially in northern part of the field.*

INTRODUCTION

Hydrocarbon production in the northern part of the western desert of Egypt is concentrated on the Cretaceous rocks. oil field exploration in concerned area attracts the attention of many workers, due to their wide distribution and their high hydrocarbon potential (Deibis, 1994).

Wadi El-Rayan occupies a depression in the northern part of the western desert of Egypt and liesbetween latitude 30° 00' 00" and 30° 34' 00" N and longitude29° 00' 00" and 29° 24' 11" E (fig. 1).

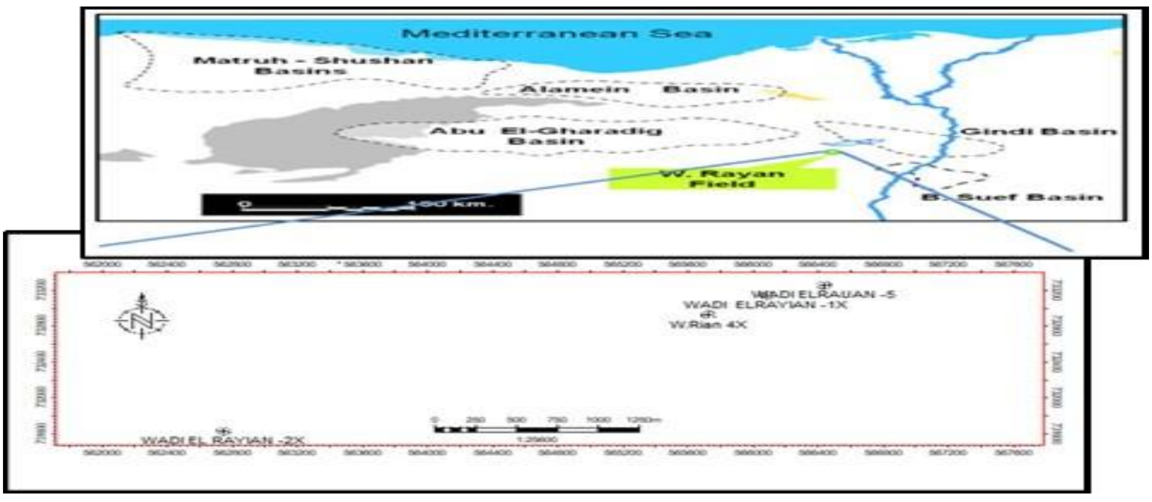

Fig. (1): Location Map of Wadi El-Rayan Oil Field Showing the Study Wells (Othman, et al., 2016).

The Wadi El Rayan block covers an area of about 1,287 km^2 and located about 140 km southwest of Cairo and 70 km southwest of the Quran oil field. It was discovered in September 1996 through drilling well WR-1x which has been drilled to a total depth of 7740 ft at the basement.

Stratigraphy of the stu*dy area*

The generalized stratigraphic column of the northern western desert includesmost of the sedimentary succession from lower Paleozoic to Recent (fig. 2). The total thickness ranges from 6000 ft in South and reaches 25,000 ft in coastal area (Shlumburger, 1984).

Through the sedimentary section of the western desert, which ranges from lower Paleozoic to Recent, four major sedimentary cycles occurred, with maximum southward transgression in Carboniferous, Upper Jurassic, Middle and Late Cretaceous, Middle Miocene and Pliocene time. Maximum northward regressive phases occurred during Permo-Triassic and Jurassic and continued in Lower Cretaceous, and again in Late Eocene to Oligocene with a last phase in Late Miocene time (WEC, 1984).

In the study area, the sedimentary sequence of the wadi El-Rayan field ranges in agefrom Lower Cretaceous to Middle Eocene (fig. 3). The study area is within wadi Rayan Platform. The majority of the drilled wells are characterized by the absence of the Paleozoic and Jurassic rocks as a result of non-deposition on the wadi El-Rayan platform (Abd El Aziz et al., 1998). Nomenclature used in the study area are mainly those suggested by (Norton, 1967) and later followed by many authors.

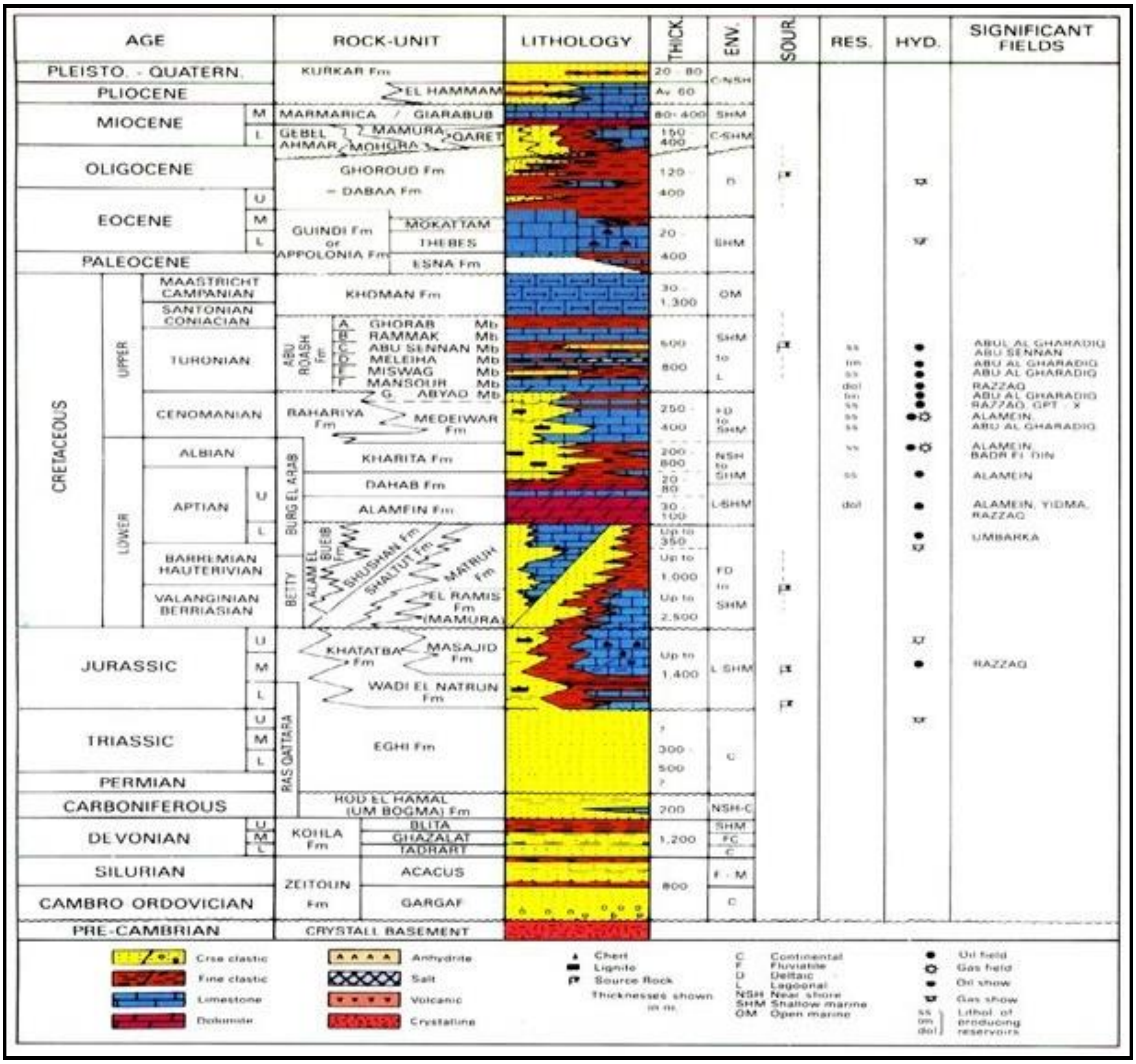

Fig. (2): Generalized Litho-Stratigraphic Column of the Northern Western Desert (After Schlumberger, 1984).

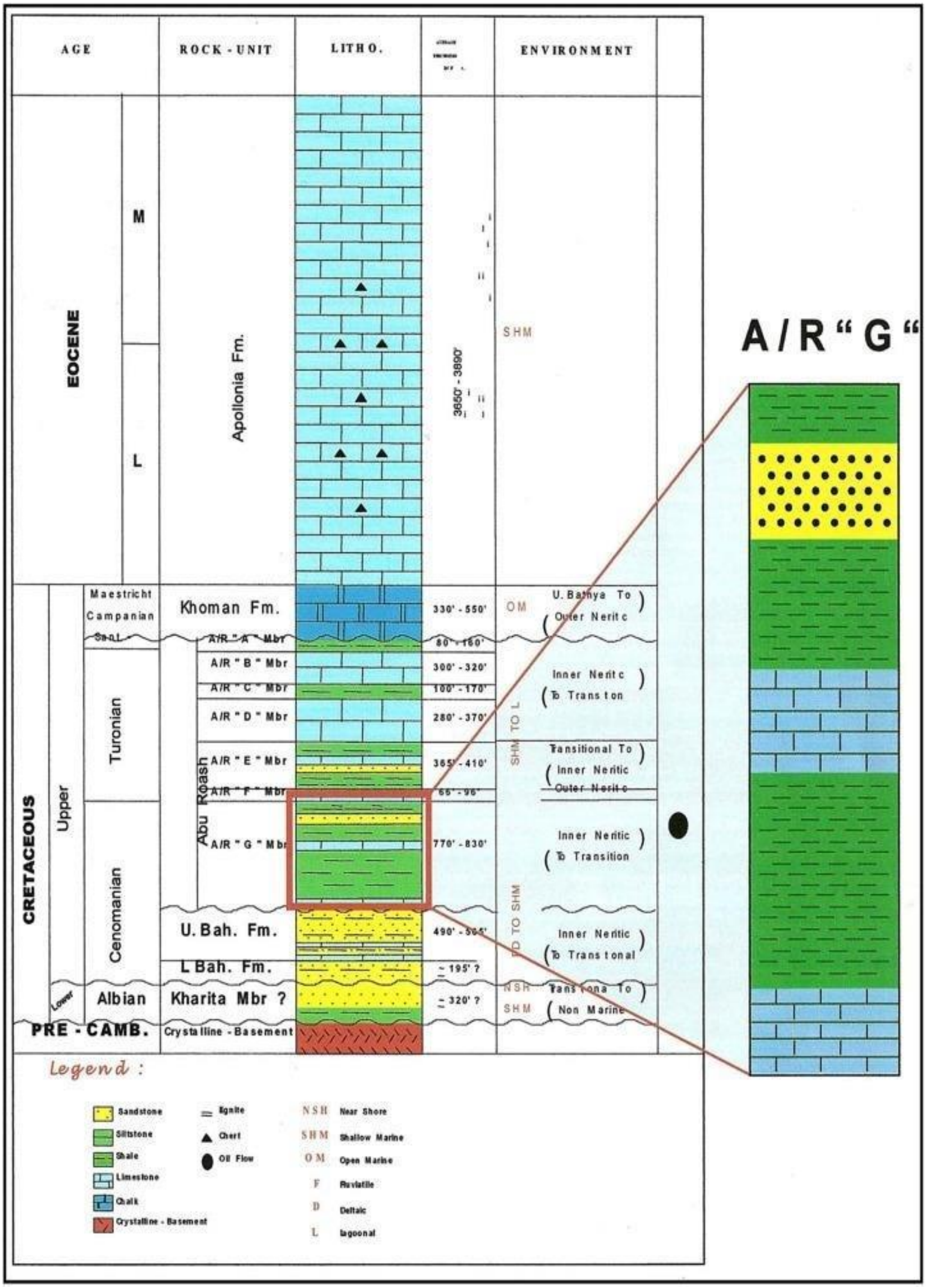

Fig. (3): The Sedimentary Sequence of the Wadi El-Rayan Field (Qarun Petroleum Company, Internal company study, 2006).

Structural setting of the study area

The study area is located within the northern Egypt fold belt that is part of the Syrian Arc System that extends from Palmera Mountains in Syria to the central western desert of Egypt, passing through northern Sinai.

The northeastern part of western desert, including study area exhibits tectonic evaluation through four main phases. These phases of deformation have inverted the Catatonia Jurassic/Lower Cretaceous and the older rocks in most parts of the area toward the south-southeast direction (SSE). (Afifi, et al., 2018).

The structures of the study area include both folds and faults. Folds in the Wadi EL-Rayan platform is symmetric and have gentle dipping flanks and have NE-SW orientation. (Othman, el al., 2016).

Faults of the study area have three main orientations. They are oriented ENE- WSW, NE-SW, and NW-SE. ENE-WSW oriented faults are common in the most northern and southern parts of the study area (Abdel Aal et al., 1990). These faults have an apparent normal slip and active in the Early and Late Cretaceous times.

Methodology

The main approach of this study is based on performing a petrophysical analysis on the Abu Rawash G Member using the available well logs for four wells to find its reservoir properties.

The well-log analysis was performed using Techlog software. This program allows to make good and reliable interpretation of raw data.

Procedures of Formation Evaluation

The most common types of well logs (resistivity, neutron, gamma- ray, sonic, density, etc.) of 4 wells (WR-1x, WR-2x, WR-4X, and WR-5X) are used mainly in performing the petrophysical analysis of ARG Member to detect the most important reservoir properties (shale volume, porosity, reservoir fluids, lithology, pay cutoffs, etc.).

These formation evaluation techniques include the following steps: -

1. ***Determination of Formation Temperature (FT):***

The formation temperature is an important parameter in formation evaluation, in which temperature increases with increasing depth. So, it has a great effect on the resistivities of the drilling mud (Rm), the mud filtrate (Rmf) and the formation water (Rw) in which resistivities vary considerably with temperature.

The formation temperature is determined from the following equation (Edwardson, et al., 1962 and Helander, 1978):

$$FT=ST+\left(\frac{BHT-ST}{TD}\right)*FD \quad \textbf{(1)}$$

where:

FT: formation temperature

ST: surface temperature

BHT: bottomhole temperature

TD: total depth (ft)

FD: formation depth (ft)

2. ***Formation Water Resistivity (Rw):-***

The corrected water resistivity (Rw) is necessary for the correct determination of fluid saturation. In this study Pickett plots (1966 & 1973) areapplied to determine cementation exponent (m) andRw.

3. ***Determination of Shale Content (Vsh):-***

Gamma ray (GR) logs measure the natural radioactivity in formations and can be used for identifying lithologies and for correlating zones. Because shale is usually more radioactive than sand or carbonate, gamma ray logs can be used to calculate volume of shale in porous reservoirs (Asquith and Krygowski, 2004).

The basic equations which are expressing the relation between the intensity of natural gamma-ray radiation and volume of shale Vsh (the following formula from Schlumberger, 1974).

$$\mathbf{Vsh} = \frac{[\mathbf{GRlog} - \mathbf{GRmin}]}{[\mathbf{GRmax} - \mathbf{GRmin}]} \quad \textbf{(2)}$$

where:

Vsh: shale volume derived from gamma- ray curve(fractional);

GRlog: the reading value of Gamma ray at the interesting interval (API units); **GRmin**: the reading value of Gamma ray at the clean sand (API units); **GRmax**: the reading value of Gamma ray at the shale interval (APIunits).

The different zones are classified into clean, shaly and shale zones according to the following bases (Hilchie, 1978).

- if Vsh< 10%. This means clean zone,
- if Vsh from 10% to 35%. This means shaly zone, and
- if Vsh> 35%. This means the shale zone.

4. ***Determination of Formation Porosity(ϕ):***

Theporosityofformation is veryimportantforcalculationfluidsaturation.Porositycan be obtained from one of the three porosity logs, sonic, density, and neutron, and a combination of two of them such as neutron-density and neutron- sonic. Two types of porosities were calculated; total porosity and effectiveporosity.

Total Porosity (ϕDt):

In clean and shaly zones, total porosity can be determined from density log applying the Following formula (Schlumberger, 1974).

In Clean Zones:

Total porosity **ϕDt** from Density log in Clean zones:

$$"\phi Dt" = "\rho ma - \rho blog/\rho ma - \rho f" \quad (3)$$

where:

ϕDt: is the porosity derived density (%)

ρma: is the matrix density (gm/cc)

ρblog: is the Density log reading for each interval (gm/cc)

ρf: is the fluid density in gm/cc (salt mud=1.10, fresh mud=1.0 a n d oil-basedmud=0.90).

In shaly zone:

In shaly formations, the porosity calculated from the above equation should be corrected to shale effect, because it will give inaccurate values where the shale density **(ρsh)**is smaller than the clean matrix density.

So, the corrected density porosity **ϕDc** is determined from the following formula (Dresser Atlas, 1983):

$$\phi Dc = \phi Dt - (Vsh * \phi Dsh) \quad (4)$$

where:

Vsh: The shale volume.

ϕDsh: The shale porosity derived from the density log which is calculated by:

$$\phi Dsh = (pma - psh)/(pma - pf) \quad (5)$$

where

psh: is the shale zone density.

Effective porosity (ϕDe):

Effective porosity **(ϕDe)** determined from the density log as follows (Schlumberger, 1972):

$$\phi De = [((\rho ma - \rho b))/(\rho ma - \rho f)] - Vsh * [(\rho ma - \rho sh)/(\rho ma - \rho f)] \quad (6)$$

5. Water Saturations Determination (Sw and Sxo):

Determination of the water saturation (Sw and Sxo) in clean zones by using the Archie equation (1942).

Water saturation (Sw) of the uninvaded zone is calculated by the Archie (1942) formula:

$$s_W = \left[\frac{a}{\varnothing^m} * \frac{R_W}{RT}\right]^{(1/n)} \quad (7)$$

where:

Sw: Water saturation of the uninvaded zone (%)

Rw: Formation Water Resistivity at formation temperature Rt: True formation resistivity (ohm.m)

ϕ: Porosity

a: Tortuosity Factor =1.0

m: Cementation factor

n: Saturation Exponent

Water saturation (SXO) of the uninvaded zone is calculated by the Archie (1942) formula:

$$S_{xo} = \left[\frac{a}{\varnothing^m} * \frac{R_{xo}}{R_{mf}}\right]^{(1/n)} \quad (8)$$

where:

Sxo: Water Saturation of Flushed Zone. (%)

Rmf: Resistivity of the Mud Filtrate at Formation Temperature (ohm.m)**.**

Rxo: resistivity of invade zone (ohm.m).

-Water Saturations Determination (Sw and Sxo) in shaly zone:

Water saturation (Sw) of the invaded zone is calculated by the ((Indonesia equation) Schlumberger, 1972):

(Sw)2 n/2* [(Vsh (1- (Vsh/2))/ Rsh1/2) + (ϕm/2/ (aRw)1/2] =1/(Rt) ½ (9)

where:

Rt: True formation resistivity (ohm.m)

Vsh: Shale volume (%)

Rw: Connate water resistivity

Rsh: Shale resistivity (ohm-m)

Sw: Water saturation (%)

Φ: Effective porosity (%)

a: Tortuosity constant = 1.0

m: Cementation factor = 1.7

n: Saturation exponent = 1.8

Water saturation (sxo) of the invaded zone is calculated by the ((Indonesia equation) Schlumberger, 1972):

(Sxo)2 n/2*[(Vsh (1-(Vsh/2))/Rsh 1/2) +(ϕm/2/(aRmf)1/2] =1/(Rxo)1/2 (10)

where:

Rxo: flushed zone resistivity (ohm.m)

Vsh: Shale volume (%)

Rmf: mud filtrate resistivity (ohm.m)

Rsh: Shale Resistivity (ohm.m)

Sxo: Water saturation of flushed zone (%)

ϕ: Effective porosity (%)

a: Tortuosity constant = 1.0

m: Cementation factor = 1.713

n: Saturation exponent = 1.86

6. Hydrocarbon Saturations Determination:

The hydrocarbon saturation was determined as follows (Asquith and Krygowski, 2004).

Sh = 1–Sw. (11)

These hydrocarbons are normally discriminated into movable and residual hydrocarbon. The determination of (Sxo) leads to calculating the residual hydrocarbons (Shr) as follows:

Shr = 1–Sxo. (12)

And the movable hydrocarbon (Shm) is calculated also from the following relation:

Shm = Sh – Shr. (13)

7. Net pay, bulk pore volume and oil in place calculation

The net pay determination is a great target for well log analysis, where it is calculated through the layer that fitted with cut offs (more than 10% effective porosity, less than 35% shale volume and less than 50% water saturation) Table (1).

The bulk pore volume is one of the most important properties of reservoir characterization which represents the bulk pore volume of that reservoir which responsible for fluid potential.

The calculation of porosity volume is carried out using the following equation (Alsayed, 2008):

PHIH = ϕ*h (14)

Where

h: is the net pay thickness.

The oil in place indicator is an item that expresses the hydrocarbon volume in the target rock unit and is calculated using the equation (Petcom, 1997).

HPVH = PHIH*(1-sw) (15)

Results and Discussion

The study of Abu Rawash G Member from four studied wells of oil field using different log types and different methods to give a better and more reliable estimate of petrophysical properties resulted in several points which enhance our understanding and evaluation of the reservoir characters of Abu Rawash G Member.

1. Lithologicidentification

The most useful logs for Lithology identification are gamma-ray, density, neutron, and sonic logs. Lithology identification charts (Día-porosity and Tri-porosity cross-plots,) are important information evaluation processes. A Number of neutron porosity-density, density-photoelectric, and M- N cross-plots are used through Tech-log software for lithology identification These cross-plots can be illustrated asfollows:

Neutron porosity versus density crossplot:

Figures (5) and (6) are selected as an example to represent neutron-density cross plots of Abu Rawash G Member in this study.

These cross-plots show that the main lithology type of Wadi EL Rayan-1X well fig. (5) is shale with little content of limestone and sandstone, while the main lithology of Wadi El Rayan-5X well fig. (6) is shale with little content of limestone and sandstone, while the effect of shale shifts points down.

Table (1): Average petrophysical parameters of the different zones of ARG Member, Wadi El-Rayan field.

Well	Zones	Flag name	Top (ft)	Bottom (ft)	Net to Gross	V s h (%)	PHIE (%)	S w (%)	Hydrocarbo n volume
WADI_ELRAYAN- 1	A/R G	RES	5545	6375	0.087	0.145	0.216	0.403	0.597
WADI_ELRAYAN- 1	A/R G	PAY	5545	6375	0.073	0.122	0.227	0.346	0.654
WADI_ELRAYAN- 2	A/R G	RES	4781	5579	0.062	0.169	0.173	0.999	0.001
WADI_ELRAYAN- 2	A/R G	PAY	4781	5579	0				
WADI_ELRAYAN- 4	A/R G	RES	5557	6329	0.03	0.201	0.159	0.707	0.293
WADI_ELRAYAN- 4	A/R G	PAY	5557	6329	0.012	0.22	0.192	0.491	0.509
WADI_ELRAYAN- 5	A/R G	RES	5580	6378	0.118	0.114	0.207	0.499	0.501
WADI_ELRAYAN- 5	A/R G	PAY	5580	6378	0.079	0.075	0.23	0.367	0.633

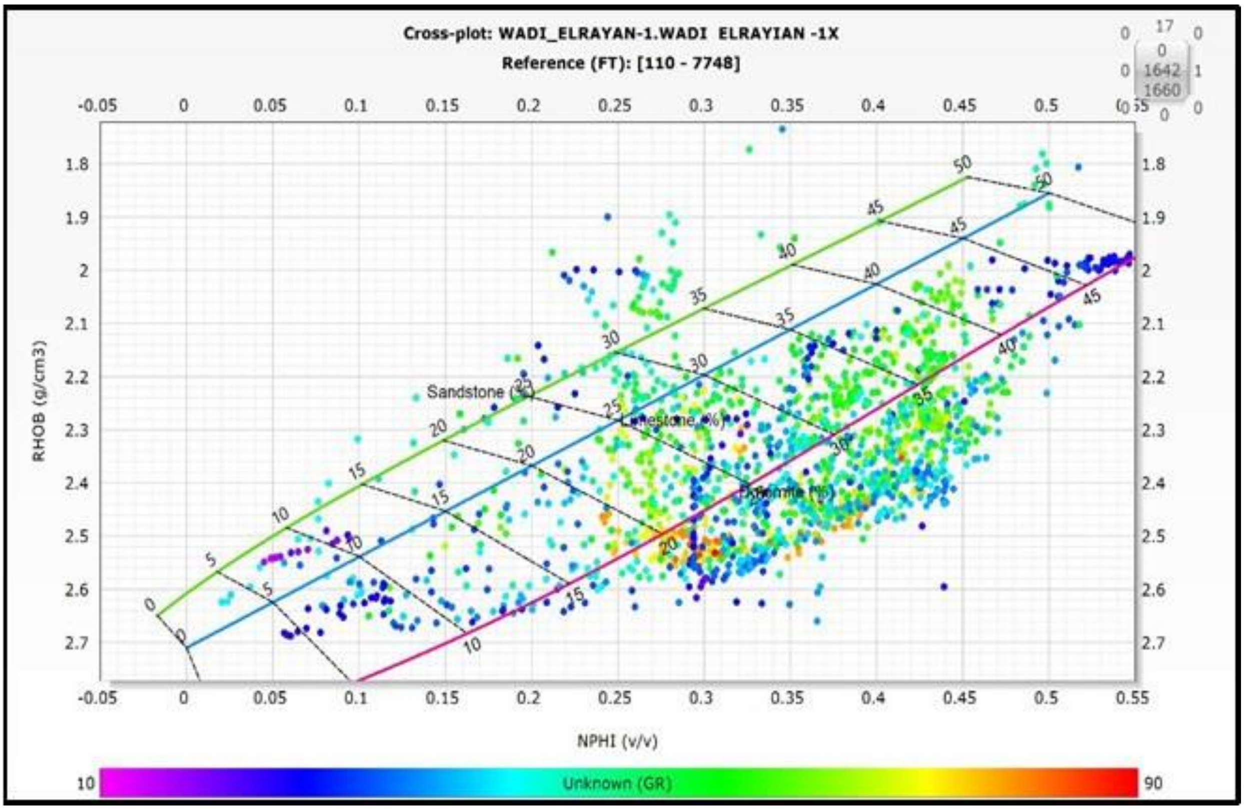

Fig. (5): RHOB-NPHI Cross Plot for Wadi EL Rayan-1X well.

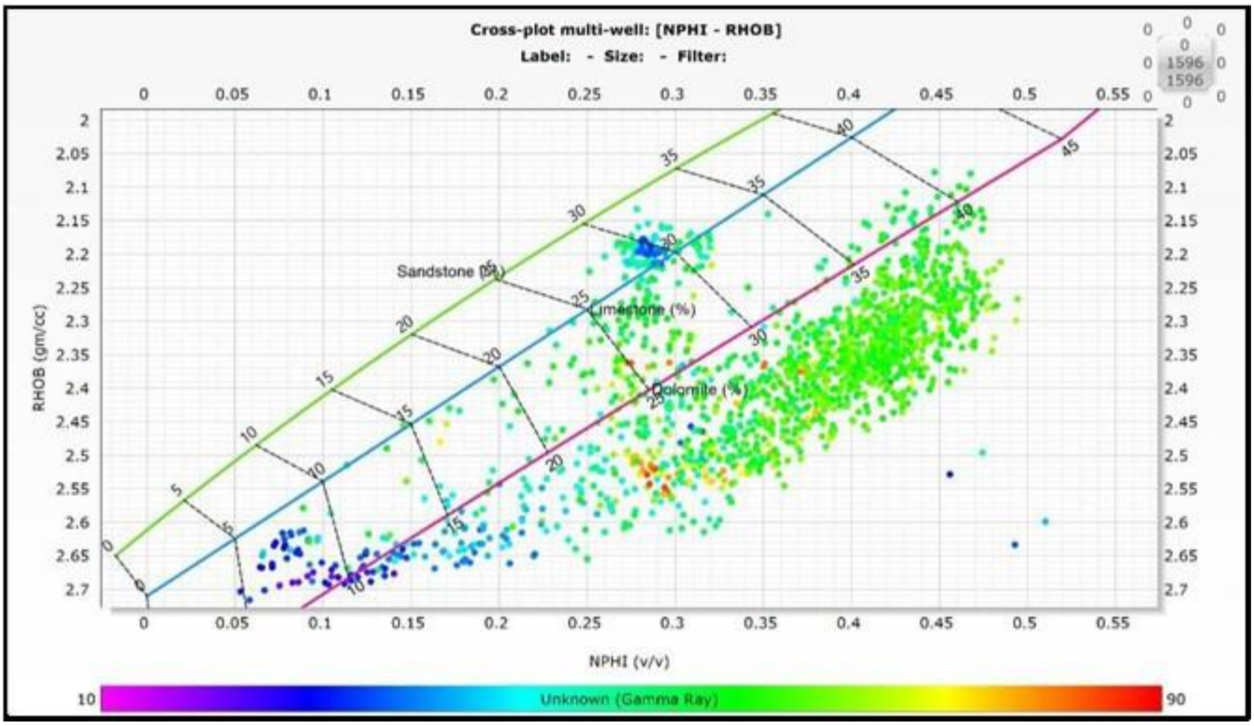

Fig. (6): RHOB-NPHI Cross Plot for Wadi El Rayan-5X.

4.1.2. Density versus Photoelectric cross-plot

The density versus photoelectric cross plot showed that the main lithology of Wadi El Rayan-1X well fig. (7) is shale with little content of limestone and sandstone, while the main lithology of Wadi El Rayan-5X well fig. (8) is shale with little content of limestone andsandstone.

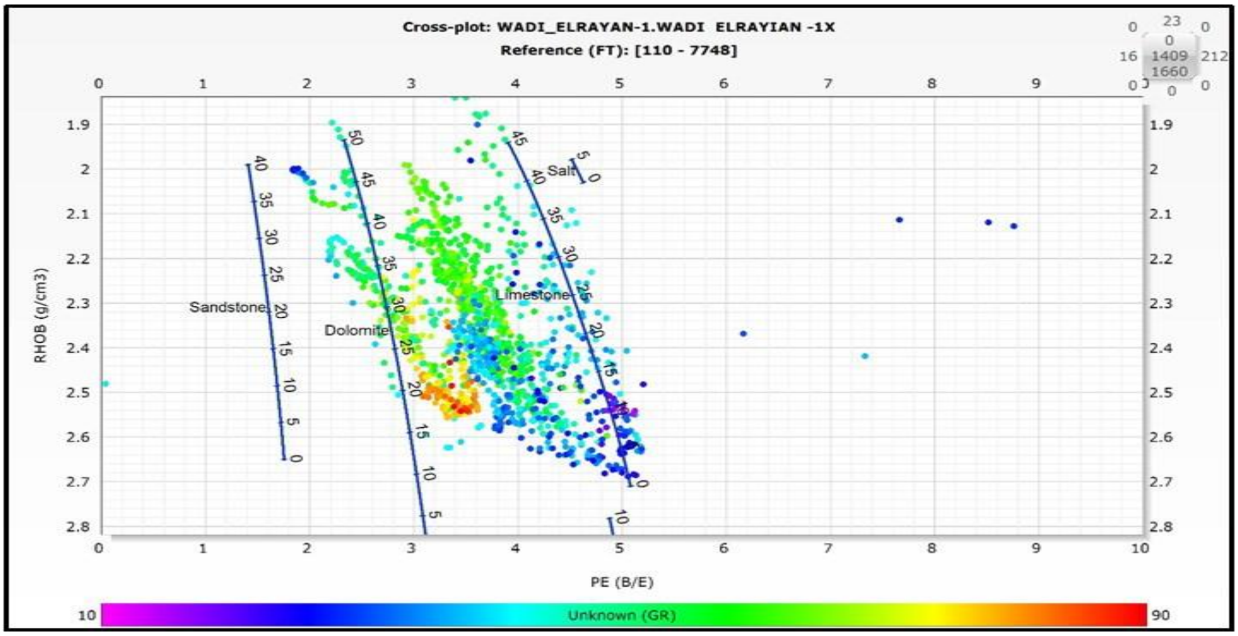

Fig. (7): PE-RHOB Cross Plot for Wadi El RayaAYAN-1X.

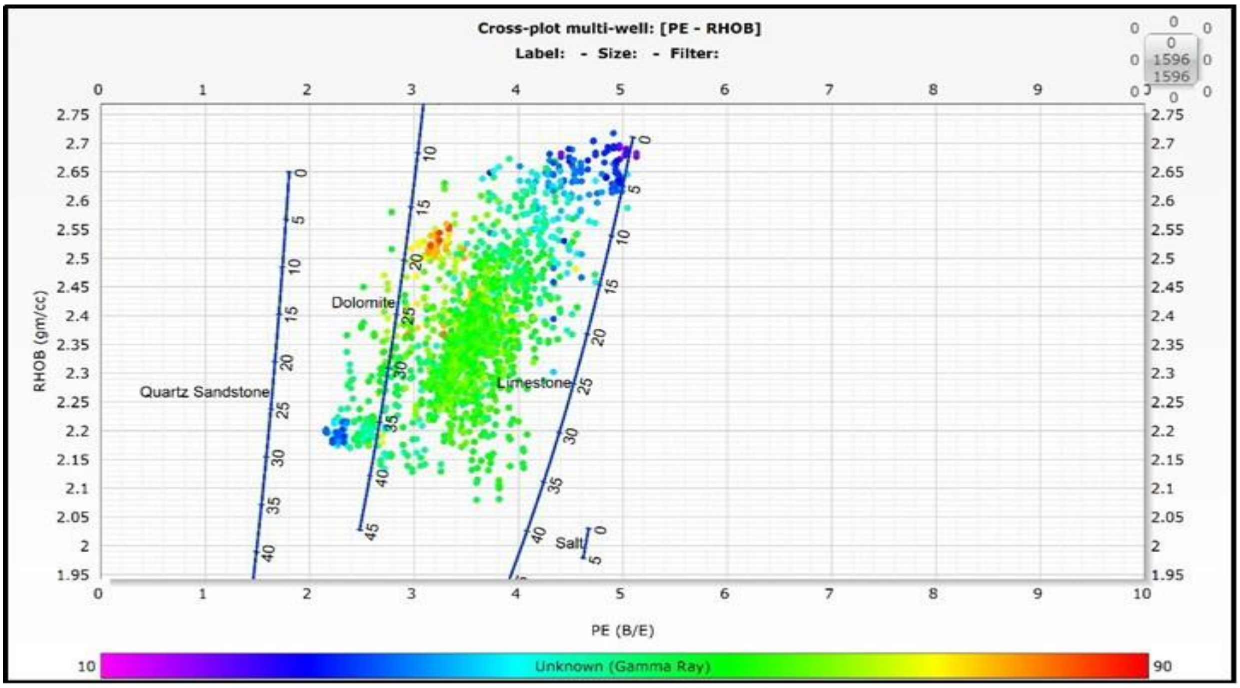

Fig. (8): PE-RHOB Cross Plot for WADI EL RAYAN-5X.

3. M-N cross plot

The M-N cross-plot is used to detect the lithology interpretation in which a relation between neutron, sonic, and density in terms of M and N is plotted. It is a two-dimensional display of all three porosity logs responses in complex reservoirs rocks.

These cross-plots show that the main lithology of Wadi El Rayan-1X well fig. (9) is mainly shale with little content of calcite and quartz, while the main lithology of Wadi El Rayan-5X well fig. (10) is shale with a little content of calcite and quartz.

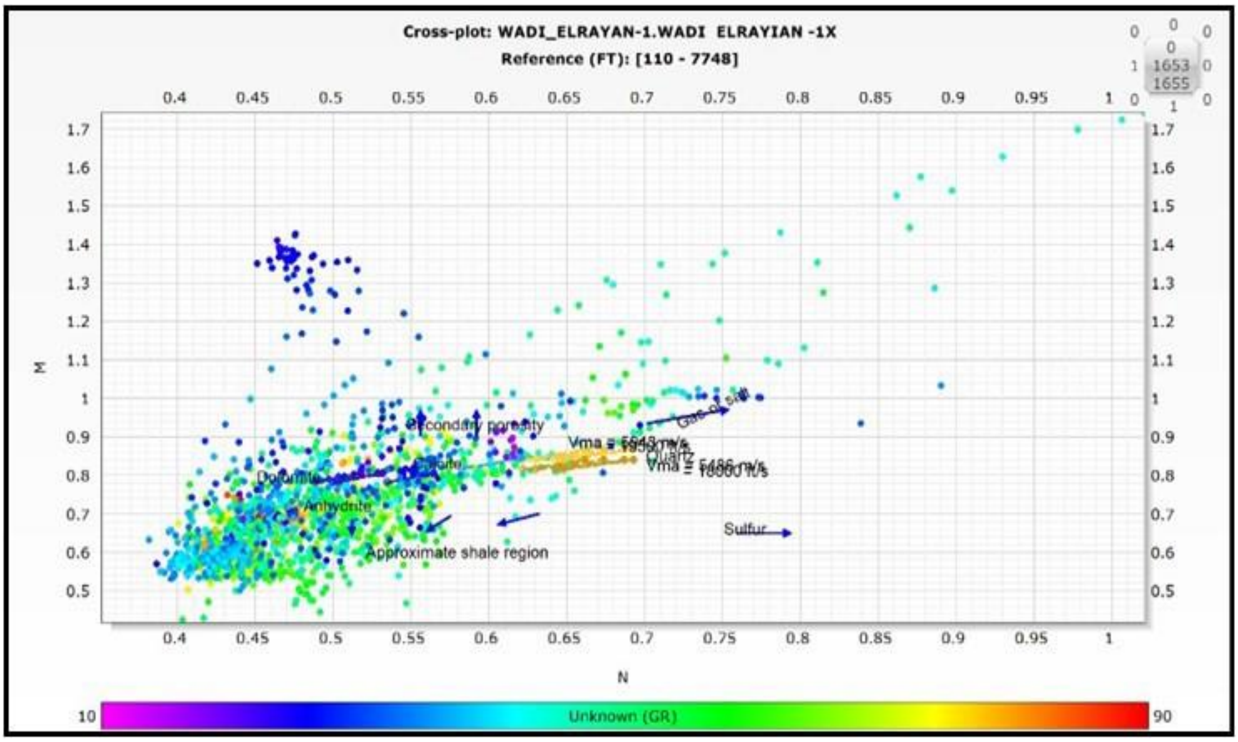

Fig. (9): M-N Cross Plot for Wadi El Rayan-1X.

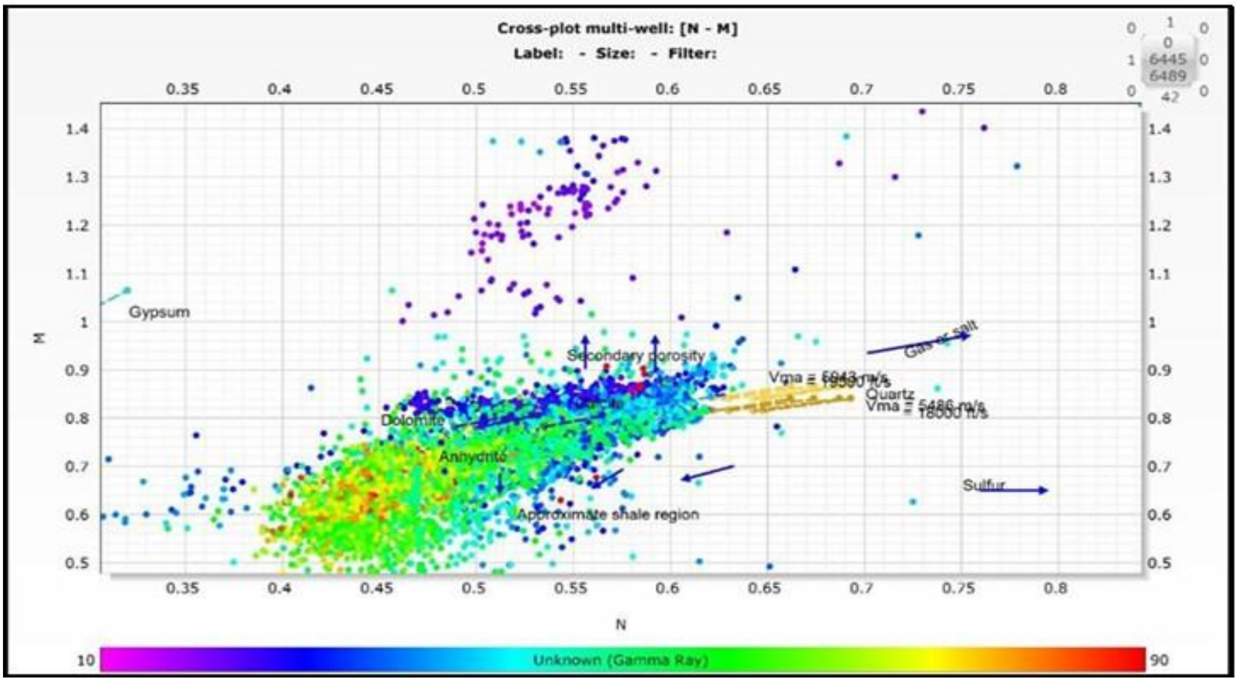

Fig. (10): M-N Cross Plot for Wadi El Rayan-5X.

Litho-saturation plots for the wells in the study area:

Litho-saturation plot shows the vertical variations of lithology, porosity, density, water, and hydrocarbon saturations with depth.

The petrophysical analysis and the reservoir/net pay characteristics of the Abu Rawash G Member are represented in figures 11, 12, 13 and 14. Four wells are selected to represent the petrophysical properties of Abu Rawash Greservoir.

litho-saturation cross plot of Wadi El-Rayan-1X well:

Figure (11) shows litho-saturation cross plot of Abu Rawash “G” Member in Wadi El Rayan-1X well. It is encountered at depth ranges from 5545ft to 6375ft. The gross interval is 830ft.the main lithologies are shale with intercalations of limestone and sandstone, where the sandstone increases in the upper part of formation, the average volume of shale is 12.2 %, average effective porosity is 22.7%, average water saturation is 34.6 %, average hydrocarbon saturation is 65.4%, and the net pay thickness is 60.5 ft.

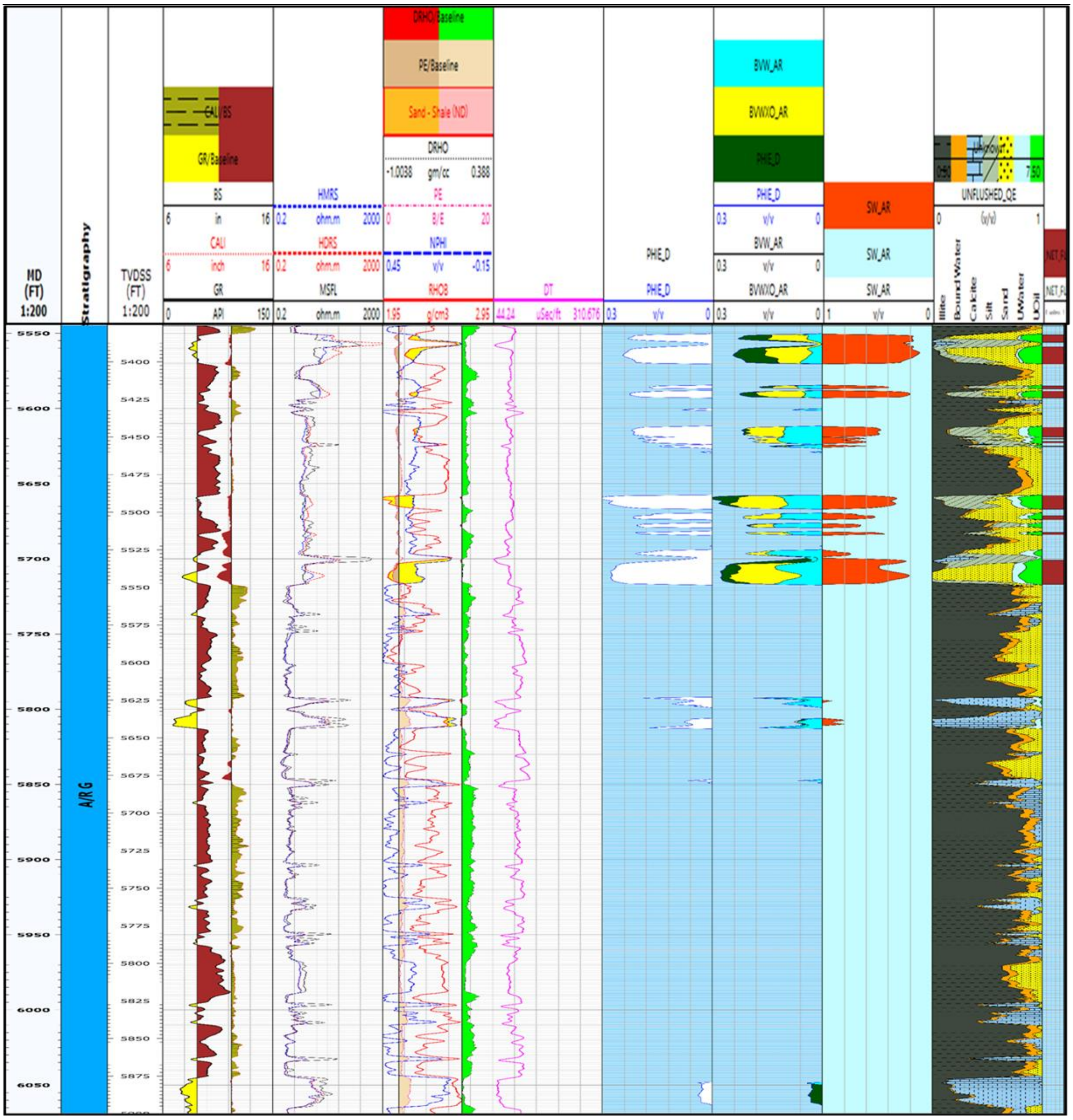

Fig. (11): Litho-Saturation Cross Plots of Wadi El Rayan-1X.

litho-saturation cross plot of Wadi El-Rayan-2Xwell:

Figure (12) shows litho-saturation cross plot of Abu Rawash"G" Member in Wadi El Rayan-2X well. It is encountered at depth ranges from 4781 ft to 5579 ft. The gross interval is 798 ft. the main lithologies are shale and limestone with intercalation of sandstone, the average shale content ranges about 17 %. The average effective porosity ranges about 17 %. The average water saturation ranges about 99%. The net pay thickness is zero. The well is containing only water.

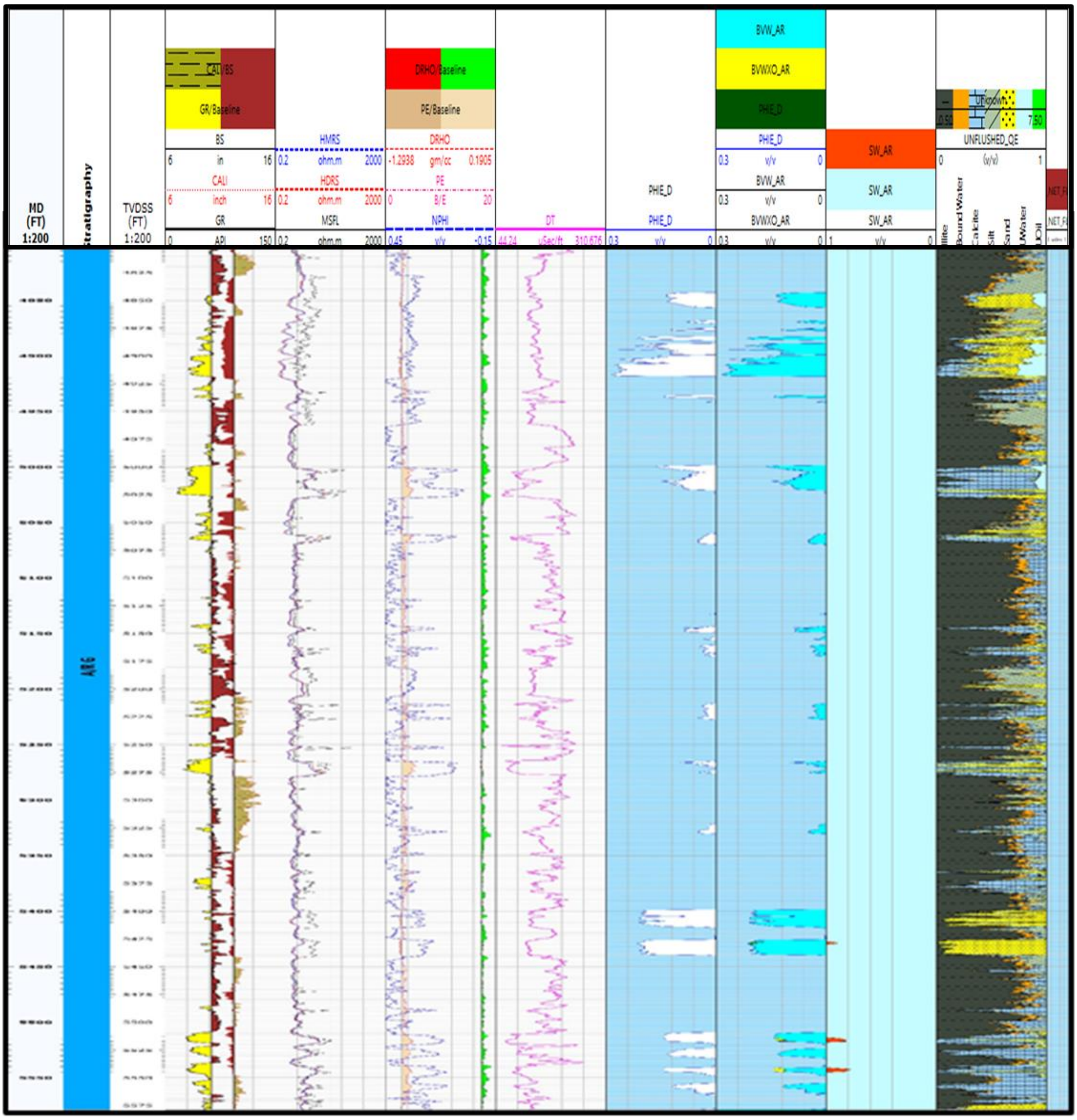

Fig. (12): Litho-Saturation Cross Plots of Wadi El Rayan-2X well.

- litho-saturation cross plot of Wadi El-Rayan-4Xwell

Figure (13) shows litho-saturation cross plot of Abu Rawash "G" Member in Wadi El Rayan-4X well. It is encountered at depth ranges from 5557 ft to 6329 ft. The gross interval is 772ft. the main lithologies are shale and limestone with intercalation of sandstone where the sandstone tends to increase in the middle and upper part of formation. In this well, the average volume of shale is 22 %, average effective porosity is 20%, average water saturation is 50 %, average hydrocarbon saturation is50 % and the net pay thickness is 9.5 ft.

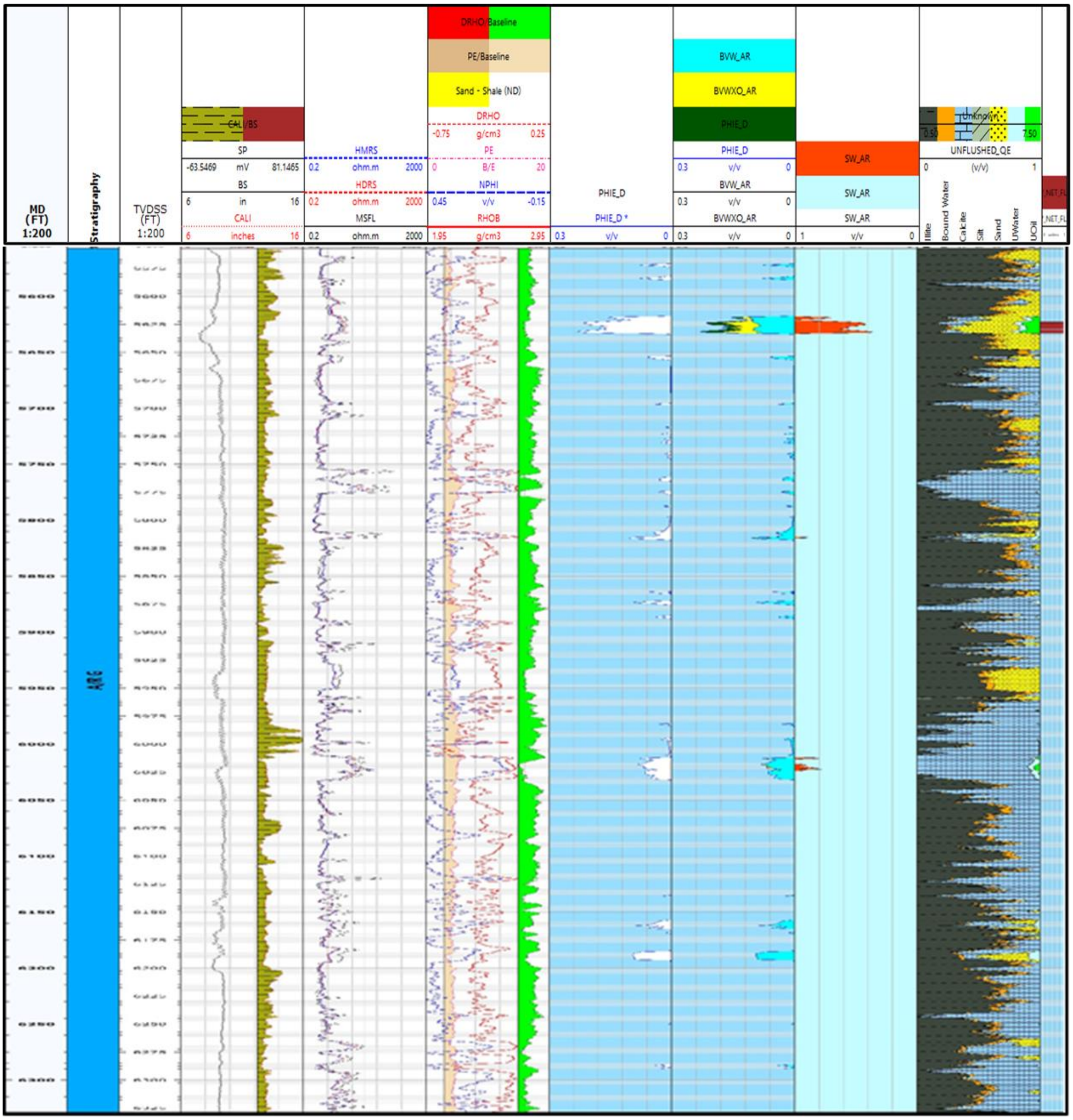

Fig. (13): Litho-Saturation Cross Plots of Wadi El Rayan-4X well.

- litho-saturation cross plot of Wadi El-Rayan-5Xwell

Figure (14) shows litho-saturation cross plot of Abu Roash "G" Member in Wadi El Rayan-5X well. It is encountered at depth ranges from 5580ft to 6378ft. The gross interval is 798ft. the main lithologies are shale with intercalation of limestone and sandstone, the average volume of shale is 7.5 %, average effective porosity is 23 %, average water saturation is 36.7%, average hydrocarbon saturation is 63.3% and the net pay thickness is 63ft. From the above, Abu Roash "G" is a good reservoir quality that contains hydrocarbon ranges in values from 50% to 65%.

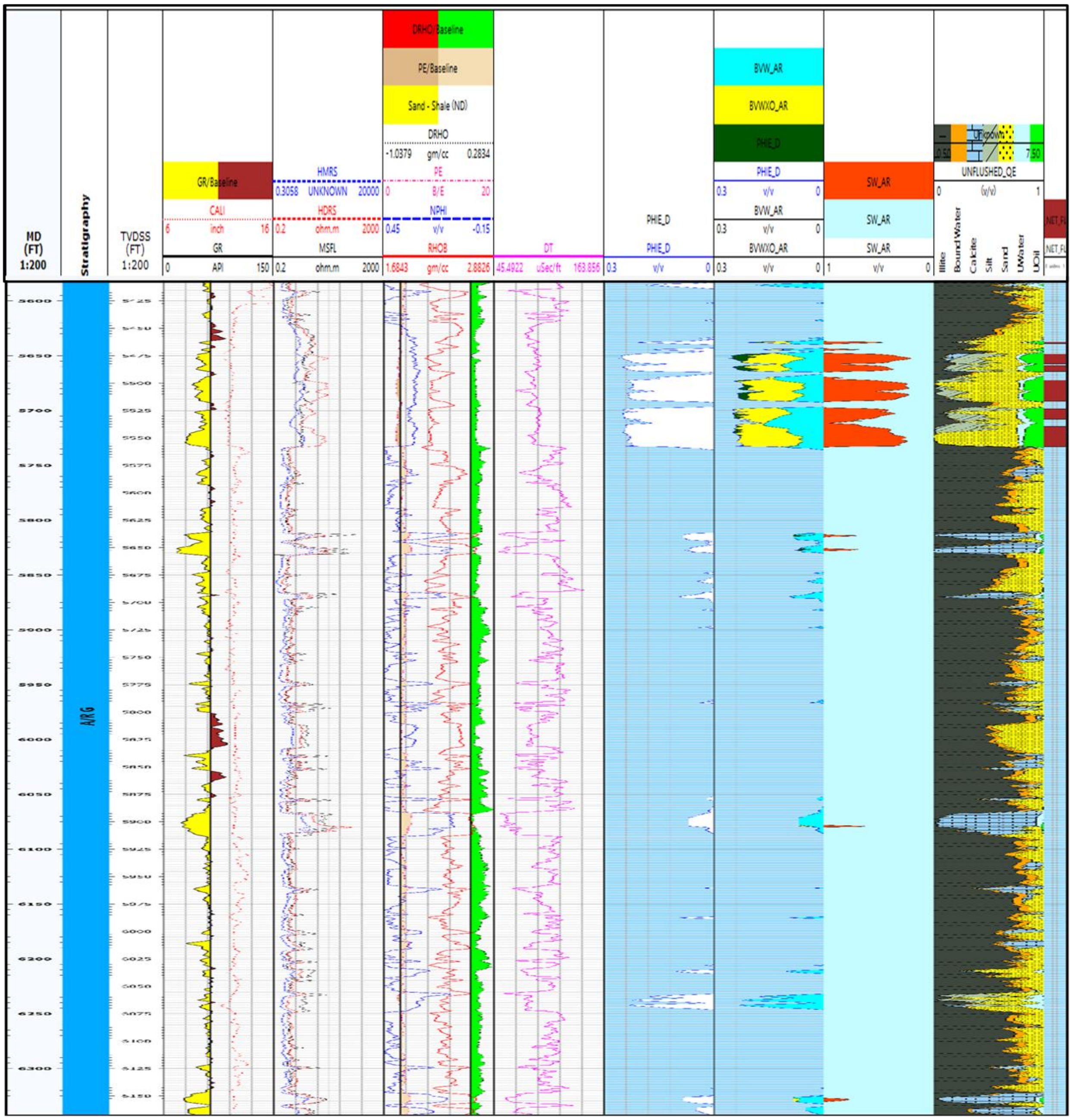

Fig. (14): Litho-Saturation Cross Plots of Wadi El Rayan-5Xwell.

CONCLUSIONS

Evaluation of Abu Rawash G Member in the area of the Wadi El-Rayan oil field was achieved through well logs analysis. Different cross-plots are constructed (neutron-density, neutron-photoelectric and M- N cross-plots) to show the lithology. These cross-plots reflect that the main lithology of Abu Rawash Gis shale with little content of limestone andsandstone.

The Petrophysical properties derived from conventional well logging analysis are generally diverse vertically in the form of litho-saturation cross-plot (CPI).

The results of petrophysical analysis shows that the effective porosity ranges in values from 19 % to 23%, the volume of shale ranges in values from 7.5 % to 17 %, the water saturation ranges in values from 35% to 50% and the hydrocarbon saturation ranges in values from 50% to 65% which indicate good quality reservoir.

Further calibration of the log analysis parameters with core and production data is necessary to verify the calculated values.

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