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RESERVOIR CHARACTERIZATION AND OOIP ESTIMATION FOR FIELD LOCATED IN NORTH BAHARIYA CONCESSION

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Abstract

The aim of this study is to present an intensive reservoir characterization process and petro - physical interpretation methodology for a field located in north Bahariya to estimate the original oil in place. The first step in the process is to interpret 3D seismic data to identify the reservoir structure and top depth of Abu Roash and Bahariya formations through analyzing velocity, digitization, time to depth conversion, constructing geo-seismic cross-sections. The seismic interpretation reflects the outstanding role of faulting and folding on the top of the formations in the studied area. Then the available logs from the field wells are used to determine the properties and fluid contents for Abu Roash "G' and Bahariya formations. The porosity values range as high as 16% in the good quality sandstone to 12% in the bad quality sandstone sections with clear increasing in Sw towards the top of Bahariya formation ranging from 0.40 to 0.80. While in Abu Roash "G' (A/R"G") formation, the porosity values varied from 18% to 14% while the Sw range is from 0.27 to 0.70 .In addition, all wells encountered in A/R"G" considered as hydrocarbon bearing reservoir. The original oil in place has been calculated for the oil-bearing formations using volumetric and material balance equations. The results show that the calculated oil in place using both methods are in a close agreemen.

Keywords: *Original oil in place; Material balance; Western desert; North Bahariya.*

1. Introduction

The general structural and stratigraphically aspects of the Western Desert have been the subject of many studies, such as [1-12] and others. The generalized stratigraphic column of the northern Western Desert is thick and includes most of the sedimentary succession from Pre-Cambrian basement complex to Recent. In the North Bahariya concession area, the proven oil-producing reservoirs are sands within the Cretaceous with deeper potential reservoirs in the Jurassic Bahrain and Khatatba Formations. Potentially all Cretaceous clastic units are productive reservoirs. The key reservoirs are the sands of the Albian Kharita Formation, the upper and lower units of the Lower Cenomanian Bahariya Formation, the Upper Cenomanian to Turonian Abu Roash Formations. Within the Abu Roash Formation the Upper Cenomanian Abu Roash "G" sand (upper and lower pays) and the Turonian Abu Roash "C" and "E" are the producing reservoirs in the North Bahariya Concession.

The Stratigraphic column of the Western Desert is composed of alternated clastics and non-clastic sediments; such alternations were strongly controlled by the sea level fluctuation as well as terrigenous influxes. The known formal oldest penetrated section above the Basement rocks is the Permo-Carboniferous Safi Formation while the recent most formation is the Wadi Quaternary terraces topping Marmarica Middle Miocene.

2. Bahariya Formation

Bahariya is of Early Cenomanian age; however, the lower part (lower Bahariya :350 +/- 450') is late Albian in age. It represents the onset of the global sea level rise during the Late Cretaceous. The whole formation is dominated by sandy and silty facies with some streaks of shale and limestone (especially in the so called middle Bahariya). The various cores and log data support the marginal marine origin of the sediments having the Lagoons, tidal flats, barrier bars and tidal channels as the main depositional components. However, the tides regime and especially mud flats are the reason behind the massive heterolithity complex of the upper Bahariya (200′ to 350′).

3. Abu Roash (A/R) Formation

As the Sea level rises after Bahariya time the whole A/R formation was deposited in marine to the deep marine environment as going upward. It consists of seven members, but the current study focuses on Abu Roash "G" formation. The Abu Roash "G" is of Cenomanian in age (av.750′). Shale, limestone, and sandstone are the main liothological components. According to the interpreted paleo-depositional regimes, this member was deposited during the general global sea level rise conditions, in much deeper water than Bahariya.

The fair to weak porosity is highly controlled by quartz over growth that may be due to carbonate matrix dissolution in basin-ward areas versus the silica precipitation (new post diagenesis cement).

Sedimentological environment. This part will focus only on the formations holding the producing reservoirs, namely; Abu Roash G and Bahariya formations. The Abu Roash G" Formation (Upper Cenomanian) can be divided into a mudstone-dominated lower part, which grades upwards into a succession of relatively fine-grained ripple laminated sandstones that constitutes the upper part.

4. Trap

Structurally, the studied field prospect located in an NW-SE elongated tilted block bounded from the south by a major old E-W fault (probably Jurassic in origin). On seismic the fault appears to be active in the Upper Cretaceous. The trap has a structural relief of 200′, from the lowest closing contour (see Fig. 1).

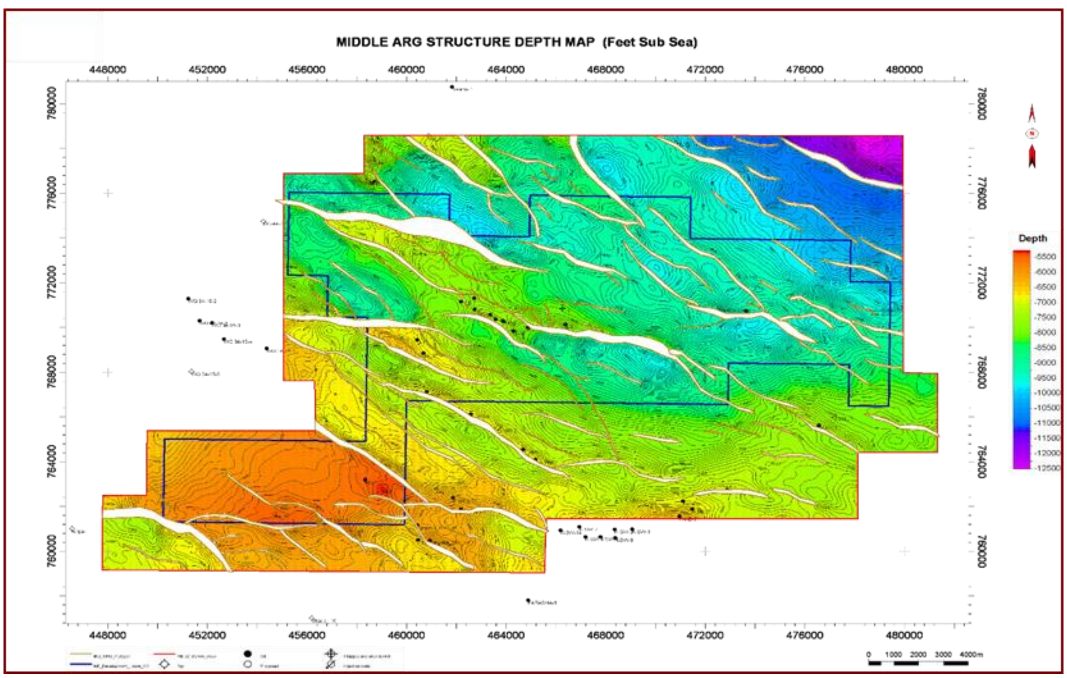


Fig.1. Middle AR/G depth structure contour map

5. Reservoir characterization

Sedimentological studies are based on A-5 and A-22 cores (see Fig. 2) for Middle A/R "G" and Upper Bahariya reservoirs. The interpretation for the cores sample from The Abu Roash

"G" formation is as follows: The Abu Roash "G" is composed of fine-grained laminated sandstones in the upper part, which grade downwards into a mudstone-dominated succession with interbedded bioclastic limestone units in the lower part. The ripple laminated sandstones can be broadly divided into relatively coarser grained upper part which is mainly composed of fine to medium grained, slightly argillaceous and moderately to heavy oil-stained sand, and relatively finer grained lower part, which is composed of very fine to fine grained, generally highly argillaceous sand with patchy very light to light oil-staining.

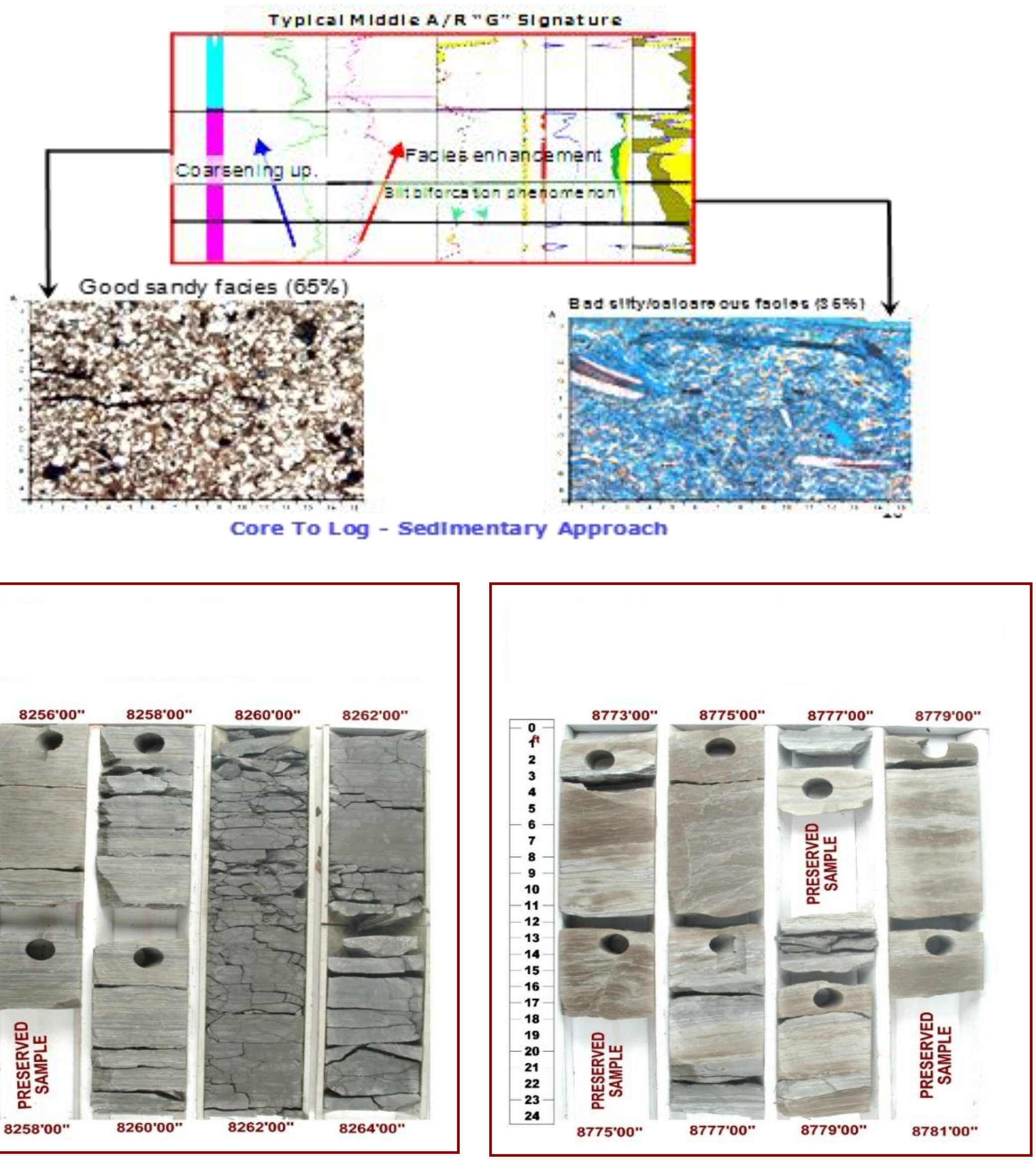


Fig. 2. Middle A/R "G" core and Log sedimentology

5.1. Lower AR/G reservoir

Based on analogies and GR response, Lower A/R "G" can be interpreted as mudflats barrier bar tidal incised with several tidal channel inlets in mudflats

5.2. Upper Bahariya reservoir

The Upper Bahariya Formation (Lower Cenomanian) is mainly composed of relatively thin sandstone beds (Commonly less than one foot thick), which are interbedded with minor sandy, muddy heterolithite, siltstone and mudstone intervals. The sandstone units are dominantly relatively fine-grained (very fine to fine sand), variably argillaceous, carbonaceous and/or calcareous. Some sandstone units are slightly coarser grained (medium to coarse grained sand) and contain clasts (mainly phosphatic fragments) in pebble-size, which are most abundant in the pebbly and conglomeritic sandstone units in the lower part. The sandstones commonly display variably intensive laminations including planar, wavy, irregular, convolute, ripple, lenticular and/or flaser lamination.

From the detailed stratigraphic log correlation, zonation and using six transgressive flooding surfaces of good lateral extinction, the Upper Bahariya was classified into six sandstone units of the prograding cycle, called UB1,2,3,4,5 and UB6; each cycle is separating by flooding surface. The first three units are completely isolated from the other ones by thick transgressive shale which representing the maximum folding surface, in addition, the two-folding surface between UB-2 and UB-4 has some intercalation of transgressive sandstones. The detailed stratigraphic correlation (see Fig. 3) over Bahariya and Abu Roash "G" of A-1 with the nearby wells, revealed that all the penetrated reservoirs in A-1 well is Upper Bahariya UB2 and UB3.

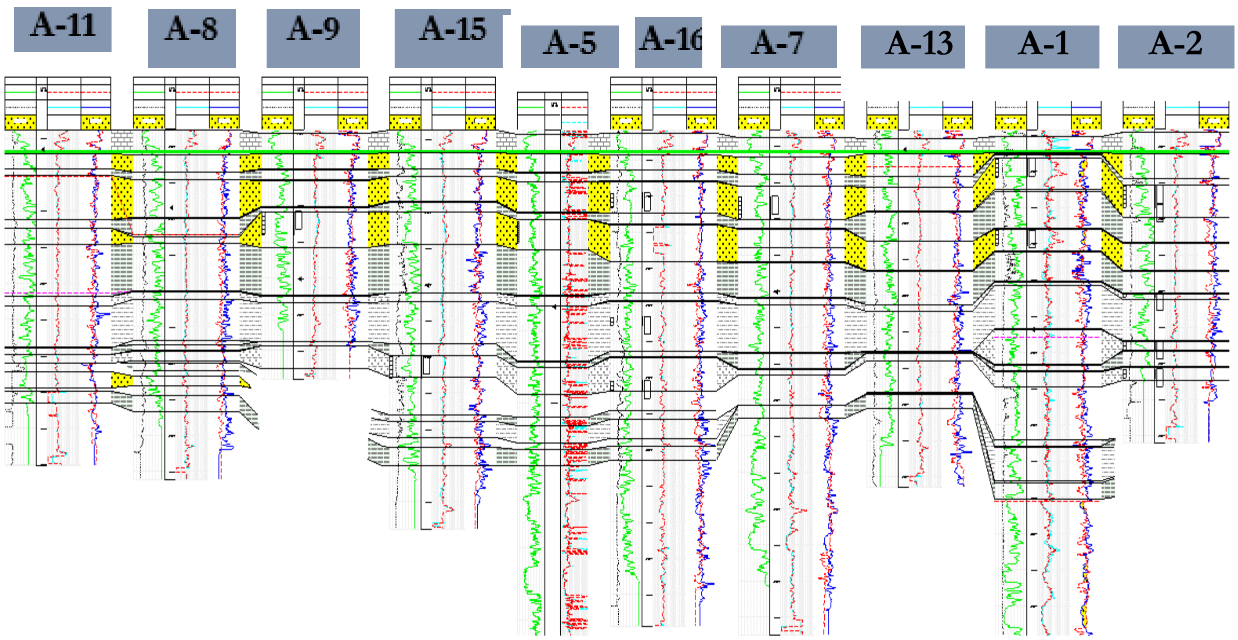


Fig. 3. Studied field Upper Bahariya stratigraphic cross section

5.4. Log analysis

Most of the wells in the studied field that have been drilled to evaluate Abu Roash "G" and Bahariya formations except A-4 well; the Total depth was in top Bahariya formation.

The wire line operations have been conducted all over the field wells, except in A-5 the wire line tool have stopped in the bottom of Abu Roash"G" due to the hole constrains, so it was decided to run LWD over the Bahariya formation. Based on the regional log correlation The Abu Roash "G" is subdivided into three units based upon the reservoir occurrence and the intraformational seals, While Bahariya formation is subdivided in to two members Upper and Lower Bahariya based upon depositional environment and reservoir quality which upper Bahariya is characterized by heterolithic nature composed mainly of shale, sandstone interbeded with siltstone and limestone stingers represent the shallow marine deltaic environment, while Lower Bahariya is composed

5.5. Saturation calculation parameters

The analysis has been performed over Bahariya using the standard electrical parameters, and Rw 0.04 ohm was derived from Pickett plot over the Upper and Lower Bahariya clean water bearing sand intervals and adjusted to water analysis sample of TODS 80,000 ppm salinity. V_{cl} is computed using radioactive index (IRA) provided that no other radioactive mineral besides clay minerals [10].

$$I_{RA} = \frac{GRcleansand_{log}}{GR_{clay} - GR_{cleansand}} \quad (1)$$

Zones having low water saturations apply this equation

$$V_{cl} = \frac{\Phi_N \times (\Delta t_{ma} - \Delta t_{fl}) - \Delta t(\Phi_{Nma} - 1.0)_{maNmaf_{llog}}}{(\Delta t_{ma} - \Delta t_{fl}) \times (\Phi_{Nsh} - 1.0) - (\Phi_{Nma} - 1.0) \times (\Delta t_{sh} - \Delta t_{fl})} \quad (2)$$

where: Φ_N is Neutron porosity; Δt_{fl} is travel time for fluid; Δt_{ma} is travel time for matrix; Δt_{log} is the travel time reading obtained from the sonic log; Φ_{Nma} is the matrix Neutron porosity; Φ_{Nsh} is the shale neutron porosity; Δt_{sh} is travel time for shale.

We apply the harmonic equation to calculate the average porosity of neutron and density porosity. The harmonic equation is applied for water bearing sands

$$\Phi_{N-D} = \sqrt{\frac{\Phi_{D-C}{}^2 + \Phi_{N-C}{}^2}{2}} \quad (3)$$

where: Φ_{N-C} is neutron log readings in the formation which has been corrected for shaliness; Φ_{D-C} is Density log readings in the formation which has been corrected for shaliness.

Below is Archie's second equation to calculate water saturation in the unflushed zone.

$$S_w = \left(\frac{a \times R_W}{\Phi^m \times R_t}\right)^{\frac{1}{n}} \quad (4)$$

where: a = 1.0 ; m = 2.0; n = 2.0; R_w is formation water resistivity; Φ is Wyllie porosity ; R_t is uninvaded formation resistivity.

5.6. Water saturation using Indonesia model [13]

Apply Indonesia model for fresh water: -

$$C_t = \left(\frac{C_W}{F} \times S_W{}^2\right) + \left(2 \times \left(\sqrt{\frac{C_W \times V_{sh} \times C_{sh}}{F}} S_W{}^2\right)\right) + V_{sh}{}^2 \times C_{sh} \times S_W{}^2 \quad (5)$$

Substitute the followings into Equation (1)

$$F = \frac{a}{\Phi^m} \quad (6)$$

$$S_W = \left(\frac{C_t}{\left(\frac{C_W}{F}\right) + \left(2 \times \left(\sqrt{\frac{C_W \times V_{sh} \times C_{sh}}{F}} S_W{}^2\right)\right) + V_{sh}{}^2 \times C_{sh} \times S_W{}^2}\right)^{\frac{1}{2}} \quad (8)$$

where: m = 2.0; ; a = 0.8; V_{sh} or V_{cl} is minimum clay content read from column 26 which is basically the clay content from Gamma Ray curve; R_{sh} is the shale resistivity in unit ohm-m; R_w is formation water resistivity; Φ is effective porosity in hydrocarbon-bearing sand, calculated in column 34; R_t is uninvaded formation resistivity.

Indonesia model is used to calculate water saturation in shaly sands where Archie second equation is not applicable. This is because Archie equation is only meant for clean sands.

6. Results

Based on the log correlation, available logs, the petrophysical interpretation can be concluded as follows:

Abu Roash "G' upper unit consists of shale with a thin streak of non-prospective salty sandstone.

Abu Roash "G' Middle unit consists mainly of shale and limestone interbeded with laterally extended sandstone barrier bar. The porosity values ranged from 19% in the better-quality sand to 13% in the laterally deteriorated sandstone with Sw varied from 0.30 to 0.70, and all wells encountered A/R"G" Middle as hydrocarbon bearing reservoir. Except A-4 the sand was deteriorated.

Abu Roash "G' Lower unit consists mainly of shale interbedded with sandstone and overlaid by intra A/R"G' limestone and underlaid by base A/R"G" Limestone. This sandstone is laterally extended shoreface sandstone. the porosity values varied from 18% to 14% while the Sw

ranged from 0.27 to 0.70 and all wells encountered A/R"G" as hydrocarbon bearing reservoir except in A-11,4, the Sw reached more than 0.80, considered as water bearing.
Upper Bahariya shows intervals of shale, sandstone, siltstone and thin streaks of limestone. The sandstone intervals are ranging in litho-quality from clean sandstone to salty sandstone. the porosity values range as high as 16% in the good quality sandstone to 12% in the bade quality sandstone with clear increasing in Sw towards the top of Bahariya formation and ranged from 0.40 to 0.80. This increasing in Sw is due to the abundance of glauconitic and pyrite in addition to the bound water, which reduces the resistance of electric currents.
Lower Bahariya mainly consists of Sand stone and siltstone with shale streaks. There are three wells have penetrated Lower Bahariya, A-1,5,7, The porosity values ranged as high as 15.5 %, while the Sw is more than 0.85, which classified as water bearing sandstone.

Table.1. Field petrophysical results

Well	Top	Bottom	Gross	Net	N/G	Av Phi	Av Sw	Av Vcl
A-1	8628.5	9400	694.5	281	0.405	0.155	0.77	0.198
A-2	8513.5	9275	337	118	0.35	0.135	0.671	0.227
A-4	8767.83	9234.08	110	46.5	0.423	0.147	0.787	0.179
A-5	8237.08	8511.83	90.5	60.25	0.666	0.188	0.281	0.259
A-7	8291	9322.25	510.25	283.25	0.555	0.142	0.73	0.136
A-8	8391.45	9145.2	343.5	192.63	0.561	0.132	0.748	0.281
A-9	8343.08	9007.33	269.25	158.88	0.59	0.154	0.506	0.233
A-11	8441.08	9193.08	318.5	113	0.355	0.153	0.732	0.151
A-13	8476.51	9236.51	310.25	195.75	0.631	0.134	0.752	0.224
A-15	7903.25	9043	323	189.63	0.587	0.145	0.532	0.244
A-16	8260.08	9196.58	482.25	277.13	0.575	0.151	0.668	0.171

6.1. Calculations of field original oil in place

The available RFT data were used in order to determine the FWL (free water level) in each reservoir in the studied field as there was no oil/water contact (OWC) detected in the electric logs of any of the field wells except the contact which was detected in well A-1 @ 8866 ft RKB in Upper Bahariya Formation. Figures 4 a and b show the detailed analysis of the FWL estimation for each formation.

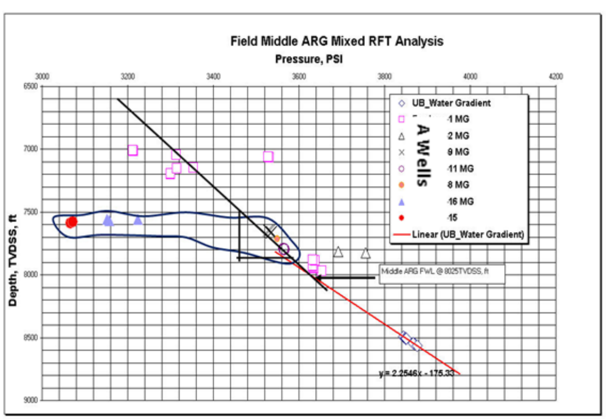
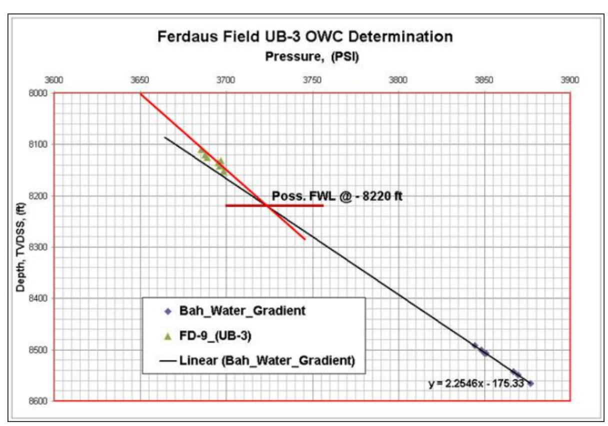


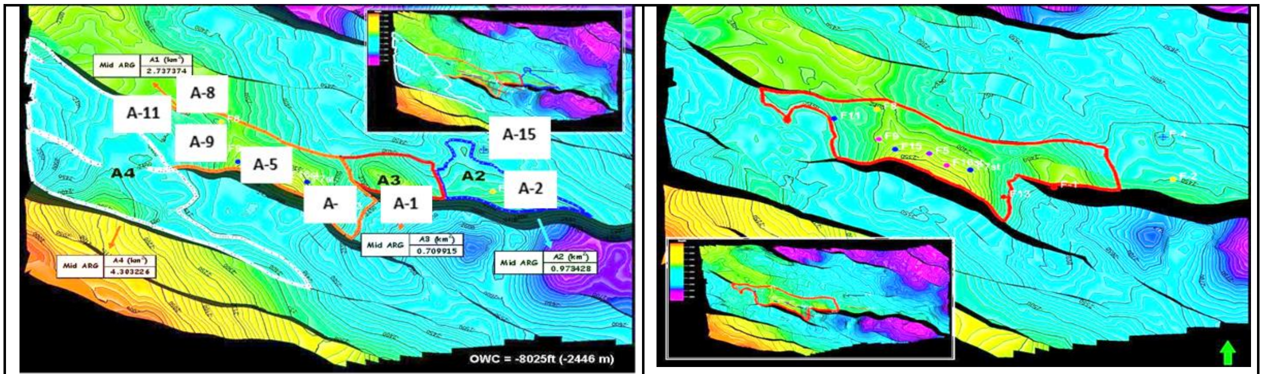
Fig. 4. (a) Middle A/R "G" Free Water Level Determination and



(b) Upper Bahariya Free Water Level Determination

6.2. Volumetric calculations

The average petrophysical parameters of each formation and the recent structural maps after calibrating the seismic cube were used to calculate the OOIP within the FWL determined by the Repeat Formation Tester (RFT) analysis. Figures 5 a, b and c show the structural maps on the top of each flow unit which were used for volumetric calculations.



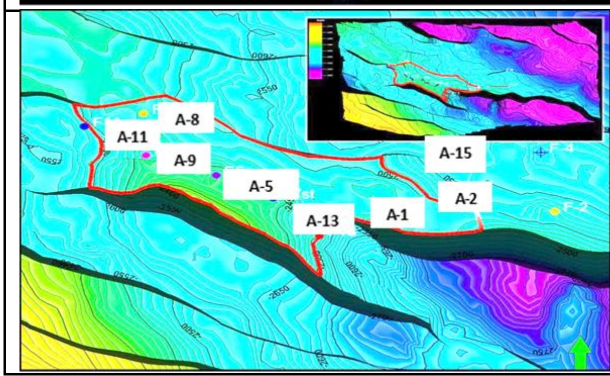


Fig. 5 (a) Top Middle A/R "G" Depth Structure Contour Map (b) Top Lower ARG Depth Structure Contour Map and (c) Top Upper Bahariya (UB-1, UB-2 & UB-3) Depth Structure Contour Map

Table 2. summarizes the petrophysical properties which used in calculating the volumetric for each flow unit.

Table.2. Field petrophysical properties

Property	Middle ARG		Lower ARG	UB-1	UB-2	UB-3	UB-4	UB-5
	N. Field	S. Field						
AVG Phi	0.141	0.17673774	0.172518594	0.174135	0.151193	0.165722	0.1524	0.156257
AVG Sw	0.297	0.321585668	0.372431173	0.587051	0.548766	0.460601	0.564481	0.506702
Net Pay	13.5	14.65625	29.355	1.9075	13.50167	20.70833	5.833333	7.6

6.3. Material balance

Because of the availability of pressure history, production data, and PVT data, it has been decided to build a tank model for each formation in each compartment for a better realistic estimation of the original – Oil in place.

6.4. Middle AR/G tank model analysis

Based on the analysis of the pressure history of Middle A/R "G" sand in the studied field, it was concluded that there are three separate areas as it is clearly seen on the structural map of top Middle A/R "G" Sand. These areas are A1: South Middle ARG; A2: North Middle ARG; A3: North Middle ARG (A-12 Area).

Also, based on the FWL estimation and the recent structural map on the top of Middle A/R "G," there is another area A4 to the west of field. although this area is located inside the proven FWL, it is classified as probable in terms of the reserves and OOIP calculations as it was not tested by any well.

6.5. Black Oil MBE

The used MBE for OOIP calculation as follows [14]:

$$N_p\left[B_o+\left(\frac{G_p}{N_p}-R_s\right)B_g\right]+\left(W_p-W_i\right)B_w=NB_{oi}\left[\frac{(B_o-B_{oi})+(R_{si}-R_s)B_g}{B_{oi}}+m\left(\frac{B_g}{B_{gi}}-1\right)+(1+m)\left(\frac{c_wS_{wi}+c_f}{1-S_{wi}}\right)\Delta\bar{p}\right] \quad (9)$$

Figure 6 and Table.3 show the calculated OOIP for the calculated field using both volumetric and material balance equation. The results show that the error percentage for the calculated volumes between the mentioned method is very not big, which indicates that the interpretation was successful.

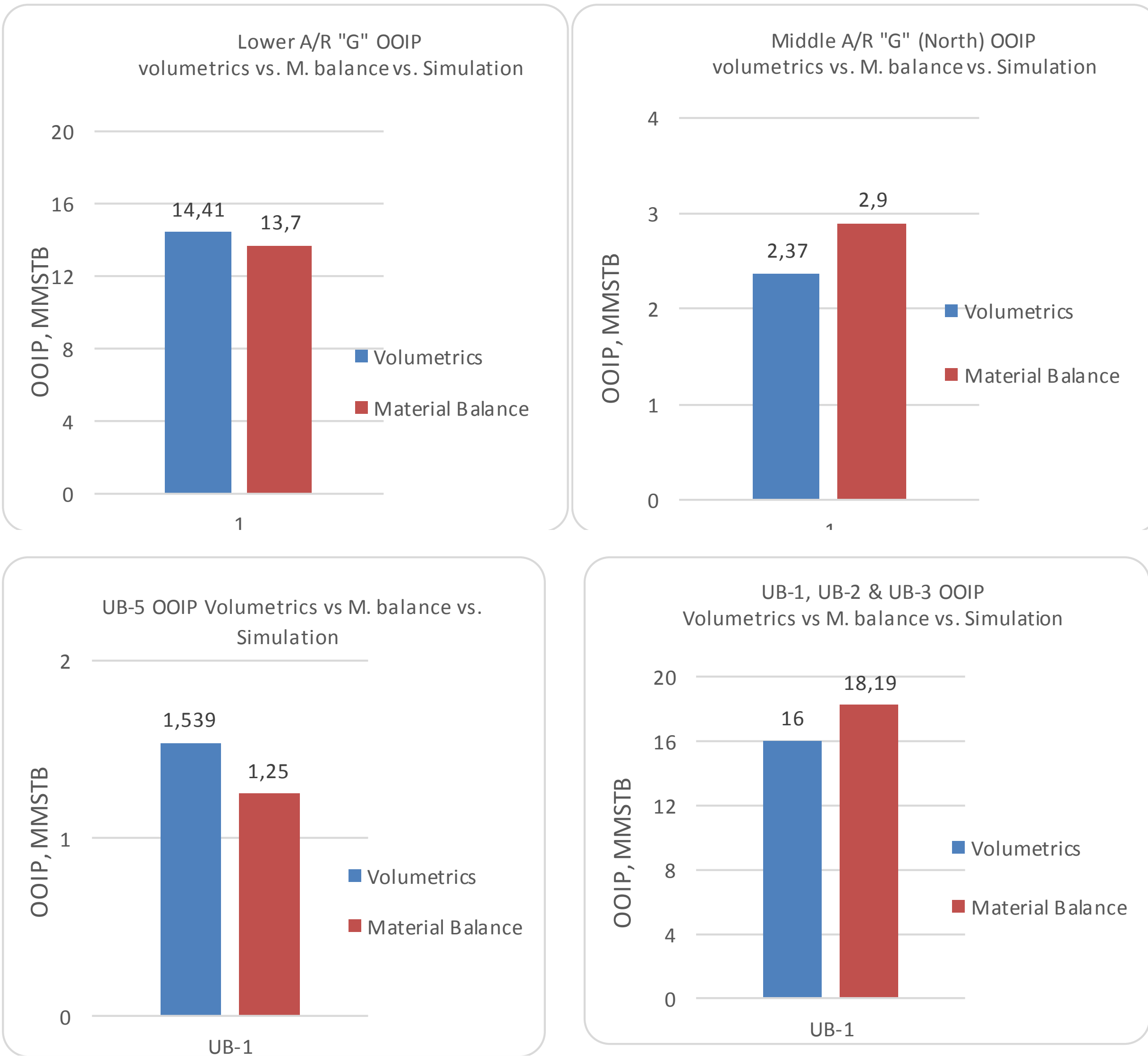


Fig.6. Calculated OOIP using volumetric and MBE method

Table.3. Summary of the material balance calculations of the studied field

Upper Bahariya					Lower ARG	Middle ARG	
UB-1	UB-2	UB-3	UB-4	UB-5		North	South
18.19 *			NA	1.25	13.7	2.9	4.05**

** 8.42 MMSTB in UB-3 West A-5 Compartment; * 2.5 MMSTB in UB-2 and UB-3 in the Eastern Part*
** 7.27 MMSTB from UB-2 in A-1.*
*** 3.9 from Middle A/R "G" in South (A-5 Compartment); ** 0.14 MMSTB in Middle A/R "G" around well A-11.*

7. Conclusion

Upper Bahariya (UB) reservoir vertically classified into 6 layers names as (UB1 to UB6) and separated by shale intercalations has different thickness, the thickest shale bed between UB2 and UB3.

The Abu Roash "G" is subdivided into three units based upon the reservoir occurrence and the intraformational seals.

The south part of Middle A/R "G" sand includes wells A-8, A-5, A-7, A-9, A-15 & A-16 in a separate area knowing that in this area Middle A/R "G" only was produced through well A-8, but the pressure data indicated the presence of communication between the rest of the wells. So, the production data of well A-8 was used to build a tank model for Middle A/R "G" sand in the south part of the field.

It should be noted that the Lower A/R "G" sand is communicated all over the southern part of the studied field as it is clear from the analysis of the pressure history plot.

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