JP&M Engineering

Journal of Petroleum and Mining Engineering

Sandstone Reservoir Assessment of Nukhul Formation Using Well Logging Analysis, Eastern Gulf of Suez, Egypt

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Abstract

The Nukhul Formation in Abu Rudeis Marine Field is regarded as one of the most important oil production reservoirs in the Gulf of Suez. Abu Rudeis Marine Field is an oil producing field located on the eastern side of the Gulf of Suez. The present study deals with the petrophysical examination of Nukhul Formation in Abu Rudeis Marine Field by using well logging data for four wells. The studied formation was classified into three units (A, B, C) according to the hydrocarbon potentiality. The lithology of three units was examined using logging parameter cross plots, and petrophysical parameters such as shale volume, effective porosity, and water saturation were calculated. The neutron/density and lithosaturation cross plots reveal that the main lithology of the three units are sandstone with shale intercalations and sometimes limestone at the lower part of Nukhul Formation for example ARM-21 well, in addition to Thomas Stieber cross plot for the shale type investigation was applied. The qualitative interpretation of the well logging data for the investigated wells identified three intervals with good petrophysical parameters and the capacity to store and produce oil.

Introduction

From north western end of the Red Sea to the north, the Gulf of Suez Basin stretches 325 kilometres [1, 2, 3]. The Gulf of Suez is one of the world's oldest oil basins, and it is considered the most productive oil rift basin in Africa and the Middle East, with over 80 oil fields yielding from Precambrian to Quaternary [4, 5, 6, 7, 8]. Due to its highly fractured nature, the Nukhul Formation is considered a major heavy oil reservoirs from Early Miocene in the Gulf of Suez area [9], and it also consists excellent hydrocarbon reservoirs in more over fifteen oil fields in the Gulf of Suez area [10]. As a consequence, the main work attempts to evaluate the hydrocarbon prospect of Nukhul Formation in terms of enhancing the existing reserves in the Abu Rudeis Marine Field (Figure 1) based on the four well logging- data and an assessment of petrophysical rock properties like as shale content, pore space, and saturation of both hydrocarbon and water.
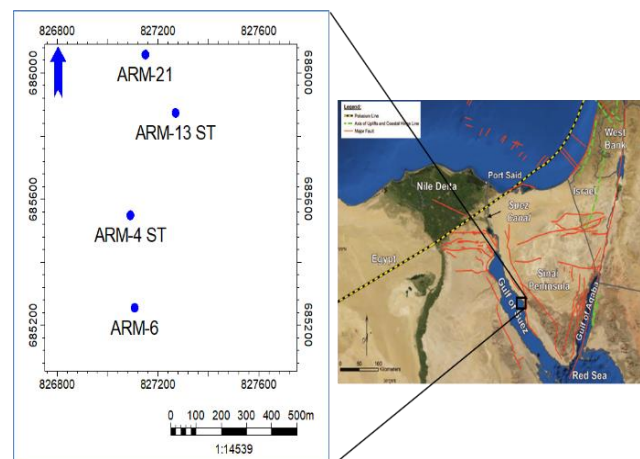

Figure 1 The location map of Abu Rudeis Marine Field at the eastern side of Gulf of Suez, Egypt.

Geologic Setting

The Gulf of Suez is a Paleogene-Neogene continental rift formed by the separating of African and Arabian plates between the Late Oligocene and Early Miocene. It constitutes the Clysmic Gulf, a regenerated, slightly sinuous NW-SE topography depression. Its width varies from about 50 kilometres

in the north to about 90 kilometres in the south according to [2]. [11] concluded that structural fault blocks formed during the rifting process serve as traps for hydrocarbons and control the accumulation of petroleum oil fields. The hydrocarbon reserves in the Gulf of Suez are mostly found in the syn-rift Miocene sandstones, with the remainder mostly found in the Nubia Formation [12]. A complicated pattern of faults divides Gulf of Suez: N/S to NNE/SSW in addition to E/W trending normal faults near rift boundary and through rift of basin, clysmic trend NW-SE and N/E trending strike slip faults (Figure 2). According to [13, 14, 15, 16], the connection of the major fault systems produced a complicated structural trend comprised of multiple horsts / grabens of varying sizes.

The Nukhul Formation of Early Miocene is first syn/ rift formation in Gulf of Suez basin [9]. Nukhul Formation is mainly composed of clastic sediments (sandstones / shale) in addition to evaporated and limestones beds, the early clastic layer of Nukhul Formation [17, 18] accumulated in shallow marine characters and partially filled submarine canyons that carried debris from uplifted areas [9]. Some parts of the Nukhul Formation, on the other hand, may have been deposited in a deep marine environment [19, 20]. The Gulf of Suez geological sequence can be classified into three lithological sections based on surface and subsurface data based on [15]. Basement rocks (Proterozoic) and Palaeozoic - Upper Eocene sediments are among the pre-rift units. These formations are significant as reservoir and source rocks. Upper Oligocene and Miocene syn/rift sections contain volcanic rocks as well as source, reservoir, and cap lithologies. The post/rift sections range in age from the Pliocene to the Pleistocene.
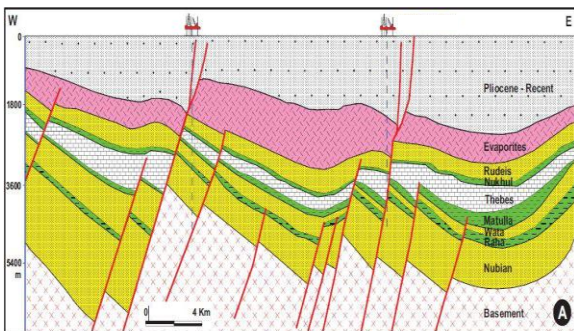

Figure 2 Geological - Seismic Section through the Gulf of Suez Province [13].

Data and methodology

In this research, the existing logging data includes four wells in the Abu Rudeis Marine Field; namely ARM-6, ARM-4ST, ARM-13ST and ARM-21at Eastern border of Gulf of Suez Basin. Gamma-ray, shallow/deep resistivity, bulk density, and neutron porosity are all available logs. Mud logs for the four wells are also accessible. The current work's approaches included mud log and logging data assessment of the studied Formation in the Abu Rudeis Marine Field. Initially, the mud logs from four wells were analysed qualitatively in order to identify prospective pay zones in Nukhul Formation. The

lithological composition of Nukhul Formation for studied wells were investigated using the mud log, crossplots (dia porosity density/neutron crossplots, and lithosaturation crossplot) [21], [22] was applied for shale distribution. Using Techlog Software, the well log data was examined in order to derive the most essential petrophysical parameters for the zones of interest. Shale volume, effective porosity, water saturation, and net pay thickness are the variables at each well.

Volume of Shale (Vsh)

The shale amount in the investigated intervals was calculated using the [23] equation and the gamma-ray log as a linear response:

$$V_{sh} = (GR-GR_{min}) / (GR_{max}-GR_{min}) \tag{1}$$

Where Vsh: shale- volume; GR: value reading of gamma ray; GRmin: lowest value of gamma ray; and GRmax: maximum gamma ray value.

Porosity (Effective φe)

Only fluids can be transferred between connected voids are measured by effective porosity [23]. The following equation was used to determine it.

$$\Phi e = \Phi T \times (1-Vsh) \tag{2}$$

Where Φe: porosity (effective); φT: porosity (total) and Vsh: shale volume.

Saturation of water (Sw)

To estimate saturation of water for the sections studied, the Indonesia model [24] was used. This model was applied in the case of a shale reservoir, which is what we have now, because the shale volume is up to 22%. The following equation used to calculate saturation of water in this model:

$$s_w = \left\{ \left[\left(\frac{V_{sh}^{2-V_{sh}}}{R_{sh}} \right)^{1/2} + \left(\frac{\phi_e^m}{R_w} \right)^{1/2} \right]^2 R_t \right\}^{-1/n} \tag{3}$$

Sw: saturation of water; Vsh: shale volume; φe: porosity (effective); Rsh: resistivity of shale; Rt: deep resistivity; Rw: formation resistivity for water; m: cementation exponent; (n): saturation exponent; and (a): tortuosity factor.

Result and discussion

Mud logging analysis

Nukhul Formation sandstones facies at ARM-21well showed promising parameters for storing hydrocarbons, according to the qualitative analysis of the mud logs. These favourable indicators include high ditch gas analysis results as well as the presence of oil shows opposing three pay zone intervals located through the three units A, Band C, as indicated in Figure 3. In the mud log report (25), the Nukhul sandstones were identified as yellowish white, friable, medium- to coarse grains, sometimes fine and very coarse, subangular, occasionally subrounded, poorly sorted with calcareous cement reached to sandy

limestone, the argillaceous cement also present. All the preceding features are typical of sandstones with good to moderate textural maturity.

Lithological interpretation using Neutron / Density Plot

In examined wells, the lithological composition of the Nukhul Formation was researched using an integration of various log like the NPHI/ RHOB plot as well as the Thomas Stieber plot for shale type investigation.

Nukhul sandstone in studied wells was divided petrophysically to three units, from upper to lower as unit A, unit B and unit C. The NPHI/ RHOB plot (Figure 4) illustrate that, the main lithology in three units of the Nukhul Formation appears to be intercalated shale in sandstone; the lithology of the three units is composed mainly of sandstone with occasional shale intercalations in wells ARM-21, ARM-4ST2 and ARM-13ST, and becomes more shaly in well ARM-6 toward the south direction of the studied area. Some points are directed towards the limestone line that reflected the presence of calcareous materials as acement. The scattered points of Unit A shifted to northwest because of the effect of gas.
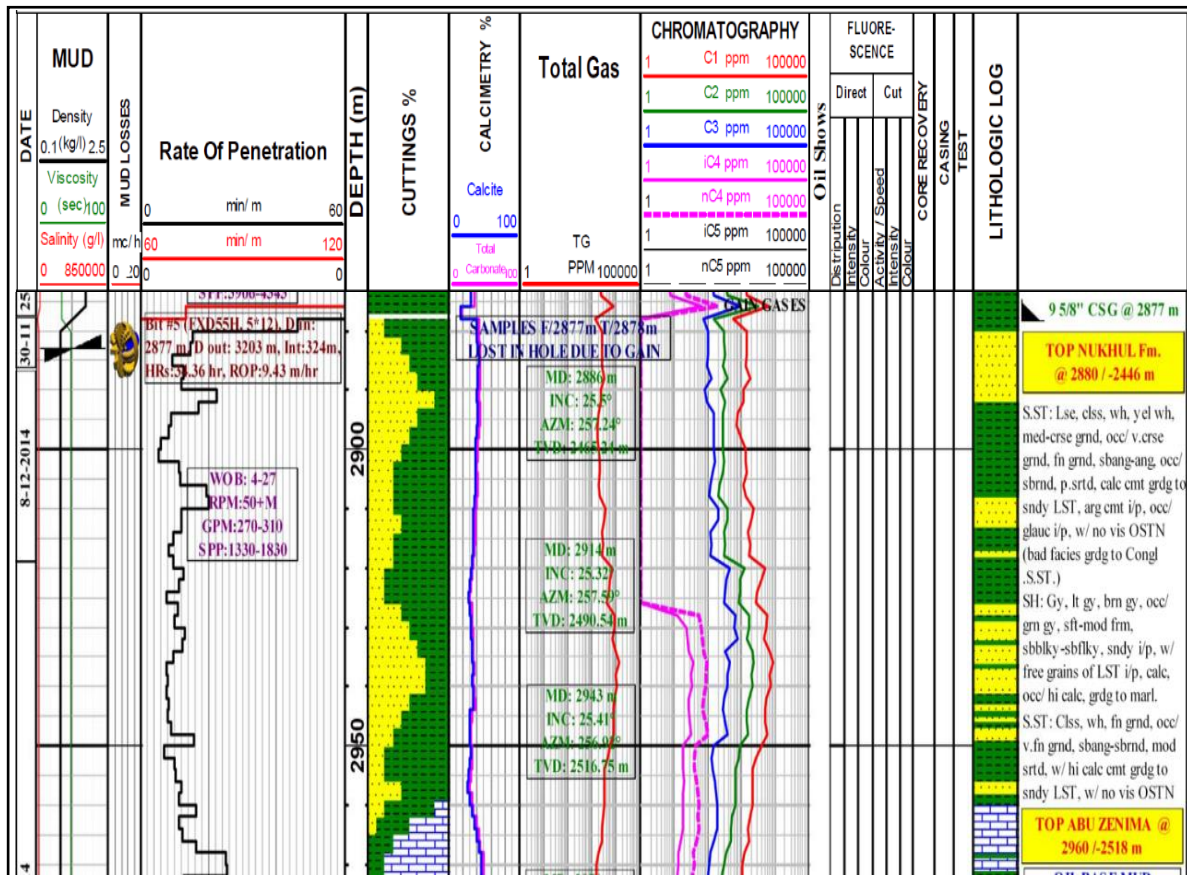

Figure 3 Mud log displays in ARM-21 Well as an example showing the lithology and the oil shows through the Nukhul Formation.
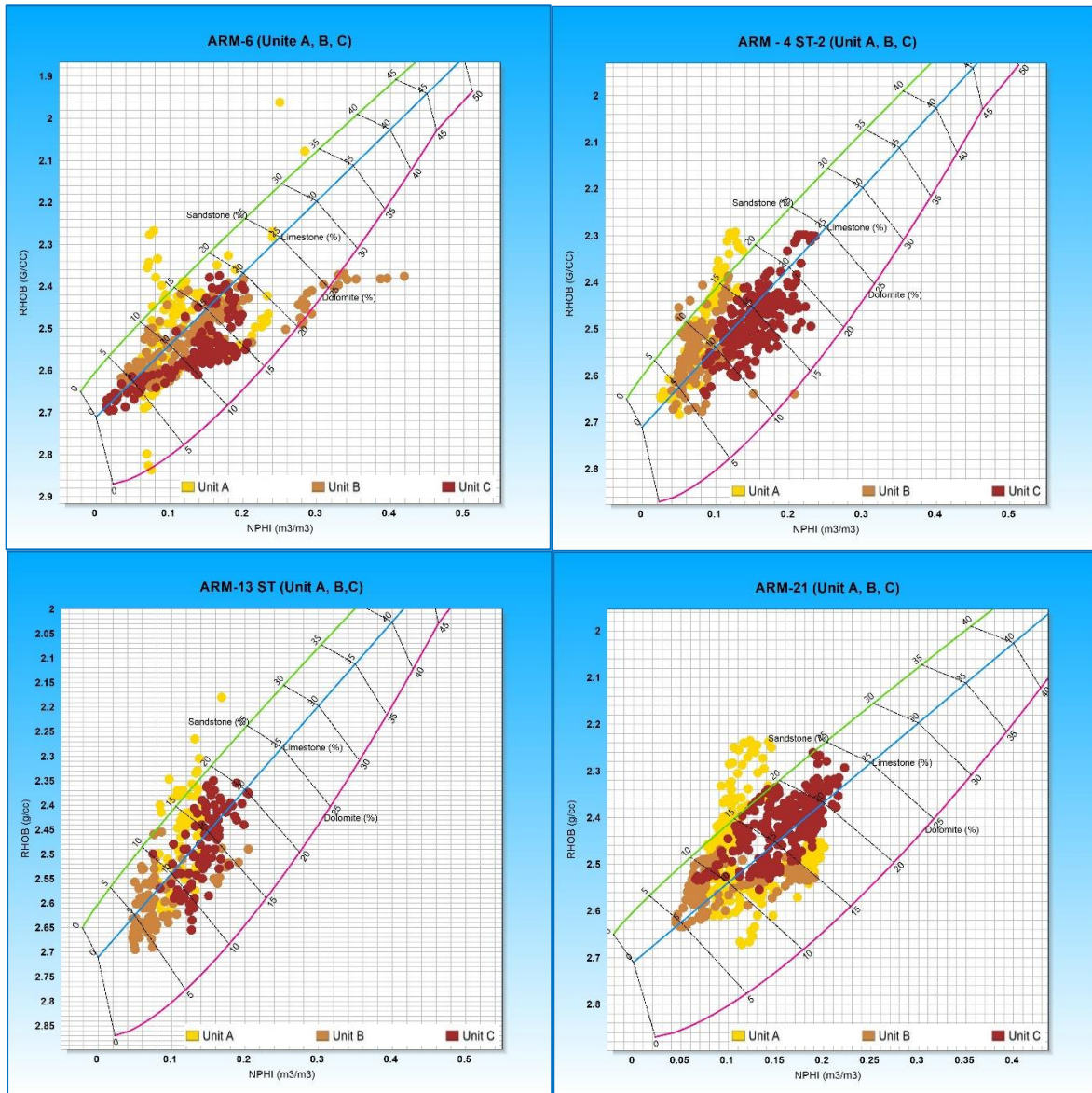
Figure 4 Lithological identification with neutron/density cross plots of the three units through Nukhul Formation in Abu Rudeis Marine Field.

Shale distribution in sand

Shale can be scattered in sand in four different ways: layered, structured, scattered, or a mixture of the above. To determine shale distribution in sand, which has an impact on reservoir quality, a complete analysis of logging data is necessary [26]. Based on RHOB – NPHI porosities, [22] suggested a shale distribution diagram that reflects the extent shale, sand percentage, and porosity of the sand (Figure 5). Laminated shales can be found within reservoirs as clay sheets that affect vertical permeability between reservoir rocks but not connected porosity, saturation of water, or horizontal permeability of rock [27] Clay, which occur after the deposition stage, make up the majority of scattered shale. [28], dispersed shale reduces porosity significantly by filling pore spacing and pore throats. During the early stages of deposition. By filling pores between grains, structural shales may not always alter reservoir properties [29].

Data points are arranged in a specific order based on their location in the Thomas and Stieber of RHOB – NPHI porosities cross plot (Figure 5), the type of shale for the identified three units (A, B and C) through Nukhul Formation indicates that almost all shales are scattered in sand layers, reducing porosity and decreasing reservoir quality.

Pickett plot

Through the Nukhul Formation, a Pickett plot [30] has also been generated for the studied three units. (Figure 6). On logarithmic scales, this graph shows the relationship between deep resistivity on the x-axis and effective porosity on the y-axis. Because the hydrocarbon saturation estimated to be greater than 50%, The hydrocarbon development of units A, B, and C is shown by all data points reflecting the studied units clustered and positioned less than Sw = 50% line. This result is consistent with the calculated water saturation values, verifying the precision of the calculations as well as the significance of these units as hydrocarbon zones.
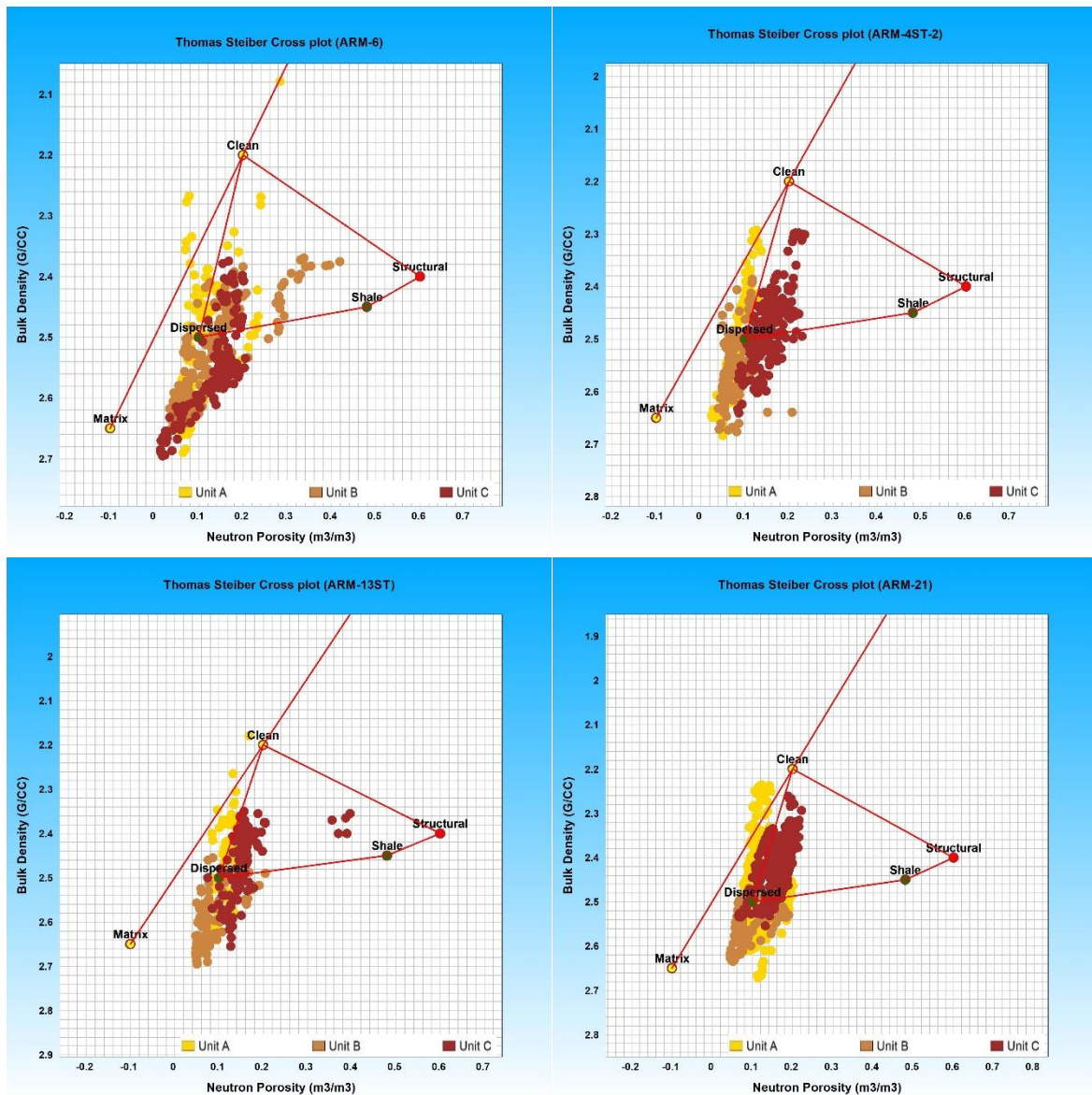
Figure 5 Shale type distribution model proposed by Thomas and Stieber (1975) cross plot of Nukhul Formation in Abu Rudeis Marine Field.

Lithology- saturation cross-plot

Lithology saturation crossplot illustrates the variation in lithology, volume of shale, saturation (water-hydrocarbon) vertically for every component of the Nukhul units, utilizing various water saturation formulas for shaly and non shaly sand units. To evaluate various reservoir intervals, gamma ray, bulk density, neutron porosity, and resistivity were used.
Wireline logs of the Nukhul Formation for the ARM-21 Well were visually evaluated, and the prospective intervals (Unit A, B, C) as indicated in Figure 7 were identified. The presence of a minor amount of shale is evident in the three investigated units, as demonstrated by the low gamma ray curve (first track) in (Figure 7) with percentages ranging from 13 to 45 percent. The sandstone matrix are reflected in neutron - density curves, which show crossover pattern (second track) in Figure 7. Resistivity (deep) values in track 3 of Figure 7 range from 4 to 26 ohmm.

Evaluation of quantitative logs for units A, B, and C, additional mathematical calculations were performed by computing most essential petrophysical characteristics to estimating hydrocarbon rocks of reservoirs, such as gross and net pay thickness, effective porosity, water saturation, and shale volume, as shown in Table 1. In Unit A, shale volume varies between 10.2 and 18.4 Effective porosity varies between 11.6 -14.4%, while water saturation varies between 30.1 - 50.2 % (Table 1). However, in Unit B, shale volume varies between 11.7 and 19.2 %, the effective porosity ranges between 6.5 and 10.7 %, and the values of water saturation fluctuates between 45.5 and 55.3% (Table 1). In addition to Unit C characterized by shale volume ranges from 9.2 to 22.3%, effective porosity varies between 11.9 and 17.2 % and values saturation of water differ from 38.2 to 66.9 % (Table 1).
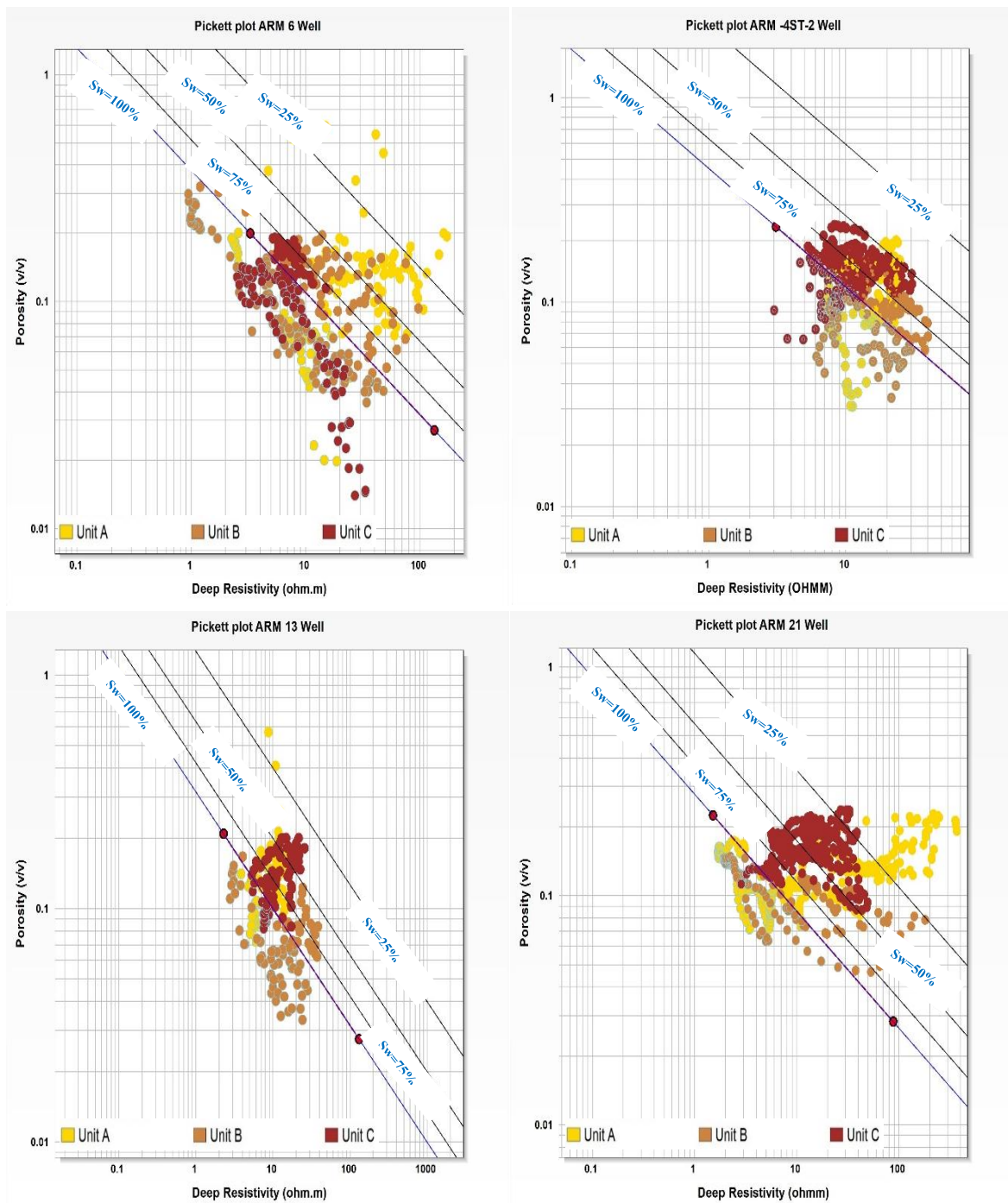
Figure 6 Pickett plot for units A, B, C through Nukhul Formation in Abu Rudeis Marine Field. Note that the all points locate less than Sw = 50% line representing the hydrocarbon prospective zones.

A computer-processed interpreting correlation profile A-A\ was used to construct a vertical presentation of the data (Figure 8), it can be seen that the thickness of Nukhul Formation for the studied wells increases toward the southern part in ARM-6 well, the net pay thickness through the unit A increased generally toward the north in ARM-21 well, the Unit B mainly through the central part of the studied area in ARM-4ST-2 well, however the net pay thickness for Unit C decreased around the southern part of the studied area.

Conclusions

The existing production data support the current analysis, indicating that the sandstones of the Nukhul Formation have great petrophysical properties. The net pay zones in three units A, B, and C have excellent oil production reservoir characteristics, according to a complete petrophysical investigation for sandstones of Nukhul Formation at Abu Rudeis Marine Field. These properties include high effective porosity values reached to 17.2 % in addition to the low water saturation reached to 30.1 %. The reservoirs in the three units are lithologically described as thick porous sandstone with occasional shale intercalations and calcareous cement, according to the cross-plot

investigation. According to the Thomas and Stieber cross-plot, the Nukhul Formation has more dispersed shale than structural shales, resulting in decreased porosity and increased water saturation.

For Unit A; saturation of water (22–44 percent) and shale volume (10.2-18.4 %,) are among the petrophysical characteristics calculated and effective porosity (11.6- 14.4 %).

Table 1: Reservoir parameters for Unit A, B and C through Nukhul Formation.								
Well	Unit	Top	Bottom	Gross Thickness (m)	Net pay Thickness (m)	Av_Vsh %	Av_PHIE %	Av_Sw %
ARM-6	Unit A	3238.48	3255.48	17.00	10.11	13	11.6	30.1
	Unit B	3267.22	3296.07	28.85	5.21	18.6	6.5	45.5
	Unit C	3298.10	3320.64	22.54	4.11	22.3	11.9	66.9
ARM # 4 ST-2	Unit A	3274.35	3290.04	15.69	9.60	10.2	13.4	44.2
	Unit B	3310.11	3331.60	21.48	8.84	11.7	10.7	55.3
	Unit C	3339.09	3371.89	32.79	20.23	9.2	17.2	41.2
ARM-13 ST	Unit A	3205.86	3223.11	17.25	11.75	14.2	14.4	50.2
	Unit B	3238.65	3261.11	22.46	4.33	16.3	10.3	53.2
	Unit C	3264.08	3289.23	25.15	19.34	11.2	13.6	43.2
ARM-21	Unit A	2878.33	2906.31	27.98	15.45	18.4	12.3	45.7
	Unit B	2906.31	2916.68	10.37	5.211	19.2	10.2	50.3
	Unit C	2925.15	2948.39	23.25	22.39	17.1	12.5	38.2

Unit B exhibits water saturation (45.5- 55.3%), shale volume (11.7 -19.2 %) and effective porosity (6.5-10.7 %,). In which Unit C has water saturation (38.2 - 66.9 %), shale volume (9.2- 22.3 %,) and effective porosity (11.9- 17.2 %). The sandstones of the Nukhul Formation in the Abu Rudeis Marine Field have good petrophysical characteristics for producing oil, according to this investigation. The main reservoir in the investigated area is unite C, according to the results of evaluating reservoir rock in the Abu Rudeis Marine oil Field using Computer Processed Interpretation. Unit C is composed of sandstone in addition to carbonate and argillaceous cementing materials, with a net-pay thickness reaching 22.39 m in the Arm-21 well. The potential locations for oil accumulation are located toward the north and central parts of the area, according to the lateral variation. Finally, the Nukhul Formation in study area has potential reservoir features, making it a suitable place for oil accumulation in the centre and northern parts of the study area.
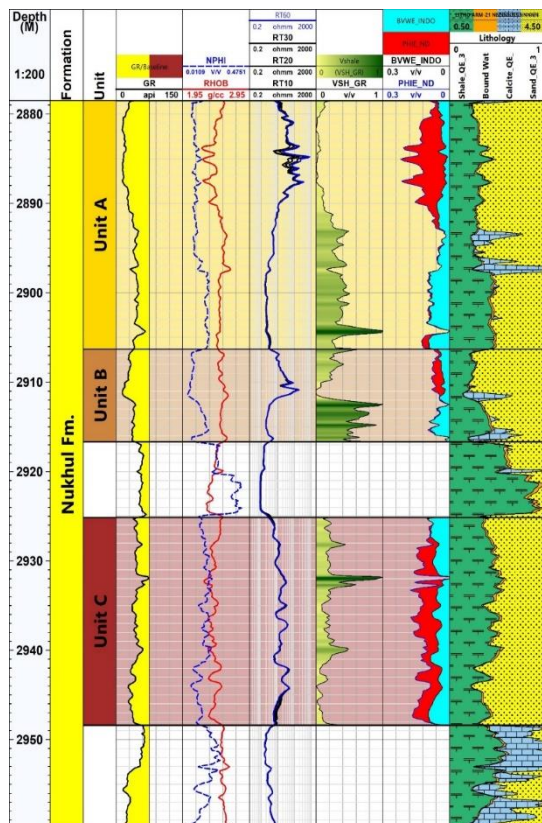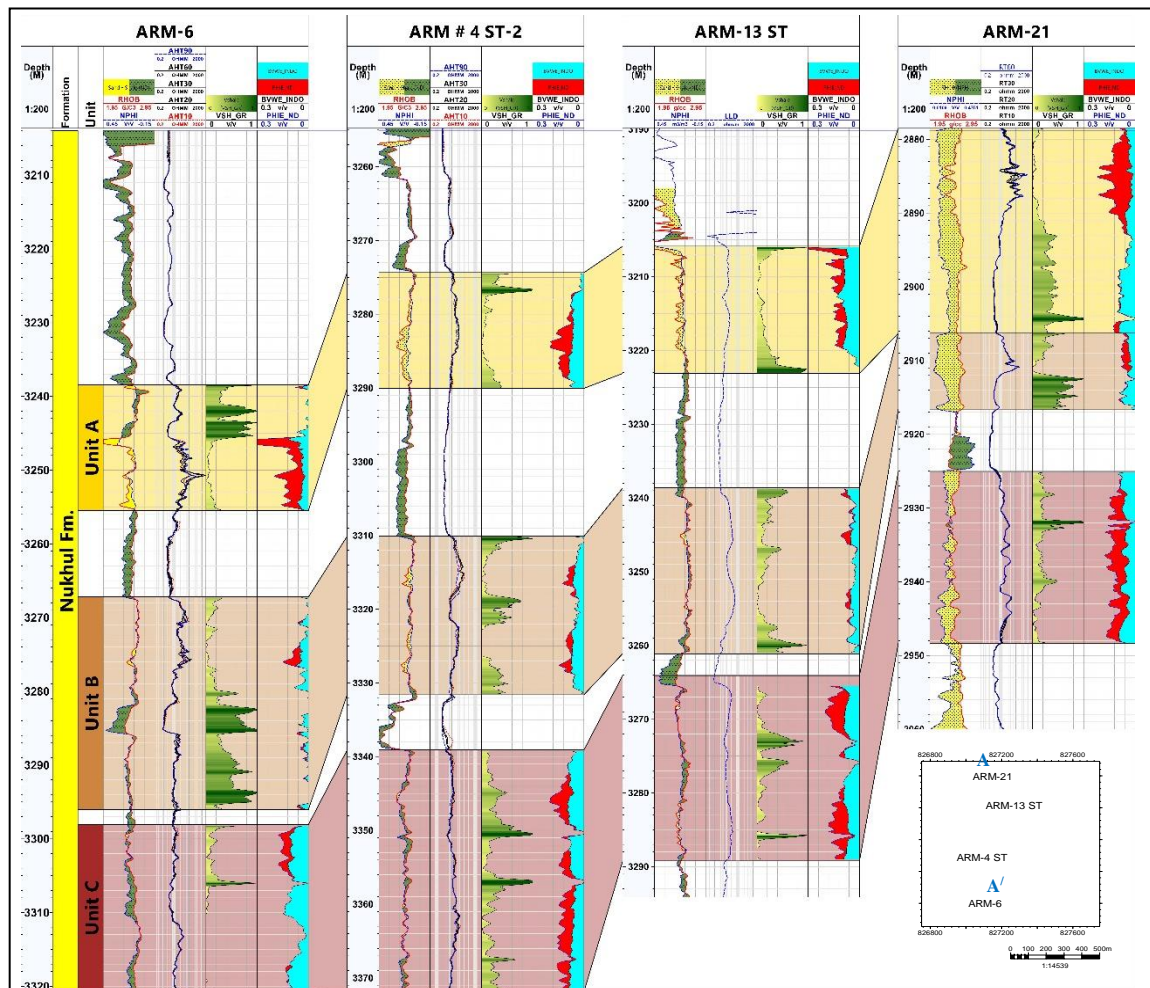
Figure 7 Litho-saturation crossplot for well ARM -21 (as an example) of the three units through Nukhul Formation in Abu Rudeis Marine Field, Eastern Gulf of Suez, Egypt.

Figure 8 South- North well-tie profile through Nukhul Formation in Abu Rudeis Marine Field, Eastern Gulf of Suez, Egypt.

Funding sources

Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgements

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