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# Spectrometry and Reservoir Characteristics of Rudeis Formation in Belayim Marine Oil Field, Gulf of Suez, Egypt

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*Abstract.* Gamma ray spectrometry is used to determine the stability of radioactive elements, shale volume and clay type. Three spectrometric variables eU, eTh and K% are recorded in seven wells of Rudeis Formation in Belayium marine oil field, Gulf of Suez, Egypt. Statistical analysis of the radioactive elements (uranium and thorium) reflects their concentrations in Rudeis Formation. Spectral gamma ray and Scanning Electron Microscope photographs elaborate that, the clay minerals of Rudeis sandstone are montmorillonite, kaolinite, chlorite and mixed layered clay. Beside these traditional roles, Gamma ray spectrometry is used to identify hydrocarbon accumulation zones in Rudeis Formation. The DRAD arithmetic means plus three standard deviations for the data set are computed. Positive DRAD values identify the hydrocarbon accumulation zones in petroleum reservoirs.

Well log analysis reflects that the Rudeis Formation is composed mainly of sandstone and minor shale which act as a good reservoir for hydrocarbon. Eight estimated reservoir parameters from well logs are used to construct the development map. Development decision map illustrates high probability in the south and northeast parts to explore, drill, develop and produce hydrocarbon from Rudeis formation in Belayim marine oil field. The results of normalized thorium highly agreed with the results of well log interpretation of Rudeis reservoir in Belayim marine oil field. So, the gamma ray spectrometry can be used with some limitations to determine hydrocarbon bearing zones of Rudeis Formation.

Conventional and special core analyses have been used to evaluate the reservoir characteristics of Rudeis Formation in Belayim marine oil field. The average porosity is 20% while, the average permeability is 890 md. Relationships between porosity and formation resistivity factor are used to determine the tortousity factor (a) and cementation factor (m), respectively. The relationship between resistivity index and water saturation is used to determine saturation exponent (n), and constant (c). The calculated reservoir parameters a, c, m and n are 0.78, 0.8, 1.86, and 2.2, respectively. The porosity values were affected negatively by increasing the overburden pressure. The radii of the pore throats range from 10 μm to 30 μm. It is very suitable to path the different types of fluids (gas and oil) through reservoir. From capillary pressure data, we determined the irreducible water saturation, effective porosity, recovery efficiency, average pore radius, hydraulic pore radius and packing radius and the relationships between these parameters are determined. The correlation coefficients related to these parameters give the possibility to estimate one parameter from the other.

## Introduction

Belayim marine oil field is located between latitudes 28° 34` 45``and 28° 38` 32`` N and between longitudes 33° 05` 17`` and 33° 10` 38`` E in the eastern side of the Gulf of Suez, 165 km southeast of the Suez city (Fig.1). According to Takasu *et al.* (1982), the Rudeis Formation overlies conformably the Nukhul Formation and underlies conformably the Kareem Formation. The Rudeis Formation consists mainly of sandstone and shales (Fig. 2). It varies in thickness from 11m to 1304m. The depositional setting of the Rudeis Formation is considered to be shallow to deep marine, (Alsharhan and Salah, 1994). The Rudeis Formation is deposited during the rift-climax stage, at which time, many of the intra-block faults became inactive and fault activity is partially progressively localized close to the master fault after initial rifting (Patton *et al.,* 1994. and Sharp *et al.,* 2000b). The Rudeis Formation is the most important productive formation for oil in the Gulf of Suez province.

The aim of this work is, (1) to evaluate the spectrometry of Rudeis Formation, (2) to determine the oil bearing zones of the Rudeis Formation using gamma ray spectrometry log, (3) to evaluate the reservoir characteristics of Rudeis Formation in Belayim marine oil field. To fulfill these aims, gamma ray spectrometry and well log data of BM 30, BM 35, BM 37, BM 57, 113 M 27, 113 M 34 and BMNW 2 wells as well as core analysis reports of 113 M 11 and 113 M 81 wells are used.

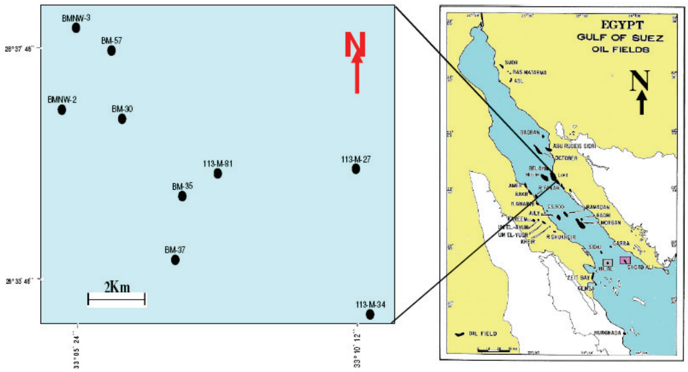



**Fig. 1. Location map of the study wells in Belayim Marine oil field, Gulf of Suez, Egypt.**

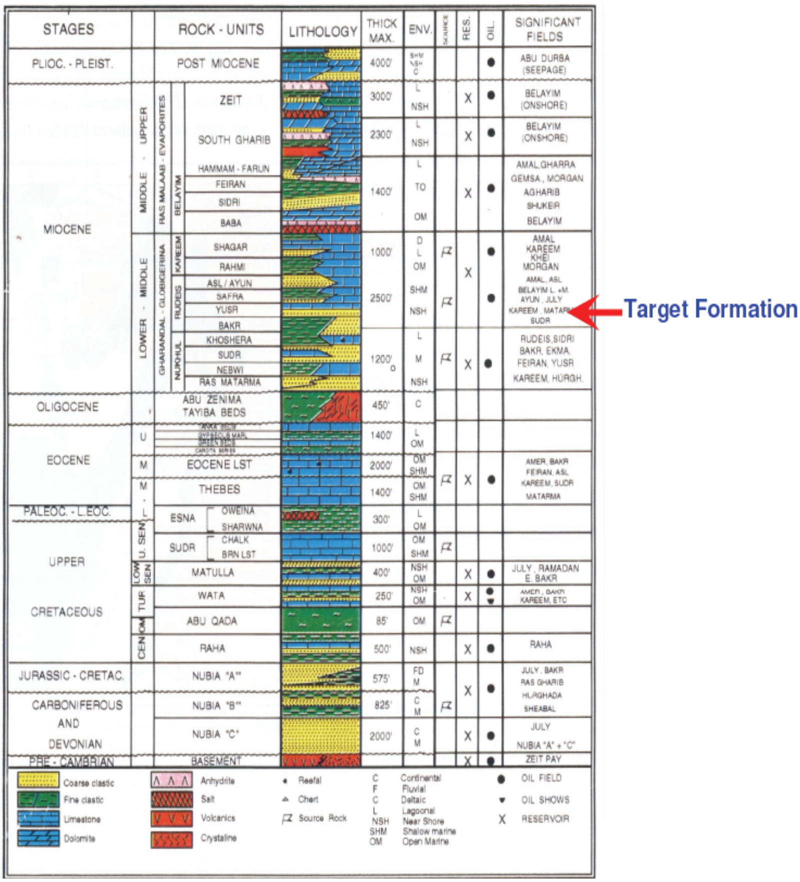



**Fig. 2. Stratigraphic column of Gulf of Suez fields, After EGPC, 2005.**

## Methodology

A new method has been developed using spectral gamma ray measurements for hydrocarbon prospection in stratigraphic and structural traps. The three logs eU, eTh and K are registered in seven wells of the study area. The DRAD arithmetic means plus three standard deviations for the data set are computed. Positive DRAD represents a valid anomaly for hydrocarbon accumulation zones.

Equivalent uranium and potassium data for subsurface gamma-ray spectrometry log are normalized to equivalent thorium data, using the procedures of Saunders *et al.* (1993). Plots are made for the measured logs values of $K_s$ versus $eTh_s$ and $eU_s$ versus $eTh_s$. The simplest effective equations (1), (2) relating these variables are determined to be linear and pass through the origin. The slopes of the lines are determined by the ratios of the means Ks to eThs, or eUs to eThs. The equations are:

$$K_i = (\text{mean } K_s / \text{mean } eTh_s)\, eTh_s \quad (1)$$

$$eU_i = (\text{mean } eU_s / \text{mean } eTh_s)\, eTh_s \quad (2)$$

Where, Ki is the ideal equivalent thorium defined potassium value for the reading with a real equivalent thorium value of eThs.
eUi is the ideal equivalent thorium defined equivalent uranium value for that reading.

By using this approach, the equations are calculated directly from the data and quick field evaluations may be made without preparing the plots and resorting to curve fitting. Deviations of the real values from the calculated ideal values for each reading are obtained using equations of the form:

$$KD\ \% = (K_s - K_i) / K_s \quad (3)$$

$$eUD\ \% = (eU_s - eU_i) / eU_s \quad (4)$$

Where, Ks and eUs are the measured values at the reading. KD% and eUD% are the relative deviation expressed as a fraction of the reading values. Experience has shown that the KD% yields small negative values and eUD% yields smaller negative or sometimes positive values (Saunders *et al.,* 1993).

KD% and eUD% variations can be combined as a single positive number of DRAD, which is the difference between both of them:

$$DRAD = eUD\% - KD\% \quad (5)$$

The present work is devoted to apply the thorium normalization technique for the Rudeis Formation in Belayim marine oil field.

The core porosity, nitrogen permeability and mercury injection capillary pressure (Pc) are calculated for Rudeis Formation in 113-M-11 well. The capillary pressure is calculated using equation of Wardlaw (1976):

$$Pc = 2\,\gamma\cos\theta / r \quad (6)$$

Where, $\gamma$ = surface tension of Hg   r = radius of the pore
$\theta$ = contact angle of mercury in air

The laboratory measurements of the capillary pressure have been converted to reservoir conditions using equation of El Sayed (1993):

$$Pc_r = Pc_l \frac{(\delta_r \cos\theta_r)}{(\delta_l \cos\theta_l)} \quad (7)$$

Where; $Pc_r$ = brine/hydrocarbon   $\delta_r$ = 21 mN/m   $\theta r = 0^o$
$Pc_l$ = air/mercury   $\delta_l$ = 485 mN/m   $\theta l = 140^o$

The displacement pressure is measured as the value on capillary pressure axis intersected by the tangent of the capillary curve parallel to the water saturation curve, while the irreducible water saturation is measured as the value on water saturation axis intersected by the tangent of the capillary curve parallel to capillary pressure axis (El Sayed, 1995).

The effective porosity ($\phi_e$) can be calculated using the equation

$$\phi_e = \phi_t (1 - Sw_{irr}) \quad (8)$$

The mercury recovery efficiency (Re) is calculated by using the equation of Hutcheon and Oldershawa (1985)

$$Re = \frac{(S_{max} - S_{min})}{S_{max}} \times 100 \quad (9)$$

Shouxiang *et al.* (1991) mentioned that the hydraulic radius ($r_h$) can be calculated using the following equation:

$$(\frac{k}{\phi})^{0.5} = \frac{r_h}{\sqrt{5}} \quad (10)$$

While, the average pore radius $r_p$ can be calculated using the following equation:

$$r_p = \sqrt{(8k/\phi)} \quad (11)$$

On the other hand, the packing pore site R can be calculated from the following equation:

$$R = r_h \frac{3(1-\phi)}{\phi} \quad (12)$$

The capillary pressure is a function of the interfacial tension and the radius of the pore.

$$P_c = \frac{2\sigma\cos\theta}{r_c} \quad (13)$$

Where; Pc = capillary pressure $r_c$ = radius of capillary tube
σ = interfacial tension θ = contact angle

The equation is based on uniform capillary tubes, however, a rock is composed partially of interconnected capillaries with varying pore throat sizes and pore volumes. The capillary pressure required to invade a given pore is a function of the size of pore throat. Although determination of the pore throat size distribution of rocks based on capillary pressure curves is only an approximation, the distribution is an important parameter for analysis of many fluid transport properties of porous media (Obeida, 1988). The maximum pore throat size for the sample occurs at Sw = 1.0 and the minimum pore size occurs at irreducible water saturation $Sw_{irr}$.

Pore size distributions are used to analyze reductions of permeability caused by authogentic clays, clay swelling; deposition of organic matter in pores asphaltenes and paraffin's; particle migration and growth of microbes in pores and secondary precipitation of authogenetic minerals (Donaldson *et al.,* 1985).

## Results and Discussion

**a)** ***Spectrometry***

The statistical analysis of spectral gamma ray logs of Rudeis Formation are tabulated in Table 1. The potassium concentrations in this formation have the minimum value of 0.07% and the maximum value of

2.48% with mean value equal to 0.77%, and the standerd deviation value equal to 0.33%. The equivalent uranium concentration values range from 0.3 ppm to 15.1 ppm. The mean values of Ue is 2.57 ppm while, their standerd deviation is 1.32 ppm. The equivalent thorium concentration ranges from 0.1 ppm to 13.75 ppm, with a mean value of 4.33 ppm, the standerd deviation is 1.91 ppm.

**Table 1. Statistical analysis of radioactive elements of Rudies Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

| | *K %* | *eU ppm* | *eTh ppm* |
|---|---|---|---|
| **Mean** | 0.77 | 2.57 | 4.33 |
| **St. Dev.** | 0.33 | 1.32 | 1.91 |
| **Min.** | 0.07 | 0.3 | 0.1 |
| **Max.** | 2.48 | 15.01 | 13.75 |
| **Sum** | 1509.47 | 5020.16 | 8456.92 |
| **Count** | 1955 | 1955 | 1955 |

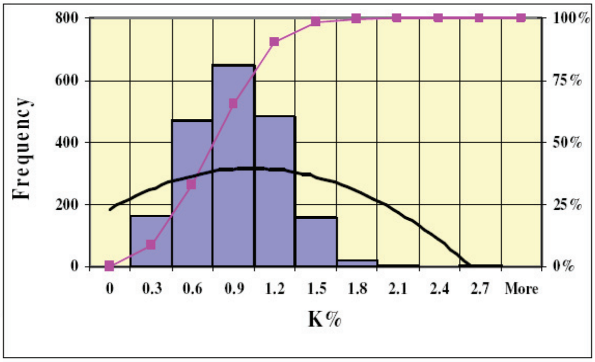
From the statistical analysis of the radioactive elements in the Rudeis Formation it is clear that the main radioactive element in this Formation is uranium. It reflects the presence of organic matter in Rudeis Formation. It contains moderate amount of equivalent thorium concentrations, therefore, the Rudeis Formation has minor clay.

The distribution of the radioactive elements K %, eU ppm and eTh ppm in Rudeis Formation is illustrated in Fig. 3. The histogram analysis of the equivalent thorium in Rudeis Formation reveals that the concentration values of eTh are presented in wide range. It means that the equivalent thorium minerals are stable and fixed in the rock and do not move to the rock of Rudeis Formation.

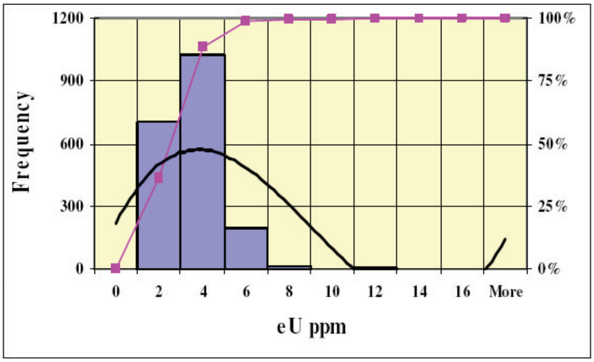
The KD%, eUD% and DRAD curves are plotted for BM 30 well in (Fig. 4). It is clear that, the plot of KD% and eUD% have negative values at depths from 2874m to 2878m and 2914m to 2918m. They have sharp negative peaks from depth 2955m to 2994m. The other depths in the well have. positive values.

The zones from depths 2873m to 2878m, 2915m to 2922m, 2940m to 2945m and 2955m to 3001m have positive values of DRAD. So, these zones are good bearing oil zones and have more amounts of hydrocarbon accumulations.

| *k, %* | *Freq.* | *Cumu.%* |
|---|---|---|
| 0 | 0 | 0.00% |
| 0.3 | 164 | 8.39% |
| 0.6 | 470 | 32.43% |
| 0.9 | 647 | 65.52% |
| 1.2 | 483 | 90.23% |
| 1.5 | 160 | 98.41% |
| 1.8 | 21 | 99.49% |
| 2.1 | 7 | 99.85% |
| 2.4 | 0 | 99.85% |
| 2.7 | 3 | 100.00% |
| More | 0 | 100.00% |




| *eU, ppm* | *Freq.* | *Cumu. %* |
|---|---|---|
| 0 | 0 | 0.00% |
| 2 | 706 | 36.11% |
| 4 | 1025 | 88.54% |
| 6 | 199 | 98.72% |
| 8 | 16 | 99.54% |
| 10 | 2 | 99.64% |
| 12 | 5 | 99.90% |
| 14 | 0 | 99.90% |
| 16 | 2 | 100.00% |
| More | 0 | 100.00% |




| *eTh, ppm* | *Freq.* | *Cumu. %* |
|---|---|---|
| 0 | 0 | 0.00% |
| 2 | 288 | 14.73% |
| 4 | 557 | 43.22% |
| 6 | 719 | 80.00% |
| 8 | 354 | 98.11% |
| 10 | 35 | 99.90% |
| 12 | 1 | 99.95% |
| 14 | 1 | 100.00% |
| More | 0 | 100.00% |

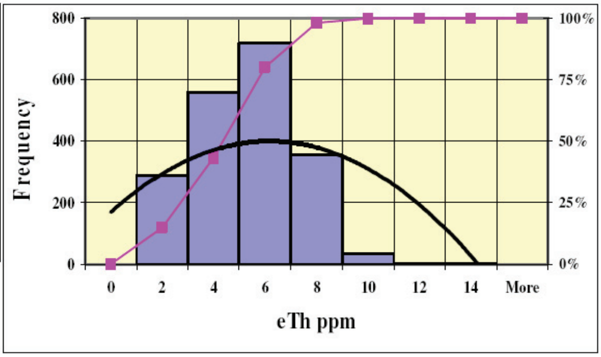



**Fig. 3. Radioactive elements of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

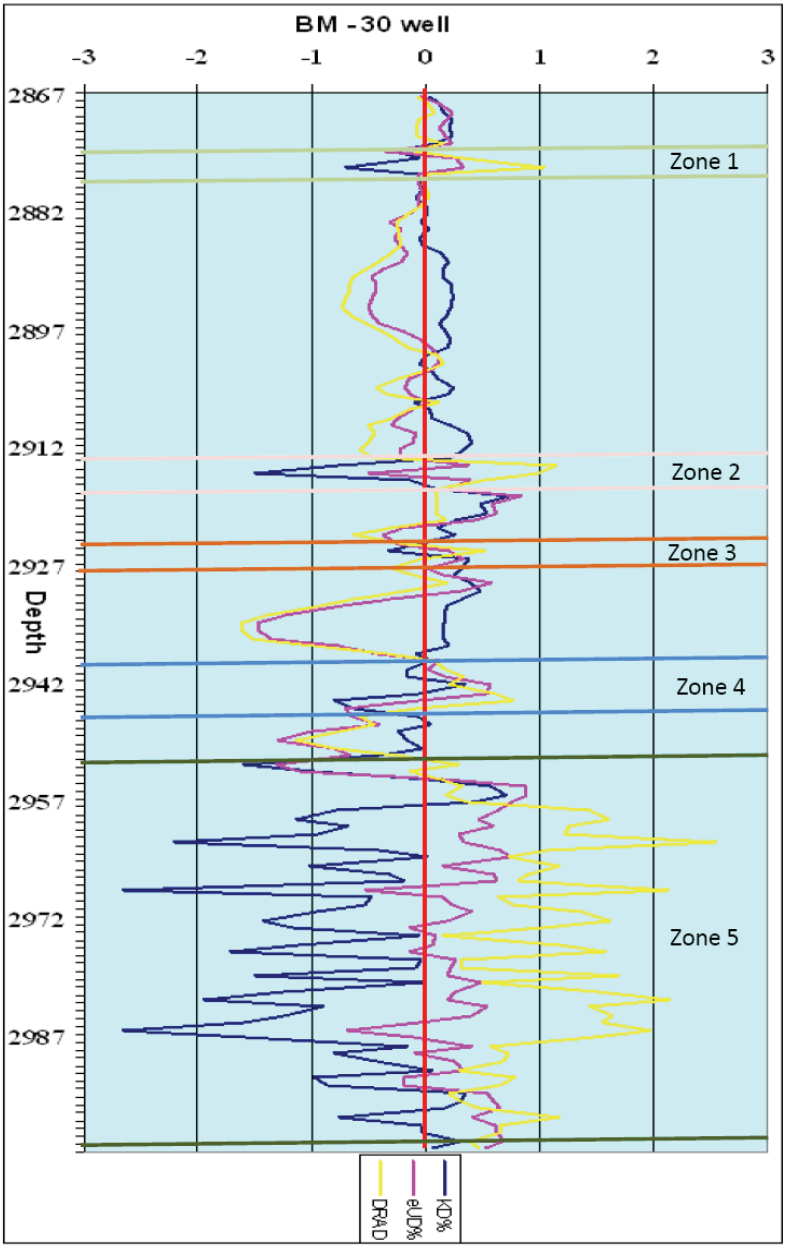



**Fig. 4. The calculated KD%, eU% and DRAD curves of Rudies Formation in BM-30 well, Belayim Marine oil field, Gulf of Suez, Egypt.**

*Clay Mineral Identification*

Spectral gamma ray method plays an important role in determination of the type of clay minerals in the studied rocks. Identification the type of clay minerals in reservoir rocks is very important because of their effect on the porosity and permeability of the rocks. The effect of kaolinite mineral on porosity and permeability is low while, the effect of montmorillonite is high.

The type of clay minerals in Rudeis Formation are determined by two methods, thorium – potassium cross-plot and Scanning Electron Microscope (SEM) photographs.

*Thorium – Potassium Cross-Plot*

The Th/K ratio gives accurate information about the type of clay minerals in the rocks using the diagram of Schlumberger (1995). The thorium–potassium cross-plot is carried out on Rudeis Formation in the studied wells. The clay minerals in Rudeis Formation of the studied wells consist of montmorillonite, kaolinite, chlorite and mixed layer clay with some traces of illite and glauconite clay minerals (Fig. 5a). These clay minerals reduce the reservoir porosity.

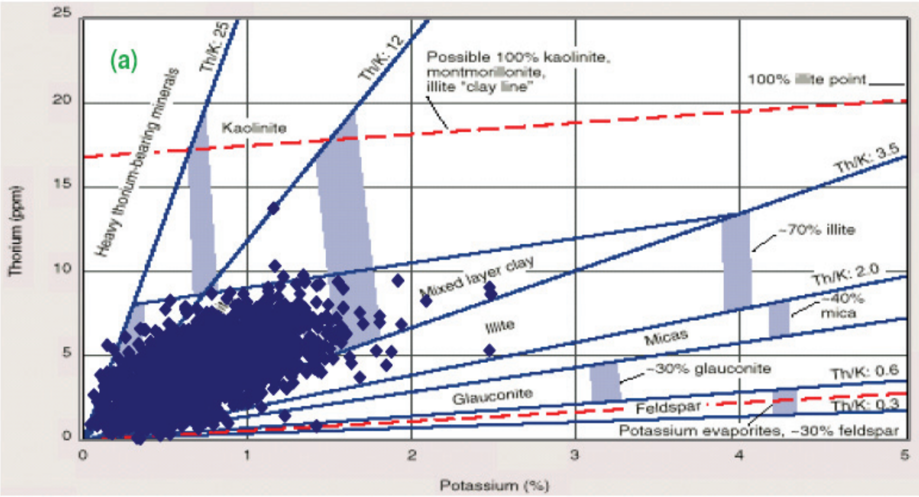



**Fig. 5a. Thorium – potassium cross-plot to identify clay type of Rudies sandstone in Belayim Marine oil field, Gulf of Suez, Egypt.**

*Scanning Electron Microscope (SEM) photographs*

Four core samples of from the sandstone of Rudeis Formation are examined for the type of clay minerals using the scanning Electron

Microscopy. It is found that kaolinite and illite exist in the Rudeis Formation sandstone (5b, c, d & e).

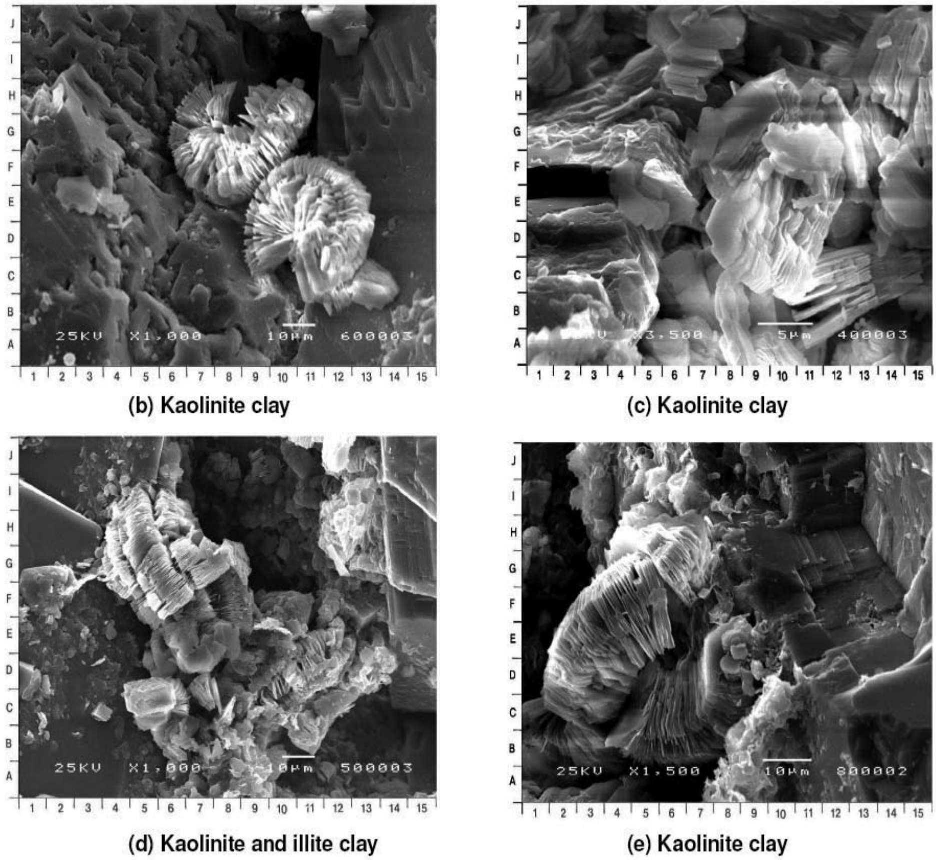



**Fig. 5 b, c, d & e. Clay type of Rudies sandstone in Belayim Marine oil field, Gulf of Suez, Egypt.**

### *b) Well Log Analysis*

The input data and output results of Rudeis Formation in BM-30 well are drawn in (Fig. 6). It is clear that the lithology of Rudeis Formation is mainly composed of sandstone and small percentage of shale. The average effective porosity is 20% that mean it has a good amount of hydrocarbon. Thus, the Rudeis Formation is considered as a very good reservoir.

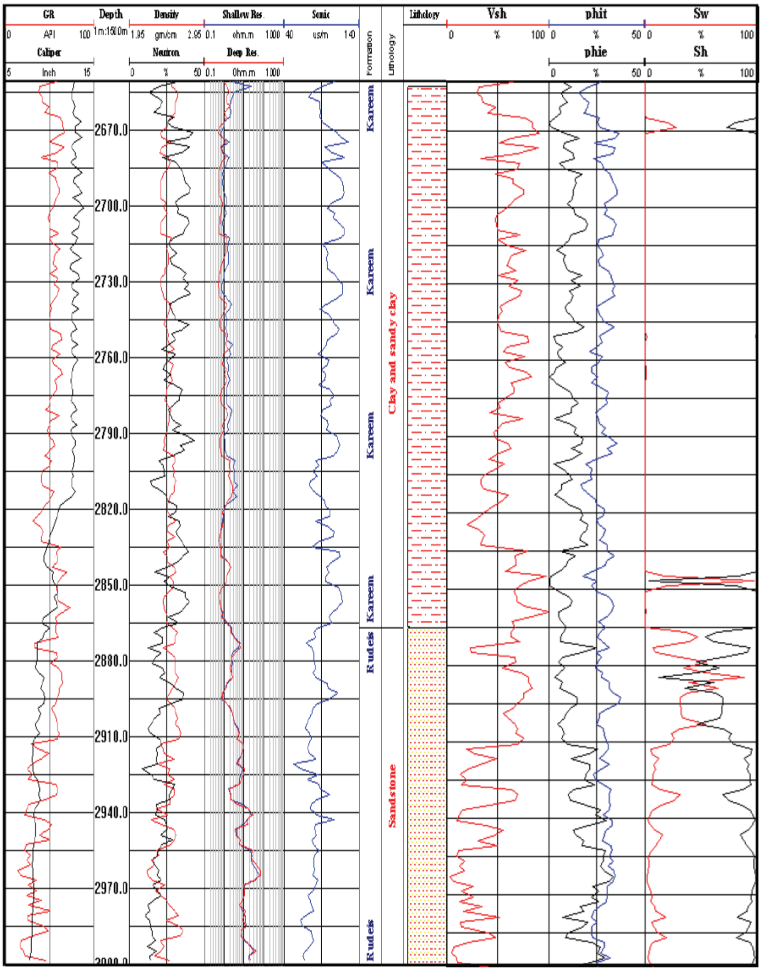



**Fig. 6. Well log analysis of Rudies Formation in BM-30 well in Belayim Marine oil field, Gulf of Suez, Egypt.**

## *Reservoir Mapping*

The results of well log analyses for the Rudeis Formation of Belayim marine wells are listed in Table 2. The results of the interpreted parameters are listed in contour maps to show the lateral distribution of these reservoir parameters. Figure 7(a) illustrates the horizontal distribution of the shale volume of Rudeis Formation in the study area. The volume of shale values increase toward the northwest where, the maximum value (44%) is recorded at BM–57 well. These values decrease to the minimum value (16%) in the northeast part of the study area at 113–M-27 well.

**Table 2. Well log analysis parameters of Rudies Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

| Well Name | V Sh % | Phi. T % | Phi. E % | Sw % | Sh % | Oip m | BPV m | Thick, m |
|---|---|---|---|---|---|---|---|---|
| BM-30 | 38 | 29 | 18 | 16 | 84 | 19.5 | 22.5 | 131 |
| BM-35 | 30 | 33 | 21 | 17 | 83 | 96.3 | 118 | 613 |
| BM-37 | 36 | 31 | 20 | 19 | 81 | 48.9 | 58.3 | 295 |
| BM-57 | 44 | 31 | 14 | 27 | 73 | 16.4 | 22.4 | 169 |
| BMNW-2 | 36 | 25 | 13 | 14 | 86 | 20.9 | 25 | 178 |
| BMNW-3 | 35 | 28 | 17 | 42 | 58 | 14.6 | 27.4 | 165 |
| 113-M-27 | 16 | 30 | 25 | 35 | 65 | 44.3 | 63.1 | 233 |
| 113-M-34 | 26 | 26 | 18 | 20 | 80 | 35.7 | 44.7 | 255 |
| 113-M-81 | 32 | 26 | 16 | 27 | 73 | 32.9 | 43.8 | 288 |

The maximum value of the total porosity (33%) in center is recorded in BM–35 well at the central part of the study area (Fig. 7b). The total porosity decreases in the NW and SE directions of the oil field. The minimum value (25%) is recorded in BMNW–2 well at the northwest part of the study area. Thus, the total porosity values of Rudeis Formation reflect very good porosity. The effective porosity values range from 13 to 25 %. The effective porosity values decrease from the NE toward the NW directions as it is shown in (Fig. 7c). The horizontal distribution of the effective porosity ensures that the Rudeis Formation has a good permeability.

Figure 7(d) illustrates the horizontal distribution of the water saturation parameter in the study area. The water saturation increases toward the NE and NW directions, while it decreases toward the SW direction. The maximum water saturation value is 42% while, the minimum value is 14%. Thus, the southeast part of study area which has a little amount of water is considered to have a very good potentiality for reserving oil.

On the other hand, Fig. 7(e) illustrates the horizontal distribution of hydrocarbon saturation. The southwest part of the study area has very good amount of oil accumulation. The hydrocarbon saturation decreases toward the NW and NE directions.

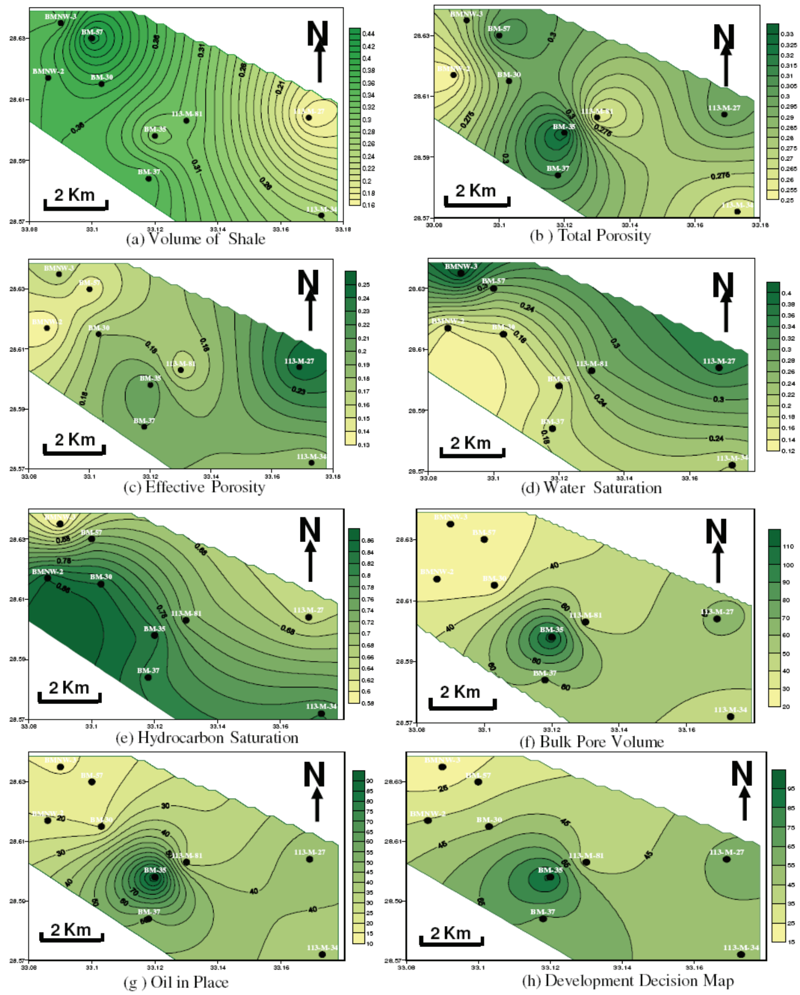



**Fig. 7. Formation evaluation parameters of Rudeis Formation, Belayim Marine oil field, Gulf of Suez, Egypt.**

In the study area, the values of hydrocarbon saturation range from 58 to 86%. Thus, the Rudeis Formation is very good reservoir and has good amounts of hydrocarbons.

Figure 7(f) illustrates the horizontal distribution of bulk pore volume of Rudeis Formation, The bulk pore volume increases in the central part and decreases outwards. The bulk pore volume values range from 22.4m at BM– 57 well to 118m at BM–35 well.

The amount of the oil in place is very huge and it decreases toward the NW and SE directions (Fig. 7g). The maximum amount of oil is 96.3m while the minimum amount is 14.6m. Eight reservoir parameters are used to estimate the development map. The development map is dependent on the estimated reservoir parameters. Figure 7h illustrates the development map of Rudeis Formation in Belayim marine oil field. It illustrates that the south central and northeast parts of the study area are profitable to explore, drill, develop and to produce oil.

*Comparison of Spectrometry with Well Log Analysis*

The results of the thorium normalization technique (DRAD Curve) are correlated with the results of the well log analysis. The positive DRAD values are related with high total porosity, high effective porosity, high oil in place and low shale volume values. On the other hand, the negative DRAD values are related with low total porosity, low effective porosity, low oil in place and high shale volume values (Fig. 8). The results of thorium normalization technique agree with the results of the well log analysis by 95% percent. Thus, it can be used safely to determine the oil bearing zones by using gamma ray spectrometry log.

### *c) Core Analysis*

Routine and special core analyses are used to evaluate the Rudeis Formation samples in Belayim marine oil field. Routine core analysis includes porosity and permeability, while special core analysis includes measurements of electrical properties, porosity under stress and capillary pressure.

*Porosity*

Table 3 illustrates the descriptive statistical analysis for the porosity of Rudeis Formation in 113-M-11 and 113-M-81 wells.

The porosity of Rudeis Formation in 113-M-11 well ranges from 9.9 to 23.3% and the mean value is 15.6%. On the other hand, the minimum porosity value of Rudeis Formation in 113-M-81 well is 14.1%, the maximum value is 32.2%, and the mean porosity value is 24.7%. The standerd deviation values for 113-M-11 & 113-M 81 are 3.6% and 4.3%, respectively. It indicates that the Rudeis Formation has a heterogeneous porosity values. The statistical analysis for the porosity values ensure that the Rudeis Formation is represented by very good reservoir.

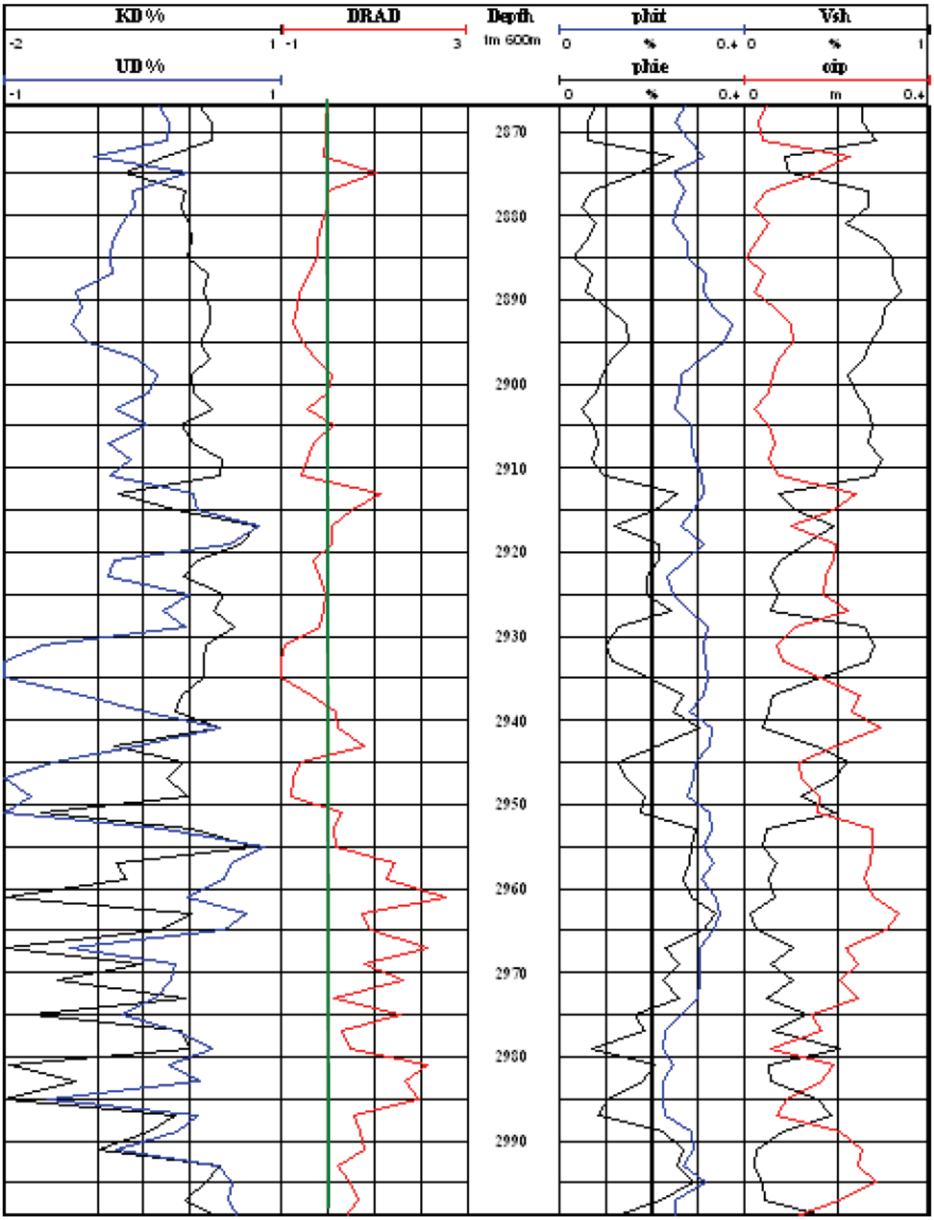
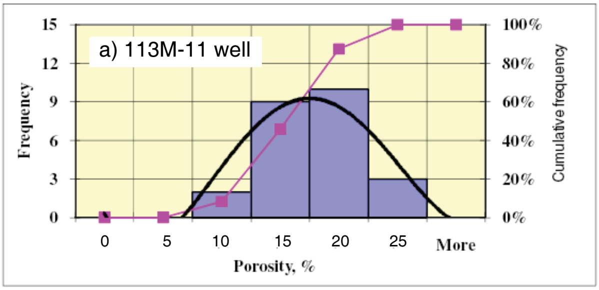



**Fig. 8. Comparison of spectrometry and well log analysis of Rudeis Formation in BM-30 well in Belayim Marine oil field, Gulf of Suez, Egypt.**

**Table 3. Statistical analysis of porosity of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

| Well Name | 113-M-11 | 113-M-81 |
|---|---|---|
| Mean | 15.60% | 24.70% |
| Standerd Deviation | 3.60% | 4.30% |
| Minimum | 9.90% | 14.10% |
| Maximum | 23.30% | 32.20% |
| Count | 373.70% | 417.70% |
| Number | 24 | 17 |

| porosity | Frequency | Cumu. |
|---|---|---|
| 0 | 0 | 0.00% |
| 5 | 0 | 0.00% |
| 10 | 2 | 8.33% |
| 15 | 9 | 45.83% |
| 20 | 10 | 87.50% |
| 25 | 3 | 100.00% |
| More | 0 | 100.00% |




| Porosity | Frequency | Cumu. % |
|---|---|---|
| 10 | 0 | 0.00% |
| 15 | 1 | 5.88% |
| 20 | 1 | 11.76% |
| 25 | 6 | 47.06% |
| 30 | 8 | 94.12% |
| More | 1 | 100.00% |

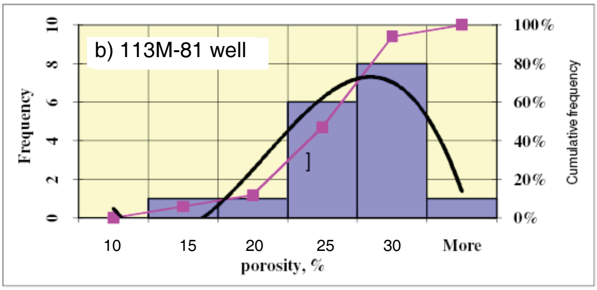



**Fig. 9 (a & b). Porosity histograms and cumulative frequency curves of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

The histogram and cumulative frequency curve for the porosity of studied samples of Rudeis Formation are represented in (Fig. 9). If the porosity cut off (10%) is applied, 91.67% of the studied samples of 113-M-11 well have porosity values larger than the porosity cut off (Fig. 9 a), while about 100% of the studied samples of 113-M-81 well have values larger than the porosity cut off (Fig. 9 b). These high values of porosity indicate that the Rudeis Formation is considered an excellent reservoir.

*Permeability*

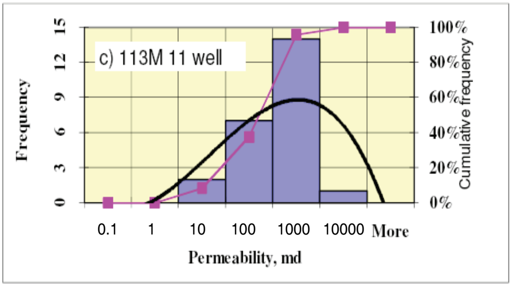
The permeability of Rudeis Formation is studied in 113-M-11 and 113-M-81 wells. Table (4) illustrates the descriptive statistical analysis for the permeability of Rudeis Formation in these two wells. The minimum permeability value of Rudeis Formation in 113-M-11 well is 5.3md, and the maximum value is 1195md. The mean value of the studied samples is 272md. On the other hand, the permeability of Rudeis Formation in 113-M-81 well ranges from 42.3md to 3148md. The mean value of these samples is 1490md. The Rudeis Formation has a heterogeneous permeability according to the high standerd deviation values of 297md and 831md for the samples of 113-M-11 and 113-M-81 wells, respectively. From the statistical analysis, the permeability ensuring that the Rudeis Formation is considered as a very good reservoir.

**Table 4. Statistical analysis of permeability of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

| Well Name | 113-M-11 | 113-M-81 |
|---|---|---|
| Mean | 272 md | 1490 md |
| Standerd Deviation | 297 md | 831 md |
| Minimum | 5.3 md | 42.3 md |
| Maximum | 1195 md | 3148 md |
| Count | 6517 md | 25345 md |
| Number | 24 | 17 |

The permeability histogram and cumulative frequency curve for the studied samples of Rudeis Formation are represented in (Fig. 9 c and d). In 113-M-11 well, if the permeability cut off of 10md is applied, 91.67% of the studied samples have permeability values larger than the permeability cut off (Fig. 9 c). If the permeability cut off of 10md is applied in 113-M-81 well (Fig. 9 d), 100% of the studied samples have values larger than the permeability cut off. These high values of permeability indicate that the Rudeis Formation is considered as an excellent reservoir.

| Perm. | Frequency | Cumu. % |
|---|---|---|
| 0.1 | 0 | 0.00% |
| 1 | 0 | 0.00% |
| 10 | 2 | 8.33% |
| 100 | 7 | 37.50% |
| 1000 | 14 | 95.83% |
| 10000 | 1 | 100.00% |
| More | 0 | 100.00% |




| Perm. | Frequency | Cumu. % |
|---|---|---|
| 10 | 0 | 0.00% |
| 100 | 1 | 5.88% |
| 1000 | 3 | 23.53% |
| 10000 | 13 | 100.00% |
| More | 0 | 100.00% |

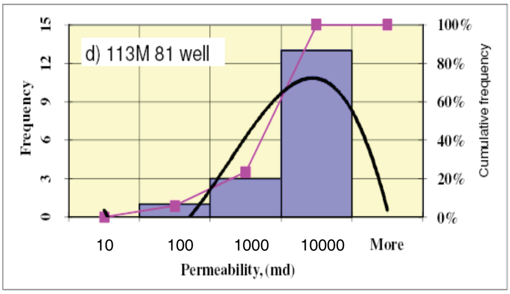



**Fig. 9 c & d. Permeability histograms and cumulative frequency curves of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

### *Porosity – Permeability Relationship*

The porosity-permeability relationship of Rudeis Formation in 113-M-11 well is illustrated in (Fig. 10 a). The correlation coefficient of this relation has a positive value of 0.78 and the regression equation for this relationship is;

$$K = 0.658\ e^{0.37\phi}$$

Figure 10 (b) illustrates the relationship between porosity and permeability for Rudeis Formation in 113-M-81 well. The correlation coefficient is 0.78 and the regression equation for this relationship is;

$$K = 10.26\ e^{0.2\ \phi}$$

### *Porosity – Formation Factor Relationship*

The special core analysis data are available for Rudeis Formation in 113-M-81 well. Figure 10 (c) illustrates the relationship between porosity and formation factor of Rudeis Formation.

(a) = 0.79 and cementation factor (m) = 1.86

The correlation coefficient have very high negative value (-0.99) and the regression equation for this relation is;

$$F = 0.79 \text{ x } \phi^{-1.86}$$

*Water Saturation – Resistivity Index Relationship*

Figure 10 (d) illustrates the relationship between resistivity index and water saturation. The relationship reflects that, (c) = 0.8 and saturation exponent (n) = 2.2. The correlation coefficient has a very high negative value (-0.96) and the regression equation for this relation is:

$$RI = 0.8 \text{ x } S_w^{-2.2}$$

The samples of Rudeis Formation reflect the phenomena of water wet. The determined parameters from cores are used to do well log interpretation.

*Effect of Pressure on Porosity*

The total porosity of the Rudeis Formation samples is affected by increase in pressure as a consequence of the increase of overlying weight. The increase in pressure causes decrease in porosity. Figure 10 (e) illustrates the relationship between porosity and pressure in 113-M-81 well. The total porosity is correlated negatively with the pressure, where the correlation coefficient reaches 1, and the regression equation is:

$$\phi_t = 28.8 \text{ x } Pc^{-0.03}$$

*Pore Size Distribution-Pore Throat Radius Relationship*

Figure 10 (f) illustrates the relationship between the pore throat radius and the pore size distribution of Rudeis Formation in 113-M-81 well. The pore throats for the Rudeis Formation samples have radius range from 6µm to 30µm. These radii values indicate that the different types of fluids (water and hydrocarbon) can pass easily through these wide pore throats.

*Capillary Pressure*

The eight samples of Rudies Formation in 113-M-11well are studied for capillary pressure. The results of capillary pressure data of Rudeis Formation are tabulated in Table 5.

**Table 5. Capillary pressure parameters of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

| Sample | $\phi_t$ | (k) | $Sw_{irr}$ | $\phi_e$ | Re | R | $r_h$ | $r_p$ |
|---|---|---|---|---|---|---|---|---|
| 675 | 0.23 | 2964 | 0.08 | 0.21 | 80.6 | 2589 | 255 | 322 |
| 724 | 0.03 | 0.1 | 0.5 | 0.01 | 40.2 | 473 | 4.3 | 5.5 |
| 754 | 0.21 | 548 | 0.14 | 0.18 | 82.5 | 1254 | 113 | 143 |
| 774 | 0.23 | 1534 | 0.1 | 0.21 | 78.5 | 1849 | 183 | 232 |
| 813 | 0.09 | 3.7 | 0.37 | 0.06 | 74.2 | 451 | 14.5 | 18 |
| 1044 | 0.24 | 200 | 0.28 | 0.17 | 79.6 | 640 | 65.4 | 82.7 |
| 1088 | 0.17 | 45 | 0.28 | 0.12 | 79.9 | 560 | 63.8 | 46.5 |
| 1134 | 0.19 | 33 | 0.42 | 0.11 | 69.3 | 387 | 29.7 | 38 |

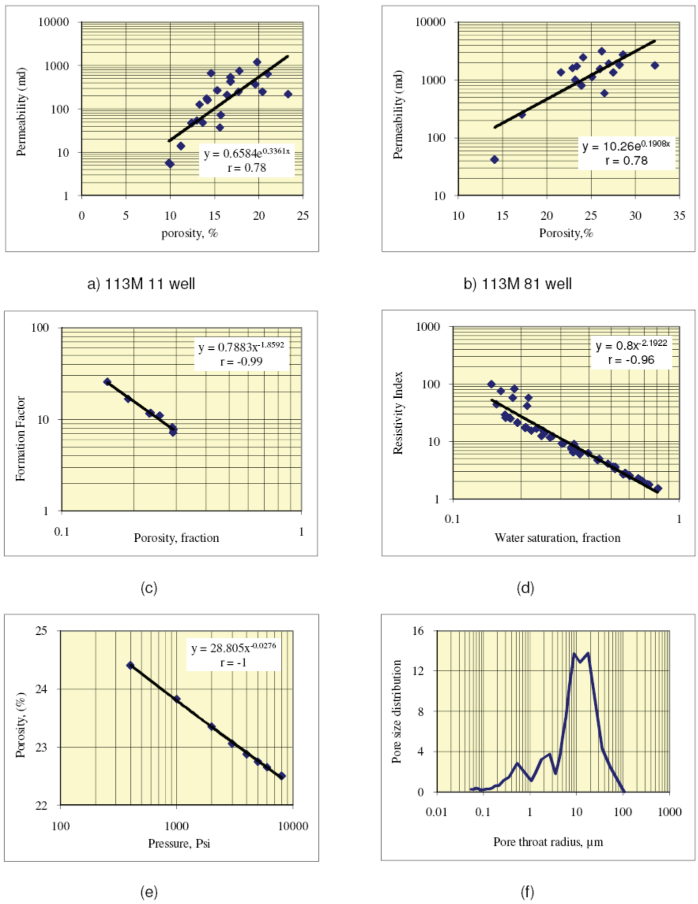



**Fig. 10. Core analysis relationships of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

*Capillary Pressure Derived Parameters Relationships*

Figure 11 (a) illustrates the relationship between capillary pressure and brine water saturation for the studied samples. The relationships between the irreducible water saturation and the different capillary pressure derived parameters are represented by negative fair relations as illustrated in (Fig. 11 b and f). The correlation coefficients of these relations are -0.4, -0.4, -0.57, -0.4 and -0.4 for the relations between irreducible water saturation and hydraulic radius, pore radius, packing, permeability and recovery efficiency, respectively. The negative and low values of the correlation coefficients indicate that the independence of the estimation of one variable from the other. Irreducible water saturation increases when the capillary pressure derived parameters decreases. The regression equations for these relationships are also illustrated in (Fig. 11 b and f).

On the other hand, the relationships between the effective porosity and the other capillary pressure derived parameters are found by excellent positive (0.9 and 0.9) relationships with hydraulic radius and pore radius (Fig. 12 a and b). The correlation coefficient of the positive relationship between the effective porosity and packing is represented by a moderate value of 0.52. The correlation coefficient of the relationship between the effective porosity and recovery efficiency is found to be -0.51 with negative trend (Fig. 12 c and d). Thus, the effective porosity increases by increasing the hydraulic radius, pore radius and packing while, it decreases by increasing the recovery efficiency. The regression equations are illustrated on (Fig. 12). The relationships between the recovery efficiency and both hydraulic radius and pore radius are represented by negative relations (Fig. 12 e and f). The correlation coefficients are -0.56 and -0.56, respectively.

The correlation coefficients of the relations between the packing and both hydraulic radius and pore radius are found by very good positive values, 0.8 and 0.8, respectively. The recovery efficiency decreases by increasing the hydraulic radius and pore radius, while, the packing increases by increasing the hydraulic radius and pore radius (Fig. 12 g and h).

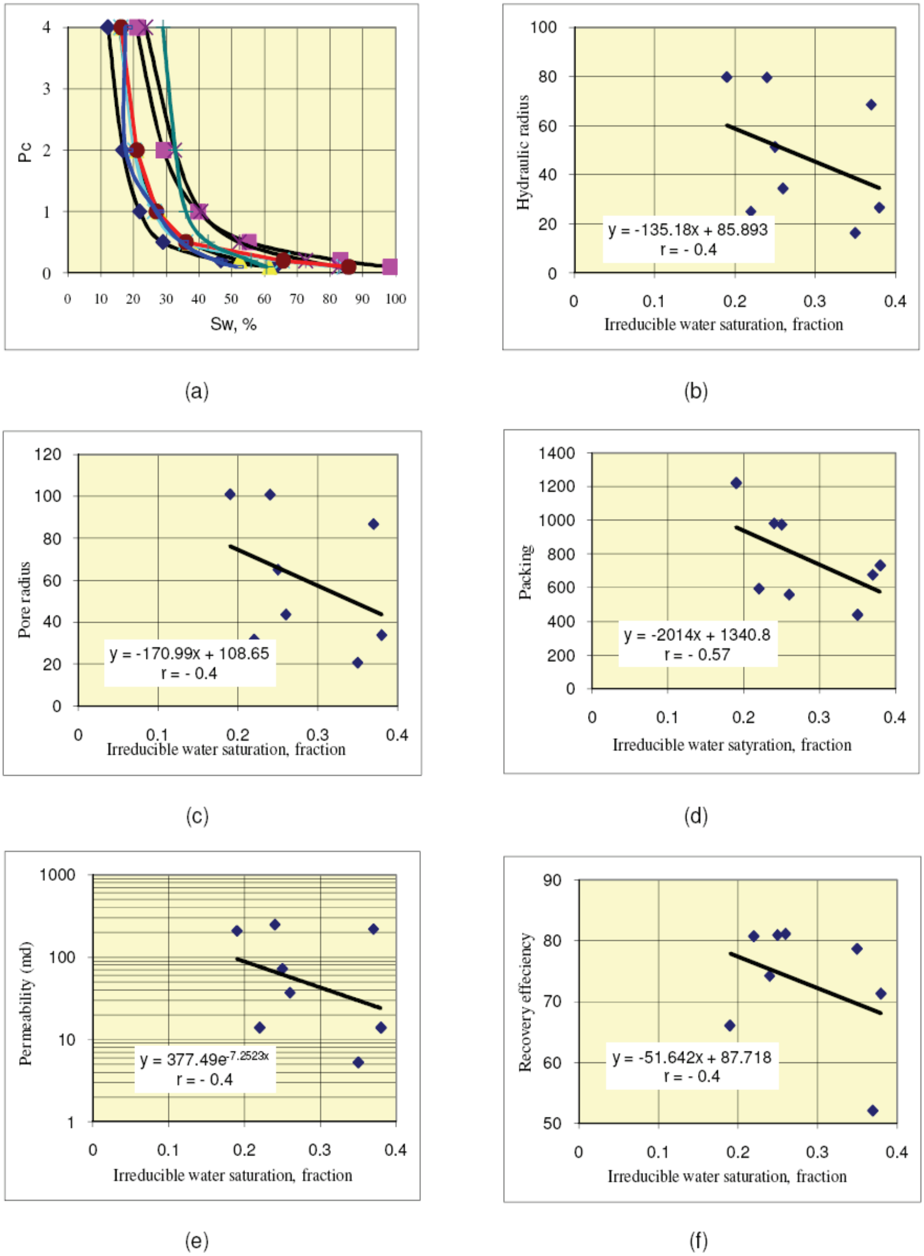



**Fig. 11. Relationships of capillary pressure measurements of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

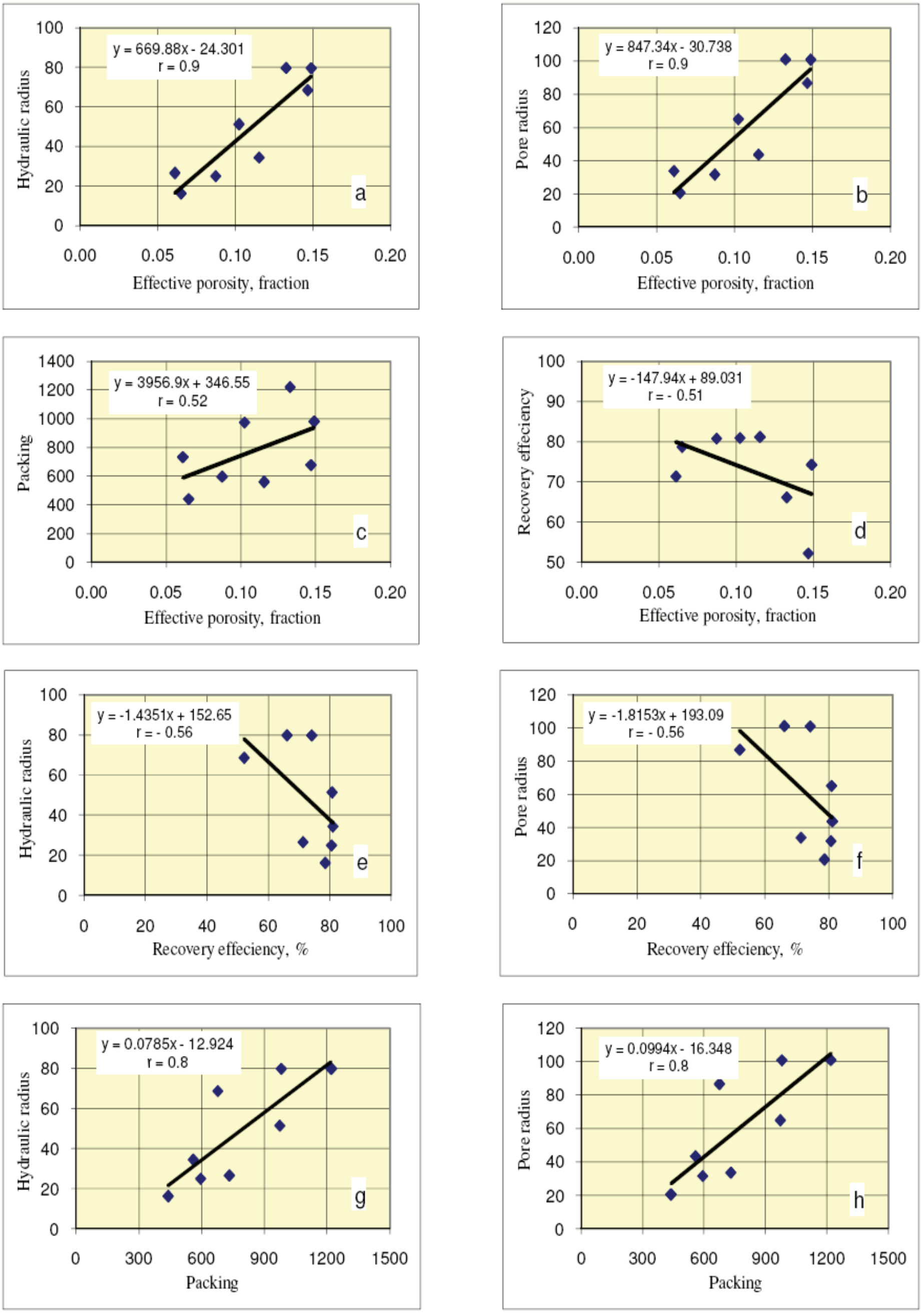



**Fig. 12. Relationships of capillary pressure parameters of Rudeis Formation in Belayim Marine oil field, Gulf of Suez, Egypt.**

## Conclusions

1. By thorium normalization technique, the hydrocarbon accumulation zones can be determined.

2. The results of the new technique (thorium normalization) are highly in agreement with the results of the conventional well log analysis by 95%.

3. The gamma-ray spectrometry log can be safely used as hydrocarbon accumulation log.

4. The high values of porosity and permeability estimated from both core and well log analyses, indicate the high storage capacity of Rudeis Formation and its ability to store and pass the fluids.

5. The cementation factor (m), saturation exponent (n) and other constants (a) and (c) for the Rudeis Formation are determined from the special core analysis data.

6. The wide pore throat radius in the studied samples indicates that the different types of fluids can path easily through the pores.

7. Irreducible water saturation, displacement pressure, effective porosity, hydraulic radius, pore radius and packing parameters are derived from the capillary pressure data.

8. The high correlation coefficients values between the different capillary pressure derived parameters indicate that any parameters can be estimated from the other.

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# إشعاعية وخواص خزان متكون روديس بحقل بترول بلاعيم بحري، خليج السويس، مصر

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*المستخلص.* تستخدم تسجيلات العناصر المشعة المكونة لأشعة جاما لتحديد مدى ثبات هذه العناصر، وتحديد نسبة الطفلة، بالإضافة إلى نوعية معادن الطين في صخور الخزان. تم قياس ثلاثة تسجيلات إشعاعية لمكافئ اليورانيوم، ومكافئ الثوريوم، ونسبة البوتاسيوم لمتكون روديس في ٧ آبار في حقل بترول بلاعيم بحري. عكست نتائج التحليل الإحصائي لعناصر أشعة جاما في متكون روديس بأن العنصر المشع الرئيسي، هو اليورانيوم، بما يدلل على احتواء متكون روديس على مواد عضوية. كما عكس التحليل الإحصائي ثبات عنصر الثوريوم، بما يدلل على عدم انتقال هذا العنصر إلي هذا المتكون لاحقا. أوضحت نتائج العناصر المشعة المكونة لأشعة جاما، وصور الماسح الإلكتروني، بأن معادن الطين في صخور الخزان تتمثل في المنتمورلونيت، والكاولينيت، والكلوريت، والطين المختلط.

بجانب هذا الدور التقليدي للعناصر المشعة المكونة لأشعة جاما، فإنها لعبت دورا جديدًا وهاما في هذا البحث، حيث تم استخدامها في تحديد النطاقات الحاملة للزيت في متكون روديس.

أوضح تحليل تسجيلات الآبار بأن متكون روديس يتكــون بصورة رئيسية من أحجار رملية، والقليل من صخور الطفلة، وأن خواص الخزان المستنتجة تبين بأن متكون روديس يعتبر خزانًا ذا كفاءة عالية. تم تكامل بيانات معــاملات الخــزان الثمانيــة التــي استنتجت من تسجيلات الآبار، في رسم خريطة تطــوير متكــون روديس في حقل بترول بلاعيم بحري. أوضحت خريطــة اتخــاذ قرار تطوير متكون روديس بمنطقة الدراسة، بأن اتجاه الجنــوب، واتجاه الشمال الشرقي لمنطقة الدراســة، همــا أفــضل الأمــاكن للاستكشاف، والحفر، والتطوير، والإنتاج. بينت النتائج التــي تــم التوصل إليها من أشعة جاما لتحديد النطاقات الحاملة للزيت توافقًــا تامًا مع نتائج تسجيلات الآبار.

أمكن تقييم الخــواص البتروفيزيائيــة لمتكــون روديــس، باستخدام تحاليل العينات اللبية من بئرين ممثلين لهــذا المتكــون، حيث بلغ متوسط قيمة المسامية في هذه العينــات ٢٠٪ ومتوســط النفاذية ٨٩٠ مللى دارسى. تم استخدام تحاليل العينات الأســطوانية الخاصة لتحديد بعض معاملات الخزان الهامة، مثل تحديد معامــل التماسك (m) والذى بلغ ١,٨٦، ومعامل التشبع الأسى (n)، والذي كان قيمته ٢,٢, كما أمكن تحديد قيمة كل من (a)، وكان يــساوي ٠,٧٩، بينما بلغت قيمة (c) ٠,٨ ، ومن خــلال العلاقــات بــين المعاملات المختلفة وجد أن المسامية ترتبط ارتباطا قويًا بمعامــل مقاومة الخزان، حيث أن معامل الارتباط بينهما وصل إلى ٠,٩٩، بينما وصل معامل الارتباط بين نسبة التــشبع بالمــاء، ومعامــل المقاومة إلى ٠,٩٦ . بدراسة قطر عنــق المــسام فــي العينــات الأسطوانية تبين أن معظم المسام في متكون روديس يتراوح أقطار أعناقها بين ١٠ إلى ٣٠ ميكرومترًا مما يــسمح بمــرور الموائــع المختلفة بين المسام. بإجراء قياسات الضغط الشعري، أمكن تحديد

كمية الماء المقترن المتعذر إخراجه من الصخر. كما تم اســتنتاج بعض الخصائص الهامة للحبيبات والمسام الموجودة في الــصخر، مثل متوسط كفاءة قطر المسام، وقطر تقارب وتمــاس الحبيبــات، وقطر مرور المياه. تم عمل علاقات بين هذه المعاملات المختلفة، وتبين أنها ترتبط ببعضها البعض بمعاملات قوية، وبــذلك يمكــن استنتاج بعض المعاملات من بعضها البعض.