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Research Article

GEOLOGY

Petrophysical Evaluation and Hydrocarbon Potentialities of the Abu Roash C Member of the Abu Roash Formation, Badr El Din-3 and Badr El Din-15 Oil Fields, Abu Gharadig Basin, Northern Western Desert, Egypt

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KEY WORDS

Petrophysical analysis, Abu Roash “C” Member, Reservoir characterization, Hydrocarbon potentiality, Badr El-Din Oil Fields.

ABSTRACT

The BED-3 and BED-15 oil fields are situated in the northwestern portion of the Abu-Gharadig sedimentary basin. The Basin is ENE-WSW-oriented, and ranges in age between the Late Jurassic and Early Cretaceous. The presence of sandstone streaks in the Abu Roash “C” Member of the Abu-Roash Formation, which has a relatively high resistivity signature in the electric logs in most wells within these fields, is the primary reason for investigating its petrophysical parameters in order to describe the main characteristics of these sands and to assess their ability for hydrocarbon accumulation as well as production. The aim of this study was completed based on information from well log data from nine boreholes. The petrophysical evaluation of the BED3-8 well reveals approximately 87.4% oil saturation within the reservoir rock, whereas the hydrocarbon saturation of the other wells in BED-15 is estimated to vary between 56.1 and 78.8%. As a result, this study reveals that the BED-3 and BED-15 oil fields have a high probability of producing hydrocarbons.

Introduction

The Abu-Gharadig sedimentary basin is the largest in the Egyptian Western Desert's northern part. In terms of hydrocarbon potential, it is deemed one of the utmost important basins **(Bayoumi and Lotfy 1989).** The study region is in the northwestern part of the Abu-Gharadig sedimentary basin and extends between latitudes 29° 47' to 29° 54' N and longitudes 27° 50' to 27° 58' E **(Fig.1).** The Abu-Gharadig sedimentary basin is ENE to WSW orientated, covering approximately 60 km width and 300 km long and representing 3% of the Egyptian Western Desert, the age of this basin ranges from the Late Jurassic to the Early Cretaceous Period **(EGPC, 1992)**. The main focus of the present study is to investigate the petrophysical parameters in the Abu Roash “C” sandstone Member in order to describe the main characteristics of these sands and estimate their ability to accumulate and produce hydrocarbons. To achieve the objective of this study, nine wells were chosen: BED-15 (1, 3, 7, 7A, 8, 9) wells for the BED-15 field and BED-3 (8, C9-A, C9-2) wells for the BED-3 field. All existing logs were used in this study, which included (Gamma-ray, Sonic, Neutron, Density and Resistivity logs).

GEOLOGICAL SETTING

Structural Features

The Abu-Gharadig sedimentary basin's dominant structural characteristics include NE to SW trends that divided the basin into structural features known as the Mubarak High, the Abu-Gharadig anticline, and the Mid Basin Arch from E to W. **(Meshref, 1990)**. Consistent with Bayoumi and Lotfy (1989), the Abu-Gharadig sedimentary basin was formed during the Late Jurassic as a result of the intrusion of a dolerite mantle bulge and deep-seated basaltic rock; this was related to the early stage of the Alpine Orogeny. The faults that dissected the basin run east-west, north-south, and WNW–ESE **(Guiraud *et al*., 2005; Bevan and Moustafa, 2012; Taha *et al*., 2022)**. The basin's seismic survey revealed three types of faults: strike-slip (right and left lateral), reverse, and normal faults. Normal faults are the most common; the Abu-Gharadig basin is impacted by 771 normal faults that trend east-west, west-northwest, and east–northeast **(Mahmoud *et al*., 2019; Taha *et al.*, 2022)**. The reverse faults are few and tend to run east-west and east–northeast. The strike-slip faults are the rarest. Small numbers of folds are then recognized in the basin **(Barakat and Nooh, 2017)**.

Stratigraphic Framework

The subsurface stratigraphic column of Egypt's North-Western Desert is thick enough to include the majority of the sedimentary succession from Precambrian basement rocks to Recent **(Moustafa, 2008; Barakat and Nooh, 2017; Taha *et al*., 2022) (Fig.2).** In general, the upper cretaceous succession of the North-Western Desert has been subdivided into three lithostratigraphic formations: Bahariya, Abu Roash, and Khoman or Apollonia Formation at the top, if the Khoman Formation is missing. In the Abu Gharadig basin, the average thickness of the Upper Cretaceous succession is nearly 2100m **(Schlumberger, 1995; Abdelmaksoud *et al*., 2019)**. The Abu Roash Formation is primarily made up of clastics and carbonates that alternate between transgressive and regressive phases. This formation has been further subdivided into seven lithostratigraphic members, which have been named from top to bottom as follows: (A to G). Members B, D, and F are relatively clean carbonates, whereas the other units contain varying amounts of detrital material (clastics with limestone). The main target unit in this work is the Abu Roash "C" Member (Turonian), which is primarily composed of sandstone, shale, and siltstone with a few limestone streaks and was formed in a restricted shallow marine shelf **(Labib, 1985)**.

MATERIALS AND METHODS

This research aims to assess the petrophysical characteristics and hydrocarbon potentiality of the Abu Roash “C” sandstone in Badr El Din-3 and Badr El Din-15 Oil Fields, Northern Western Desert, Egypt. To analyze this zone of interest and evaluate the vertical and lateral distributions of the petrophysical characteristics, a thorough well logging analysis was performed using various logging data for each well log. The analysis and interpretation of several types of well logs were used to assess the petrophysical parameters of the Abu Roash “C” sandstone Member. All petrophysical properties were calculated using Interactive Petrophysics (IP, V. 3.5). The analyses focused on shale volume, porosity, and water and hydrocarbon saturation. All of these characteristics are more significant in determining the petroleum potential of a reservoir. The following parameters were used to do the petrophysical evaluation for wells in BED-3: At 104.4°C and 24°C at the surface, a = 1, m (cementation exponent) = n (saturation exponent) = 2, Rw = 0.03 Ohm.m. Core samples were collected over the A/R″ C″ formation from wells BED 15-3, BED 15-7, and BED 3-8 and used in the study. The values of m and n in BED-15 were determined from the special core analysis, with a = 1, m = 2, and n = 1.85; Rw = 0.04 Ohm.m at wells BED 15-7 and BED 15-7A, and Rw= 0.07 Ohm.m at wells BED 15-1 and BED 15-3. During the initial production test of well BED 15-1, the reservoir temperature was measured to be 107.8°C at 3137 mss. The static surveys conducted in the new wells revealed that the reservoir temperature is 111.1°C.

Volume of shale (Vsh)

A gamma-ray log was used in this investigation to calculate the volume of shale by Eq. (1). The Abu Roash “C” units' accessible well logging data demonstrate high-level gamma-ray and neutron porosity log responses as identified against zones of high shale contents.

$$V_{shGR} = \frac{GR_{max} - GR_{log}}{GR_{max} - GR_{min}} \quad \textbf{(1)}$$

Porosity and water saturation (Sw)

The porosity can be determined using a shale correction and weighted average neutron density. Archie's equation [Eq. (2)] was used to compute water saturation.

$$S_w^n = \frac{R_w}{(\phi^m \times R_t)} \quad \textbf{(2)}$$

Hydrocarbon saturation (S_{hr})

The petroleum saturation is computed at a given temperature by Eq. (3): Hydrocarbon Saturation =

$$S_{hr} = 1 - S_W \qquad (3)$$

RESULTS AND DISCUSSION

Petrophysical properties of reservoir rocks

Table (1) outlines the pay averages per well of the Abu Roash "C" unit in the BED-3 and BED-15 fields. The average petrophysical characteristics of the Abu Roash "C" unit in specific wells in the BED-3 and BED-15 fields. According to the petrophysical property estimates for the selected wells, the shale content or volume (Vsh) characterization of the Abu Roash "C" unit sandstone in the BED-15 wells demonstrates a relatively little shale content with an average of 7%, a minimum of 6.5 %, and a maximum of 10%. The Abu Roash "C" unit sandstone in the BED-3 wells has an average shale ratio of 10%, with a minimum of 8.2 % and a maximum of 12 %. The Abu Roash "C" unit sandstone in the BED-3 wells has an average shale content of 10%, with a minimum of 8.2% and a maximum of 12%. The effective porosity (Φeff) interpretation of the Abu Roash "C" unit sandstone, on the other hand, shows a moderate value of 23% with a maximum of 32.6 % in the BED 15-7 well. In BED 3-8 wells, Abu Roash "C" unit sandstone has good porosity, averaging 20.8 %. The water saturation (Sw) averages 32%, with a maximum of 44% in the BED15-9 well. In the BED 3-8 well, the Abu Roash "C" unit sandstone has an average Sw of 12.6 %. The hydrocarbon saturation values in the BED-15 field are high, with an average of 67.7 %, with the lowest value of 56.1 % in the BED15-9 well and the highest of 78.8 % in the BED 15-3 well. Only the BED 3-8 well of the BED-3 field have a high hydrocarbon saturation value, with a value of 87.4 % in this research.

Hydrocarbon potential

Because petrophysical parameters collected from hole analysis are typically various laterally and vertically, two basic procedures have been done throughout the oil scenario investigation. The first stage is to investigate the lateral distribution or variation of petrophysical parameters in the area, which includes creating iso-parametric map of shale content, net pay, effective porosity, and oil saturation. The second stage is to determine the vertical distribution of the rock properties, which is accomplished using the petrophysical data log generated by the software approaches.

Lateral variations

A selection of iso-parametric maps could be used to investigate the lateral variation of petrophysical features. The study of these characteristics is critical in determining their lateral variation and the factors governing them, which may be structural control, stratigraphic control, or both.

Shale volume mapping

The shale volume is an essential petrophysical parameter that represents reservoir quality; low shale content often implies a good reservoir. **Fig. (3)** depicts the shale distribution in the Abu Roash "C" unit sandstone. It fluctuates between 6.5 to 10%

in the BED-15 field and reaches a maximum of 12 % in the BED 3-C9-A dry well.

Net pay mapping

A net pay map was developed to depict the lateral distribution alterations in the effective thickness (Heff %) of the studied rock beds. **Fig. (4)** depicts the net pay thickness distribution of the Abu Roash "C" unit sandstone. This reservoir has high net pay values, which are associated with the high hydrocarbon saturation values where the study area's primary depocenter is located; but, net pay values fall in other locations of the study area and vanish in the BED 3-C9-A and BED3-C9-2 wells. These differences point to a sedimentation slope generated from the depocenter to the other locations in the Abu Roash "C" unit.

Effective porosity distribution

The most significant petrophysical parameter in evaluating petroleum potential is effective porosity. Porosity improvement is greatly influenced by structural elements **(Attia *et al.,* 2015)**. **Fig. (5)** depicts the effective porosity distribution of the Abu Roash "C" unit sandstone. The maximum effective porosity value in the BED 15-7 well of the BED-15 field is 32.6 %. However, the highest porosity value from the BED-3 field in the BED 3-8 well is 20.8%.

Hydrocarbon saturation distribution

The primary goal of this effort is to determine petroleum saturation (1-Sw). It should be noted that determining petroleum saturation based on water saturation is a difficult petrophysical computation because numerous methodologies can be utilized to analyze Sw. These methods produce somewhat varied Sw values, which can result in significant variations in the original gas in place (OGIP) or the original oil in place (OOIP) volumes. The petroleum saturation distribution in the Abu Roash "C" unit sandstone is depicted in **Fig. (6)**. Petroleum saturation in the BED-15 field ranges between 56.1 and 78.8% and equals 87.4 % in the BED 3-8 well in the BED-3 field. A total of 11m of net pay sand was tested over the BED-3 field, with an average porosity of 20.8% and hydrocarbon saturation of 87.4 %, and it tested 2337 b/d oils of 42.2 OAPI and 2.215 MMscf/d gas through BED 3-8. As a result, the BED 3-8 region offers optimal reservoir potentiality according to the parameters established by **Amigun and Odoli (2013), Rider, (1986) and Shah *et al.*, (2017)**. While the Abu Roash "C" Member is not prospective through BED3-C9-1 and BED3-C9-2. In BED-15, net pay sand inside the Abu Roash "C" Member ranges from 5m to 21.04m, with an average porosity of 18% to 32.6%. In contrast, the hydrocarbon saturation ranged from 56.1 to 78.8% tested 3220 b/d oil with 36.4 OAPI and 0.663 MMscf/d gas through BED 15-3. The net-to-gross ratio (NTG) of the Abu Roash "C" Member as a prospective sandy reservoir describes the sandstone quality. The higher the NTG rating, the better the reservoir quality **(Al-Baldawi, 2014; Adelu *et al*., 2016)**.

Vertical variation setting

Litho-saturation analysis can detect the vertical distribution of lithology (shale content and matrix) and petrophysical parameters (porosity and also water and hydrocarbon saturation ratios) in boreholes and compare them. **Figs. (7& 8)** show litho-saturation cross-plots for the Abu Roash “C” unit's BED 15-1 and BED 3-C9-A wells in the BED-15 and BED-3 fields, respectively. According to existing core data and litho-saturation analyses, the Abu Roash “C” unit consists primarily of siltstone, shale, and sandstone with a few streaks of carbonate that formed within a restricted shallow marine shelf. The petrophysical data log of the Abu Roash “C” unit in the BED 15-1 well is depicted in **Fig. (7)**. This portion demonstrates that the lower part of the Abu Roash “C” unit is made up of sandstone with shale intercalations and acts as the main net pay internal reservoir in the majority of wells. The Vcl track indicated that the average shale volume in the net pay zone is 6.5%; however, the shale volume distribution is not comparable. The shale content decreases in the bottom portion, as it does in all net pay zones, then increases in the rest of the reservoir to as much as 34%. Furthermore, the porosity track shows that the average effective porosity for the lower section of the net pay zone is 17.3 %, while the whole net pay thickness is 20.7%. The average porosity of all reservoirs in the research area is 20.8%. Furthermore, the saturation track shows that the Sw decreases through the net pay zone and increases in the rest of the reservoir. The hydrocarbon potential increases in the lower portion due to a low shale ratio and decreases in the top section due to a high shale ratio.

Figure (8) depicts a non-prospective well with the smallest shale occurrence (average 12%) and maximum porosity (average 18%), as well as low-resistivity zone (average deep resistivity 2.05-Ohm.m) in the reservoir zone. A low-resistivity pay is typically identified by low readings for deep resistivity curves (generally 0.5-ohm.m to 5-ohm.m) or by low contrast in resistivity log responses caused by a variety of factors including mineralogy, micro porosity, and water salinity, as well as layer dip, thickness, and anisotropy. The low-contrast pay zone indicates a lack of deep resistivity contrast between pay sands and surrounding shale. As a result, distinguishing between pay and wet zones is difficult. Possible reasons for low-contrast or low-resistivity pay zones are mentioned in detail in **(Darling *et al.*, 1993)**.

CONCLUSIONS

Based on the results of core data and well logs, the petrophysical study results can be summarised in the following part;

Abu Roash “C” mainly consists of siltstone, shale, and sandstone intercalation with streaks of limestone. A total of 11m of net pay sand was tested over the BED-3 field, with an average porosity of 20.8% and hydrocarbon saturation of 87.4%, and production was tested at 2337 barrels per day (b/d) of oils of 42.2 OAPI and 2.215 million standard cubic feet per day (MMscf/d) of gas in well BED 3-8. As a result, the BED 3-8 region has the best reservoir potential. While the Abu Roash “C” Member is not prospective through BED3-C9-1 and BED3-C9-2. In BED-15, net pay sand inside the Abu Roash “C” Member ranges from 5m to 21.04m, with an average porosity of 18% to 32.6%. In contrast, the hydrocarbon saturation ranged from 56.1 to 78.8% tested 3220 b/d oil with 36.4 OAPI and 0.663 MMscf/d gas through BED 15-3. The net-to-gross ratio (NTG) of the Abu Roash “C” Member as a prospective sandy reservoir describes the sandstone quality. As a result, the Abu-Roash "C" sandstone in BED-15 has an excellent chance to produce hydrocarbons.

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Table1. Outlines the average petrophysical parameters of the Abu Roash "C" sandstone member in the studied wells

Well name	Net pay (m)	Shale volume (Vsh %)	Average porosity (%)	Water saturation (SW %)	Hydrocarbon saturation (Shr %)
BED15-1	**5**	**6.5**	**20.7**	**28.6**	**71.4**
BED15-3	**21.04**	**10**	**20.15**	**21.2**	**78.8**
BED15-7	**6**	**7**	**32.6**	**34**	**66**
BED15-7A	**16.59**	**7.3**	**30.2**	**32**	**68**
BED15-8	**6**	**7**	**18**	**34.3**	**65.7**
BED15-9	**5.93**	**10**	**20.5**	**43.9**	**56.1**
BED3-8	**11.2**	**8.2**	**20.8**	**12.6**	**87.4**
BED3-C9-A	**0**	**12**	**-**	**-**	**-**
BED3-C9-2	**0**	**11**	**-**	**-**	**-**

Fig.1: Location map of the study area (modified after Bakry and Eid, 1996).

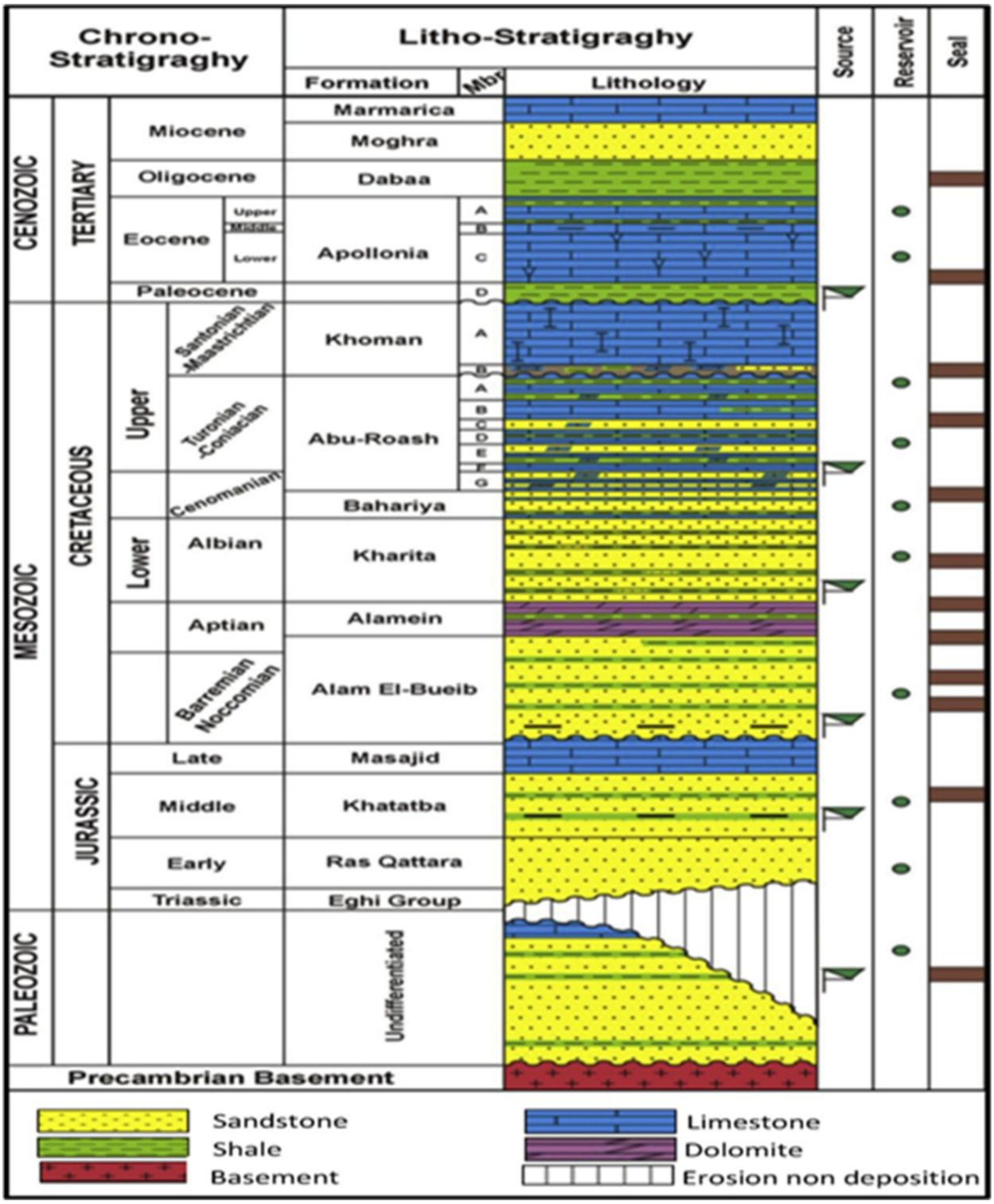

Fig.2: Generalized lithostratigraphic column of North of Western Desert of Egypt (Moustafa, 2008).

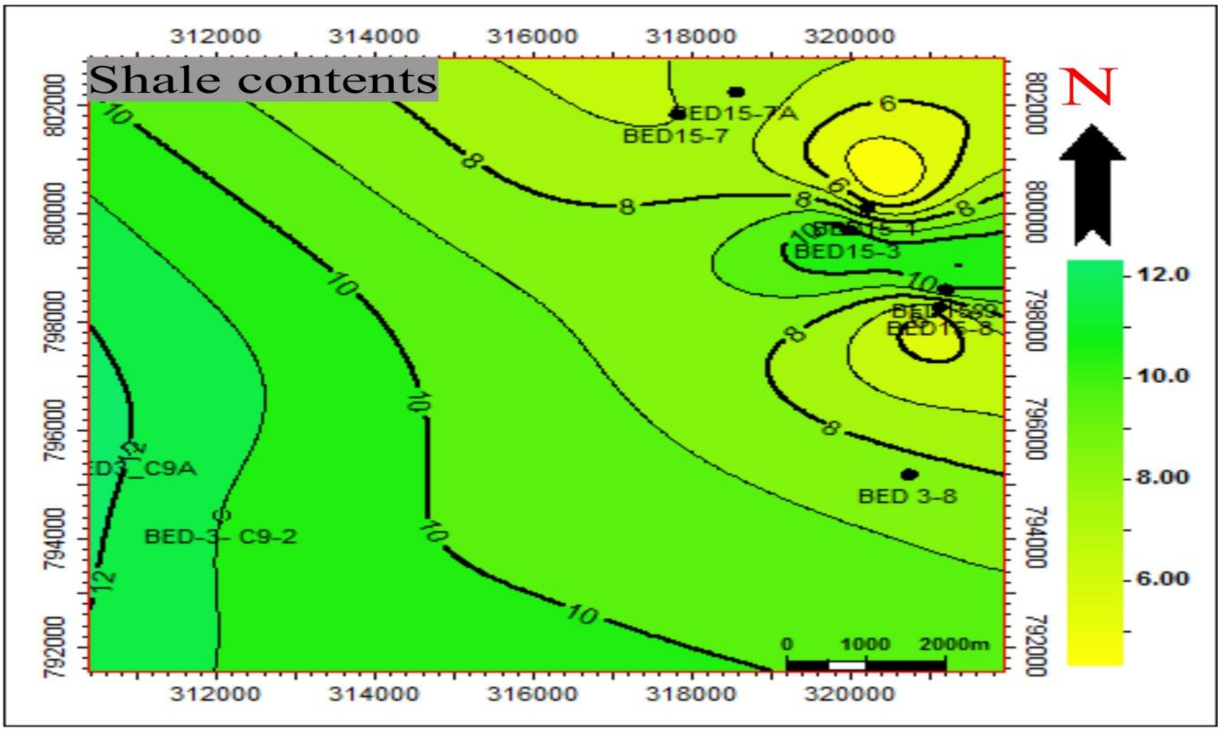

Fig. 3: Iso-parametric map (the Shale content map) of the Abu Roash "C" sandstone.

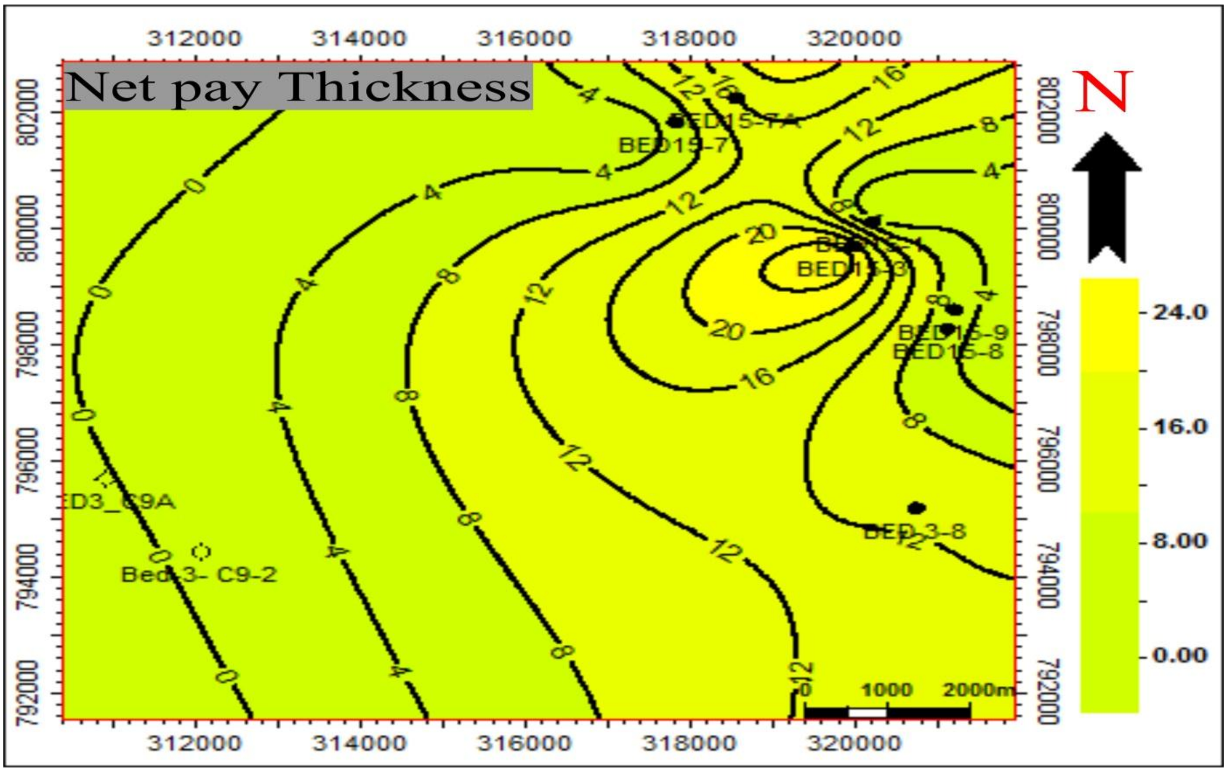

Fig. 4: Iso-parametric map (the net pay map) of the Abu Roash "C" sandstone.

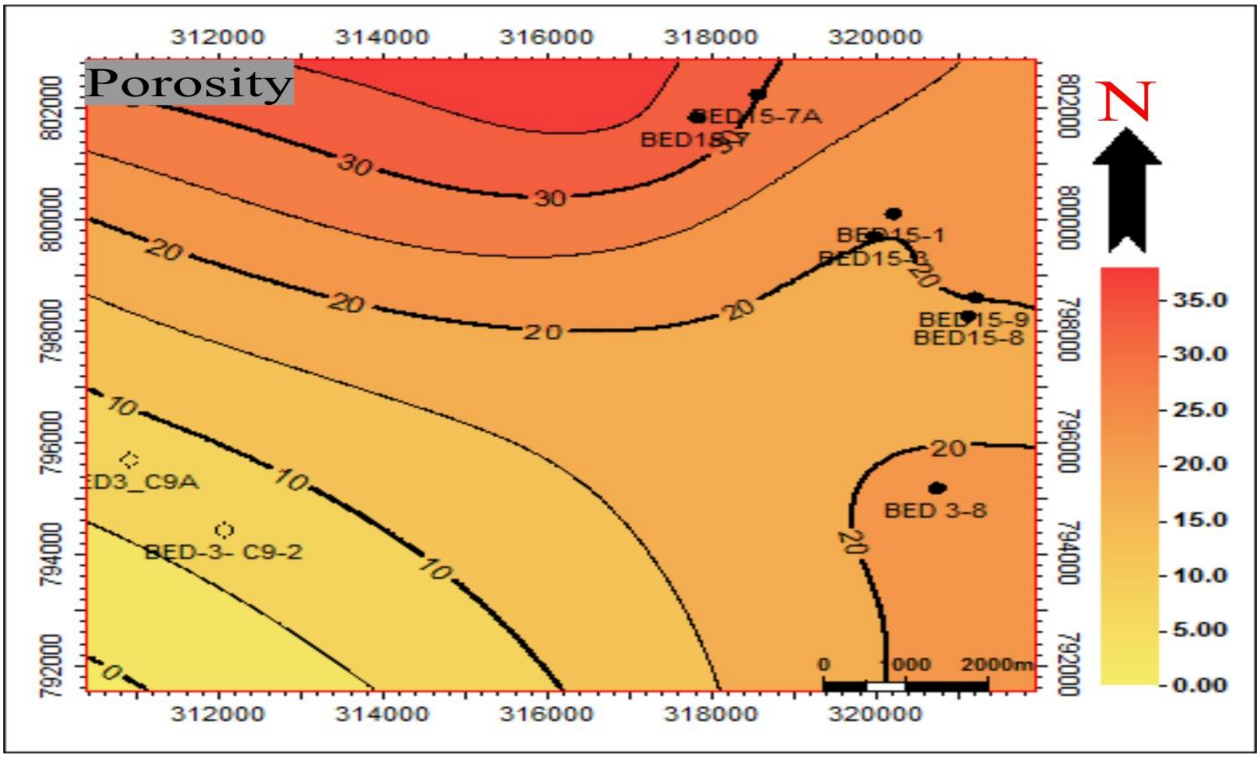

Fig. 5: Iso-parametric map (the porosity map) of the Abu Roash "C" sandstone.

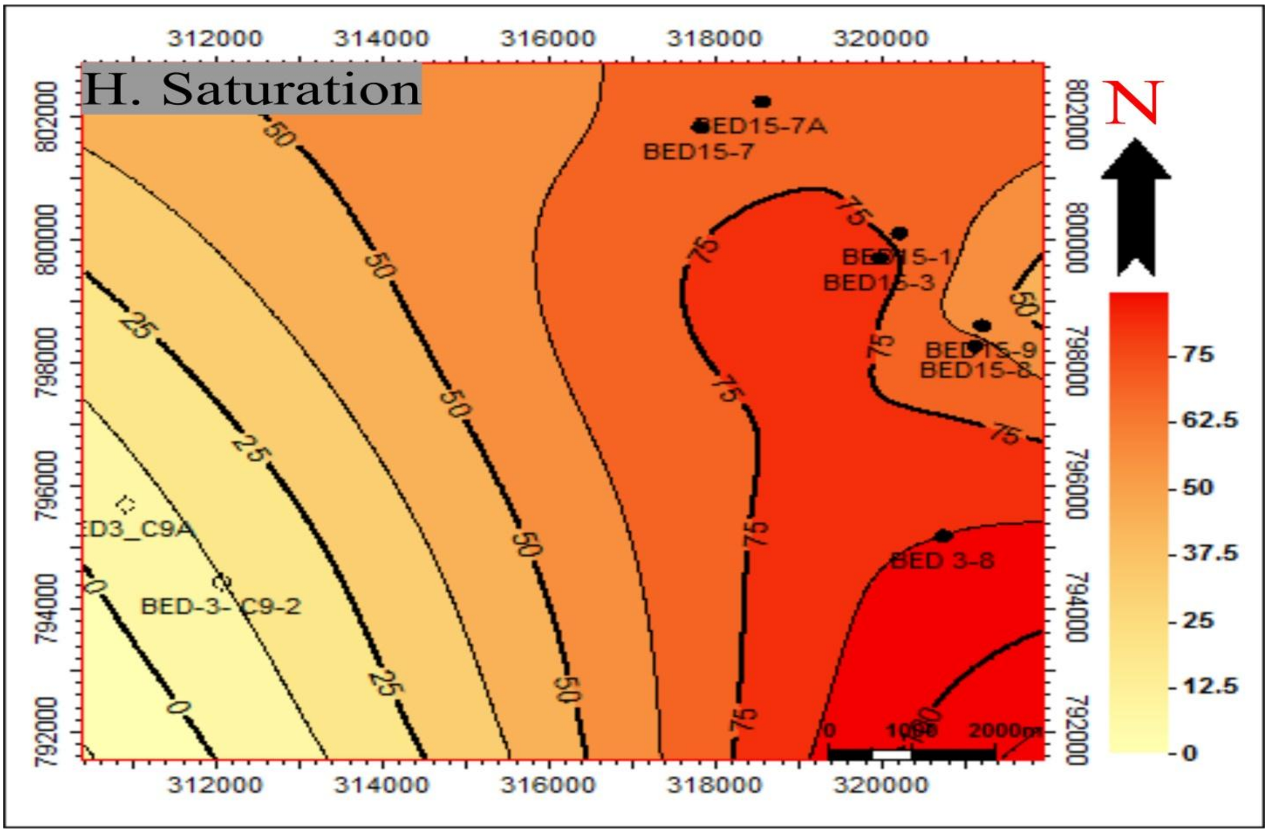

Fig. 6: Iso-parametric map (the hydrocarbon saturation map) of the Abu Roash "C" sandstone.

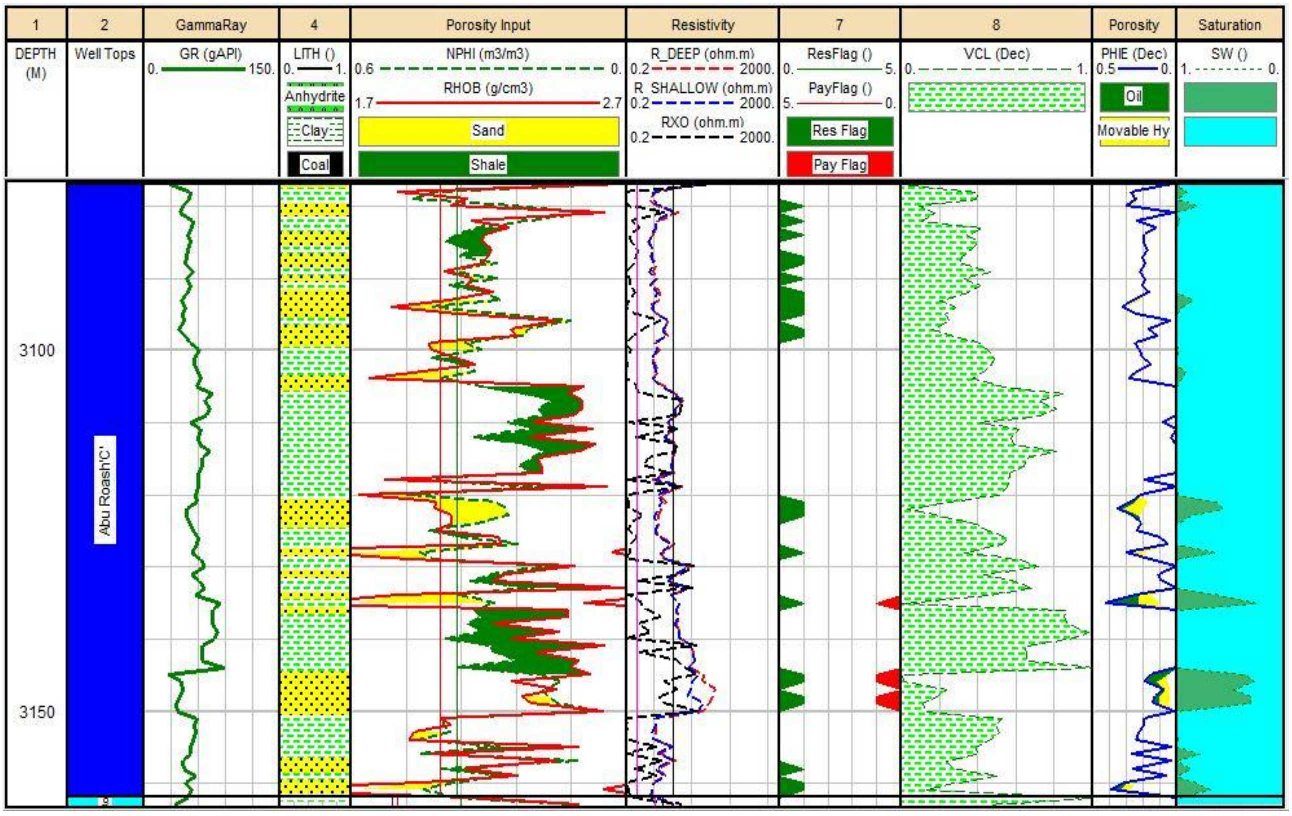

Fig. 7: Litho-saturation cross-plots of BED15-1 well.

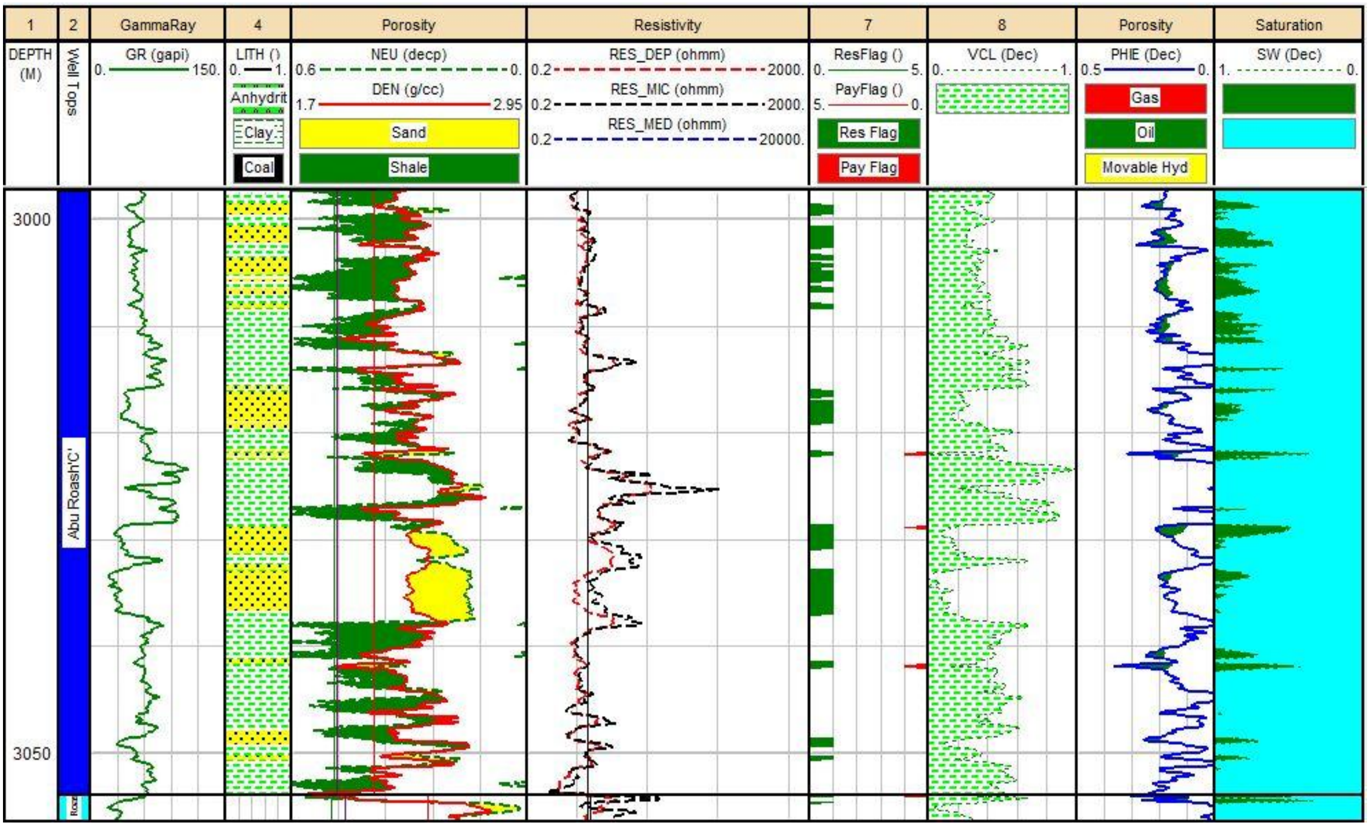

Fig. 8: Litho-saturation cross-plots BED3-C9-A well.

التقييم البتروفيزيقي وإحتمالية تواجد الهيدروكربون بعضو أبو رواش سي بتكوين أبو رواش بحقلي نفط بدرالدين ٣ وبدرالدين ١٥ ، بحوض أبوالغراديق ، شمال الصحراء الغربية ، مصر

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يقع حقلا النفط بدرالدين٣ وبدرالدين١٥ في الجزء الشمالي الغربي من حوض أبو الغراديج ، شمال الصحراء الغربية ، مصر، ويتراوح عمره بين أواخر العصر الجوراسي وأوائل العصر الطباشيري. تمتاز منطقة الدراسة بوجود طبقات رقيقة من الحجر الرملي في عضو أبو رواش سي في تكوين أبو رواش ، والتي لها بصمة مقاومة كهربية عالية نسبيًا في تسجيلات الأبار في معظم الآبار ضمن هذه الحقول ، وذلك هو السبب الرئيسي لفحص ودراسة معاملاته البتروفيزيقية من أجل وصف الخصائص الرئيسية لهذه الرمال وتقييم قدرتها على تراكم الهيدروكربونات وكذلك الإنتاج. تم الانتهاء من هذه الدراسة بناءً على معلومات من بيانات سجل الآبار من تسعة آبار. يكشف التقييم البتروفيزيقي لبئر بدر٣- ٨ عن نسبة تشبع بالهيدروكربون = ٨٧.٤٪ داخل صخر المكمن ، في حين يقدر تشبع الهيدروكربون للآبار الأخرى في حقل بدر١٥ بين ٥٦.١ و ٧٨.٨٪. نتيجة لذلك ، تكشف هذه الدراسة أن حقلي النفط بدرالدين٣ وبدرالدين١٥ لديهما احتمال كبير لإنتاج الهيدروكربونات.