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Facies Analysis and Depositional Environments: A Case Study of the Upper Cretaceous Abu Roash "C" Member in the Karama Southwestern Field, Western Desert, Egypt

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ABSTRACT

Abu Roach "C" Member (ARC Mbr) is an important hydrocarbon-bearing zone in the Karama SW oil Field. The geometry and spatial distribution of Abu Roash C sandstone reservoir is a vital objective in the area in order to follow and delineate the reservoir extension for further oil production and field development. This study aims to explain the conditions and factors affecting sedimentological characters of ARC Mbr in the form of a depositional model and facies analysis. The procedures have been conducted throughout the sedimentological analysis for mud logs, ditch cutting samples, electro-facies analysis for wire line logs, lithofacies, and routine core analysis of more than 30 feet of cored interval against the ARC Mbr reservoir, which is mainly composed of shale, siltstone, and carbonate with one reservoir unit of sandstone near the base. The mentioned reservoir was deposited in a near-shore environment with slightly high current energy and marine influx facies. Distributary channels of Abu Roash C sandstone are mainly oriented NE-SW, perpendicular to the ancient shoreline in the area. Abu Roash C sandstone reservoir is calculated to have an average of 25 feet of net pay with 22% porosity, 85% hydrocarbon saturation, and 15% water saturation.

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تحليل السحنات الصخرية وبيئات الترسيب: دراسة حالة طبقة أبو رواش "C" للعصر الكريتاسي العلوي بحقل كرامة الجنوب غربي، الصحراء الغربية، مصر

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الملخص

تعتبر طبقة أبو رواش C من اهم الطبقات الحاملة للبترول في حقل كرامة الجنوب غربي. يعد تحديد التوزيع المكاني والجغرافي لخزان أبو رواش C من الاهداف الحيوية في المنطقة وذلك لتتبع وتحديد الامتداد الافقي للخزان على مستوى منطقة التنمية؛ وتهدف هذه الدراسة إلى توضيح الظروف والعوامل التي أثرت على الخصائص الترسيبية لطبقة أبو رواش C في صورة نموذج ترسيبي وتحليل السحنات. اعتمدت هذه الدراسة على التحليل الترسيبي لسجلات الطفَل، العينات الصخرية المحفورة، تحليل السجلات الكهربية والتحليل الصخري لـ 30 قدم من العينات الصخرية اللبية المأخوذة من خزان ابو رواش C، المتكون بشكل أساسي من الحجر الطمبي والحجر الجيري مع طبقة صغيرة من خزان الحجر الرملي؛ ومن الواضح ان طبقة هذا الخزان قد ترسبت في بيئة قريبة من الشاطئ حيث يظهر بها بعض آثار الامواج والسحنات البحرية. تتميز القنوات الفرعية من الحجر الرملي لطبقة أبو رواش C باتجاهها شمال شرق–جنوب غرب حيث تكون عمودية على خط الشاطئ للمنطقة آنذاك. سجلت طبقة الخزان الرملي لأبو رواش C متوسط 25 قدما في الآبار المحفورة في المنطقة بمعدل مسامية 22%، 85% تشبع بالهيدروكربون، و15% بالمياه المصاحبة.

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Introduction

Northwestern Desert in Egypt has the most prolific petroleum province after the Red Sea region; it comprises a considerable number of significant petroleum basins (Abu El Naga, 1984), such as Alamein, Matruh- Shushan, Faghur, Gindi, and Abu Gharadig Basin, in which the study area exists. Abu Ghaardig basin is described as a main pull-apart basin in the area by several tectonic event stages, resulting in multi-stage structural regimes. Karama SW oil field is positioned in the most eastern trough of basin (Mubarak sub-basin) in East Bahariya concession, covering an area of about 6000 acres (20 km^2) (Fig. 1). The study area is located SW from Aqsa and Karama main oil fields and NE from Farasha oil field and E from Amana field and lied between latitudes 29° 32’ 00” N and 29° 34’ 00” N and longitudes 29° 27’ 00” E and 29° 30’ 00” E. Karama SW oil field is developed by 30 drilled wells (oil producer and water injector).

Data and Methodology

The current work uses numerous data, such as well logs, ditch cutting samples, seismic data, and core data reports, to build a depositional model and perform facies analysis for Abu Roash C Member in the Karama SW area. The well-log data, including GR, resistivity, log of neutron, and log of density, also mud log for selected wells (KSW-8, KSW-9, KSW-12and KSW-13), are used for petrophysical analysis. The core data for KSW-9 well and ditch cutting samples are used to conduct a facies scheme and depositional cyclicity for the Abu Roash C Member. Petrographic investigation is performed using thin-section reports and ditch-cutting samples.

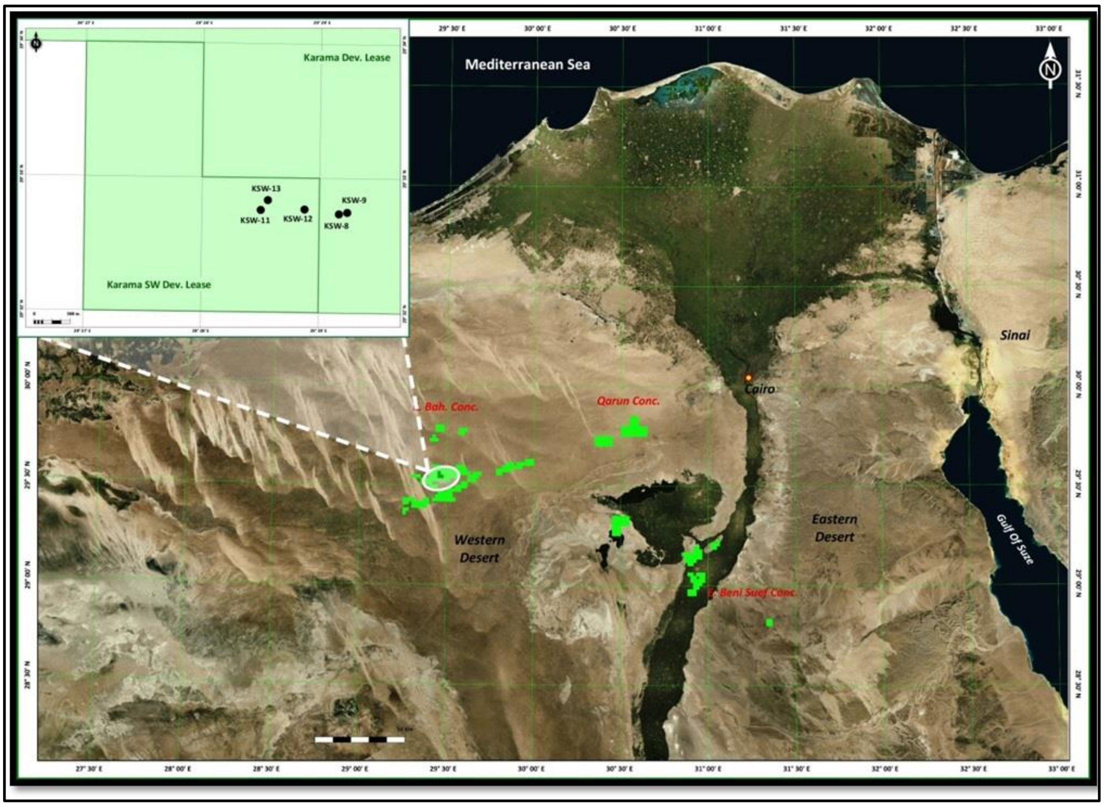

Fig. 1. Location Map of Karama SW oil field in East Bahariya Concession.

Geological Setting

Like most of the basins in the northwestern desert, the Abu Gharadig basin is a major structural basin in the Western Desert in Egypt with numerous hydrocarbon opportunity, such as carbonate of ARF (Upper Cretaceous) and shale of Khatatba (Jurassic), ARF and Khatatba represent a mature source rock; otherwise the reservoir rock is represented by sandstone of Bahariya, Kharita and Abu Roash Formation, also the cap rock and lateral by carbonate of Khoman and shale and carbonate of Abu Roash Formation (Schlumberger, 1995). There are several different types of traps in this basin including structural, stratigraphic, and combination types (Enayet, 2002), elongated or rounded, with a surface area that varies from a few square kilometers to hundreds of square kilometers. The reservoir pressure values are also variable, and the production rate is also variable due to the diverse lithology as porosity and permeability also fluid saturation and fluid characteristics. Karama SW field is related to Jurassic source rock (Khatatba Formation) although the carbonate of ARF is immature in the area. On other hand, Bahariya Formation and Abu Roash sandstone are the the main reservoirs which are sealed by the shale and carbonate of Abu Roash Formation; and the trap is of a structural style as shown in the interpreted seismic line (Fig. 2).

Tectonic and structural perspective

Abu Gharadig Basin was subjected to three main events that influenced its stratigraphy and structural style: a) Jurassic NE extension, b) Early Cretaceous NW extension and c) Late Cretaceous NE extension, these complex events had resulted in huge variety structural features in Abu Gharadig basin (Meshref et al., 1988). The geometry of the basin reflects the presence of fault series as E-W fault direction, also NE-SW and WNW-ESE fault directions (Moustafa, 2008).

Karama SW field locally shows almost the regional structural regime of the area around where the major fault trends are WNW-ESE and E-W and some synthetic and antithetic minor faults with the same trend. The structural closure in the field classified as a fault-related fold (roll-over anticline) in the down dip of the major normal fault WNW-ESE on the Abu Roash C Mbr as shown on the structure contour map (Fig. 3).

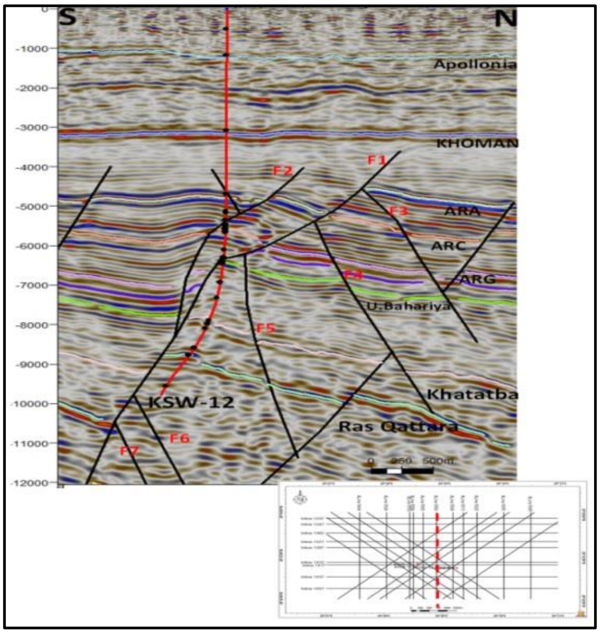

Fig. 2. N-S Seismic cross line 5581 among Karama SW (Interpreted inside Qarun Co.).

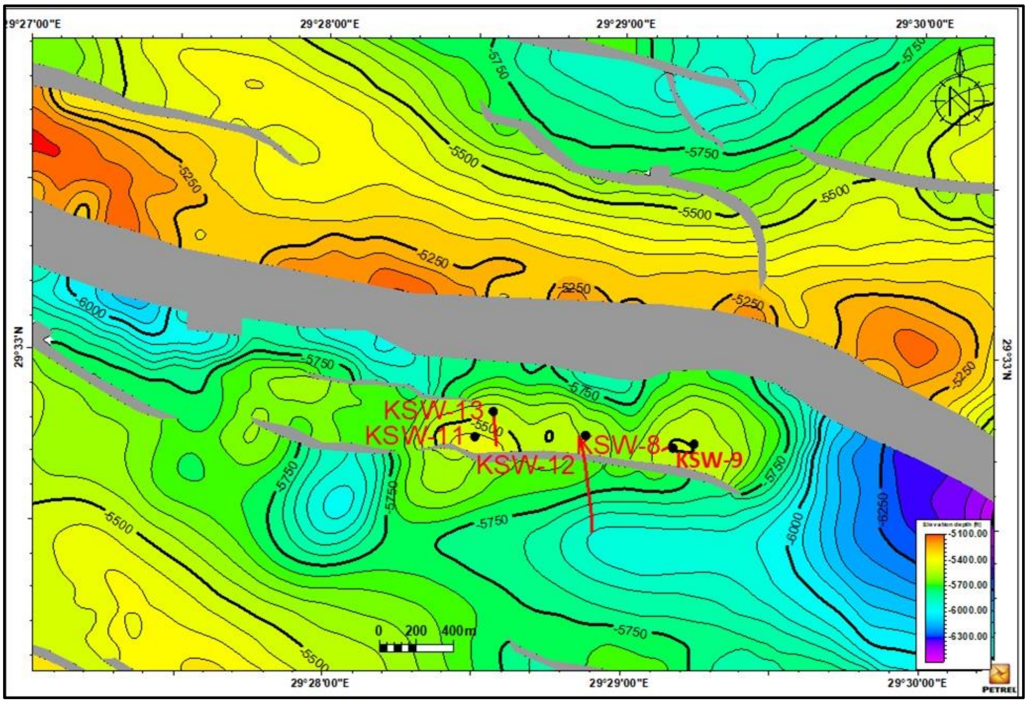

Fig. 3. Depth structure contour map for the top of Abu Roash "C"Member field (Karama model).

Stratigraphy

As a result of multi-stage and multi-scale tectonic events (Fig. 4a), local depocenters of various dimensions were developed with highly diversity of deposited strata ranging from deep marine carbonate, shallow marine intercalations, and fluvial systems (Said, 1990).

In the Karama SW block, the stratigraphic succession ranged in age from Precambrian to Miocene. The deepest penetrated formation was Ras Qattara sandstone overlaid by Jurassic Khatatba Formation, that considered the main source rock in the area; and then Aptian section (Alam El Bueib, Alamien and Dahab Formation) beneath Kharita and Bahariya formations, that considered the most common reservoir rock in Western Desert. Abu Roash Formation was deposited in the form of alternating cycles of clastic and non-clastic deposits, providing Abu Roash C, E, and G sandstones. All of these sands have potential reservoir quality, and are oil-bearing in several fields in Abu Gharadig Basin, Abu Roash F secondary source rock in the area, and Abu Roash A and D carbonate as a good top and lateral seal. Succession was continued by deposition of Khoman, Apollonia, Dabaa, and Moghra to the surface (Nio, 2010). The figure below shows the standard stratigraphic column in the Karama SW area (Fig. 4b).

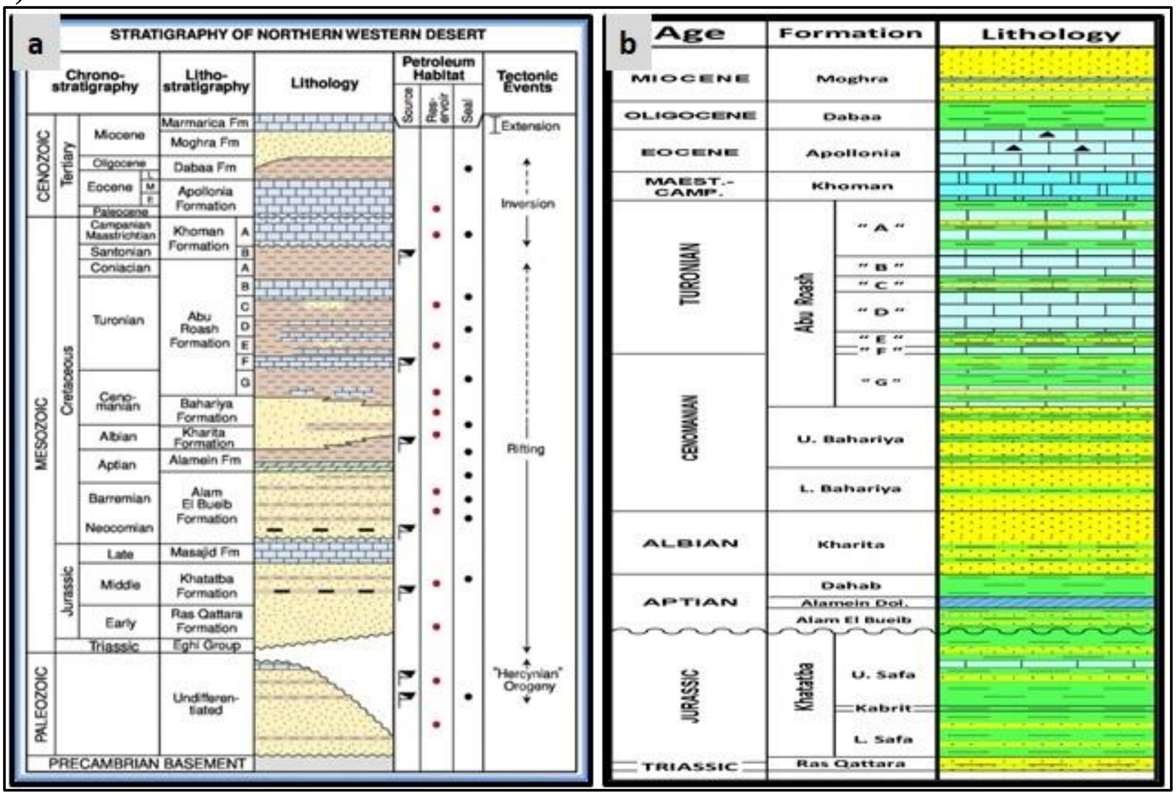

Fig. 4. (a) Generalized stratigraphic column of the North Western Desert of Egypt (modified after Schlumberger, 1984 and 1995; and EGPC, 1992), (b) Lithological section in Karama SW oil field.

Results and Discussion

Facies analysis

Based on the description of a total 30 feet cored interval (Figs. 5and6) and 220 feet ditch cuttings from KSW-9 well (Table 1), integrated with well logs interpretation, sedimentary facies are easily identified into four lithofacies types:

Lithofacies 'A' (***sandy facies***): It is composed of sandstone, siltstone, and shale. Quartz-arenite and litharenite sandstones, dominated by quartz grains with little feldspar, lithic fragments, and glauconite pellets (Pettijohn, 1975), mainly represent it. It is subdivided into three sub-facies according to the grain size; i.e., gravel, coarse, and fine sandstone facies.

Lithofacies 'B' (***silty facies***): It is represented by siltstone with mica, pyrite, and glauconite accessories.

Lithofacies 'C' (***clay facies***): It includes claystone and shale with micaceous, pyritic, and glauconitic pellets.

Lithofacies 'D' (***carbonate facies***): It is represented mainly by mudstone to wackestone texture carbonates, as Dunham classification (Dunham, 1962). Few fragments, especially in the middle part of the AR"C" Member, reflect the dolomitization effect on some of the wackestones. Most of the carbonate framework contains mainly molluscan and oolitic shell fragments.

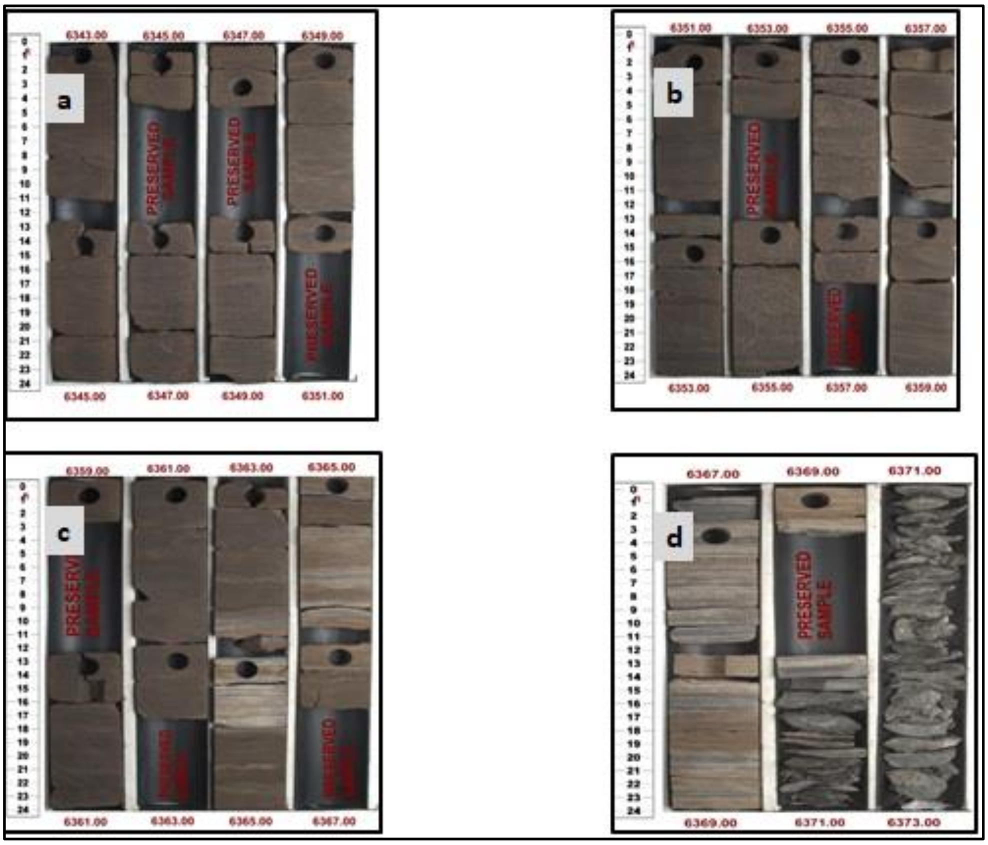

Fig. 5. Core image of KSW-9 Well. (a) Intervals (6343`-6351`), (b) Intervals (6351`-6359`), (C) Intervals (6359`-6367`), (d) Intervals (6359`-6367`).

Figure (6) below shows index photos for each facies (sandy, silty, clay and carbonate) as mentioned above.

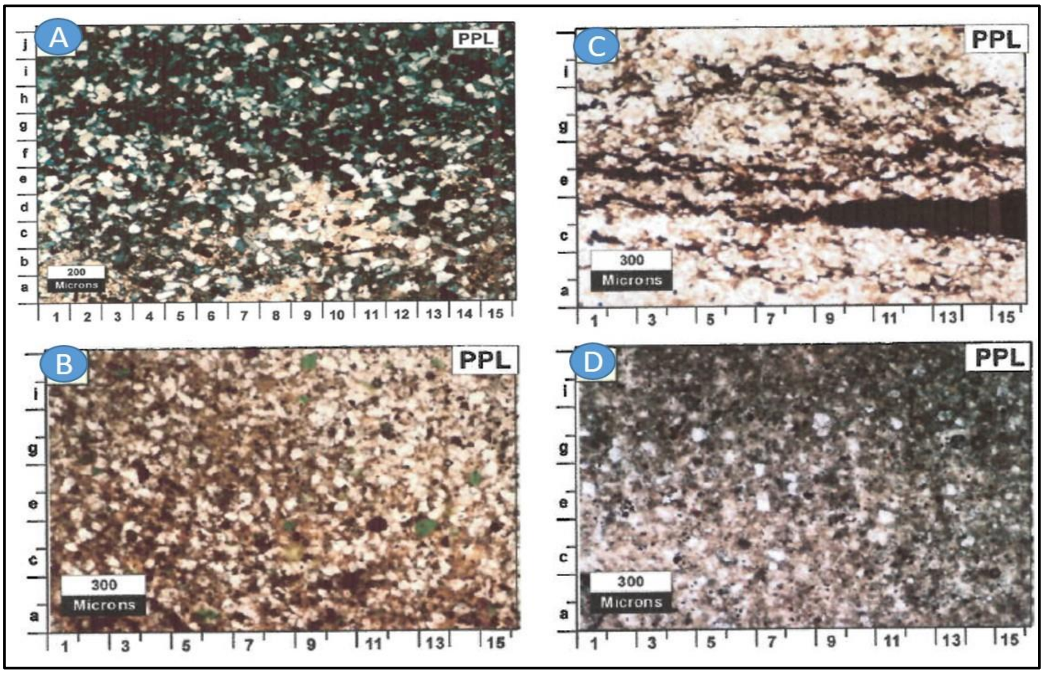

Fig. 6. Microscopic plate of different lithofacies in KSW well.

Pattern of depositional cyclicity

Along the sedimentary drilled section in Karama SW field, the different sedimentary cycles reflect the sea level fluctuation that resulted in differentiation of grain size whether fining and/or coarsening upward. Three main lithologic cycles are recognized for the interval from depth (6200' to 6440') from base to top as follow (Fig. 7).

Cycle-I: It is built-up of bioclastic limestone that represents the lower carbonate marker; i.e. Top AR 'D' from 6420`to 6380`, intercalated by shale and siltstone with highly glauconitic and fossiliferous sandstone facies.

Cycle-II: It is mainly composed of oil-saturated glauconitic sandstone showing fining upwards pattern as seen in the cored interval in the well Karama SW-9.

Cycle-III: It is dominated by mixed shale and fine-grained sandstone interbred by carbonate.

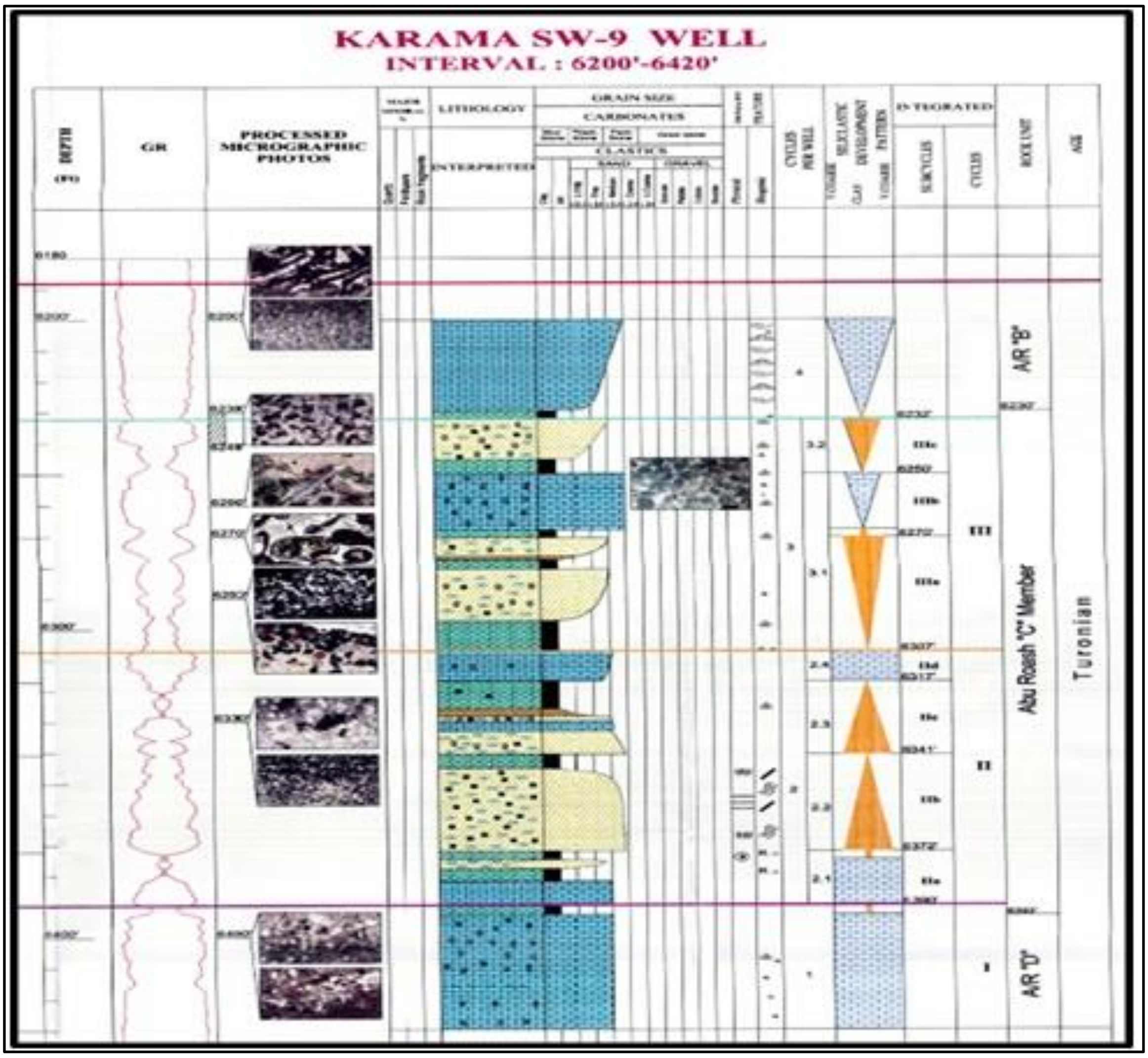

Fig. 7. Sedimentary cycles of KSW-9 ditch cuttings plotted among the KSW-9 well.

Petrography

Petrographic examination is carried out on eleven samples to highlight the main mineral components, textural aspects, diagenetic features, and pore type geometry (Fig. 8). It illustrates that the majority is glauconitic quartz-arenite and argillaceous glauconitic litharenite, which are texturally mature to sub-mature with some accessory minerals such as calcite, pyrite, and iron-oxides.

Argillaceous matrix exists in considerable amounts in the bioturbated sandstone samples. Glauconite is also recorded as either pellets or oxidized brown forms. Most of the quartz grains are monocrystalline, angular to sub-angular, with some rounded shapes. Feldspar grains are recorded in rare amounts, especially those with high argillaceous content. The feldspar fragments are partly altered, and fresh plagioclase and microcline. Calcite cement is not common and is found in a patchy distribution in some samples, where quartz grain corrosion is observed. In some samples, poikilotopic calcite cement is recorded with a displative growth habitat. The rock framework gets an open-packed texture. Little amorphous silica cement is recorded, filling some intergranular spaces, and is affected by partial aggrading neomorphism.

Table 1: Karama SW-9 Well Core summary description.

Sample No.	Depth (ft)	Lithological description and remarks	
1	6343	S. S	Lt gy,vf- f g, w srtd, m cmtd,sil cmt, arg lam, carb mtr.
2	6344	S. S	ltgy, f g, w srtd, m cmtd,sil cmt.
3	6345	S. S	ltgy, f g, w srtd, m cmtd,sil cmt, carb mtr,pbl.
4	6346	A. A	
5	6347	S. S	ltgy, f-m g, m srtd, m cmtd,sil cmt, sl glauc, carb mtr,pbl.
6	6348	A. A	--
7	6349	A. A	--
8	6350	S. S	ltgy, f-mg, w srtd, w cmtd,sil cmt, sl glauc,pbl.
9	6351	A. A	
10	6352	S. S	ltgy, f-mg, w srtd, w cmtd,sil cmt,sl calc, sl glauc,pbl.
11	6353	A. A	--
12	6354	A. A	--
13	6355	A. A	--
14	6356	A. A	--
15	6357	S. S	ltgy, f g, w srtd, m cmtd,sil cmt, carb mtr,sl glauc,pbl.
16	6358	A. A	--
17	6359	A. A	--
18	6360	A. A	--
19	6361	S. S	ltgy, f g, w srtd, m cmtd,sil cmt,hi carb mtr,sl glauc.
20	6362	S. S	ltgy, f g, w srtd, m cmtd,sil cmt, carb mtr, sl glauc.
21	6363	A. A	
22	6364	S. S	gy,vf- f g, w srtd, w cmtd,sil cmt, arg lam.
23	6365	A. A	
24	6366	S. S	gy,vf- f g, w srtd, w cmtd,sil cmt, sid lam, arg lam.
25	6367	S. S	gy,vf- f g, w srtd, w cmtd,sil cmt, arg lam,h plug fr.
26	6368	A. A	
27	6369	S. S	gy,vf- f g, w srtd, w cmtd,sil cmt, arg lam, carb mtr, calc i/p.
28	6370	Shale	--
29	6371	Shale	--
30	6372	Shale	--

Key

Lt: light **Gy:** grey **Vf**: very fine **Fg**: fine grained **i/p**: in part
w srtd: well sorted m **cmtd**: moderate cement **Sil**: siliceous **Arg**: argillaceous **Lam**: laminated **Carb**: carbonaceous **Pbl**: pebble **Glauc**: glauconitic **SS**: sandstone AA: as above

Facies association depositional environment

High-resolution facie discrimination is performed on Abu Roash “C” Member, resulting in vertical classification into different depositional systems.

Subtidal channel system: It’s recognized by small-scale planar and trough cross beds in addition to a little sense of herring bone style in coarse sandstone facies, with a fining upward pattern (bell-shaped gamma-ray; almost represented in all wells) (fig 8-a).

Tidal flat system: this association represents the base of ARC Mbr. It includes:

Sand flat encountering sandstone of high current energy with good quality reservoir properties with flaser bedding style (Fig. 8-b).

Mixed flat encountering wave rippled fine sandstone and siltstone that may represent a reservoir of low quality in addition to the mud drapes, which are deposited during slack tide periods (Fig. 8-c).,

Mud flat, including carbonate and muddy facies that characterized by shell hash in black mudstone (Fig. 8-d).

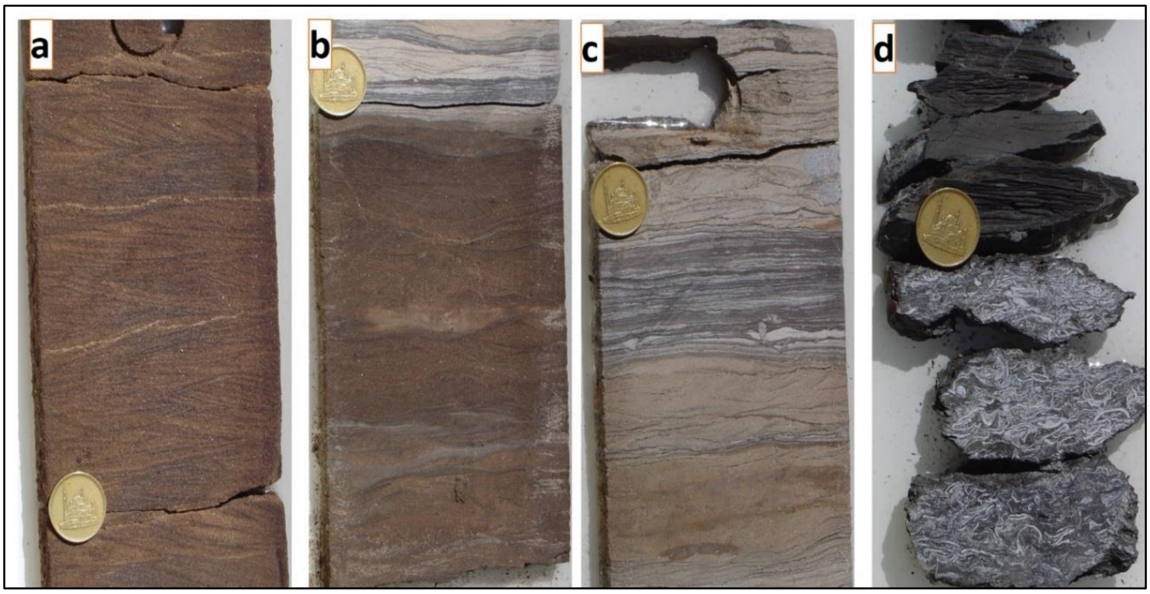

Fig. 8. Selected core photos of KSW-9 well core (Qarun Company core Report, 2004).

Regionally, Abu Roash C Member is referred to be of a marine tidal dominated environment with some associations of fluvial presence. Abu Roash C reservoir exhibits more than one depositional form, such as tidal channel, distributary channels, sand flat, and mixed flat (Fig. 9). Mouth bars also may be involved in Abu Roash C Member depositional styles (Salama et al., 2017).

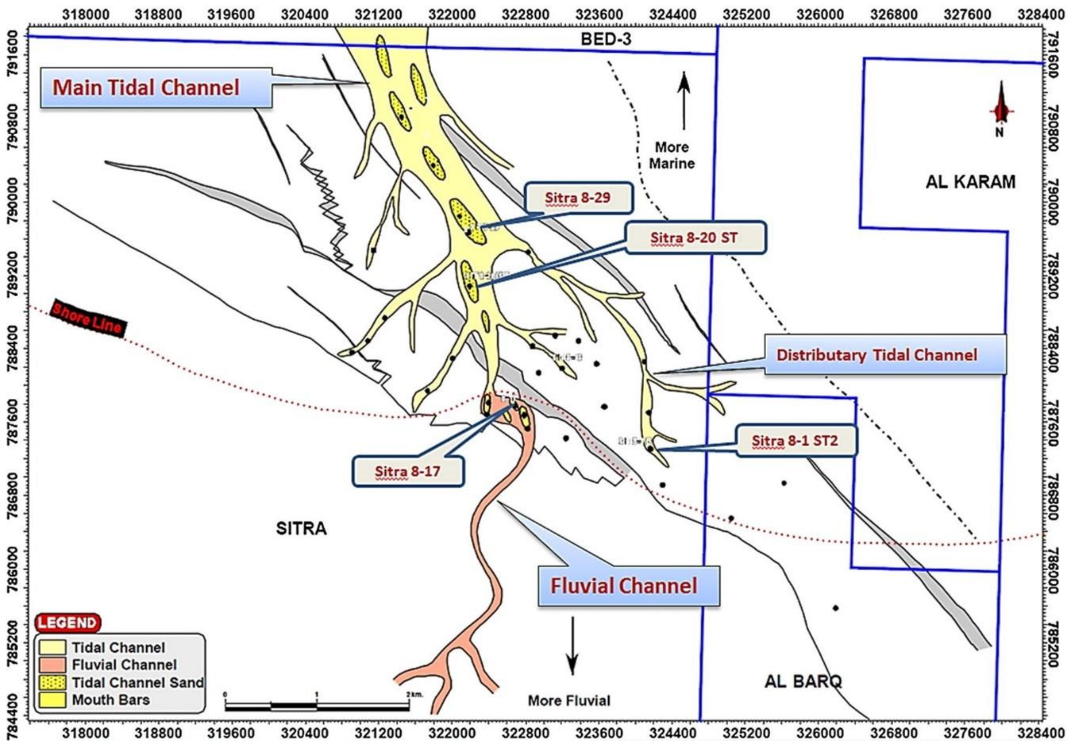

Fig. 9. Depositional model of Abu Roash C tidal channel (Salama et al., 2017).

Reservoir petrophysics

The well logging analysis in the KSW oil field has been carried out by Interactive Petrophysics Program (IP software) to evaluate the petrophysical parameters in ARC Member, and below is the result of the KSW-9 well log analysis (Fig. 10). Petrophysical assessment resulted in that Abu Roash “C” Member among the Karama SW oil field has calculated an average of 25 feet net pay, 22 % for the effective porosity, 2 % for the volume of shale, 85%

for hydrocarbon saturation, and 15% for water saturation. The best cut-offs applied in the KSW oil field are indicated from production history in the area, which showed the matched cut-off porosity of 12 % and clay volume of 30% and the water saturation ranges from 55 to 45%.

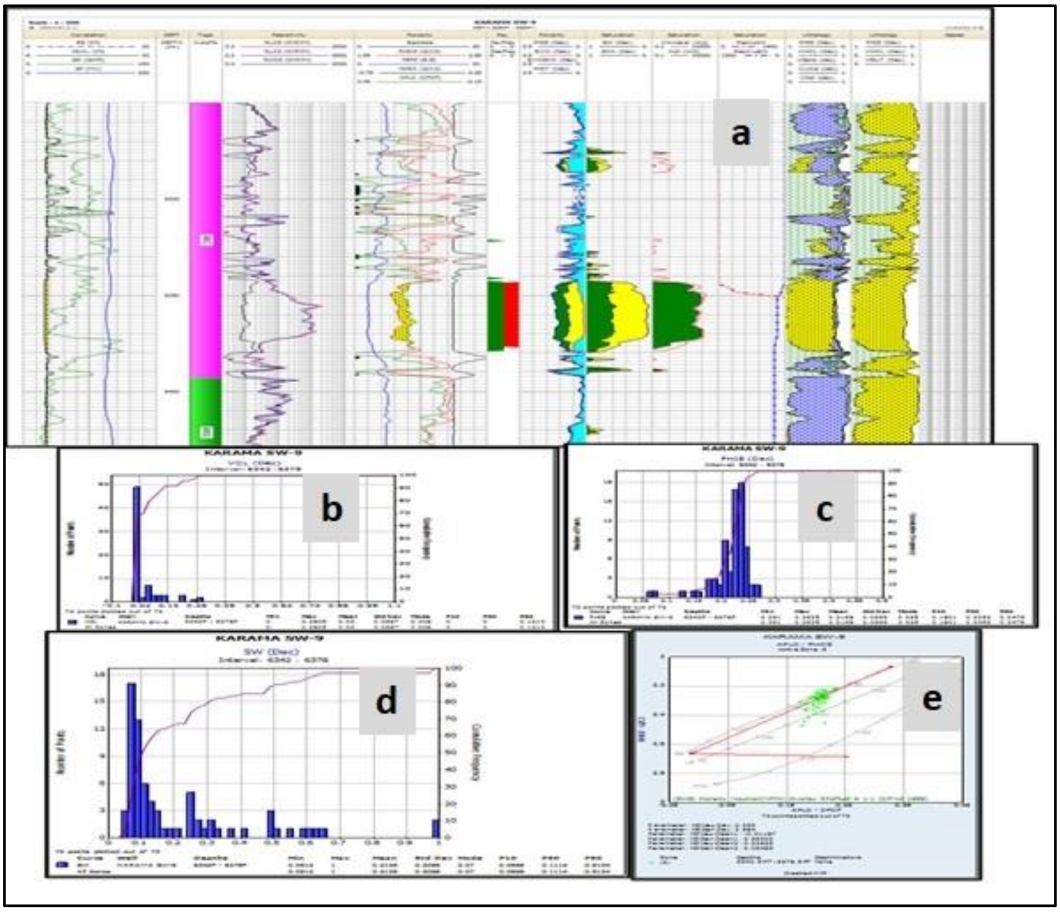

Fig. 10. The well logging analysis results in the KSW-9 well. (a) Well log interpretation for ARC sand in KSW-9 well, (b) Vsh histogram in KSW-9 well, (C) Phie histogram in KSW-9 well, (d) SW histogram in KSW-9 well, (e) Neutron/density cross plot of the ARC Sand in KSW-9 well.

Conclusions

An integration between description of ditch and core samples, interpretation of wireline logs, petrophysical analysis, and petrography may be a suitable method for understanding facies heterogeneity of the reservoir and building a depositional environment model for Abu Roash “C” Member among the Karama SW oil field. Generally, the Karama SW structure is mapped as a four-way dip closure from the down-dip direction of the major fault (fault-related fold), and three-way dip closure from the up-dip direction of the major fault at the top of the ARC Mbr, where the oil was trapped in a roll-over anticline at the down side of the main fault. The selected wells in the Karama SW area were drilled in a sedimentary section ranging from the Jurassic Ras Qattara and Khatatba Formation to the Miocene Moghra Formation, and the Turonian Abu Roash C Member is the reservoir. Abu Roash C Member has four lithofacies (sand, silt, clay, and carbonate). The mineralogy stated that the main components are referred to as arenite, such as glauconitic, lithic, and argillaceous arenite, with some accessory minerals as calcite, pyrite, and iron oxides. The depositional systems of Abu Roash C Member are recognized by the presence of glauconite, wavy and flaser bedding, trough, planar, and some herring bone cross beds with finning upward style of grain size as a sub-tidal channel that represents the main reservoir sandstone and the tidal flat system of silty and muddy facies. Petrophysically, the reservoir is calculated to have 25 feet of net pay sandstone of porosity 22 %, 15% water saturation, and 2% volume of shale.

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