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RESERVOIR CHARACTERIZATION AND PETROLEUM GEOLOGY AT ESH EL MALLAHA FIELD, SOUTHERN GULF OF SUEZ, EGYPT

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ABSTRACT

Reservoir quality assessment, pointing to possible capacities for holding hydrocarbons, is crucial during exploration-phases of petroleum. This investigation closely examines the petrophysical properties of Nubia-Sandstone Formation upon performing well-log analysis of the available well-log data located at West Esh El Mallaha area, southern part of the Gulf of Suez, Egypt. It is an attempt to reveal the hydrocarbon potentialities within Paleozoic reservoirs of the area. Nubia Formation represents an important reservoir in the Gulf of Suez province with at least 15% of hydrocarbon production potential. Well-log analysis, in means of defining the petrophysical properties (shale-volume, porosity, and water-saturation), of Nubia intervals was an essential objective, in this study, to determine the reservoir quality and hydrocarbon potential capacity of reservoirs in the area. The petrophysical properties have been vertically and laterally illustrated to point out to the ultimate distribution of characteristics within the area. 1D-basin modeling approach was also performed, in this study, to retrieve the geohistory of the area confirming charging of hydrocarbons from intervals of source-prone rocks to reservoir-zones. It has been revealed that Nubia Formation is composed of sandstones interbedded with shales. It possesses a net pay reaching up to 50 feet (from lowest meaningful-value of 1 foot to highest value of 50 feet); with considerable effective porosities up to 20 %. It has been obvious that the southeastern-part of the area features good quality petrophysical characteristics capable of storing and transmitting hydrocarbons within Nubia Formation, leading to big discoveries, at the southern-part of the Gulf of Suez.

Keywords: Petrophysics; Petroleum Geology; Nubia Formation; Esh El Mallaha Field; Gulf of Suez

1. INTRODUCTION

The Gulf of Suez rifting was formed responding to the divergence between the Arabian and African plates upon the Lower Miocene which created lots of NW-SE oriented normal fault structures [1]. The area of the Gulf of Suez covers approximately 19,000 square kilometers and is counted the most important oil basin in the Middle East and Africa. More than eighty oilfields were discovered in the Gulf of Suez within targets ranging from Paleozoic to Recent [2,3]. The Gulf of Suez is divided into three main structural provinces relying on regional dips of tilted blocks; northern, central, and southern regions (Fig. 1). The northern and southern ones dip towards the southwest, whereas the central one possesses a northeast dip orientation. These main provinces are broadly separated by two northeast-oriented accommodation zones [4–6]. The syn-rift sandstones of the Miocene time in the Gulf of Suez represent about sixty percent of the basin's oil reserves (Fig. 2), while the remaining amount is mostly considered to be found within pre-rift sandstones of the Paleozoic Nubia Formation [7].

Nubia Formation is counted a pre-Ceneomanian sediment; ranging from Paleozoic to Early Cretaceous in age [8]. It rests on basement rocks and overlain, unconformably, by a considerable succession extending from Cenomainian to Eocene, in Gulf of Suez-Red

Sea region [9], counting approximately for seventeen percent of oil potentiality in the Gulf of Suez [10]. Nubia Formation met significance interest from many authors e.g. [11–15]. It is considered the highest-quality reservoirs in the Gulf of Suez [16].

The present study aims at describing and evaluating Nubia reservoir quality via a comprehensive well-log analysis, [17–25], of four wells adequately distributed within the area of West Esh El Mallaha, south Gulf of Suez-rift. Moreover, it addresses the hydrocarbon potential, with the aid of basin modeling approach, within the Paleozoic interval proposing guidance for future oilfield development plans in the area.

2. GEOLOGICAL SETTING

The area of study belongs to the southern part of the Gulf of Suez where pre-Miocene column; Thebes, Esna, Sudr, Matulla, Raha, and Nubia formations; is marked by reduction in thickness (approximately 1050 FT). Pre-Miocene column is overlain, unconformably, by clastic and evaporite deposits of Nukhul Formation which is overlain by a succession including Zeit, South Gharib, Belayim, Kareem, and Rudeis formations (Fig. 2). In the area of study, Nubia Formation directly overlies Precambrian basement rocks. Nubia Formation varies in lithofacies and thicknesses over the area [16]. In northern parts of Esh ElMallaha, Malha (Nubia) is missing where Raha Formation overlies Naqus Formation [26]. Malha (Nubia) Formation overlies basement rocks in Wadi Qena [27], and Ashrafi oilfield [28]. This change is related to subsidence, uplifting, supply of sediments and erosion [16]. Catuneanu et al., [29] stated that tectonics are unique referring to subsidence, and depositional systems filling basins, where structural mechanisms control the basin formation. So, tectonics would be taken in consideration while building depositional models of an area [16].

Deposition of Nubia represents fluvial sedimentation of continental system with increasing of relative sea level until deposition of Raha Formation [28,30]. Efforts reported for interpretation of Nubia paeloenvironments emphasize fluvio-deltaic deposition in which delineation of sediment extension is needed [16].

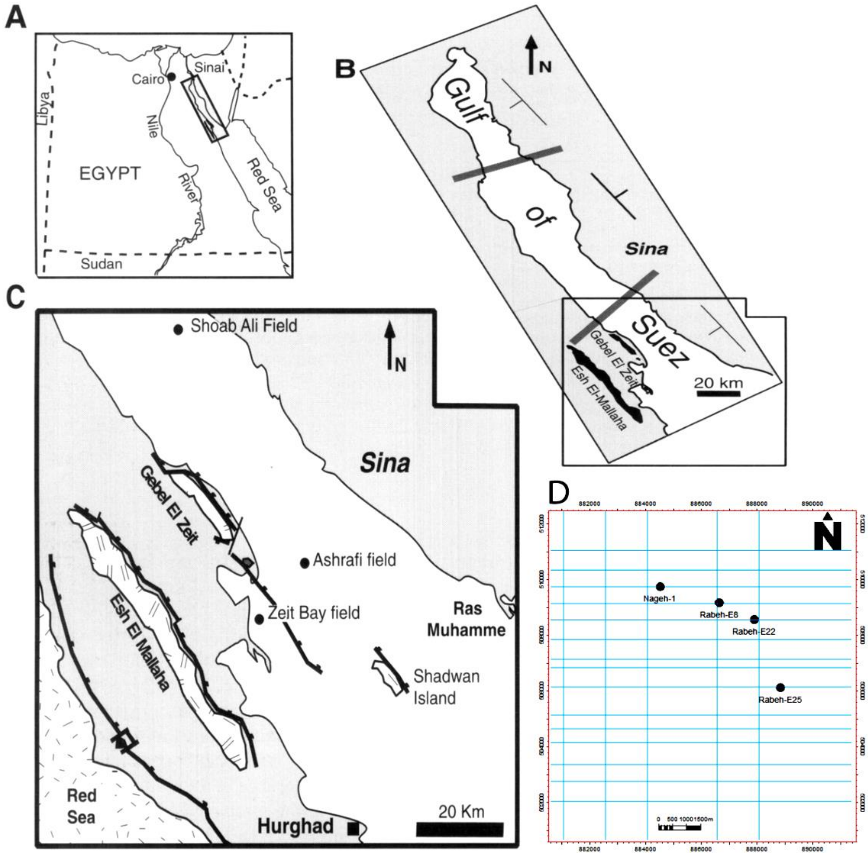

Fig. 1. A,B, C) Location map of the study area after Younes et al. [12] and D) dataset used.

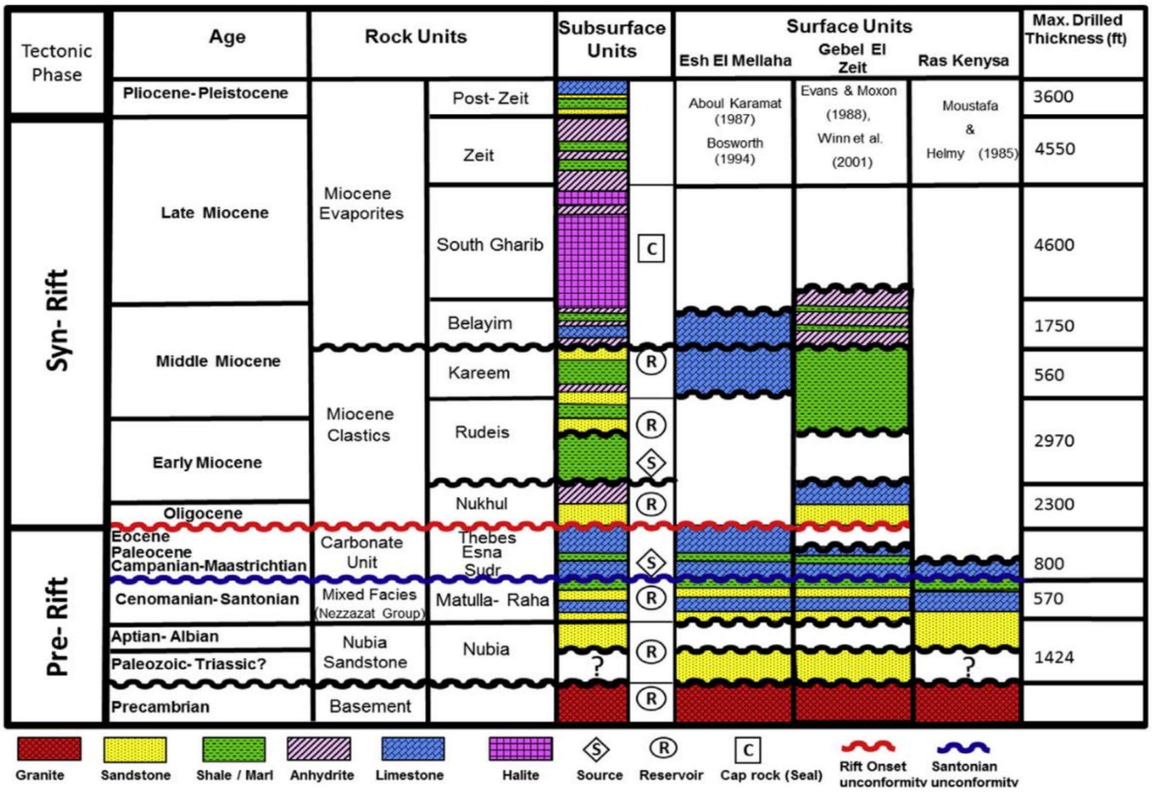

Fig. 2. Stratigraphic column of southern Gulf of Suez after Afifi et al. [31].

3. DATA AND METHODS

Using four wellbores; namely Nageh-1, Rabeh E-8, Rabeh E-22, and Rabeh E-25 (Fig. 1d); the petrophysical properties, reservoir quality, and petroleum potential of Paleozoic Nubia sandstone reservoir have been evaluated in West Esh El Mallaha area, southern part of the Gulf of Suez, Egypt. The datasets are composed of well logs such as gamma ray (GR), shallow resistivity (LLS), deep resistivity (LLD), sonic (DT), density (RHOB), and neutron (NPHI) logs. A comprehensive analytical assessment was conducted using computer software programtools like petrel and interactive petrophysics tools. The evaluation has targeted the shale volume, effective porosity, and water saturation calculation.

3.1 *Shale volume from GR*

Volume of shale has been calculated, considering consolidated and Tertiary rocks, applying the following equation [32]:

$$I_{GR} \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

where; I_{GR} is gamma ray index (corrected to formation shaliness (Vsh), considering older rocks[consolidated] or Tertiary [unconsolidated] rocks), GR_{log} is gamma ray reading, GR_{min} is minimum gamma ray for clean sand, GR_{max} is maximum gamma ray for shale.

3.2 *Porosity calculation*

Effective porosity (PHIE) has been calculated for shaly and clean zones using density and neutron logs [33,34] applying the following formula:

$$\phi_e N = \phi_t N - V_{sh} \times \phi_{sh} N \quad (2)$$

$$\emptyset_e D = \left[\frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}\right] - V_{sh}\left[\frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_f}\right] \quad (3)$$

where; $\emptyset_e N$ and $\emptyset_e D$ are effective porosities; $\emptyset_t N$ is total porosity; V_{sh} is shale content; $\emptyset_{sh} N$ is shale porosity acquired from neutron log; ρ_{ma} is matrix density; ρ_f is fluid density; ρ_{sh} is shale density; ρ_b is bulk density.

3.3 *Water saturation assessment*

Calculation of water saturation was performed considering clayey intervals applying Indonesian equation [35,36]:

$$S_w^{n/2} = \frac{\sqrt{\frac{1}{R_t}}}{\frac{V_{cl}^{\left[1-V_{cl}/2\right]}}{\sqrt{R_{cl}}} + \frac{\sqrt{\emptyset_e^m}}{\sqrt{a \times R_w}}} \quad (4)$$

where; S_w is water saturation in the uninvaded-zone, R_w is formation water resistivity, R_t is true resistivity of the uninvaded zone, V_{cl} is shale volume, R_{cl} is clay resistivity, $\emptyset_e$ is formation effective porosity, a: tortuosity factor, m: cementation exponent, and n: saturation exponent whose value varies from 1.8 to 2.5 but commonly equals 2.

3.4 *Basin modeling*

Basin modeling, retrieving burial and thermal maturation geohistories, has been performed, as a 1D modeling, after Hantschel and Kauerauf [37] and Dembicki Jr. [38].

Fig. 3. Lithological identification crossplots for Nubia Formation.

Information of depths, ages, and total organic carbon have been utilized as inputs for the 1D numerical basin model. Organic maturity was assessed overlying EASY%Ro model [39].

4. RESULTS AND DISCUSSIONS

4.1 *Lithological Identification cross-plots*

Identification of lithology is very important in the reservoir evaluation process. Logs, e.g. density, sonic, neutron, and gamma-ray, can aid as indicators for lithology. Accurate identification of porosity and lithology can be determined by cross-plotting the readings of two porosity logs, using the chart provided by the particular service company that ran the logs [40]. Figure (3) represents the lithological identification cross-plot of Nubia Formation; neutron-density (in the upper side) and the neutron-sonic (in the lower side). As is shown in this figure, Nubia Formation is mainly characterized by sandstones with interbeds of shale, siltstone, and limestone.

4.2 *Vertical variations of petrophysical characteristics*

The investigation of Nubia Formation, from the four studied wells of West Esh El Mallaha oilfield using different types of log analysis and methods, has been performed to give a better and more reliable estimates of petrophysical properties, applying appropriate property cutoffs, which could enhance our understanding and evaluation of the reservoir characters of Nubia Formation for more favorable economic situation for operating companies.

In Nageh-1 well (Fig. 4), Nubia Formation shows the ultimate petroleum potential within the area. The sand percentage increases in the central and southern parts where the shale content decreases. The Net pay equals 13 meters which is a considerable amount that deserves drilling. The effective porosity gives an average of 14 percent. The shale volume and water saturation count for 35 and 46 percent respectively.

In RE-8 well (Fig. 5), Nubia Formation shows no petroleum potential within the area. The sand percentage increases in the central and northern parts where the shale content decreases. The Net pay equals zero meters which is an amount to avoid. The effective porosity appears to be lower here in this well believed to be due to digenetic processes. The shale volume and water saturation count for a higher value pointing to a dry well.

In RE-22 well (Fig. 6), Nubia Formation

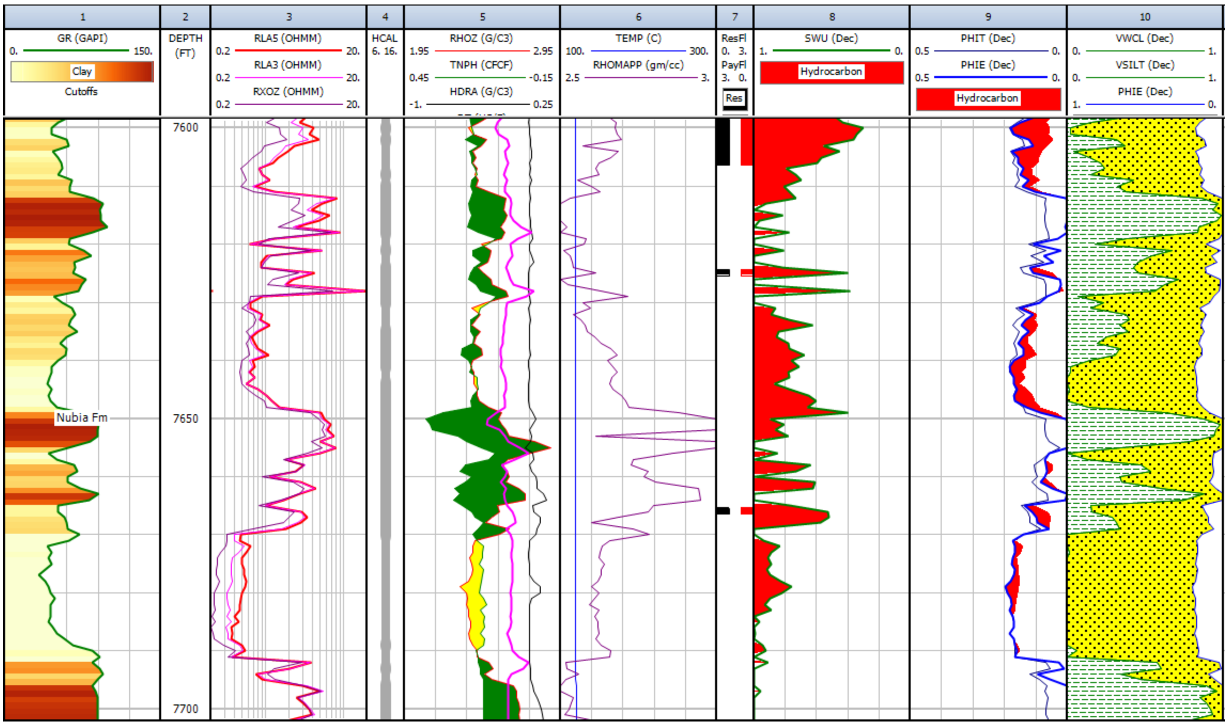

Fig. 4. Lithosaturation crossplot of Nageh-1 Well.

also shows no petroleum potential within the area. The sand percentage increases in the southern part where the shale content decreases. The Net pay equals zero meters which is an amount to avoid while considering drilling. The effective porosity reveals a lower value here in this well also might be due to digenetic processes. The shale volume and water saturation show a higher value pointing to a dry well.

In RE-25 well (Fig. 7), Nubia Formation shows the ultimate petroleum potential within the area. The sand percentage increases in the central and southern parts where the shale content decreases. The Net pay equals 50 meters which is a huge amount that deserves drilling. The effective porosity gives an average value of 20 percent. The shale volume and water saturation count for 11 and 39 percent respectively.

4.3 *Lateral variations of petrophysical characteristics*

The petrophysical characteristics of Paleozoic Nubia Formation, extracted from well-log analysis, have been shown in Table 1.

Figure (8) shows the petrophysical properties within Nubia Formation. The pattern

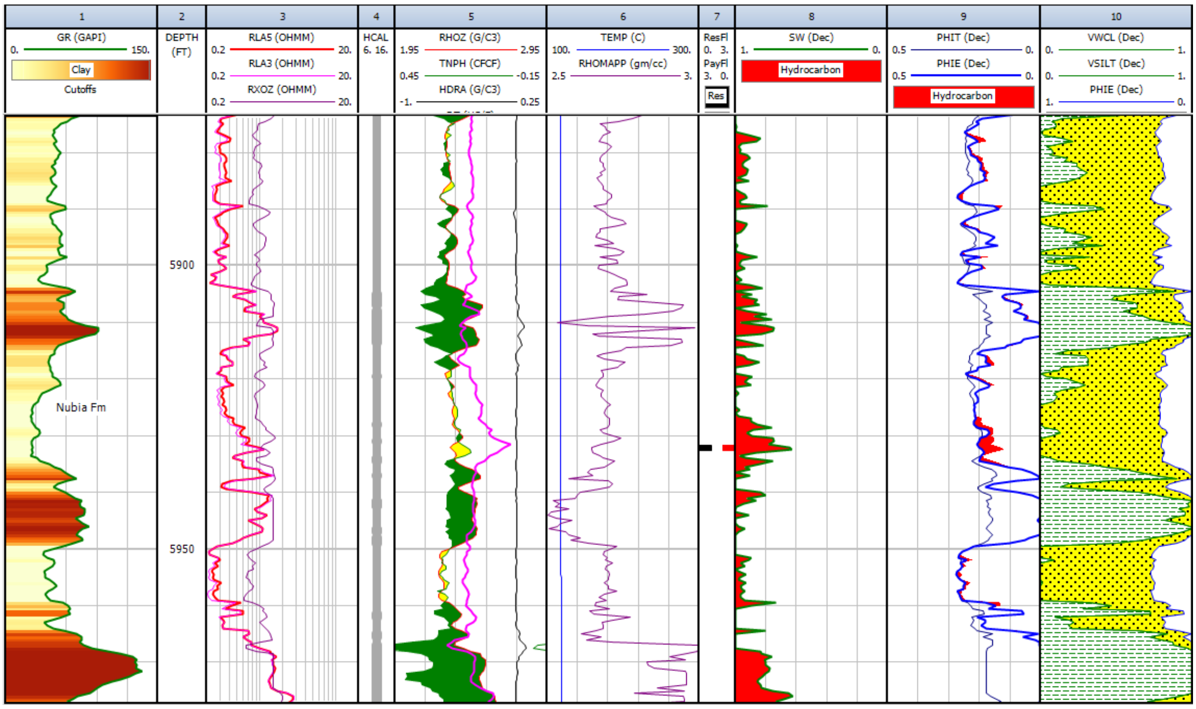

Fig. 5. Lithosaturation crossplot of RE-8 Well.

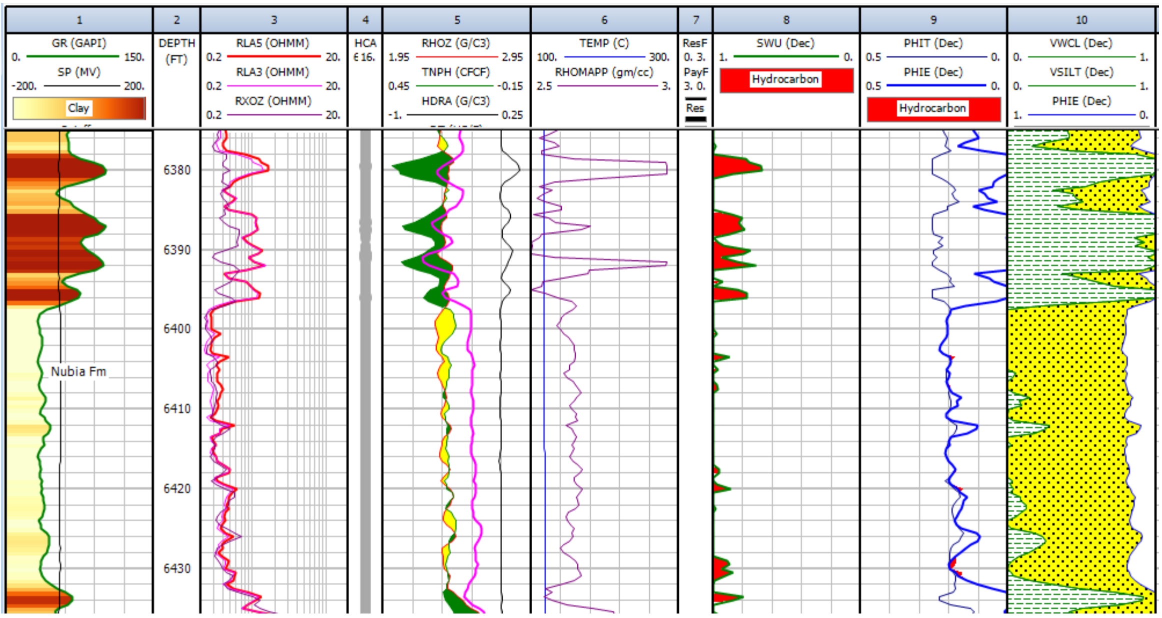

Fig. 6. Lithosaturation crossplot of RE-22 Well.

of distribution indicates that the hydrocarbon potential of Nubia Formation is mainly concentrated towards the southeastern part of the area away from the northeastern part where Nubia Formation shows insufficient properties for better reservoir quality. The effective porosity and net pay increase toward the southeastern part while water saturation and shale volume increase towards the northeastern part. As is shown in this figure the net pay is between 0 m in Rabeh East-22 and 50 m in Rabeh East-25 wells, respectively. The effective porosity occurrences are observed within the range of 10-20 %. The shale content is in the range of 11-23 %. The water saturation is observed in the range of 39-100 %.

4.4 *1D-basin modeling*

The one-dimensional basin modeling performed in this study (Fig. 9) shows a dynamic evolution of the basin, controlled by 3 stages of subsidence that surely affected the burial and thermal maturation of the sedimentary basin. One stage, at the Miocene time, was dominated by a very high rate of subsidence with a rapid rate of burial the led to the present-day thickness of Rudeis, Kareem, and South Garib formations. The other stages, at the rest of times, were characterized by a moderate to low rate of burial that led to thinner intervals of the respective units. In this investigation, it has been clear that Nubia shales are in the peak of oil generation. The oil window (0.7-1) was at the Lower Pliocene (5.25 Ma). Expulsion of hydrocarbons at Early Pliocene, that was happened after the entrapment at Oligo-Miocene Clysmic rifting, absolutely confirms hydrocarbon charging from source rocks to reservoirs. Moreover, the thermal geohistory (Fig. 10) operated the study area shows the increase of temperatures with depths; revealing Nubia's thermal potential.

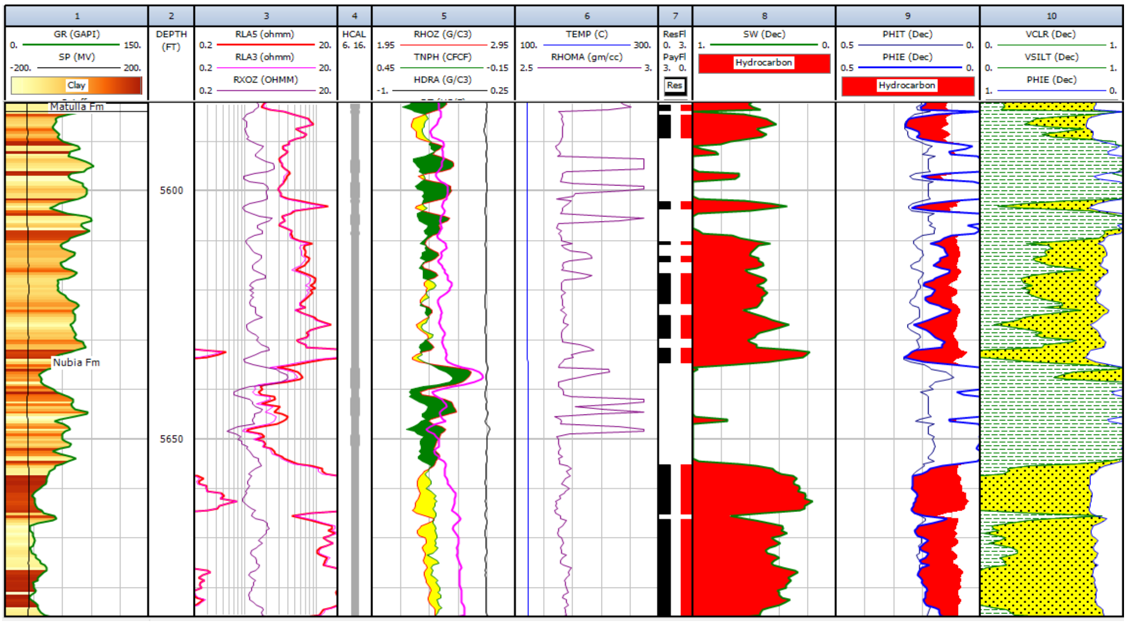

Fig. 7. Lithosaturation crossplot of RE-25 Well.

Table 1: Reservoir properties of Nubia Formation.

Well	Net Pay (FT)	PHIE (%)	Vsh (%)	Sw (%)
Nageh-1	13	17.9	14	46.4
Rabeh East-22	0	10	23	100
Rabeh East-8	1	11.1	22	93
Rabeh East-25	50	20	11	39

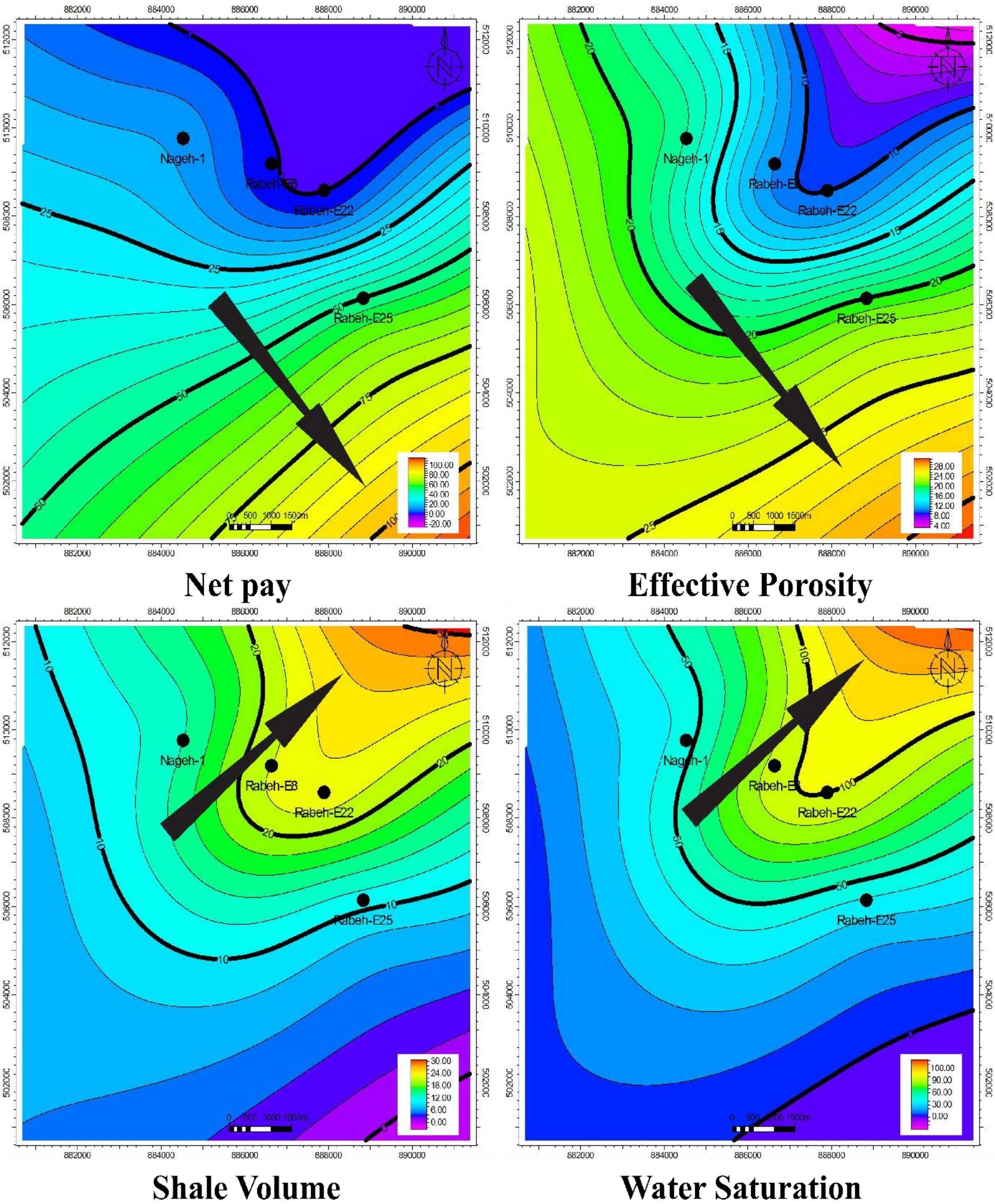

Fig. 8. Combined petrophysical distribution of reservoir characteristics for Nubia Formation.

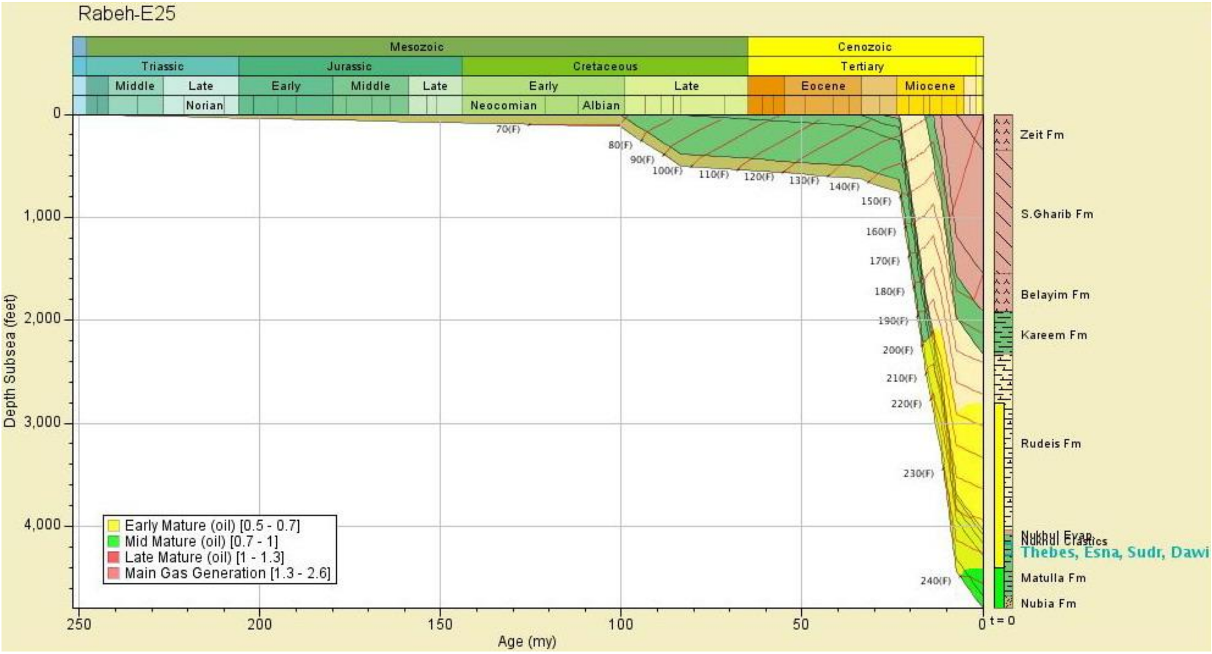

Fig. 9. 1D-basin modeling for RE-25 Well.

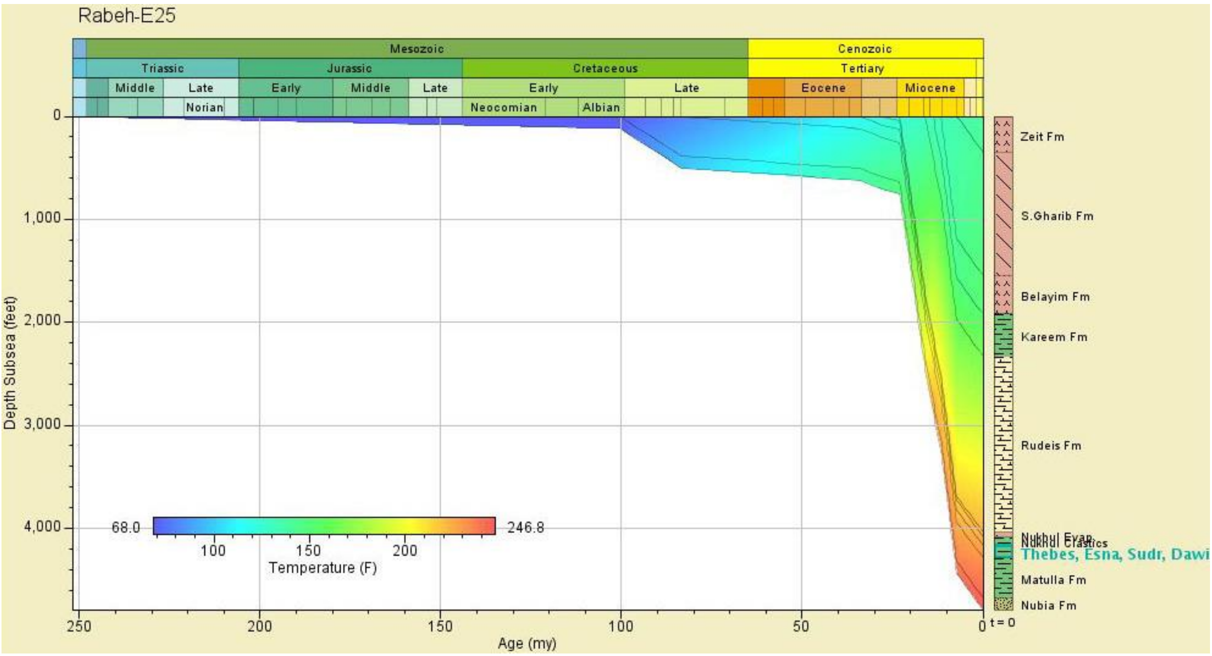

Fig. 10. Burial history with paleo-temperatures for RE-25 Well.

5. CONCLUSIONS

Petrophysical properties acquired from the well-log analysis process are chiefly varied vertically as litho-saturation cross plots and laterally as iso-parametric maps. The net-pay of Nubia Formation has the lowest value of 0 m in Rabeh East-22 well. The highest net pay value is 50 m in Rabeh East-25 well. The effective porosity ranges from 10 % to 20 % in Rabeh East-22 and Rabeh East-25 wells respectively. The shale content ranges from 11 % to 23 % at the same wells while the water saturation ranges from 39 % to 100 %. It is believed that the southeastern part of the area under investigation is the best area that can be considered as a very good hydrocarbon bearing zone; where new development wells can be drilled. Basin modeling performed in this study also confirms the hydrocarbon charging from source rocks to reservoir intervals upon reaching the oil peak stage.

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توصيف الخزان وجيولوجيا البترول بحقل عش الملاحة ، جنوب خليج السويس ، مصر

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قسم الجيولوجيا ، كلية العلوم ، جامعة الأزهر ، القاهرة ، مصر

الملخص:

يعد تقييم جودة الخزان ، بالإشارة إلى القدرات المحتملة لإحتجاز هيدروكربونات ، أمر بالغ الأهمية خلال مراحل إستكشاف البترول . تفحص جيدا هذه الدراسة الخصائص البتروفيزيائية لمتكون الحجر الرملى النوبى عبر عمل تحليل تسجيلات الآبار لبيانات الآبار المتاحة بمنطقة غرب عش الملاحة ، الجزء الجنوبى لحوض خليج السويس ، مصر . هذه الدراسة تكشف عن الإحتمالات الهيدروكربونية بخزانات الباليوزوى فى المنطقة . يمثل متكون النوبيه خزان هام فى منطقة خليج السويس بإحتمال إنتاجى للهيدروكربون لا يقل عن 15 بالمائة . تحليل تسجيلات الآبار لتحديد الخصائص البتروفيزيائية (المحتوى الطفلى ، المسامية ، التشبع المائى) لنطاقات النوبية كان الهدف الرئيسى لهذه الدراسة من أجل تحديد جودة الخزان وقدرته لأن يكون خزان ذو مكمن هيدروكربونى بالمنطقة . تم تمثيل الخصائص البتروفيزيائية رأسيا وأفقيا للإشارة إلى التوزيع الأقصى للخصائص البتروفيزيائية بالمنطقة . تم أيضا عمل نهج نمذجة الحوض إحادى البعد بهذه الدراسة لمعرفة التاريخ الجيولوجى بالمنطقة وتأكيد الإمداد بالهيدروكربونات من نطاقات صخور المصدر إلى نطاقات صخور الخزان. اتضح ان متكون النوبيه يحوى حجر رملى منفصل بنطاقات من الطفل . وهو يحوى سمك فعال يصل إلى 50 قدم (من أقل قيمة ذات مغزى وهى 1 قدم إلى أعلى قيمة وهى 50 قدم) ، ومسامية فعالة معتبرة تصل إلى 20 بالمائة . وجد بوضوح أن الجزء الجنوب الشرقى للمنطقة يملك خصائص بتروفيزيائية جيدة الجودة قادرة على تخزين والسماح بمرور الهيدروكربونات بمتكون النوبية ، تؤدى إلى استكشافات كبيرة بالجزء الجنوبى لمنطقة خليج السويس .