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Oil Potentialities of West Esh El-Mallaha Area, Southern Gulf of Suez as Deduced from Well Log Data Interpretation

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Abstract

West Esh El-Mallaha area (WEEM) is situated at the southern onshore part of Gulf of Suez and extended to about 52 km^2. The main objective of this article is to extract the most important petrophysical parameters of sedimentary sequence to evaluate and define the hydrocarbon potentiality in WEEM area using the available well log data suite. The lithology of each reservoir was detected by using a combination of different logs and different cross-plots including "Neutron-Density Cross-Plot" and" M-N Cross plot" respectively. Four wells were selected for the study (Tawoos-1, RE-4, RE-2 and RE-22) which represent most of the study area. The results of the interpretation indicated that pre-rift reservoirs lithology "Nubia, Matulla" are composed of coarse to fine-grained sandstone with fair to poor sorting. Shale inter-beds are common and some wells show a carbonate layer in the upper Nubia-A. The post-rift reservoir lithology "Nukhul Fm." is one of the chief reservoirs in our study area. Its main lithology is sandstone, limestone, dolomite and shale. The majority of points are distributed as carbonate (dolomite and limestone) with some of it back to the effect of clay minerals and calcareous cement. Different Cross Plots indicated the abundance of dolomite and limestone with minor occurrence of sandstone. The presence of high shale content in Rudies fm. shifted the point downward in M-N Cross plot. This reveals that the reservoir encountered is highly calcareous sandstone. WEEM area considered promising hydrocarbon potentiality, (especially Matulla consider oil producer zone from Tawoos-1 well, (Basement, Nubia, Matulla, and Nukhul clastics) consider oil producer zones from RE-2 well, (Matulla, Nubia) consider oil producer zone from R-4 well, and (Rudies) consider oil producer zone from RE-22 well.

Keywords: Well logging, Hydrocarbon potentiality, West Esh El-Mallaha, Gulf of Suez.

Introduction

The Gulf of Suez provenance is the greatest prospective oil basin in Egypt. It contains numerous oil reservoirs (Alsharhan, 2003; Radwan & Sen, 2021; Moustafa & Khalil, 2020; Radwan et al., 2021). The major petroleum traps and reservoirs in the Gulf of Suez oil fields are governed by structural fault blocks originating during the rifting period (Sultan, 2002; Chowdhary & Taha, 1987). The syn-rift Miocene clastics hold more than 60% of the total hydrocarbon reserve in the Gulf of Suez Basin and the rest is confined to the Nubia sandstones (Peijs et al., 2012).

Esh El-Mallaha area (WEEM) is located at the southern onshore part of the Gulf of Suez covering about 52 km^2 (Fig.1). The limestones of the Rudies and Thebes formations in addition to the sandstones of the Nubia, Matulla and Nukhul formations are the chief oil reservoirs in the Rabeh East Field (Sarhan, 2020; Sarhan, 2021a & b; Sarhan & Basal, 2019).

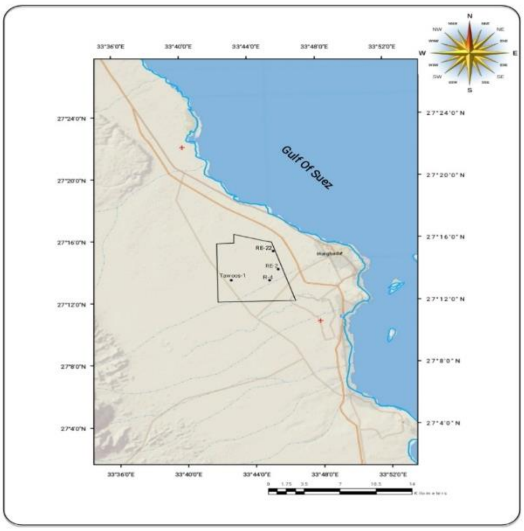

Fig. (1): Location map for the study area and the four studied wells.

In 1997 after drilling an exploratory well (Rabeh-1), Matulla (Lower Senonian) reservoir was declared commercial. This was followed by drilling other three wells (Rabeh East, RE-2, -3 and -4) to test Matulla and Nukhul (Lower Miocene) Formations. The encouraging results obtained from well RE-2 were the turning point in the exploration history of the area, where oil was found in different reservoirs.

The sedimentary succession of the Gulf of Suez area ranges from Precambrian to Holocene age and is divided into three major mega-sequences relative to the Miocene rift event; post-rift, syn-rift and pre-rift. Several units which vary in thickness and facies (Fig. 2). The stratigraphic succession of the WEEM concession can be summarized as follows:

Precambrian Basement Rocks

Precambrian rocks are the oldest exposed pre-rift rocks in the Suez rift. They are represented by granites, metamorphic rocks, and weathered crust on some uplifted faulted blocks. The uppermost section of the fractured basement yields the best reservoir potential, as a result of the enlargement of the fractures, their vertical interconnections, and the more intensive effects of diagenetic processes (Alsharhan, 2003). The weathered basement contains oil in RE-22 WELL. The top of the basement is best expressed by a sharp increase in densities and acoustic log from Nubia to Basement. This boundary corresponds to significant unconformity and sequence boundary.

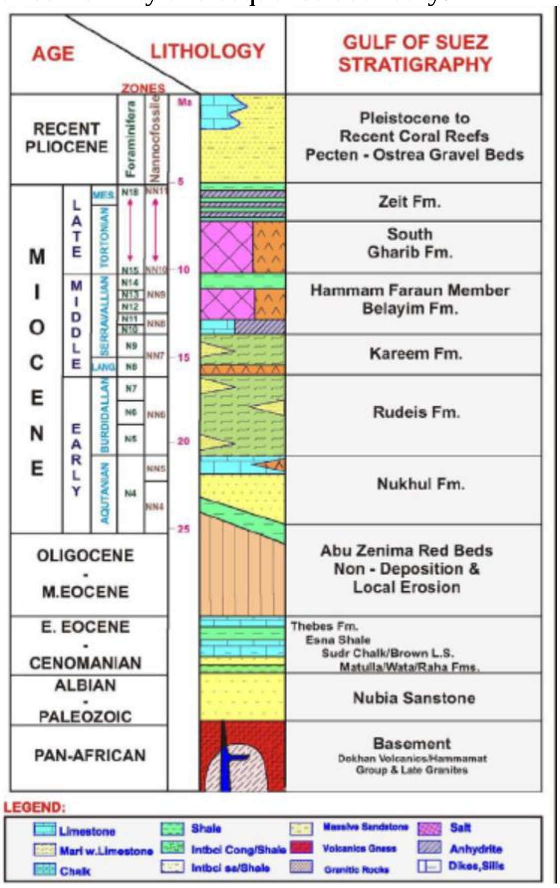

Fig. (2): Generalized stratigraphic succession of the southern Gulf of Suez (Modified after Bosworth, 1995).

Paleozoic Sequence

The Early Paleozoic Araba Formation is the equivalent name of Nubia D, Naqus Formation is the equivalent name of Nubia C, and Late Paleozoic Abu Dorba Formation is the equivalent name of Nubia B are not recorded in the west Esh El-Mallaha area (Hassan, 1967**)**.

Mesozoic sequence

Both of Triassic and the Jurassic are absent in the WEEM area as there is hiatus during the transgression of the Triassic and Jurassic seas. However, the Early Cretaceous section is represented by the Nubia (A) which is considered to be Aptian (early Cretaceous) based on pollen and spores data reports. Well known as an excellent reservoir rock in Rabeh, and Rabeh east fields. It is unconformably overlies the basement rock. It is mainly sandstone beds with shale and siltstone streaks. The quartizitic sandstone are relatively mature and resulted from multi-cycle reworking of basement rocks during the long hiatus of the Paleozoic. The size of sandstone is predominantly medium to coarse-grained. The thickness of the Nubia Sandstone Formation varies from 38 ft to 140ft. It is marked as clean with low Gamma ray (GR) log readings, a decrease in density (high porosity) and high acoustic logs readings.

The Late Cretaceous Raha and Wata formations are not documented in the study area. While, the Turonian-Coniacian Taref sandstone it is not differentiated in WEEM area while, it is widely distributed in the Esh El Mallaha area. The Matulla Formation (Coniacian -Santonian) is widely distributed in WEEM area from the north to south. It ranges in thickness from 450ft to 250ft. It is described as yellowish white, white and colorless sandstone, well sorted, fine to medium grained is tested as an excellent reservoir in Rabeh, and Rabeh East fields (from DST). It consists mainly of intercalation of gray, brownish gray shale and white, gray, yellow and green, glauconitic, pyritic sandstone with few interbeds of greenish, yellow limestone, yellowish gray mudstone, dolomitic at the top. The uppermost part of the formation is composed of sandy shale. The Campanian Brown limestone (Dawi Formation) is un-conformably overlies Matulla Formation. It is brown-dark brown, shaly and bituminous limestone. It is partially dolomitic containing dark brown chert. It is characterized by a high GR response on the electric log. However, the Maastrichtian, Sudr Formation (Sudr Chalk) overlies the argillaceous Brown limestone Formation. It is widely distributed in the study area. It is easily distinguished by its white color, with a contrast from the overlying green Esna Shale.

Cenozoic Sequence

The Paleocene (Esna Formation) is overlying unconformably Sudr Fm. and underlies the early Eocene Thebes Frm. It is represented by shale with high GR reading. The Early Eocene (Thebes Formation) displays significant thickness and lithology variations especially in the upper part, represented by limestone or cherty rocks. The limestones in some wells are massive and petrophysically interpreted as low-quality reservoir. It also reflects the deep erosion of the area due to pre-Miocene unconformity. The Brown limestone, Sudr, Esna, and Thebes Formations represent the most prolific source of rock in the Gulf of Suez especially in the southern part (Shahin & Shehab, 1984).

The Miocene rocks are subdivided into two litho-stratigraphic groups: The first one is (Gharandal Group) which it extends from the Early to Middle Miocene. It is continental to open marine sediments. The second one is (Ras Malab Group) which extends from Middle to Upper Miocene. It is predominantly evaporitic (Schlumberger, 1984). The Early Miocene Nukhul Formation has a total thickness that varies greatly from 80 ft to 360 ft. It is missed in several wells in the study area due to faulting, which implies as a result of the initial phase of rifting. The faulted intervals are recognized by correlation with offset wells. The Nukhul Formation is divided into sub formations, Nukhul clastic, and Nukhul evaporites. The Nukhul clastics is considered an oil reservoir in Rabeh and Rabeh East trends. It is dominated by medium-coarse grained sandstone, shale and sometimes with cherty limestone interbeds. On the other hand, the Nukhul evaporites represent a good seismic marker dominated by anhydrites and shale intercalations.

The Rudies Formation is unconformably overlies the Nukhul Formation and predominantly Globogrina marl that is inter-bedded with shale, limestone, medium to fine-grained, moderately to poorly sorted sandstone. Some sandstone intervals are considered oil bearing RE-22 Well. The thickness of the Rudies Formation ranges from 1120 ft to 3800 ft. The Kareem Formation represents the lowermost part of the Middle Miocene section. It is unconformably overlies Rudies Formation. It is principally composed of sandstones with shale and anhydrite interbeds. The sandstones are medium up to coarse-grained and poorly sorted. Thin evaporites and sand markers are picked at the base of the Kareem formation in WEEM Area.

The Middle Miocene (Ras Malab Group) is divided into the following formations arranged from base to top; Belayim Formation, South Gharib Formation and Zeit Formation.

The South Gharib Formation is represented by anhydrites at the base and top and massive salts in the central part. However, Zeit Formation is represented by rapid intercalations of anhydrite and shale. The boundary between South Gharib and Zeit Formations is very clear.

The present study aims to perform the petrophysical evaluation for the available well log data of four wells (RE-2, R-4, RE-22 and Tawoos-1) drilled in the West Esh El-Mallaha area. This appraisal will be helpful for the extra petroleum exploration process in West Esh El-Mallaha and the surroundings at the southern Gulf of Suez basin.

Data and Implemented Technique

The presented article is based on interpretation of well log data available in four wells (Tawoos-1, R-4, R-2, and RE-22) distributed in WEEM area (Fig.1). The data are in the form of Caliper (HCAL/inch), Gamma Ray (GR, API), Density (RHOZ, gm/cc) and Photoelectric (PEFZ), Sonic (ΔT, µsec./ft), Micro Spherical Focus Resistivity (RXO, Ώm), Deep Resistivity (RLA5, Ώm), Neutron Porosity (TNPH, fraction) logs. In addition, mud logs for these four wells and accessible well reports for some wells are also available.

Interactive Petrophysics software (IP V3.6) was used to calculate the different petrophysical parameters (Figs. 3-6) in addition to Net Sand and Net/Gross (Table 1). A number of cut-offs were selected to differentiate between productive and non-productive flags. These are effective porosity > 10%, shale volume <35%, and water saturation <65%. Neutron-Density and M-N Cross-Plots (Schlumberger,1972) for the producing zones were constructed and interpreted to verify lithology makeup." and " Cross plot" respectively. The first cross-plot consists of three lines of lithologies the first one refers to sandstone (quartz), the second refers to limestone (calcite) the latest refers to dolomite. Each line is graduated for porosity in percent. If the point falls between any of those two lines it can be assumed that its component is a mixture of the lithology of those lines that contain a greater percentage of the mineral of the line to which it is closest (Krygowski, 2003).

Table.1: Summary of calculated reservoir petrophysical parameters for the studied wells

SUMMARY of calculated reservoir pay parameters for the studied wells									
Well name	ZONE NAME	TOP Ft.	BOTTOM Ft.	GROSS INTERVAL Ft.	NET PAY Ft.	N/G	AV Phi	AV Sw	AV Vcl
Tawoos-1	Matulla	8475	8631	156	25	0.16	0.186	0.303	0.201
R-4	Matulla	5802	6146	344	42	0.124	0.219	0.362	0.206
	Nubia	6146	6191	44	25	0.573	0.195	0.340	0.166
RE-2	Nukhul Clas.	4952	4984	95	25	0.262	0.166	0.488	0.365
	Matulla	5315	5726	411	62	0.151	0.191	0.373	0.266
	Nubia	5726	5852	125	98	0.777	0.208	0.241	0.155
	Basment	5852	5973	121	24	0.193	0.153	0.409	0.161
RE-22	Rudies	3465	6000	2535	20	0.008	0.167	0.453	0.159

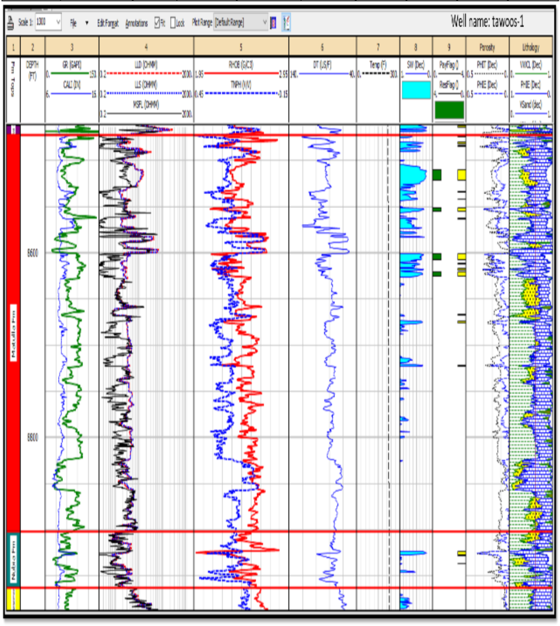

Fig. (3): CPI litho-saturation plot for well Tawoos-1 showing calculated reservoir parameters and pay flags for Matulla interval showing input well log data (tracks 3-7) and output petrophysical parameters (tracks 8-11).

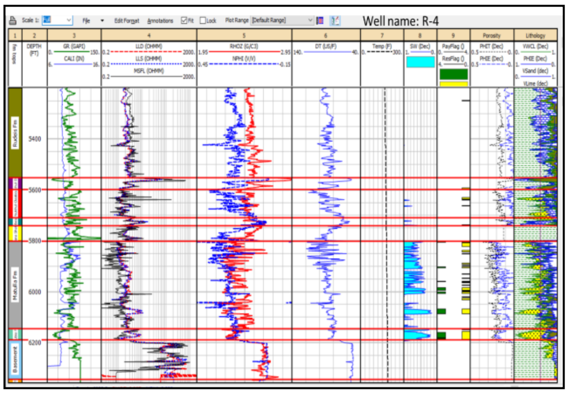

Fig.(4): CPI litho-saturation plot for well R-4 showing calculated reservoir parameters and pay flags for Matulla, Nubia intervals showing input well log data (tracks 3-7) and output petrophysical parameters (tracks 8-11).

Results and Discussion

The results obtained through applications of the above-mentioned techniques for the four studied wells using (IP) indicated as described below:

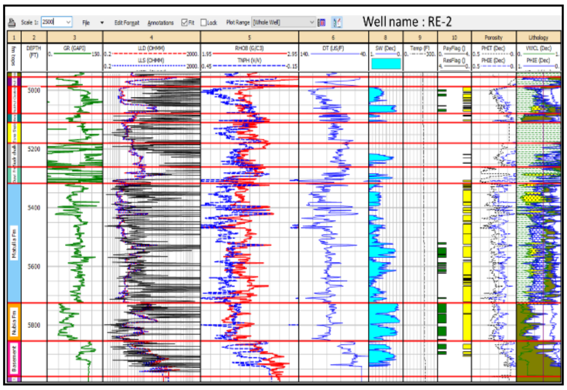

Fig.(5): CPI litho-saturation plot for well RE-2 showing input well log data (tracks 3-6) and output reservoir petrophysical parameters (tracks 8-12) with pay flags for Nukhul clas., Matulla, Nubia, Basment intervals.

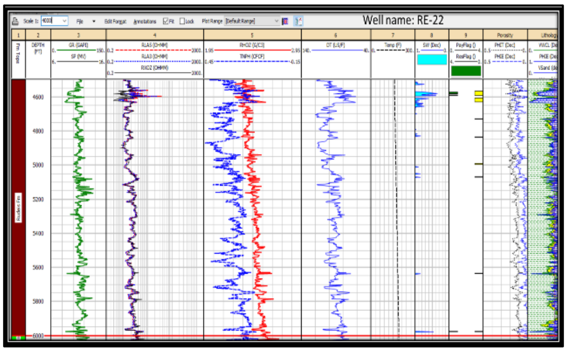

Fig.(6): CPI litho-saturation plot for well RE-22 showing input well log data (tracks 3-7) and output petrophysical parameters (tracks 8-11) with pay flags for Rudies interval.

Rudeis Reservoir

The Rudeis reservoir is encountered in only RE-22 well. The input data and output results for Rudeis Formation in this well are presented in (Fig. 6). Neutron-Density and M-N cross-plots reflected the abundance of dolomite and limestone matrix with a minor percentage of sandstone. The presence of high shale content for this formation shifted the plotted points downward on M-N cross-plot (Fig. 7). This reveals that the reservoir encountered can be described as calcareous sandstone with average porosity of 16%, SW 45% and the net pay thickness is 20 ft.

Nukhul Reservoir

It is considered one of the main reservoirs in the study area, which was encountered in RE-2 well as observed on IP output results (Fig.5). The main lithology as deduced from N-D plot (Fig. 8) is characterized by the presence of shale layers intercalating the sandstone reservoirs in Nukhul clastics, these shale layers act as a local stratigraphic barrier. The calculated net pay in RE-2 Well is around 25 ft with average porosity in Nukhul clastics is around 17%, average water saturation is 49%, average shale volume is 36.5% (table.1), and the porosity is ranging from 13% to 20% in Rabeh east wells, while the porosity in Rabeh wells is ranging from 14% to 24%. This confirms that the quality of the sandstone is enhanced and developed in the direction of Rabeh wells.

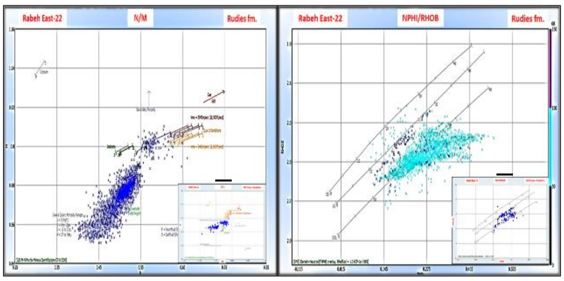

Fig. (7): N/M &Neutron-Density cross-plots for Rudies Fm. with a focus on the pay zone for RE-22 well.

Matulla Reservoir

It is considered as a pay zone in tawoos-1, R-4 and RE-2 (Figs. 3-5). In Tawoos-1 well, the plotted points in N-D plot show that the formation is characterized by Sandstone and Shale with streaks of limestone reaching to highly calcareous sandstone (Fig. 9). The average calculated parameters are: net pay is 25 ft, eff. porosity 18.6%, water saturation 30%, and shale volume 20% (Table.1). However in RE-2 well, the plotted points for this reservoir in this well (Fig. 10) showed that the majority of the plotted points are clustered between sandstone and limestone lines. This indicates that the matrix is combination of sandstone and limestone. Some points shifted towards the shale region. The average calculated parameters are: Net pay is 62 ft, eff. porosity 19.1%, water saturation 37.3%, shale volume 26.6%. (Table.1)

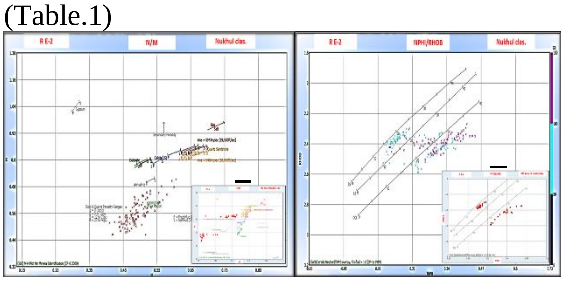

Fig. (8): N/M &Neutron-Density cross-plots for Nukhul clas. Fm. with a focus on the pay zone for RE-2 well.

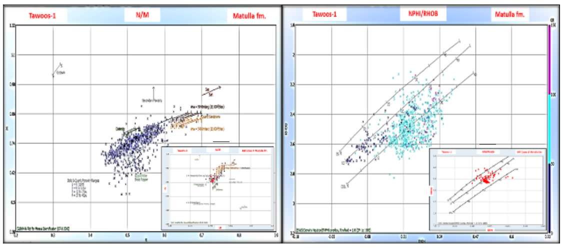

Fig. (9): M-N &Neutron-Density cross-plots for Matulla Fm. with a focus on the pay zone for Tawoos-1 well.

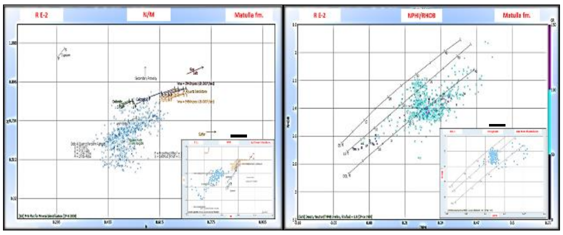

Fig. (10): N/M &Neutron-Density cross-plots for Matulla Fm. with a focus on the pay zone for RE-2 well.

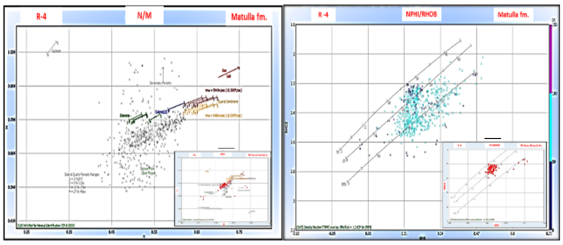

Fig. (11): N/M &Neutron-Density cross-plots for Matulla Fm. with a focus on the pay zone for R-4 well.

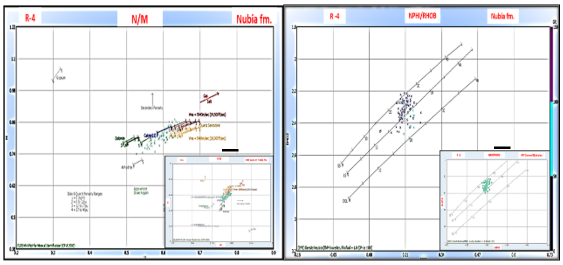

Fig. (12): N/M &Neutron-Density cross-plots for Nubia Fm. with a focus on the pay zone for R-4 well.

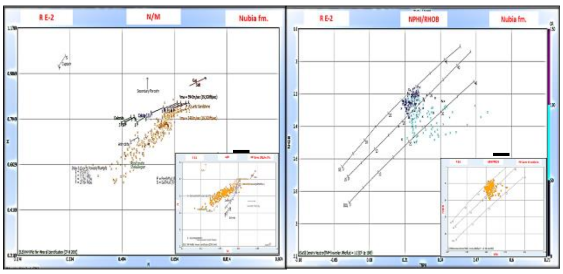

Fig. (13): N/M &Neutron-Density cross-plots for Nubia Fm. with a focus on the pay zone for RE-2 well.

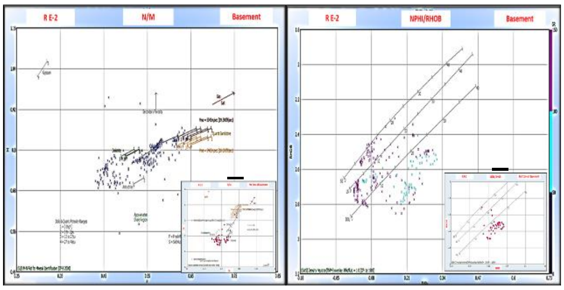

Fig. (14): N/M &Neutron-Density cross-plots for Basement with focus on the pay zone for RE-2 well.

In R-4 well, the plotted points in N-D plot showed that the formation was characterized by the presence of Sandstone and limestone streaks more than that detected in tawoos-1 with highly calcareous shale percentage as the plotted points shifted towards the dolomite line and approximate shale region (Fig. 11). The average calculated reservoir petrophysical parameters are net pay is 42 ft, eff. porosity 21.9%, water saturation 36.2%, and shale volume 20.6%. (Table.1).

Nubia Reservoir

It is reported as a pay zone in RE-2 and R-4 wells and (Figs 4 & 5). In R-4 well, the plotted points (Fig. 12) for this reservoir are located close to the sandstone line and a few points shifted toward the limestone line. Points plotted on M-N cross plot were found to be shifted toward quartz. Few points were shifted toward calcite. The average calculated parameters are: Net pay is 25 ft, eff. porosity 19.5%, water saturation 34 %, and average shale volume 16.6%. (Table.1). While in RE-2 well, the plotted points (Fig. 13) clustered close to the sandstone line with some points shifted toward limestone and dolomite lines. Points located at the southeastern direction reflect shale content. On M-N cross plot some points clustered around the quartz point with a few points shifted towards the shale region. The average calculated parameters are: Net pay is 98 ft, eff. porosity 20.8%, water saturation 24.1 % and volume 15.5%. (Table.1)

Basement Reservoir

It is considered as pay in RE-2 well (Fig. 5). The cross plots indicate that this interval contains carbonates, and some points were found to be shifted toward shale. This composition may be related to the way of weathering which is affected by or precipitation released by leaching in fractures of the basement (Fig. 14). The average calculated parameters are: Net pay is 24 ft, eff. porosity 15.3%, water saturation 40.9 % and average shale volume 16.1%. (Table.1)

Conclusion

- WEEM area is considered a promising hydrocarbon concession, especially in its eastern part due to the presence of oil producer zones within the basement rocks, Nubia, Matulla, and Nukhul clastics.
- Rudies fm. consider oil reservoir only from RE-22 well.
- Matulla fm. represents oil producers in the central and western parts of the study area.
- Nubia fm. is an oil producer in the central part of the study area.
- It is highly recommended to drill more exploratory wells to improve the productivity of the studied area**.**

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الملخص العربي

عنوان البحث: الإمكانات البترولية لمنطقة غرب الملاحة ، جنوب خليج السويس كما تم استنتاجها من تفسير بيانات سجل الآبار

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تقع منطقة غرب عش الملاحة (WEEM) في الجزء الجنوبي من الساحل الجنوبي لخليج السويس وتمتد إلى حوالي ٥٢ كيلومتر مربع. الهدف الرئيسي من هذه الدراسة هو استخراج أهم الخصائص البتروفيزيائية للتتابع الرسوبي الموجود بمنطقة الدراسة لتقييم وتحديد إمكانات الهيدروكربون في منطقة WEEM باستخدام بيانات تسجيلات الآبار المتاحة. تم اختيار أربعة آبار للدراسة (Tawoos-1 و RE-4 و RE-2 و RE-22) والتي تمثل معظم منطقة الدراسة. أشارت نتائج التفسير إلى ان منطقة WEEM بها إمكانات هيدروكربونية واعدة ، خاصة تكوين Matulla يعتبر منتج للنفط من بئر Tawoos-1 ، بينما تكوينات Basement, Nubia, Matulla, Nukhul clastics تعتبر نطاقات منتجة للنفط من بئر RE-2 ، واخيرا Matulla, Nubia تعتبر تكوينات منتجة للنفط من بئر R-4 ، وتكوين (Rudies) يعتبر ايضا منتج للنفط من بئر RE-22.