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RESERVOIR CHARACTERIZATION OF THE BAHARIYA FORMATION USING CORE ANALYSIS AND WELL LOGGING INTEGRATION AT AL ZAHRAA FIELD, NORTH WESTERN DESERT, EGYPT

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ABSTRACT

The Bahariya Formation encountered in Al Zahraa oil and gas field is subdivided informally into Upper and Lower Bahariya members, and it consists mainly of sand layers occupying the lowermost of the Bahariya section while the stacking sandy shale layers are common in the upper part. The thickness of each Upper and Lower Bahariya members along the study area ranged from 201 feet to 305 feet and 330 feet to 417 feet respectively. The Upper Bahariya Cenomanian section is dominated by shale and siltstones and thin streaks of moderate to good reservoir quality sandstones occur in this section but with questionable lateral continuity. The late Albian/ Early Cenomanian, Lower Bahariya section is dominated by sandstone, siltstone, and shale. It is the main pay in Petroshahd development leases. The Bahariya Formation is differentiated from the underlying Albian Kharita Formation by its fine to very fine-grained, chloritic, and glauconitic sandstone. Otherwise, the top of the Kharita Formation is characterized by its silica cement and the absence of chloritic and glauconitic facies. The main objective of this study is the evaluation of hydrocarbon reservoirs in the Al Zahraa oil field based on using petrophysical characteristics, and identifying the sandstone distribution of the Bahariya Formation reservoir and it's vertical and lateral changes.

Keywords: Bahariya Formation; Cenomanian; Core; Effective porosity; Hydrocarbon; Petrophysical characteristics; Reservoir characterization.

1. Introduction

Egypt covers an area of almost 1,000,000 km2. It can be divided into five geographic areas: (1) Sinai Peninsula, (2) The Eastern Desert, (3) Nile Plateau, (4) Nile Delta, and (5) the Western Desert. The Western Desert comprises the area west of the Nile River and Nile Delta covering 700,000 km2, about two-thirds of the area of Egypt. It stretches for 1000 kilometres from the Mediterranean Sea to the Sudanese border in the south, and 600 to 800 kilometres from the Nile valley to Libya in the west. The northern part of the Western Desert has a lot of potential for hydrocarbon development. Its significance stems from an active depositional history that led in the formation of multiple Mesozoic rift basins, including Matruh, Shushan, Abu Gharadig, and Gindi, among others. Bahariya and Abu Roash formations contain a large proportion of the discovered oil reserves and they are developed in several basins. East Ras Qattara concession is located in the northwest of Qarun oil fields and to the northeast of North Bahariya oil fields in the northern part of the Western Desert of Egypt approximately 140 km west of Cairo. The area under study Fig. (1) lies principally between latitude 29° 52' 00" and 29° 54' 00" N, and Longitude 30° 01' 00" and 30° 03' 00" E with an area of about 12 km2. It is located to the east of Qattara Depression, northeast of Abu Gharadig basin, north of Kattaniya Inversion.

The study area is penetrated by a number of wells, four approved selected wells (Al Zahraa-1, Al Zahraa-2, Al Zahraa-4 and Al Zahraa-5) with some reference wells surrounding the area which includ their electric log records, and twenty seismic lines. In addition to core analysis reports of conventional, and sedimentological studies of Al Zahraa-2 well 60 feet (10221feet to 10281 feet) mainly includes conventiona and sedimentological studies for Lower Bahariya member.

To summarize the workflow of this study, it will start by understanding the regional structure of the north Western Desert. Another important aspect to look for is the stratigraphy and the depositional environments of Upper and Lower Bahariya members. Integration of well-logs analysis and core data have been obtained to subdivide the reservoir into different flow units which would help to evaluate the reservoir quality and to estimate properites in uncored intervals of wells. Different lithological interpretation methods will be applied to interpret the different facies using well logs and will be followed by well log correlation to identify lateral continuity of the reservoir. Finally, petrophysical data analysis will be calculated for each well in Al Zahraa area.

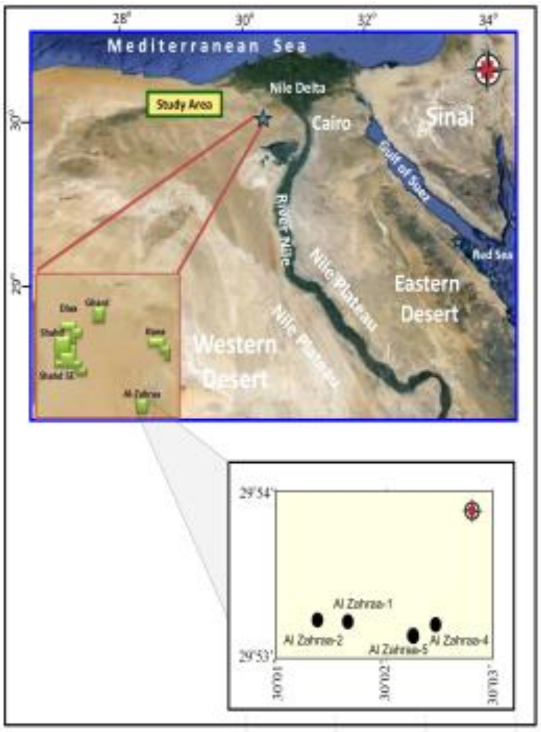

Fig. (1). Landsat of Northern Egypt showing the main five geographic Areas, and the Location of the Study Area

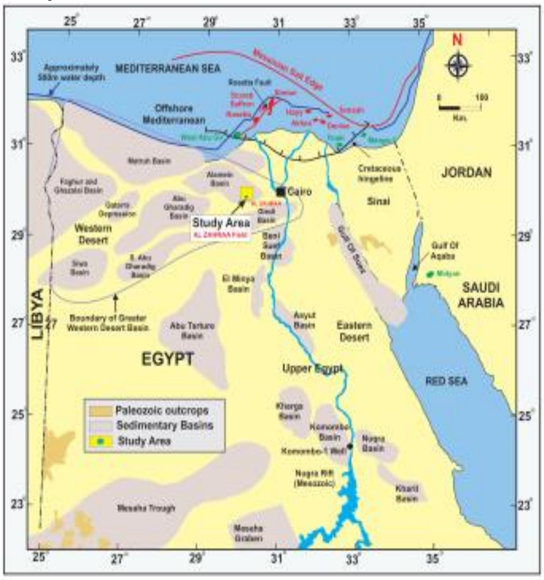

Fig. (2). Index map of the sedimentary basins of Egypt, (Modified from Dolson et al., 2000).

2. Geological Setting

2.1 Regional Geological Setting

The Western Desert extends westward from the Nile Valley to the Libyan border, including an area of over 681,000 km2, or more than two-thirds of Egypt's total land area, excluding Fayum. The sedimentary succession of the Western Desert of Egypt ranges from Lower Paleozoic to Recent. According to Said (1), four major sedimentary cycles occurred with comparable maximum southward transgression during the Carboniferous, late Jurassic, Middle and late Cretaceous and Pliocene times. During the period when major reservoir bodies were being deposited (Jurassic-Cretaceous, 195 - 65 Ma age), the Tethys shoreline was moving across the Western Desert (2). As the Tethys extended southwards, coastal and tidal Sandstones were deposited, in addition to marine shelf carbonates being developed which eventually became hydrocarbon sources and producing zones. According to EGPC (2). According to Ayyad and Darwish (3), Several anticlinal structures related to the Syrian Arc inverted basins are present across the stretch from the Gulf of Suez to the Western Desert, passing through the Kattaniya high, Sharib-Sheiba platform, Qarun, Abu Gharadig, Alamein, and Matruh basins, Fig. (2)

2.2 Regional Structural Setting

The Western Desert has a complicated, multi-phase tectonic history starting in the Paleozoic time through Tertiary tectonic history and had significant effects on the sedimentary records.

Emam et al. (4) discussed; there are six major geotectonic phases, which recognized in the Western Desert Fig. (3), these are:

a) Caledonian Cycle (Cambrian-Devonian).
b) Variscan-Hercynian (Late Paleozoic).
c) Cimmerian/Tethyian (Triassic-Early Cretaceous).
d) Sub-Hercynian-Early Syrian Arc (Turonian-Santonian).
e) Syrian Arc main phase (Paleogene).
f) Red Sea phase (Oligocene-Miocene).

The general tectonic settings that controls Al Zahraa field is expressed in a form of a dextral slip wrenching regime, this wrenching is forming two major E-W faults bounds the field from the north and south directions, and also some Riedel faults are formed trending in the NW-SE direction.

2.3 Regional Stratigraphic Setting

The litho-stratigraphic column of the North Western Desert where the East Ras Qattara Development Leases are located includes most of the sedimentary succession from the Precambrian basement complex to Recent. The Stratigraphic column of the Western Desert is composed of alternating clastics and carbonates sequences. Such alternation was strongly controlled by the global sea-level fluctuations as well as the major terrigenous influxes. The generalized stratigraphic column of the northern part of the Western Desert is shown in Fig. (4).

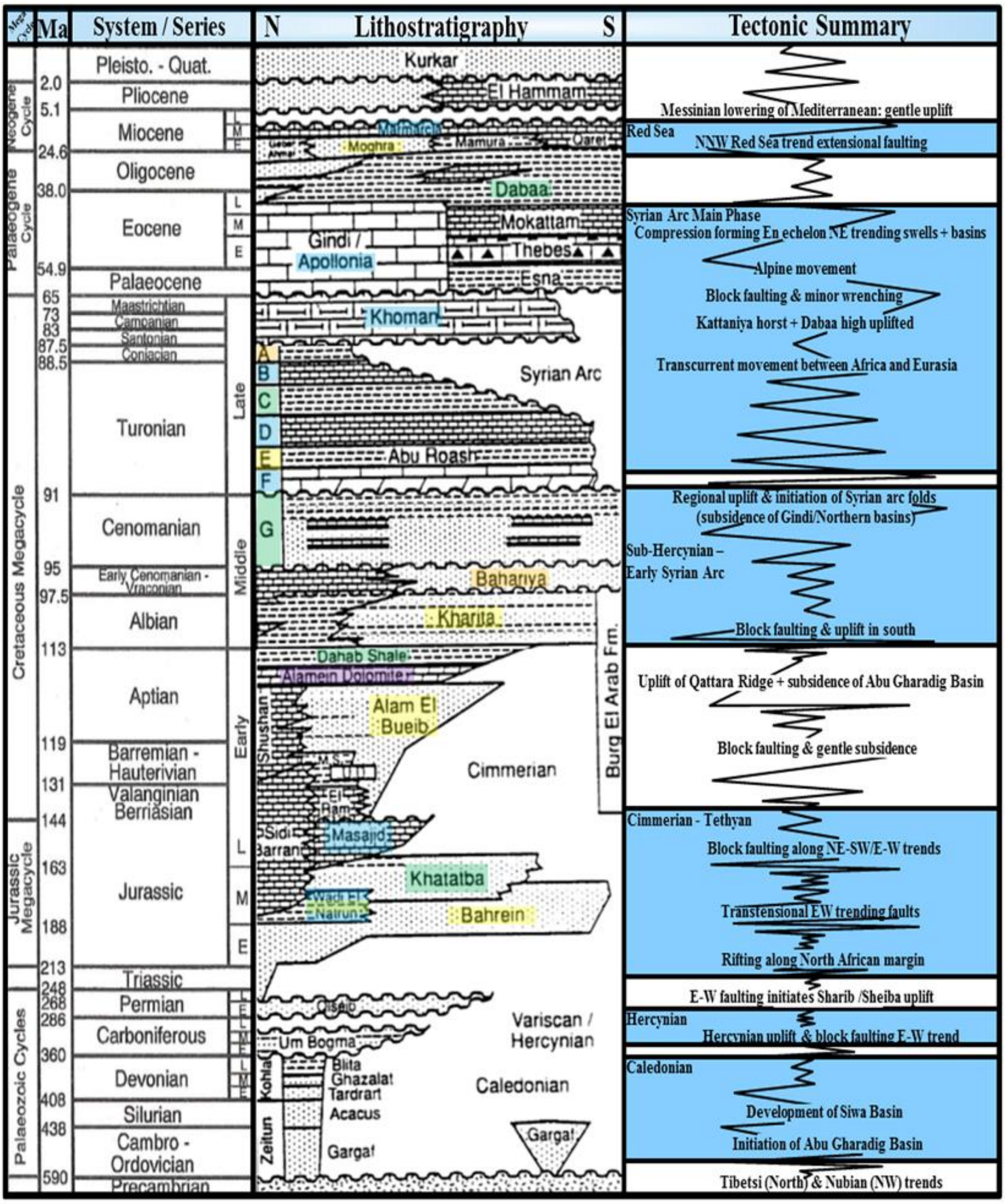

Fig. (3). Regional Tectonic Activity highlighting the major Geotectonic Phases with the generalized Stratigraphic Column of the Western Desert, (compiled after Emam et al., 1990).

Most investigations of the type section of the Bahariya Formation (Gebel El Dist of about 175m thick, Bahariya Oasis) considered the Bahariya Formation to be Cenomanian in age (5), (6) & (7). The Post-Albian/ Pre-Coniacian stratigraphic successions are summarized by different authors according to the distinctive facies parameters (8) and (9). According to Darwish, (10), the upper boundary of the Bahariya Formation is nearly accepted at the base of Upper Cenomanian (11). The lower boundary is delineated variably by different authors, even within Abu Gharadig. Darwish (10), defined the oldest boundary as the base of the Upper Albian (about 99ma). Darwish (10), interpreted sedimentary breaks of varying magnitudes (diastems and truncations).

The Bahariya Formation is divided informally into upper, middle and lower sections. The upper and middle sections are characterized by the presence of high shale and carbonate proportion and minor streaks of glauconitic sandstones.

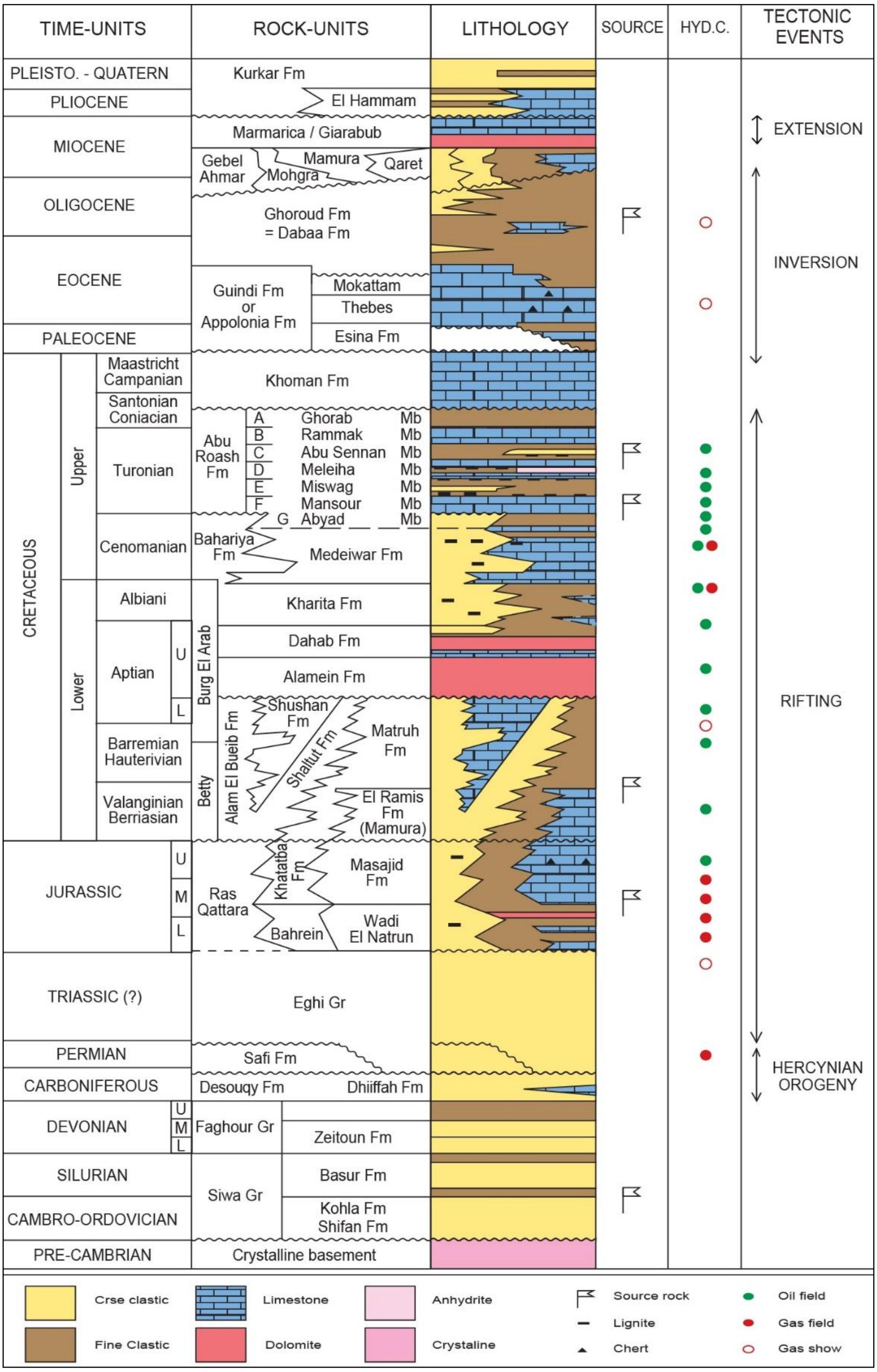

Fig. (4). Generalized Lithostratigraphic Column of the Northern Part of the Western Desert, (after Schlumberger WEC., 2008), hilighted Bahariya formation in the area of study.

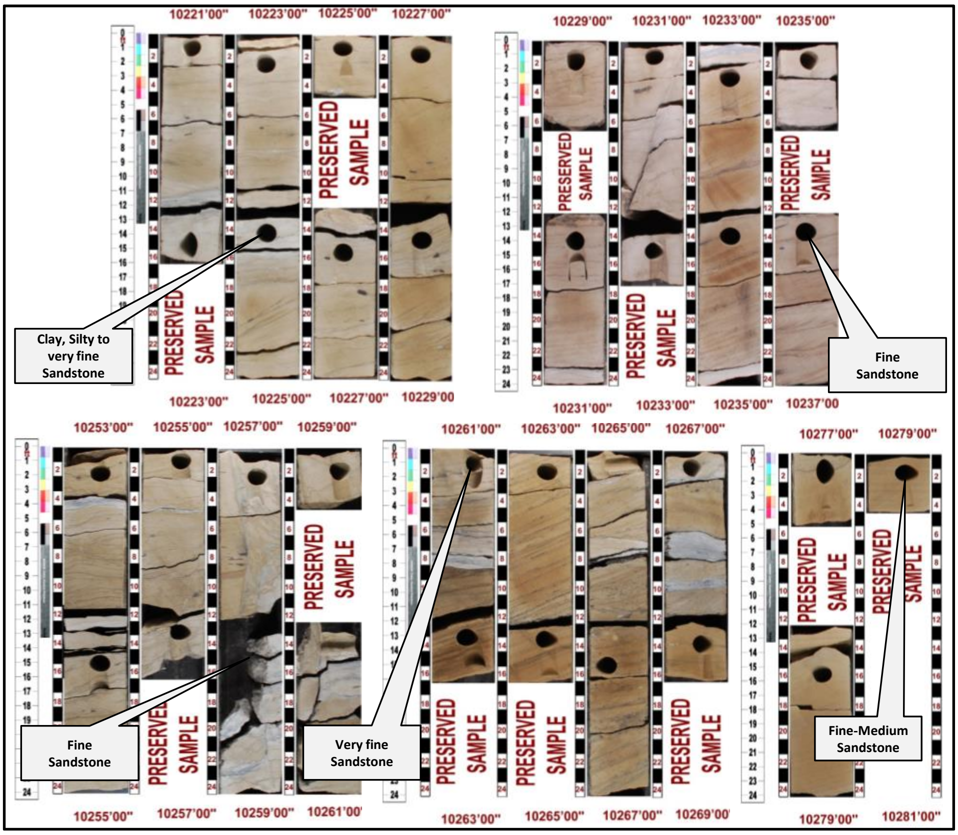

Fig. (5). Classification of the cylindrical sandstone core samples.

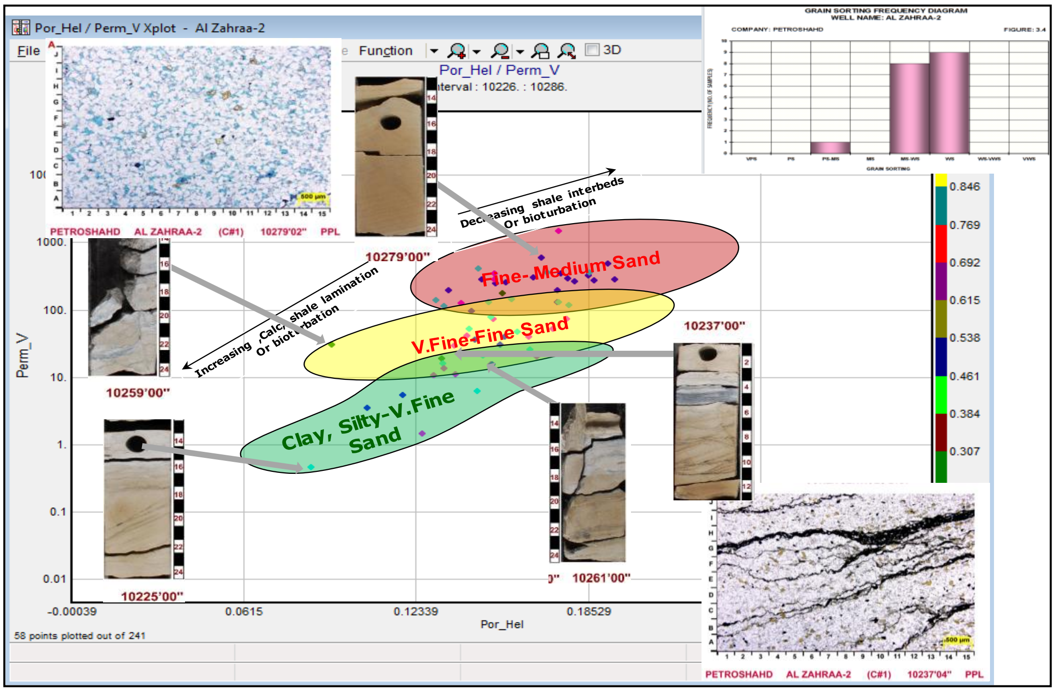

Fig. (6). Core facies classification (porosity vs permeability relative to lithofacies).

Lower Bahariya Member (Late Albian to Early Cenomanian), it represents the base of the regional Late Albian Unconformity (para-conformity) which separates the Upper Albian fluvio-marine clastics, lowermost of Bahariya Formation as interpreted by Darwish (10), from the underlying continental / Aptian to middle Albian sequences of Kharita Formation. The sediments of this member display sandstones with thin shale streaks reflecting fluvio-marine influence. In the study area the Lower Bahariya Member consists mainly of fine to medium grained and cross-bedded sandstone with intervals of relatively fine to very fine grained, glauconitic and rippled being partly and heterolithic sand/clay lithofacies. This facies association displays various criteria of deposition in a tidal flat / lagoonal setting. These criteria include lenticular and flaser bedding, presence of tidal bundles, abundance of both carbonaceous matter and glauconite, some coaly intervals, and the presence of coquina beds formed of molluscan remains and abundant bioturbation (Ichnofossils).

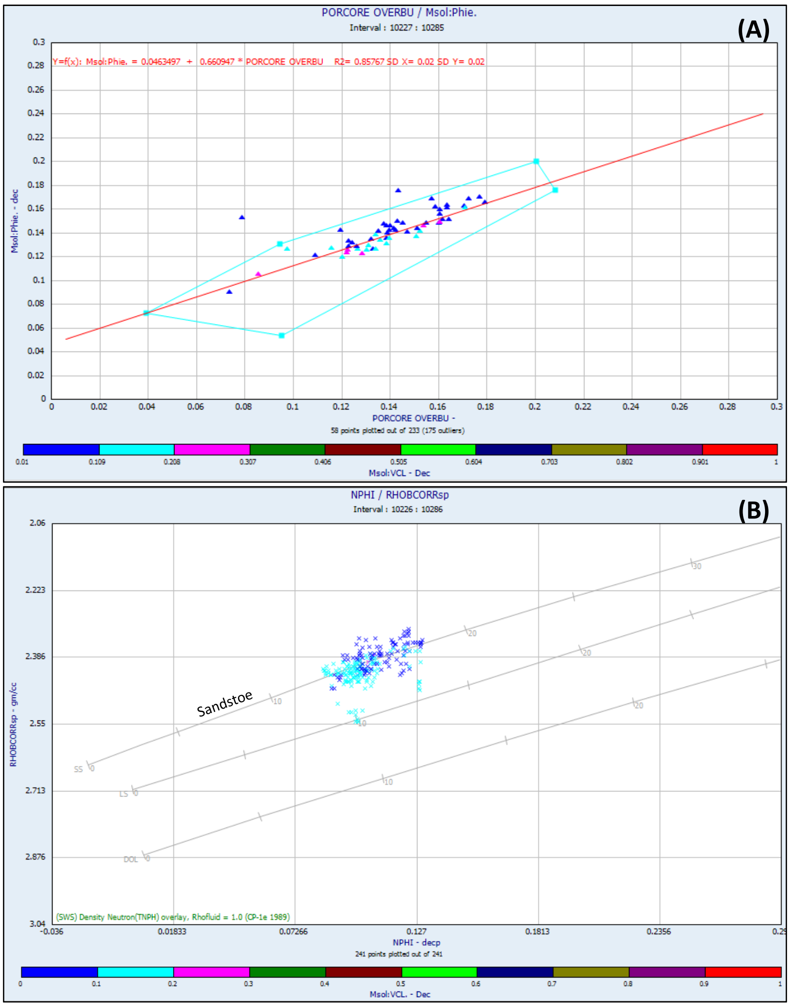

Fig. (7). (A) Core porosity versus corrected log porosity. (B) Lithological identification chart.

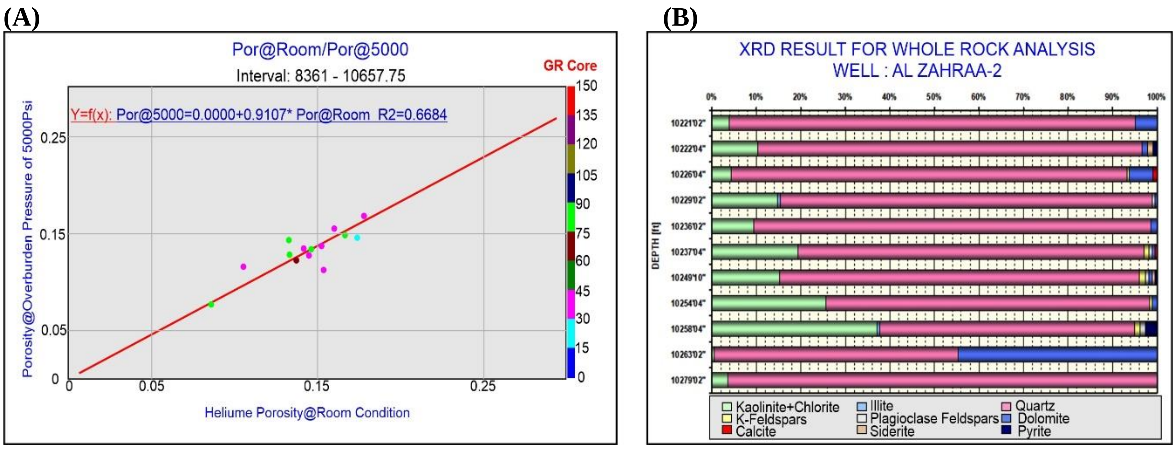

Fig. (8). (A) Relationship between porosity at room and insitu conditions, with overburden corrections applied to all porosity samples. (B) Mineralogical composition from thin Section and XRD, 11 samples were used to calculate the clay volume from XRD, and the results were the dominant clay mineral is Kaolinite-chlorite.

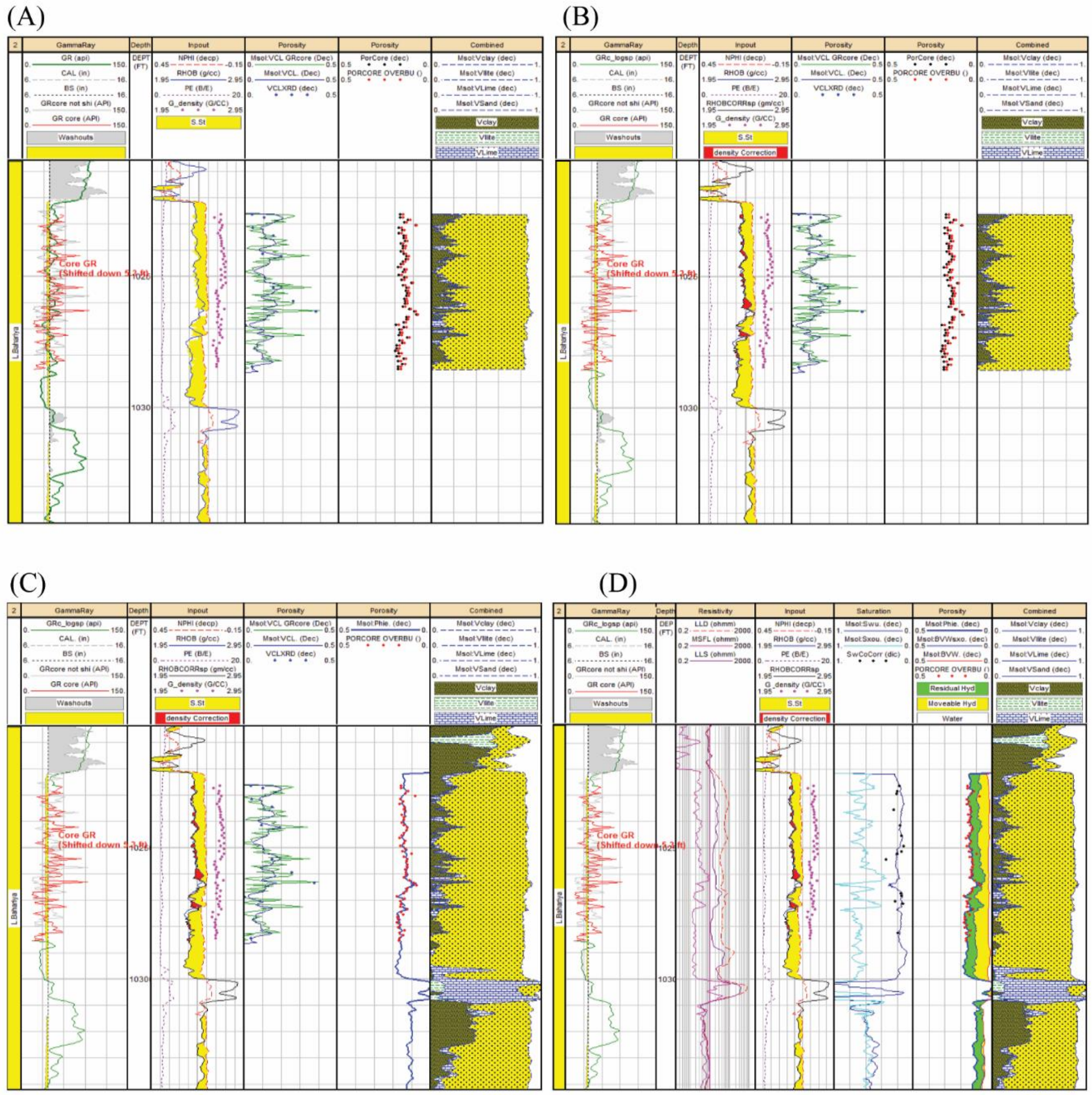

Fig. (9). (A) Core data correction, the porosity comparison after applied the overburden correction and Clay volumes comparison using core-GR/ Wireline-GR / XRD-clay minerals fraction. (B) Bulk density and gamma ray correction, core porosity converted to bulk density curve. (C) Density-Neutron effective porosity after core calibration, porosity comparison between core and log porosity. (D) Water saturation comparison between core Swi and wireline log Sw.

The Middle Bahariya Member (Early Cenomanian), it is a short diastem of about (1.0 ma.) separates the Lower and Middle Bahariya members, representing a dis-conformable relation that can be traced on the top of the lower member and the bottom of the middle member. The small eustatic drop of sea level between the Middle and Upper Bahariya members is characterized by rapid influx of channel sands, through the incised valleys and increase of sand supply towards Abu Gharadig Basin. This coincides with the upper part of the bio-zone Rotalipora protzeni (11).

The Upper Bahariya Member (Early Cenomanian), is dominated by shale/carbonate sequences with interbedded oyster beds. Sandstone beds are thinly interbedded with siltstone and mainly interpreted as tidal channel environment

3. Materials and Methods.

3.1 Well logging Evaluation and Core analysis Integration

The primary purpose of core to log data integration is to reduce the uncertainty associated with formation evaluation. This integration is very important process in reservoir rock characterization for the reason that the logs have limitation and needs some corrections and calibrations. The logs measurements were affected by many variables and the vertical resolution are limited, that is why they need a calibration process using core data. Two cores were cut in Al Zahraa field to study reservoir characterization; 98 feet (from 1022' to 10280') were taken from Al Zahraa-2 well, Lower Bahariya Member, and 149 feet (from 9980' to 10039' and from 10039' to 10129') were taken from Al Zahraa-5 well, Upper Bahariya Member.

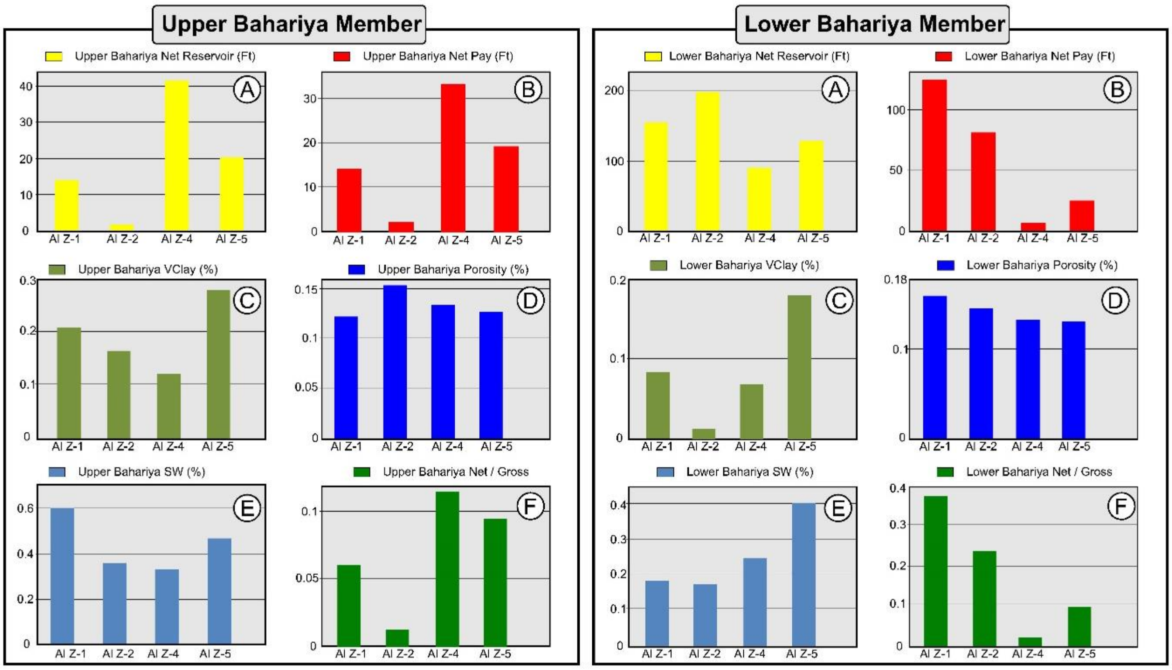

Fig. (10). Upper and Lower Bahariya members petrophysical evaluation shows histograms for; (A) net reservoir in feet, (B) net pay in feet, (C) volume of clay in percent, (D) porosity in percent, (E) water saturation percent, and (F) net to gross.

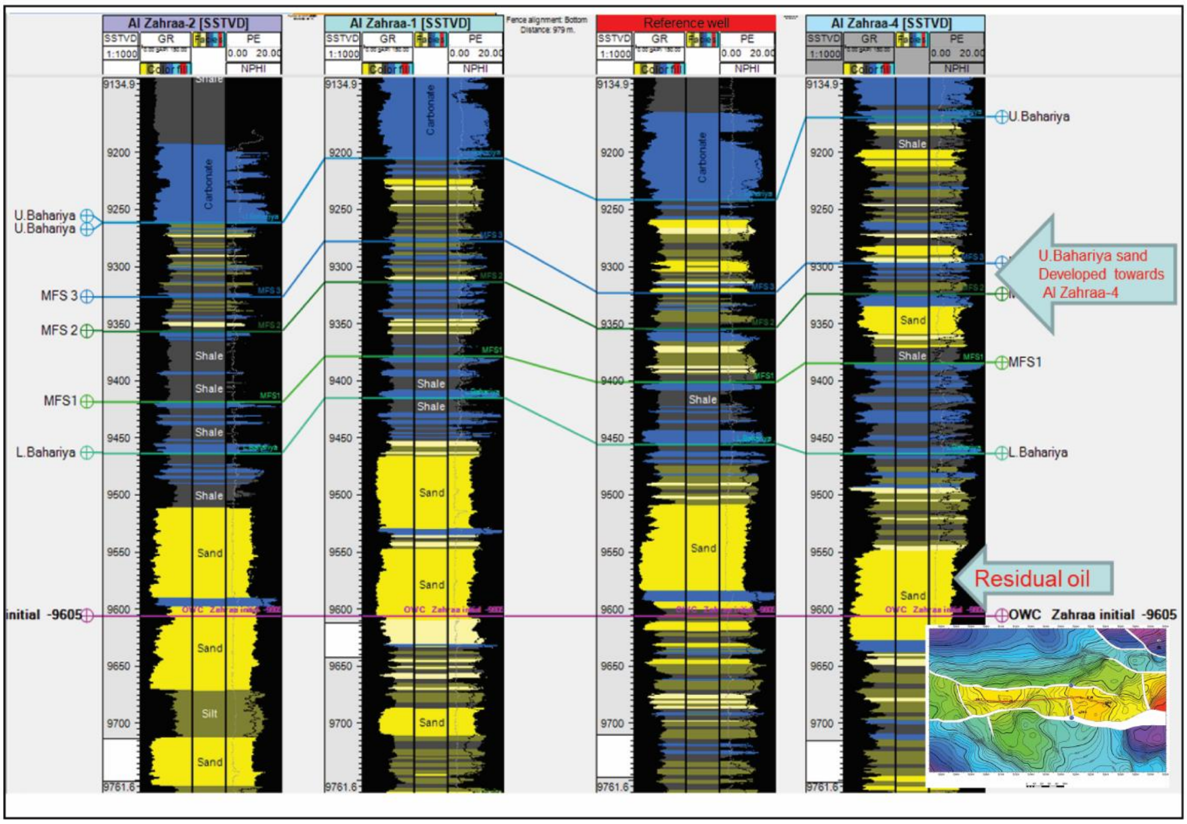

Fig. (11). well log correlation of Upper and Lower Bahariya Members

Fractures in direction of lamination were identified to be the reason of the increased permeability in horizontal direction (12). Lithologic lamination has the major effect on the petrophysical modelling and anisotropy of reservoir rock parameters because the laminas themselves composed of pyrite, rutile, glauconite, micas and iron rich minerals (13), as the microscopic image showed, Fig. (6) sample 10237'04" (Kaolinitic subfeldspathic arenite) that showed secondary intraparticle porosity through the partial to near complete dissolution of feldspars, with very poor pore interconnectivity and the sample 10279'02" (Subfeldspathic arenite) that showed pointed counted porosity 16% by volume.

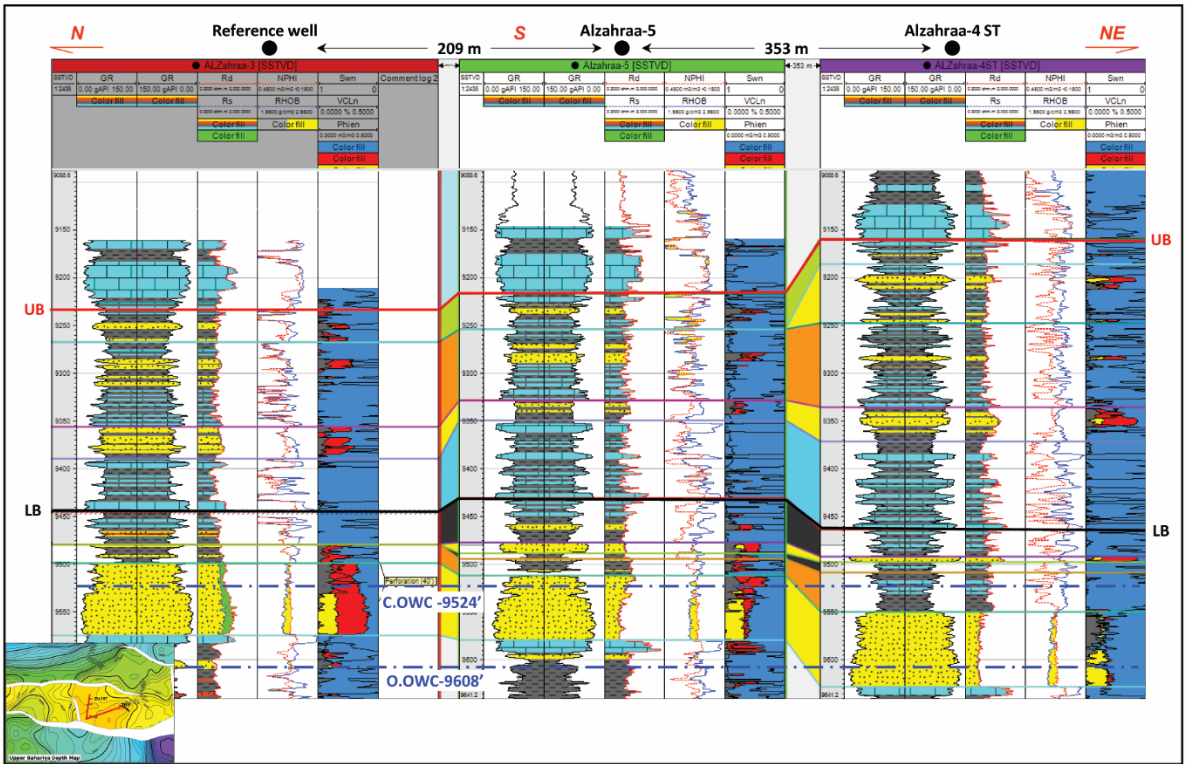

Fig. (12). Upper and Lower Bahariya members structural well log correlation pathing Al Zahraa-5 well

3.2 Core Calibration

Integration of rock facies categorization into formation permeability and porosity models is a critical step in reducing reservoir characterisation uncertainty, especially given core measurements and well log interpretations (14). The improvement of the relationship between permeability and porosity as a result of rock facies classification allows more accurate estimation of petrophysical properties in non-cored intervals (15). The discrete facies sequence is produced either from core measurements (lithofacies) or clustered from the well logging data (electro facies) (15), (16), (17) and (18).

The available full-diameter well-core samples as shown in Fig. (5) are drilled into small plugs of 2.5 cm in diameter and 4.0 cm in length. These plugs are cleaned from the residual hydrocarbons by the use of different types of organic solvents and soxhlet extractor apparatus (19).

Based on data of core, thin section, and well logging, starting from rock and pore types, the quality of reservoirs is affected by sequence stratigraphy, sedimentation, and diagenesis strongly. The completed study, which has been done on the Lower Bahariya Member core, the core facies classification porosity vs permeability relative to lithofacies which showed secondary porosity generated by partial to complete dissolution of carbonate cement and grains feldspar as Fig. (6).

According to sedimentological study and log response, the Bahariya Formation exhibits significant lateral and vertical changes of facies, but the major lithology unit is sandstones in the core interval, as shown in lithological identification cross plot charts Fig. (7. B).

Core data correction porosity as a function of overburden pressure, Fig. (8. A) showed the relationship between porosity at room and insitu conditions, with overburden corrections applied to all porosity samples.

Fig. (8. B) showed mineralogical composition from thin Section and XRD, 11 samples were used to calculate the clay volume from X-ray diffraction (XRD), and the results were the dominant clay mineral is Kaolinite-chlorite.

The reservoir parameters were corrected and calibrated with core data as per the folloeing:

Fig. (9. A) showed the porosity comparison after applying the overburden correction, and Clay volumes comparison using core-GR/ Wireline-GR / XRD-clay minerals fraction. Fig. (9. B) showed core porosity converted to bulk density curve using:

$$Rhob = Rho\ ma * (1 - \varphi) + Rho\ Fluid * \varphi$$

Where: Rhob: is the bulk density log, Rho ma: is 2.65 for sandstones, and Rho Fluid is 1.0, and φ: is core porosity.

Fig. (9. C) showed density-neutron effective porosity after core calibration and porosity comparison between core and log porosity, also as shown in cross plot Fig. (7. A) which confirmed the correlation between core and log porosity where; the correlation coefficient (R square) is equal 0.85767 percent which is a good match. Finally, Fig. (9. D) showed a water saturation comparison between core Swi and wireline log Sw.

Table (1) presented the results of the Lower Bahariya Member for the Al Zahraa-2 well, including net reservoir, net pay, average porosity, average water saturation, average clay volume, and cutoffs established after core calibration.

Table 1: The reservoir, net pay summary, and cutoffs of Al Zahraa-2 well

Reservoir Summary									
Zone	**Zone Name**	**Top**	**Bottom**	**Gross**	**Nel**	**N/G**	**Av Phi**	**AvSw**	**AvVcl**
1	U. Bahariya	9972	10198	226	2	0.009	0.138	0.44	0.229
2	L. Bahariya	10198	10543.25	345.25	196.25	0.568	0.131	0.497	0.095
3	Kharita	10543.5	10657.75	11425	24 75	0.217	0.13	0 938	0.017
	All Zones	**9972**	**10657 75**	**685.5**	**223**	**0.325**	**0.131**	**0.545**	**0.087**
Pay Summary									
Zone	**Zone Name**	**Top**	**Bottom**	**Gross**	**Nel**	**N/G**	**Av Phi**	**AvSw**	**AvVcl**
1	U. Bahariya	9972	10198	226	1.5	0.007	0.151	0.359	0.162
2	L. Bahariya	10198	10543.25	345.25	80.5	0.233	0.145	0.17	0.085
3	Kharita	10543.5	10657.75	114.25	0	0	-	-	-
	All Zones	**9972**	**10657.75**	**685.5**	**82**	**0.12**	**0 145**	**0.173**	**0.087**
Cutoffs Used									
Zone	**Zone Name**	**Top**	**Bottom**	**Min**	**Phi**	**Sw**	**Vcl**		
#				**Hight**	**Msol:Phie.**	**Msol:Swu.**	**Msol:**		
Reservir	U. Bahariya	9972	10198	0	> = 0.08		<= 0.5		
	L. Bahariya	10198	10543.25	0	>= 0.08		<= 0.4		
	Kharita	10543.5	10657.75	0	>= 0.08		<= 0.3		
Pay	U. Bahariya	9972	10198	0	>= 0.08	<= 0.5	<= 0.5		
	L. Bahariya	10198	10543.25	0	>= 0.08	<= 0.50	<= 0.4		
	Kharita	10543.5	10657.75	0	>= 0.08	<= 0 5	<= 0.3		

4. Results

The Petrophysical parameters for Al Zahraa Fields were recalculated after core calibration and the log porosity has been increased 2%.

Water saturation was adjusted by the water resistivity and was matched to Core-Swi (irreducible water saturation at reservoir conditions.

Based on the petrophysical evaluation reservoir and pay of Upper and Lower Bahariya members were summarized as below Table (2) and Fig. (10).

Al Zahraa-1 well results of evaluation indicate the following: Upper Bahariya Member has net pay of 14 feet with average porosity 12% and average water saturation 60%. Lower Bahariya Member has net pay of 123 feet with average porosity 16% and average water saturation 18%. The oil-water contact of the Lower Bahariya Member was determined at 9608 feet (True Vertical Depth Sub Sea (TVDSS)).

Al Zahraa-2 well results of evaluation indicate the following: Upper Bahariya Member has net pay of 1.5 feet with average porosity 15% and average water saturation 36%. Lower Bahariya Member has net pay of 80.5 feet with average porosity 15% and average water saturation 17%.The oil-water contact of the Lower Bahariya Member was determined at 9587 feet TVD SS.

Al Zahraa-4 well results of evaluation indicate the following: Upper Bahariya has net pay of 33 feet with average porosity 13.2% and average water saturation 33%. Lower Bahariya Member has net pay of 6 feet with average porosity 13.3% and average water saturation 24%. There is no oil-water contact in Lower Bahariya Member, only residual hydrocarbon in the initial oil-bearing sandstone.

Al Zahraa-5 well results of evaluation indicate the following: Upper Bahariya has net pay of 19 feet with average porosity 12% and average water saturation 27%. Lower Bahariya Member has net pay of 25 feet with average porosity 13% and average water saturation 18%.The Oil-water contact of Lower Bahariya Member determined at 9524 feet TVD SS.

From a stratigraphic point of view and zonation of the Bahariya Formation showed that the sandstone of the upper Bahariya Member showed developed sand due east direction. On the other hand, the Lower Bahariya Member showed developed sand due west direction. Fig. (11 & 12).

Table 2: Reservoir/pay summary for Al Zahraa-1, Al Zahraa-2, Al Zahraa-4, and Al Zahraa-5 wells.

Well	Member	Top (ft)	Bottom(ft)	Gross (ft)	Net sand	Net pay	N/G	Av. Phi	Av. Sw	Av. Vcl
Al Zahraa-1	Upper Bahariya	9919	10151	232	14	14	0.06	0.12	0.60	0.206
	Lower Bahariya	10151	10481	330	156	123	0.37	0.16	0.18	0.081
Al Zahraa-2	Upper Bahariya	9973	10174	201	2	1.5	0.007	0.151	0.359	0.162
	Lower Bahariya	10174	10545	345	196	80.5	0.233	0.145	0.17	0.009
Al Zahraa-4	Upper Bahariya	9940	10237	297	41.5	33	0.114	0.132	0.332	0.115
	Lower Bahariya	10237	10655	418	88.5	5.5	0.013	0.133	0.242	0.065
Al Zahraa-5	Upper Bahariya	9962	10170	208	20	19	0.094	0.125	0.47	0.275
	Lower Bahariya	10170	10500	330	128	25	0.093	0.131	0.40	0.18

4. Conclusions

The data used in the interpretation consists mainly of a conventional radiometric and resistivity tools (Triple-Compo) beside the cuttings description. Petrophysical evaluation was reviewed and calibrated with the core data and calculated water saturation was enhanced. The present work mainly deals with subsurface study and petrophysical characteristics to evaluate the hydrocarbon potentiality of the Bahariya Formation. The subsurface study was achieved by the construction of different aligned structural cross sections. These studies reflect that Bahariya Formation deposited in environment changes from fluvio-marine to marine environment in eastern part. All tops of Lower Bahariya Member in western part are higher. This means that the western part is more prospective than the other parts. As a result of the subsurface study and petrophysical evaluation for Al Zahraa field the most productive of Lower Bahariya Member is located in the west, and the Upper Bahariya Member most productive in the east part of the study area. The Upper Bahariya Member showed there is no developed sand due the west towards Al Zahraa-1 and Al Zahraa-2 wells. On the other hand, the Lower Bahariya Member showed developed sand due the west towards Al Zahraa-1 and Al Zahraa-2 wells. The result of Al Zahraa-2 well showed that; the Lower Bahariya Member can be subdivided into three channels classified as tidal channel deposits in transgressive system tract cycle that confirmed from core data study, only the upper one with an oil-bearing while the middle and lower channels below the original oil-water contact of Al Zahraa field, which is at -9608 feet TVD ss.

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خصائص الخزان لمتكون البحرية، باستخدام تحليل العينات الأسطوانية وتسجيلات الآبار، ودمجها، بحقل الزهراء، شمال الصحراء الغربية، مصر.

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الملخص

ينقسم متكون البحرية في حقل الزهراء للنفط والغاز بشكل غير رسمي إلى عضو البحرية العلوي والسفلي ، وتتكون أساسًا من طبقات رملية تحتل الجزء السفلي بينما الطبقات الطينية الرملية المتكدسة شائعة في الجزء العلوي. يتراوح سمك كل من أعضاء البحرية العليا والسفلى على طول منطقة الدراسة من 201 قدمًا إلى 305 قدمًا و 330 قدمًا إلى 417 قدمًا على التوالي. يمثل الصخر الطيني والأحجار الطينية معظم الجزء العلوي من متكون البحرية ، والحجر الرملي ذات الجودة المتوسطة إلى الجيدة .يتم تمييز متكون البحرية عن متكون خريطة من خلال الحجر الرملي الناعم إلى الحبيبات الدقيقة جدًا ، الكلوريت ، و الجلوكونيت. بخلاف ذلك ، يتميز الجزء العلوي من عن متكون خريطة بالسيليكا كمادة لاحمة وغياب الكلوريت ، و الجلوكونيت .الهدف الرئيسي من هذه الدراسة هو تقييم مكامن الهيدروكربونات في حقل الزهراء النفطي بناءً على استخدام الخصائص البتروفيزيقية، وتحديد توزيع الحجر الرملي في مكامن التكوين البحري وتغيراته الرأسية والجانبية. بدءًا من المعايرة باستخدام العينات الأسطوانية لأعضاء البحرية العليا والسفلى ، لتقييم آبار حقل الزهراء ، ثم سيتم تفسير السحنات المختلفة باستخدام تسجيلات الآبار وأخيرًا ، سيتم حساب وتحليل البيانات الفيزيائية لكل بئر في منطقة الزهراء.