Characterisations of the Late Cenomanian reservoirs in Asala Field, East Bahariya concession, Northern-Western Desert, Egypt

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ABSTRACT
The study aimed to combine the different available data to understand the subsurface system and the characteristic of reservoirs in Asala Field to represent the vertical and lateral heterogeneity at the well, multi-well and field scale, which could be used as a tool for reservoir management. Seismic interpretation was conducted on the seismic sections that concerned the study area to make a detailed structural interpretation to determine the structural geometry of the horizons. Petro-physical well log analysis of the reservoir rock of Lower and Middle zones of Abu Roash “G” member has been done and mapped. The estimated volume of original hydrocarbon in place of Lower and Middle zones of Abu Roash “G” member has been calculated.

KEYWORDS
Asala-Samra; Hydrocarbon potentialities; Abu Roash; original oil in place

1. Introduction
The East Bahariya concession study area lies in the northeastern portion of the western Desert of Egypt (around 170 km south-west of Cairo), between latitudes 29° 20′–29° 40′ N and longitudes 29° 20′–29° 40′ E (Figure 1). The study area encompasses the Asala Field (seven wells: AS-4, AS-13, AS-19, AS-20, AS-22, AS-27 and AS-40 distributed in the field as shown on the base map).

2. Geological setting
2.1. Stratigraphic setting
The stratigraphic section of the North-Western Desert is thick and includes most of the sedimentary succession from recent to pre-Cambrian basement complex (Schlumberger 1995) (Figure 2). The stratigraphic sequence of the study area based on deepest drilled well ranges in age from pre-Cambrian masement relief to Miocene Moghra Formation at surface (WD57-1 well). The Cretaceous mega-sequence is divided into Lower and Upper sequences, the Lower Cretaceous includes Alam El Bueib, Alamein, Dahab and Kharita formations while the Upper Cretaceous sequence incorporates Bahariya, Abu Roash and Khoman formations (Hantar 1990). The Late Cretaceous Abu Roash “G” member represent the main reservoirs in the study area, it is a Late Cenomanian in age (Abdel Aal 1990). It is heterogeneous both vertically and laterally, and becomes sandy through Abu Gharadig basin (Fawzy and Dahi 1992). In the study area Abu Roash “G” member consist of shale, limestone, sandstone, with siltstone streaks.

2.2. Tectonic setting
The structural patterns in northern Western Desert from the pre-Cambrian to Early Tertiary appear to have been influenced significantly by two primary tectonic forces related to Tethyan plate tectonics: (1) the sinistral shear during the Late Jurassic to Early Cretaceous and (2) the dextral shear during the Late Cretaceous to Paleocene time (Meshref 1990). Interpreted seismic section (x-line 5530) was selected in order to illustrate the picking of horizons and structure features in the study area. This section shows 10 seismic reflectors were picked (Basement relief, Khatatba, Alamein, Upper Bahariya Formations, Abu Roash “G”, Abu Roash “C”, Abu Roash “A”, members, Khoman, Apollonia and Dabaa formations).

3. Materials and methods
Interpretation was conducted on seismic lines and (Self Potential (SP), Gamma Ray (GR), resistivity, density, neutron and calliper) logs of seven wells extracted from Asala Field (Figure 1). Integrated methods involving seismic interpretation and petro-physical data analysis were employed to meet the objectives of this study. Interpretations of seismic sections were done, Lower and Middle zones of Abu Roash “G” member were identified and evaluated by generating various maps such as structural, net reservoir isopach, arithmetic average water saturation, arithmetic average effective porosity maps and arithmetic average shale content.
Figure 1. Location map of Asala Field, East Bahariya concession, North-Western Desert.

Figure 2. Generalised stratigraphic column of Northern-Western Desert (Schlumberger 1995).
4. Results and discussion

4.1. North-south trending seismic section (x-line 5530)

This seismic section was oriented to the N-S direction of the study area (Figure 3) passing through Asala-4 well. Late Cretaceous reflectors seem to be parallel, semi-parallel and gradually dipping towards the north. A set of normal faults affect the sequence especially the Late Cretaceous sequence (Upper Bahariya and Abu Roash formations) and older units. These faults also influence on top of Khoman and Apollonia formations which less deformed than the older Bahariya and Abu Roash formations, the effect of these faults terminates at base Dabaa formation.

4.2. Depth structure contour map

The depth structure contour map constructed on top Abu Roash “G” member based on 2D seismic data in the area of the Asala Field (Figure 4) shows that the structurally low areas exist in the north part along the major NE-SW fault and in the north-western part of the study area recording depth values between 5000 and 5700 ft. and structurally high recording depth values in the central area and north-eastern part from 4000 to 4500 ft. The main fault trends are related Africa and Eurasia, Africa and Eurasia changed from sinistral divergence to dextral convergence the movement formed some basins grabens and half-grabens, each bounded by a major fault on its down dip side (Savostin et al. 1986; Smith 1971). Away from this fault, the dip angle of the rocks within the basin decreases and at the extreme up dip edge of the basin, they have a very gentle dip and are usually referred to as platforms and these constructed high area at the south and in the central part in the trend NW formed closures making trapping to hydrocarbon at this main target reservoir rock level in the study area and the basin increasing to the northern part of the study area.

4.3. Isopach maps based on 2D extracted from 3D seismic data

4.3.1. Late cretaceous

Figure 5 is an isopach map (based on 2D seismic data) of the Upper Cretaceous A/R “G” member (between top Bahariya and top A/R “G”). This sequence exhibits maximum thickness to the central, western and south-eastern parts of the study area. It also shows thinning of this unit in southern and south-western parts of the mapped area. The change in the thickness of the A/R “G” ranges from 400 to 1050 ft. From the depth structure map and isopach map of the A/R “G”, the main basin is trending in the north-western part of the study area.

4.4. Well log analysis

4.4.1. Neutron-density cross-plot

Middle Abu Roash “G” zone represents the middle clastic reservoir zone of Abu Roash “G” member. Figure 6 reflects the neutron-density cross-plots that have been applied on the Middle Abu Roash “G” zone. It is observed that, the reservoir sandstone plotted points are scattered and lay between sandstone and limestone lines with average grain density (pma) is 2.66 gm/cc and neutron porosity $\Phi_N$ is 20% (in AS-40 as example). The zone is mainly reservoir

Figure 3. N-S trending seismic section (x-line 5530) passing through Asala-4 well.
Figure 4. Depth structure map of Top Abu Roash “G” member.

Figure 5. Isopach map (based on 2D seismic) showing the thickness variations from Upper Bahariya top to A/R “G” top.
sandstone with non-reservoir siltstone scattered and lays between limestone and dolomite lines (Figure 7), delineates the neutron-density cross-plots that have been applied on the Lower Abu Roash "G" zone. It is observed that, the major plotted points are scattered and lay between sandstone and limestone lines with average grain density (pma) is 2.67 gm/cc and neutron porosity is 24% (in AS-40 as example).

4.4.2. Petro-physical parameters

Table 1 is shown reservoir and pay summaries resulted from the petro-physical analysis.
4.4.3. Lateral variation of reservoir properties

After calculating the values of the log-parameters, the values have been averaged and mapped to represent their general distribution.

4.4.3.1. Middle Abu Roash “G” zone. Middle Abu Roash “G” sandstones were deposited in prograding deltaic distributary environment and exhibit coarsening-upward profile with related increase in reservoir quality upward (Pasley et al. 2008). The net reservoir sandstone isopach map of the Middle Abu Roash “G” zone is shown in Figure 8. Its thickness varies from 4 ft. in Asala-27 well to maximum value 18 ft. in Asala-20 well. The highest calculated net pay is restricted in the eastern part. This distribution pattern indicates that the hydrocarbon potential of Middle Abu Roash “G” member is promising in the eastern part of the study area.

The neutron-density cross over shows a dominant sand section in Middle Abu Roash “G” member. The high gamma ray against that sand may be due to the high shale content or argillaceous sandstone interval. The shale content generally increases in the centre part of Middle Abu Roash “G” member. The resistivity values in the pay zone indicate the presence of hydrocarbon accumulation where there is a good separation between deep and shallow resistivity; the deep resistivity values range from 4 to 24 ohm (Figure 12(a,b)). On the other hand, the area of low values of sandstone might represent inter-distributary fine sandstone and siltstone. The effective porosity distribution of the Middle Abu Roash “G” is shown in Figure 9. It reaches the maximum value (25%) at the mouth bar facies (in Asala-20 well) and the minimum (7%) towards the inter-distributary fine sandstone and siltstone facies (in Asala-27 well). The general trend of average porosity distribution increases towards the

Table 1. Reservoir and pay summaries resulted from the petro-physical analysis.

| Well names | Gross interval (feet) | Net reservoir (feet) | Average phi | Eff. (%) | Average SW (%) | Average Shr (%) | Average Vcl (%) |
|------------|-----------------------|----------------------|-------------|----------|----------------|----------------|-----------------|
| As-04      | 164                   | 9                    | 14          | 40       | 60             | 8              |
| As-13      | 151                   | 7                    | 11          | 42       | 58             | 0              |
| As-40      | 65                    | 14                   | 20          | 39       | 61             | 6              |
| As-19      | 162                   | 14                   | 21          | 37       | 63             | 4              |
| As-20      | 165                   | 18                   | 25          | 30       | 70             | 3              |
| As-22      | 162                   | 5                    | 9           | 46       | 54             | 12             |
| As-27      | 158                   | 4                    | 7           | 48       | 52             | 15             |

Table 2. The volumetric estimations using the parameters of Asala Field for A/R (G) Member reservoir.

| Element         | Average          |
|-----------------|------------------|
| Area, acres     | 623              |
| Net pay, feet   | 20               |
| PHI.            | 27               |
| So.             | 51               |
| Bo              | 1.015            |
| OOIP (MMSTB)    | 13.308945        |

Figure 8. Net reservoir isopach map for Middle Abu Roash “G” zone.
eastern part of the area, whereas it decreases towards the inter-distributary fine sandstone and siltstone to the west. Distribution of the shale volume (Figure 10) shows an increase of shale volume towards the inter-distributary fine sandstone and siltstone which reflects that shale volume was controlled by facies distribution. The isoshaliness map of Middle Abu Roash “G” member (Figure 10) shows a relatively intermediate content of shale ranging from 3% at Asala-20 well to 15% at Asala-27 well. The general trend of shale content in the study area increases towards northern west part, whereas it decreases towards south and east directions. The water saturation distribution map of the Middle Abu Roash “G” zone (Figure 11) exhibits the water saturation attains a minimum value of 30% in Asala-20 well and a maximum value of 48% in Asala-27 well. It generally increases in the study area towards north-west, whereas it decreases towards south and west directions. Both facies and structure elements controlled the water saturation distribution of Middle Abu Roash “G” zone. It generally increases towards west and south directions, whereas it decreases towards northern west parts of the study area.

4.4.3.2. Lower Abu Roash “G” zone. Lower Abu Roash “G” was deposited entirely in shallow marine environments where the sands exhibit strong linear trends. These sands were apparently deposited in sub-tidal bars within a marine embayment. This interval contains no evidence of incision at the base of the sands and the best sand facies exhibit current ripple cross bedding, presumably from tidal currents (Pasley et al. 2008). Lower Abu Roash “G” represents the lower clastic reservoir zone of Abu Roash “G” member, this zone represented by reservoir sandstone and siltstone. The net reservoir sandstone isopach map of the Lower Abu Roash “G” (Figure 13) illustrates a variation from 4 ft. in Asala-27 well to maximum value 34 ft. at sandstone body (in Asala-40 well). The highest calculated net pay is restricted to the south-eastern part of the area, whereas it decreases towards the northern-western part, rapidly to zero in the well Asala-19. This distribution pattern indicates that the hydrocarbon potential of Lower Abu Roash “G” member is promising in the south part of the study area. The neutron-density cross over

Figure 9. Average effective porosity map for Middle Abu Roash “G” zone.

Figure 10. Average shale volume distribution map for Middle Abu Roash “G” zone.
Figure 11. Water saturation map for Middle Abu Roash “G” zone.

Figure 12. (a) Stratigraphic correlation for Middle A/R(G) member passing through AS-04, AS-27, AS-13 and AS-22 in the study area (A-A+). (b) Stratigraphic correlation for Middle A/R(G) member passing through AS-22, AS-19, AS-40 and AS-20 in the study area (A-A+).
shows a dominant sand section in Lower Abu Roash “G” member. The high gamma ray against that sand may be due to the high shale content or argillaceous sandstone interval (Figure 14(a,b)). The shale content generally increases in the centre part and higher part of Lower Abu Roash “G” member. The resistivity values in the pay zone indicate the presence of hydrocarbon accumulation where there is a good separation between deep and shallow resistivity; the deep resistivity values range from 5 to 55 ohm.

The effective porosity distribution map (Figure 15) ranges from 7% to 24% in Asala-19 and Asala-40 wells, respectively. The general trend of average porosity distribution increases towards the south-east part of the area (towards tidal creek facies), whereas it decreases towards northwest. That reflects the influences of facies distribution on effective porosity. The shale volume distribution map (Figure 16) reveals a relatively intermediate content of shale ranging from 5% at Asala-20 well to 14% at Asala-19 well. The general trend of shale content in the study area increases towards (north-east and south-west), whereas it decreases towards north-west and south-east. The water saturation distribution map (Figure 17) shows that the water saturation attains a minimum value of 33% in Asala-20 well and a maximum value of 100% in Asala-19 well. It generally increases in the study area towards north-east, whereas it decreases towards southern part. The water saturation is decreasing towards the up-dip of the normal fault and increasing towards the down-dip of the normal fault. Water saturation distribution was controlled by the structure elements.

4.5. Hydrocarbons volume calculation

Preliminary hydrocarbon volumes have been estimated for Abu Roash “G” member. The reservoir input parameters were based on the sums and averages from seven drilled wells penetrating the reservoir section. These estimation were calculated based upon the following formula expressed in terms of original oil in place (OOIP): OOIP (MMSTB) = 7758 * A * h * Æ eff * (1-Sw) * 1/Bo, where, A = reservoir area in acre, h = net pay thickness in feet, Æ eff = effective porosity in fraction (1-Sw) = hydrocarbon saturation in fraction, N/G = net to gross reservoir ratio, Bo = formation volume factor and 7758 is an acre feet conversion for oil (Table 2).

5. Summary and conclusions

The principal structure responsible for hydrocarbon entrapment in the study area was a structural high which correspond to the three-way dip closure of NE-SW major normal fault (F1) and other normal fault of Asala Field. Middle Abu Roash “G” zone consist of sandstone was deposited as distributary river mouth bar and inter-distributary fine sandstone graded to siltstone with net reservoir thickness between (max. 18 ft. and min. 4 ft.), effective porosity reaches (max. 25%–min. 7%) at the mouth bar facies and the inter-distributary fine sandstone and siltstone, respectively, water saturation values ranging between (max. 48% and min. 30%), water saturation was controlled by structural and facies elements while effective porosity and shale volume were controlled mainly by facies distribution. Lower Abu Roash “G” consist of sandstone deposited at tidal flat environment with net reservoir thickness between (max. 34 ft. and min. 4 ft.), effective porosity reaches (max. 24%–min. 7%) at tidal creek sandstone facies and fine tidal flat sandstone, respectively. Water saturation values ranging between (max. 100% and min. 33%). The original oil in place (OOIP) estimated for the Abu Roash “G” zone is 13.308945 Million Stock Tank Barrel.
Figure 14. (a) Stratigraphic correlation for Lower A/R(G) member passing through AS-04, AS-27, AS-13 and AS-22 in the study area (A-A+). (b) Stratigraphic correlation for Lower A/R(G) member passing through AS-22, AS-19, AS-40 and AS-20 in the study area (A-A+).

Figure 15. Average effective porosity map for Lower Abu Roash "G" zone.
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Disclosure statement

No potential conflict of interest was reported by the authors.

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