Egyptian Geophysical Society
EGS Journal, Vol. 18, No. 1, 195-208 (2020)

RESERVOIR EVALUATION USING WELL LOG ANALYSIS FOR HAMMAM FARAUN MEMBER, BELAYIM LAND OIL FIELD, GULF OF SUEZ, EGYPT

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تقييم الخزان باستخدام تسجيلا ت الآبار لعضو حمام فرعون، حقل بترول بلاعيم البرى، خليج السويس، مصر

الخلاصـــــة: تهدف الدراسة الحالية إلى تفسير البيانات الجيولوجية والجيوفيزيائية لتقييم التكوين الصخرى والخواص البتروفيزيائية لعضو الميوسين الأوسط حمام فرعون الذى يمثل الجزء العلوى من متكون بلاعيم اعتمادًا على البيانات المتوفرة والممثلة في السـجلات الجيولوجية وأنواع مختلفة من سـجلات الآبار لأربع آبار في حقل بترول بلاعيم البرى.

يشمل تحليل سجلات الآبار المتاحة لحساب الخواص البتروفيزيائية لصخور الخزان الممثلة في حجم المحتوى الطفلى (Vsh) ، والمسامية الكلية والفعالة (ϕ_E و ϕ_T) ، وتشبع السوائل سواء المياه او الهيدروكربونات (S_w & S_h) ، وسمك الخزان الصافي، لتعكس الإختلاف الرأسى والأفقى فى الخصائص البتروفيزيائية للخزان من خلال خرائط التوزيع التى تم بناؤها لمنطقه الدراسة. وقد نتج عن ذلك أن لدى عضو حمام فرعون خصائص بتروفيزيائية جيدة، مما يجعله خزانًا جيدًا يتميز بمتوسط حجم المحتوى الطفلى يتراوح بين ٦٪ إلى ١٢٪ و المسامية الفعالة من ٩٪ إلى ٢٣٪ ، وتشبع الماء من ١٦٪ إلى ٧٠٪ وتشبع الهيدروكربون من ٣٠ ٪ إلى ٨٥ ٪.

ABSTRACT: *The current paper aims at using both geological and geophysical data to evaluate the petrophysical characteristics and hydrocarbon potentiality of the Middle Miocene Hammam Faraun Member in the Belayim land oil field; based on the available data represented by geological composite logs and different types of open-hole wireline logs for four wells (112-82, 112-161 ST3, 113-81 and 113-123).*

Analysis of available well logs includes the determination of the petrophysical properties of reservoir rocks namely the shale volume (Vsh), porosity (ϕ_T and ϕ_E), fluids saturation (S_w & S_H), and net-pay thickness to reveal the vertical and horizontal variations of reservoir characteristics through constructing the litho-saturation cross plots and iso-parametric maps of the study area. Also, a different type of cross-plots was constructed to identify lithology and clay minerals types.

The analysis revealed that Hammam Faraun Member has good petrophysical properties, which makes it a potential reservoir with an average shale volume ranging from 6% to 12%, effective porosity from 9% to 23%, water saturation from 16% to 70% and hydrocarbon saturation from 30% to 85%.

1. INTRODUCTION

Gulf of Suez is the north-western arm of the Red Sea rift system and partly separates the Sinai Peninsula from the remainder of Egypt. It is one of the interesting oil provinces in Egypt which has exposed to intensive exploration activities since the early twentieth century (Mokhles et al., 2009). Belayim Land Oil Field is considered one of the most important, largest, oldest and famous oil fields in Egypt and Gulf of Suez. It represents a significant portion of oil production of Petrobel Company and Egypt. It is located in the eastern coast of the Gulf of Suez at North West Gabal Ekma - Abu Durba, between Latitudes 28° 33′ 00`` to 28° 40′ 00″ N and Longitudes 33° 12′ 00`` to 33° 15′ 00″ E, About nine kilometers east of Belayim Marine field, twenty five kilometers south of Abu- Rudeis city and one hundred and sixty five kilometers southeast of the Suez city covers an area of about one hundred and thirteen km^2 (Fig. 1) (EGPC, 1996).

The Middle Miocene (Serravallian age) Belayim Formation represents an important primary target for oil production in Belayim land oil field and other many oil fields in the Gulf of Suez. It is subdivided into four members as; Baba Member, Sidri Member, Feiran Member and Hammam Faraun Member from base to top.

This paper deals with Hammam Faraun Member at Belayim land oil field and evaluates geologically and petrophysically the net pay zones based on the available data in the study area.

2. MATERIALS AND METHODS

A complete set of well logs includes Caliper (HCAL), Gamma Ray (GR), Natural gamma ray spectrometry (NGS), Resistivity (LLS, LLD), Bulk Density Log (RHOB), Neutron Log (NPHI), and Sonic Log (Δt), for four wells (112-82, 112-161 ST3, 113-81 and 113-123), in Belayim land oil field was used to estimate the petrophysical properties and evaluate the reservoir characteristics of Hammam Faraun Member within lateral and vertical variations of rock facies, through analyzing and interpreting this data, which is essentially analytical, based on a number of equations

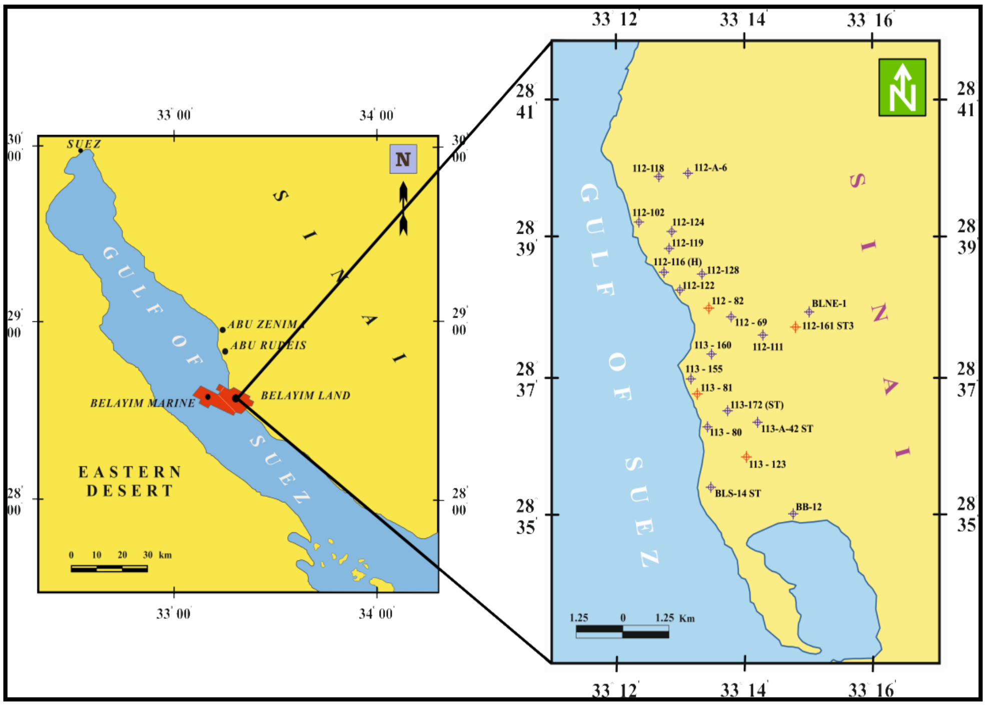

Fig. (1): Location map of the study area, Belayim land oil field, south Sinai, Egypt.

and empirical formula and charts recommended by Schlumberger Principles and Essentials (1972), Dresser Atlas, (1983), and Schlumberger Log Interpretation Charts (2009), to calculate and determine the formation temperature, volume of shale, total and effective porosity, water and hydrocarbon saturation, net bay thickness, that achieved by using integrated computer software named Techlog (2015.3), also identify lithology and clay minerals types through a number of different constricted cross-plots.

3. LITHOSTRATIGRAPHY

The NW-trending Gulf of Suez is an area of subsidence within the stable shelf and the northern part of Nubian-Arabian shield, that opening started in the Oligocene time according to (Robson, 1971), Oligocene-Miocene time according to (Garfunkel and Bartov, 1977), or early Miocene time according to (Adel R Moustafa, 1993 and Patton et al., 1994). It is subdivided into three distinct tectonic provinces; Darag basin at the northern end, the central basin or Belayim Province in the middle, and the southern Amal-Zeit Province, as a result of effect the "Clysmic" rift (Robson, 1971).

The lithostratigraphic sequence of the study area is affected by the geological setting of the Gulf of Suez. It ranges from Precambrian to Holocene in age, and subdivided into three dissimilar sedimentary phases related to the Miocene rifting events defined as the pre-rift, syn-rift and post-rift lithostratigraphic units (Fig. 2). The late Middle Miocene sequence of the Gulf of Suez represents one of a great importance stratigraphic units, due to, its role as one of the most prolific reservoir rocks

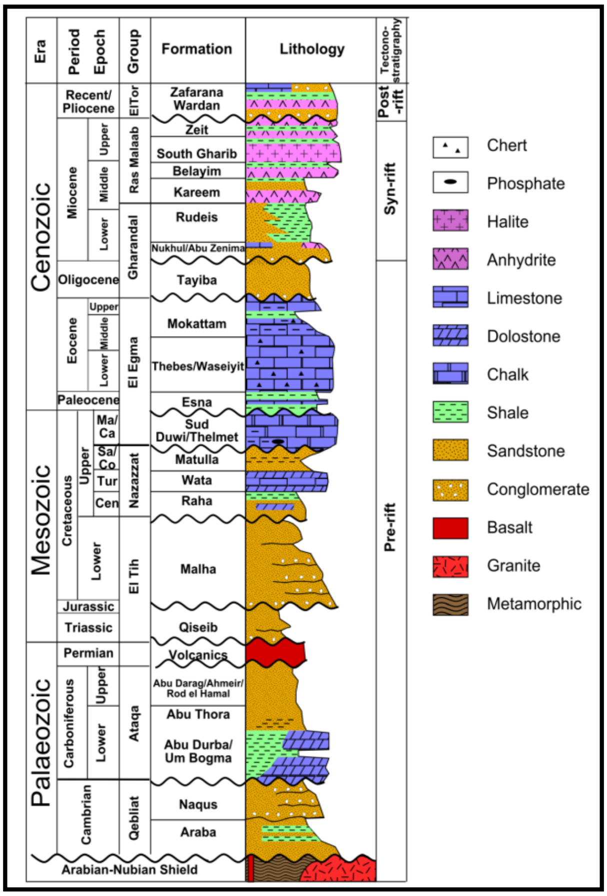

Fig. (2): Generalized Lithostratigraphic column of the Gulf of Suez (after Darwish and El Araby, 1993).

and as a seal rock in the Gulf of Suez province. It represents the marine Miocene evaporite cycle as it is deposited in NW - SE trending low areas. It is not deposited at the extreme northern part of the Gulf of Suez. It is subdivided into four formal members arranged from base to top to (Baba, Sidri, Feiran and Hammam Faraun Members) (EGPC, 1964).

Hammam Faraun Member occupies the topmost part of the Belayim Formation. It caps the evaporites of the Feiran Member and is separated from the overlying Pliocene sediments by conglomerates best observed at the area between Wadi Araba and Wadi Feiran. It is represented by 50m average thicknesses, and increases in thickness at the center, northeast and southwest direction of Belayim land oil field; with maximum thickness reaching 119m at well 113-160, also it is thinning towards the northwest and southeast part of Belayim land oil field to reaches the minimum thickness 22m at well 112-119 (Fig. 3, 4). This variation in thickness indicates the effects of faults on Hammam Faraun Member. Lithologically, it consists of calcareous shale and sandstone interbeds occasionally with dolomite interfingers were recorded in some wells in the north eastern part of the study area. The shale is light grey, brownish grey, light greenish grey, blocky to flaky, soft to moderate firm, highly calcareous grading to argillaceous limestone, fossilifery and dolomitic in parts the sands and sandstones are quartz-dominated, the grains are colorless, white, occasionally pink, fine to very fine grained, occasionally medium grained, sub-rounded to sub-angular, fairly sorted and partly with siliceous cement.

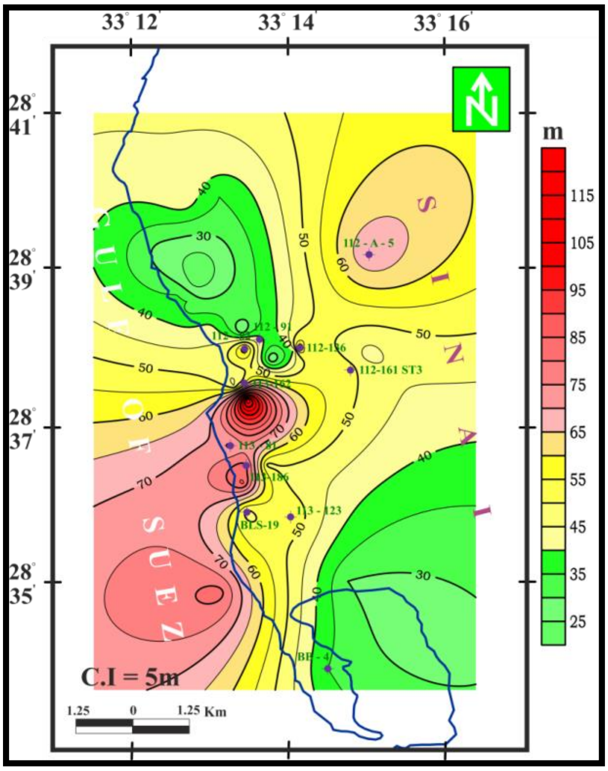

Fig. (3): Isopach map of Hammam Faraun Member, Belayim land oil field.

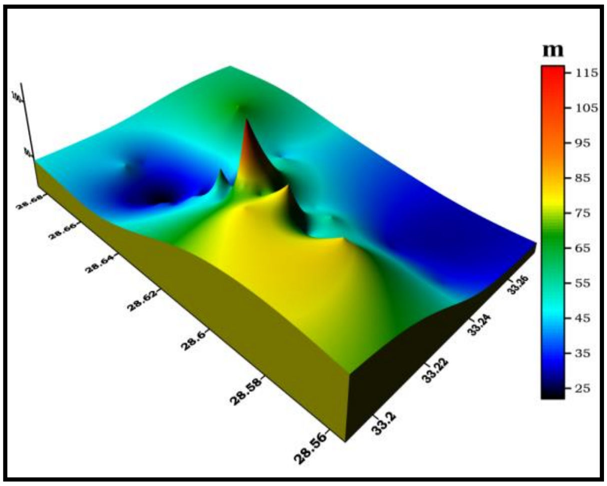

Fig. (4): Paleotopographic surface map of Hammam Faraun Member, Belayim land oil field.

4. WELL LOG ANALYSIS

The well logging analysis deduced parameters, resulted from Computer Processed Interpretation (CPI) process includes volume of shale, total porosity, effective porosity, water and hydrocarbon saturation and also net-pay zones through the following procedures, and tabulated in table (1).

4.1. Determination of Shale Volume (Vsh):

Estimation of shale volume was carried out using both single (Gamma Ray log) and double clay indicator (Neutron-Density combination) according to (Equations. 1 and 2). The final shale volume histogram of Hammam Faraun Member shows in (Fig. 5).

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} = Vsh_{GR} \qquad \textbf{(Eq. 1)}$$

$$Vsh_{N-D} = \left(\frac{\phi_N - \phi_D}{\phi_{Nsh} - \phi_{Dsh}} \right) \qquad \textbf{(Eq. 2)}$$

4.2. Determination of Formation Porosity (ϕ):

The quality of a reservoir is defined by its hydrocarbon storage capacity and deliverability that can be determined through the porosity volume of reservoir rocks. The total porosity has calculated using Neutron-Density method using Equation (3), and effective porosity has been calculated from the total porosity by using Equation (4), as obvious in (Fig. 5).

$$\phi_{N-D} = \sqrt{\frac{\phi_N^{\,2} + \phi_D^{\,2}}{2}} \qquad \textbf{(Eq. 3)}$$

$$\phi_E = \phi_t \left(1 - V_{sh}\right) \qquad \textbf{(Eq. 4)}$$

Table (1): Summary of petrophysical parameters of Hammam Faraun Member in the studied wells, Belayim land oil field.

Well Name	112-82	112-161 ST3	113-81	113-123
Interval (m)	2258 - 2336	2228 - 2287	2318 - 2399	2439.5 - 2515
Thickness (m)	78	59	81	75.5
Gross Sand (m)	38	8.5	8	2
Net Pay (m)	22.5	8.5	5.5	--
AVE. Vsh (%)	6	9	12	7
AVE. Φt (%)	23	13	23	9
AVE. Φe (%)	23	12	21	9
AVE. S_W (%)	21	16	31	70
AVE. S_H (%)	79	85	70	30

4.3. Determination of Formation Water Resistivity (Rw):

Determination of the formation water resistivity (Rw) is very important for well logging interpretation since it is required for the calculation of fluids saturation (Serra O., 1984). It represents a problematic petrophysical parameter because it is not constant in nature. It was determined by using laboratory measurement methods, which have been applied to all the studied wells, by knowing formation water salinity which is equal to 200000 ppm and formation temperature using Schlumberger chart (Schlumberger, 2009), it revealed that (Rw) values in the studied wells are equal to 0.020 ohm-m at formation temperature that equals about 175°F for all the studied wells.

4.4. Determination of Fluid Saturation (Sw & SH):

Most of the reservoirs at least consist of two different phases of liquids. These phases are gas water or oil water. Some of the reservoirs have all of the three phases of gas, oil and water (Dandekar, 2006). The determination of the fluids saturation involves principally the discrimination between the various fluid components (water and hydrocarbons). Determination of reservoirs water saturation is very important because it refers to the saturation of hydrocarbons in the reservoir. The water saturation is estimated in both the uninvaded-zone (Sw) and flushed zone (Sxo) by using Indonesia equation; accordingly the hydrocarbon saturation has been calculated depending upon the water saturation (Schon. J. H., 2011). (Fig. 5) are illustrations histograms of water and hydrocarbon saturation.

4.5. Net pay calculation:

The net pay zones have been determined by using suitable cutoffs of petrophysical parameters (Vsh is less than 0.3, (ϕ_E) is more than 0.08 and (Sw) is less than 0.55) to eliminate nonproductive rock intervals as illustrated in (Fig. 6, 7, 8 and 9).

5. RESERVOIR EVALUATION

Evaluation of reservoir rocks of Hammam Faraun Member using petrophysical parameters, namely shale volume, porosity (total and effective), and water and hydrocarbon saturation; and identifying the pay and non-pay zones related to the determined cutoffs of parameters, through Computer Processed Interpretation (CPI) using Techlog program which are represented diagrammatically in the form of litho-saturation cross-plots or iso-parametric maps which show the variations in reservoir properties in vertical and lateral extensions, respectively.

5.1. Vertical Variation of Petrophysical parameters:

Litho-saturation cross-plots represent one of the most important well logging interpretation processing data methods and reservoir evaluation for illustrating the gross characters of petrophysical parameters, in terms of lithology fractionation and fluid saturation through the well in the vertical direction.

The Litho-saturation cross-plot of well 112-82 is given in (Fig. 6), indicating that, Hammam Faraun Member covers an interval ranging from 2258m to 2336m, with 78m thickness. It is composed mainly of sandstone intercalated with shale, with 38m net-reservoir and net-pay 22.5m. The computer processed interpretation (CPI) of well logs in this well reflects a good pay that is characterized by average 6% shale volume, 23% average effective porosity and 21% average water saturation.

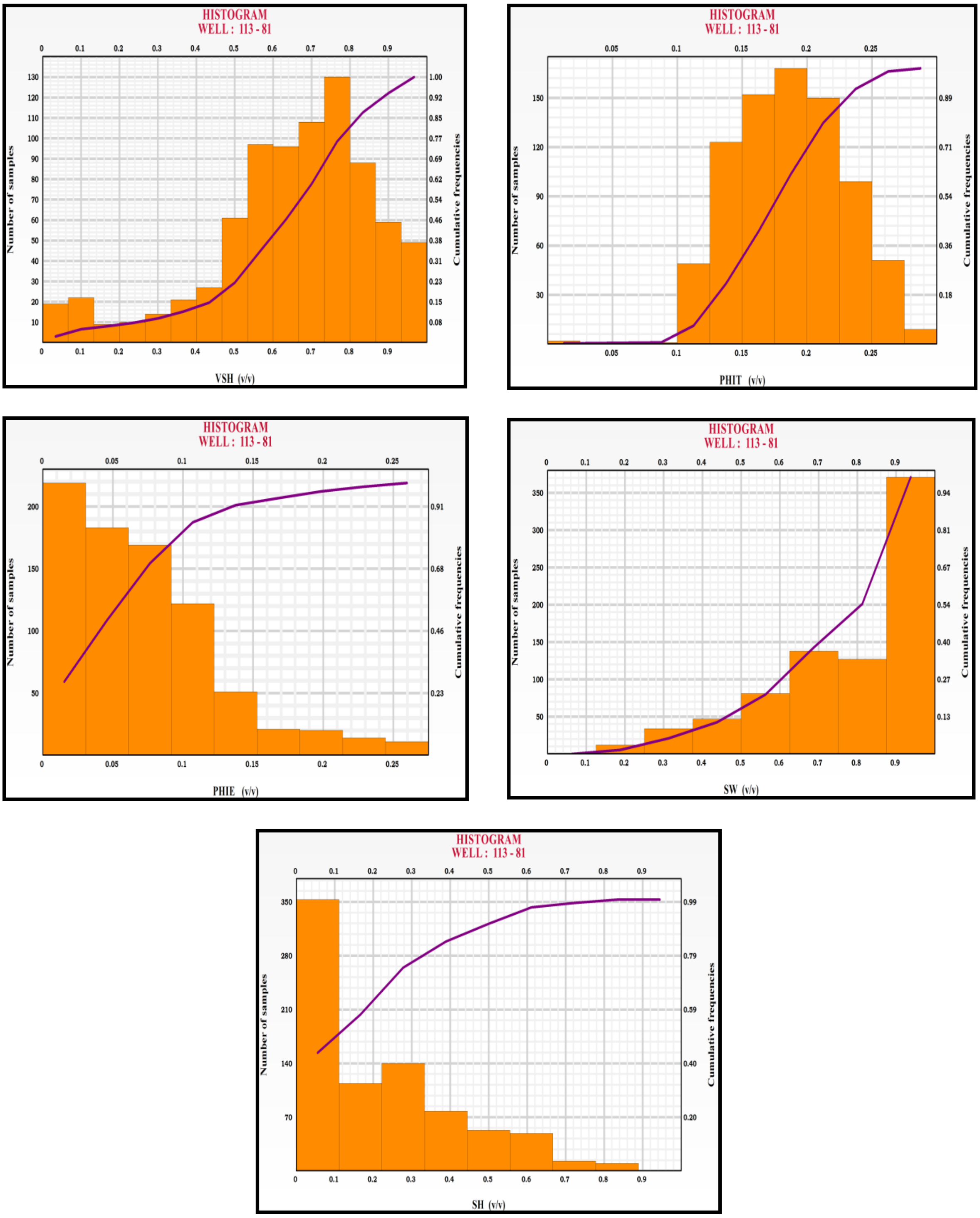

Fig. (5): Histograms of the calculated (Vsh, ϕ_t, ϕ_E, Sw, S_H) of 113-81 well.

Fig. (7) illustrates the Litho-saturation cross-plot for Hammam Faraun Member in 112-161 ST3 well. It shows that Hammam Faraun Member covers the interval from 2228m to 2287m, with 59m thickness. It is composed mainly of sandstone intercalated with shale, with 8.5m net-reservoir, that is considered a net-pay with average 9% shale volume, 12% average effective porosity and 16% average water saturation.

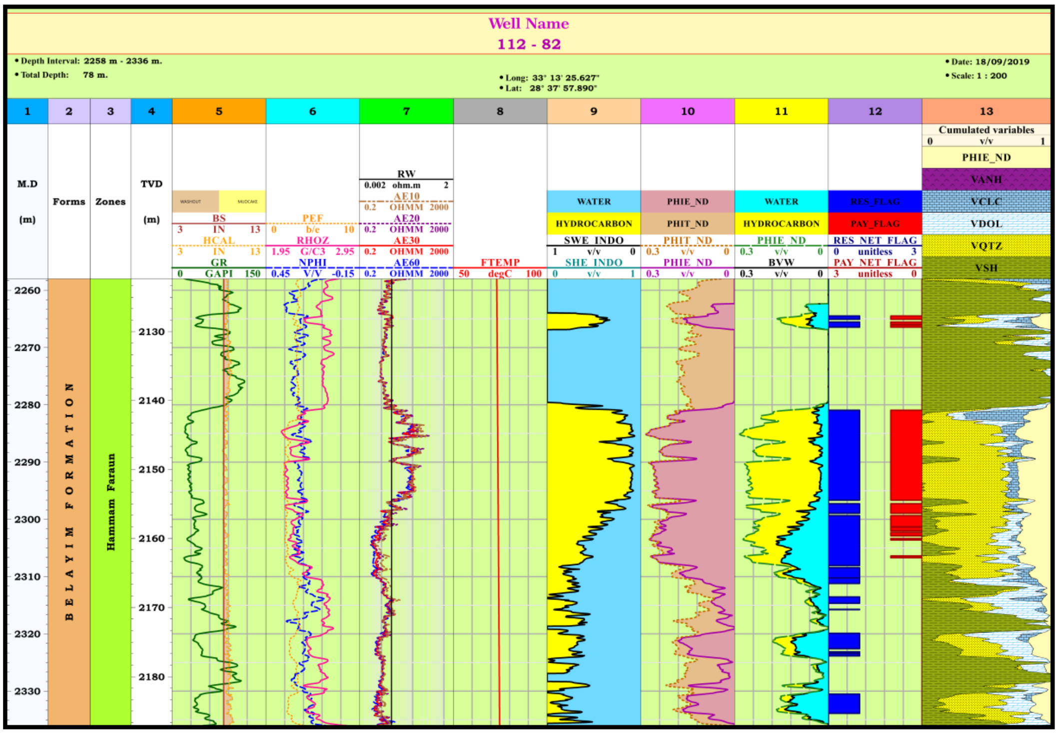

Fig. (6): Litho-saturation cross-plot of Hammam Faraun Member in Well (112-82).

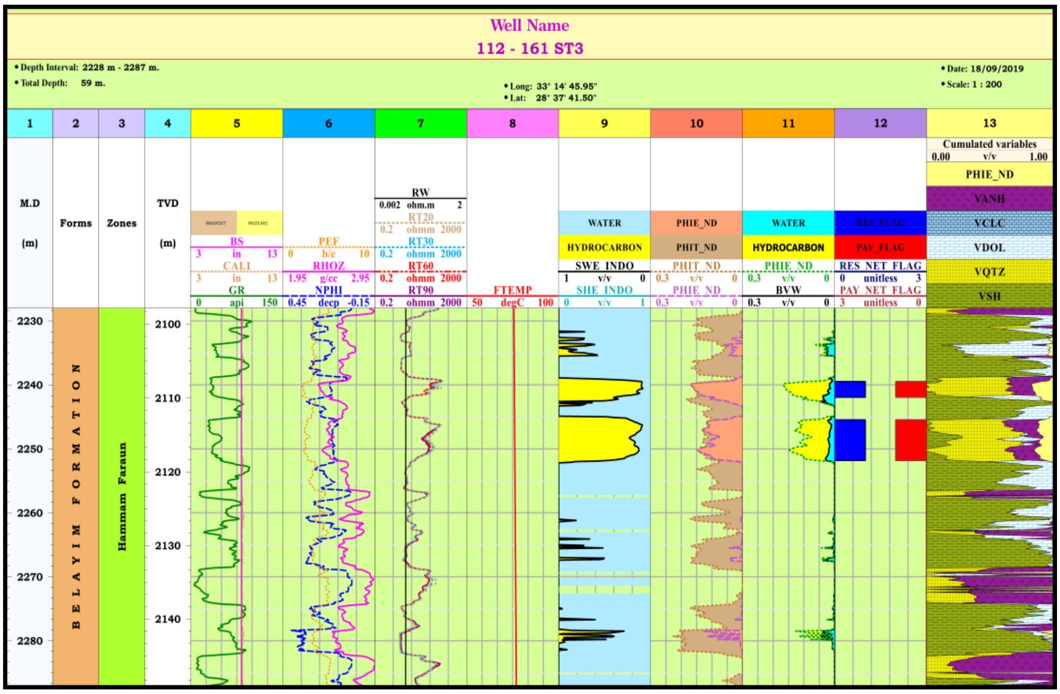

Fig. (7): Litho-saturation cross-plot of Hammam Faraun Member in Well (112-161 ST3).

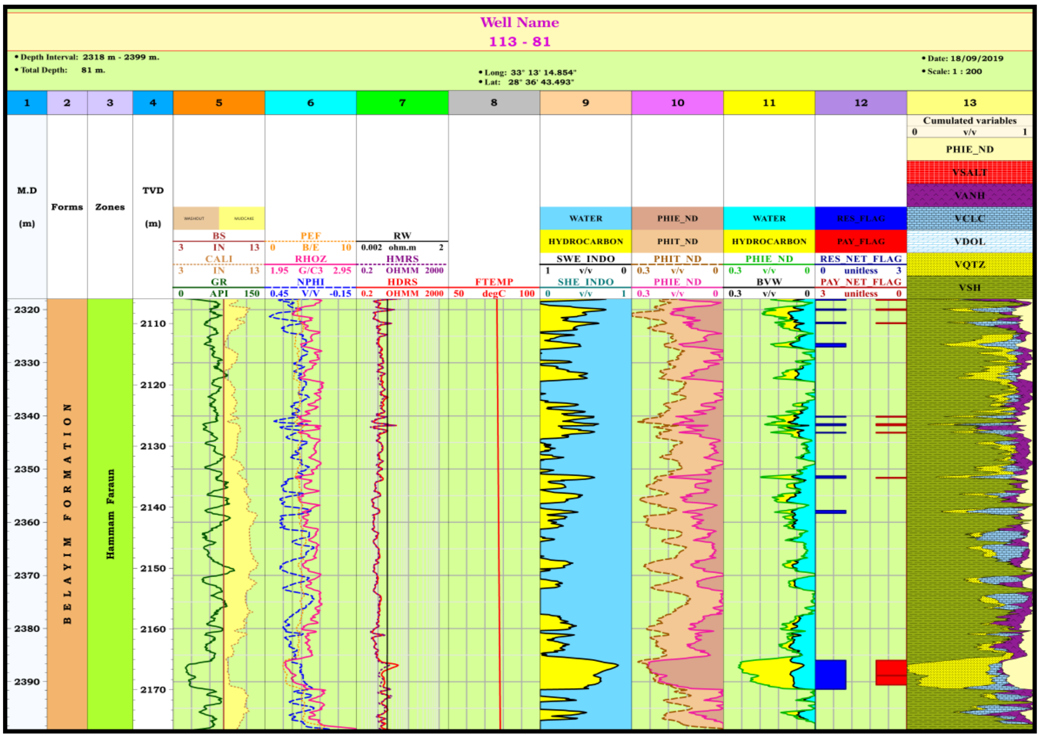

Fig. (8): Litho-saturation cross-plot of Hammam Faraun Member in Well (113-81).

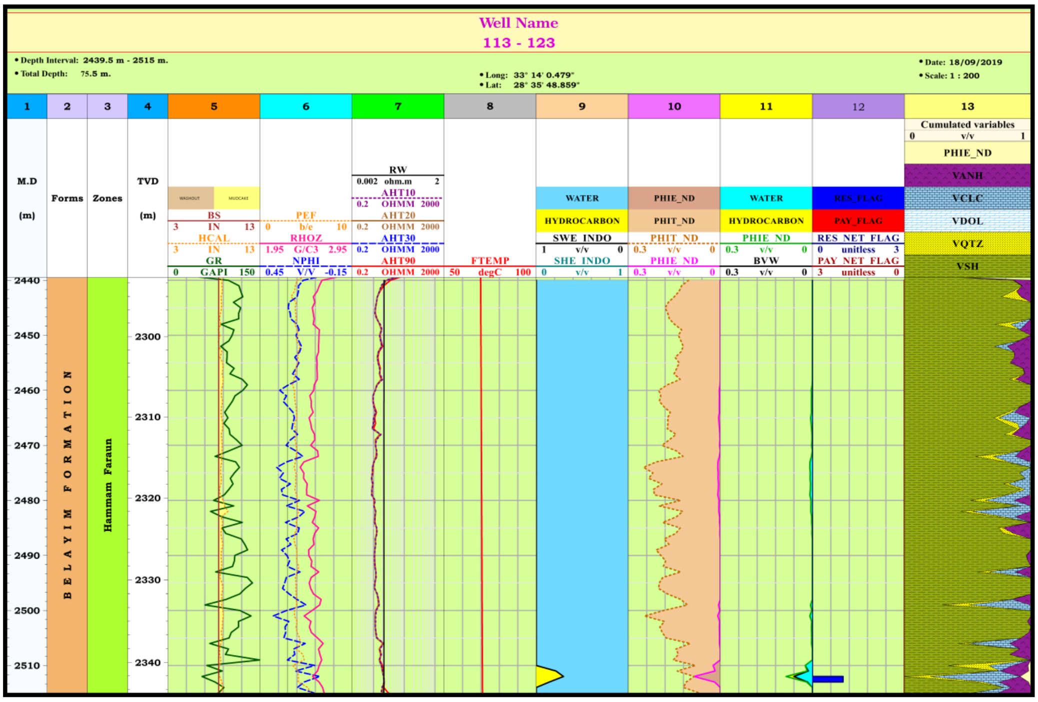

Fig. (9): Litho-saturation cross-plot of Hammam Faraun Member in Well (113-123).

In well 113-81 Hammam Faraun Member is encountered at depth ranges from 2318m to 2399m, with 81m thickness. The computer processed interpretation (CPI) of well logs for well 113-81 is illustrated in (Fig. 8), showing Hammam Faraun Member is composed mainly of shale intercalated with thin streaks of sandstone, with 8 m net-reservoir, and 5.5 m net-pay, with average 12% shale volume, 21% average effective porosity and 31% average water saturation.

Hammam Faraun Member in well 113-123 covers the interval from 2439.5m to 2515m, with 75.5m thickness. It is composed mainly of shale intercalated with thin streak of sandstone reaching two meters that is characterized by average 70% water saturation (Fig. 9).

5.2. Lateral Variation of Petrophysical parameters:

The lateral variation of petrophysical characteristics in the study area could be studied through a number of Iso-parametric Maps that represents the various distributions of petrophysical parameters through the studied wells. Such maps are net reservoir thickness, net pay thickness, volume of shale, effective Porosity, fluid saturation maps (Sw and Sh).

5.2.1. Shale volume distribution map:

The shale volume distribution map of Hammam Faraun Member (Fig. 10), illustrates that the shale contents are decreasing from outside toward the central part of the study area, whereas, the maximum value is 12% at well 113-81 in the northeastern direction, and the minimum value is 6% in 112-82 well in the central part.

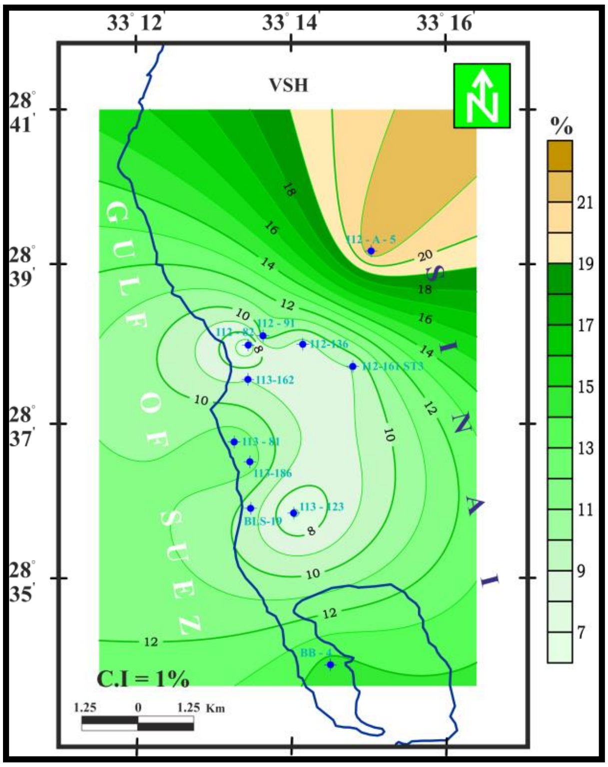

Fig. (10): Shale Volume distribution map of Hammam Faraun Member in the study area.

5.2.2. Effective porosity distribution map:

The variation of the effective porosity of Hammam Faraun Member at Belayim land oil field ranges from 23% in well 112-82 to 9% in well 113-123. The distribution map (Fig.11), shows that the effective porosity increases in the central-western part, and decreased towards the eastern and northeastern parts.

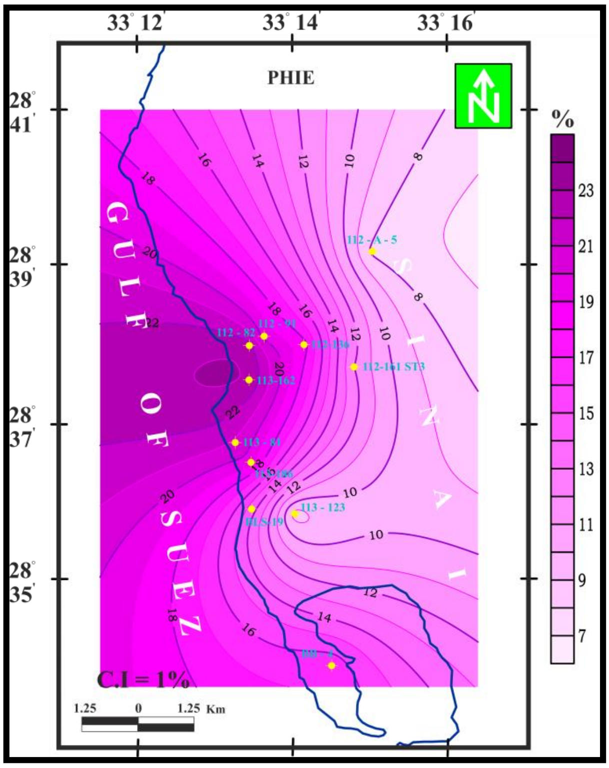

Fig. (11): Effective porosity distribution map of Hammam Faraun Member in the study area.

5.2.3. Water saturation distribution map:

The water saturation distribution map of Hammam Faraun Member (Fig. 12) showed that the distribution of water saturation in the study area varies between 70% at well 113-123, 16% in well 112-161 ST3. Generally, it increases toward the east, northeastern, and southeastern parts, and decreases in the central part toward the western part of the area.

5.2.4. Net reservoir thickness map:

Gross-sand or net reservoir thickness distribution map of Hammam Faraun Member (Fig. 13), shows that the sandstone thickness increases from south toward the north of the study area passing through the central regions, with a maximum thickness equal to 38m at the 112-82 well, and minimum thickness equals 2m in well (113-123).

5.2.5. Net-pay thickness map:

Fig. (14) illustrates the variation of net-pay thickness distribution for Hammam Faraun Member at Belayim land oil field. It demonstrates that the highest thickness of the pay zone is concentrated in the central part of the study area and decreases outside in all directions, whereas the maximum net-pay thickness 23m occurs at 112-82 well, reaching zero meter thickness through wells 112-123, which forms the border line of the pay zone of Hammam Faraun Member.

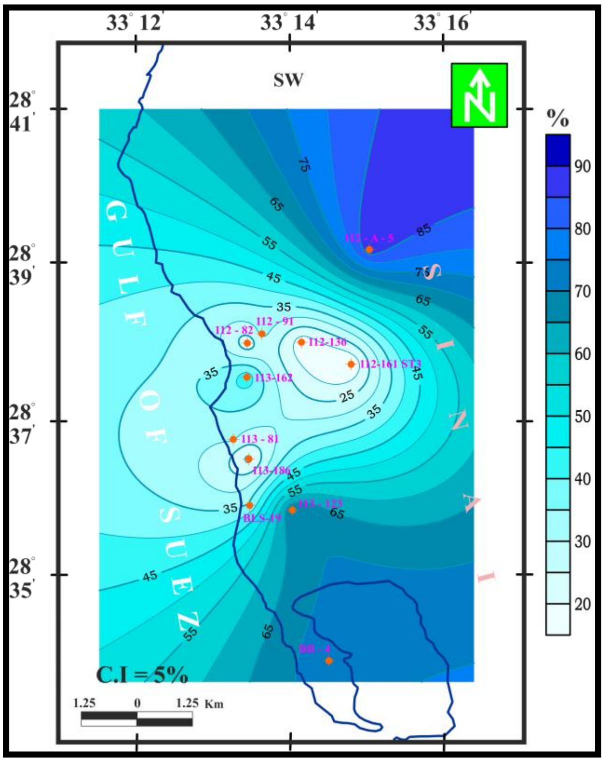

Fig. (12): Water Saturation distribution map of Hammam Faraun Member in the study area.

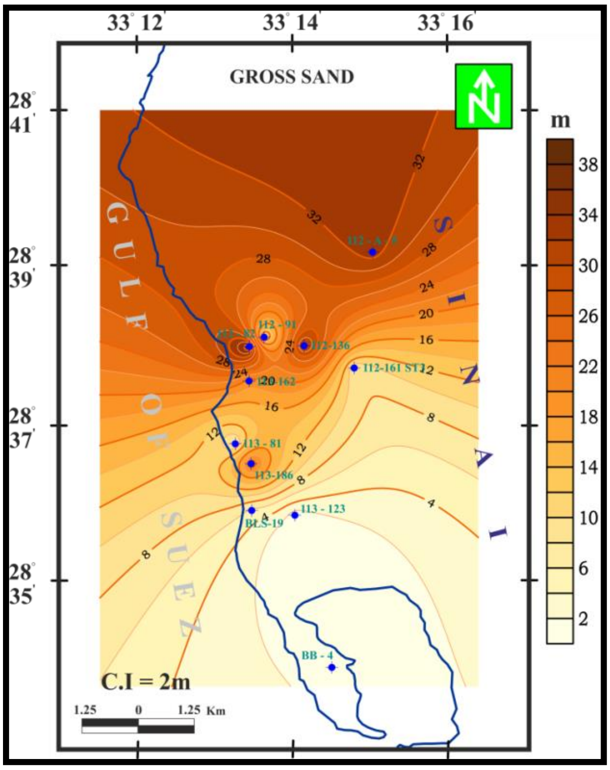

Fig. (13): Gross-sand distribution map of Hammam Faraun Member in the study area.

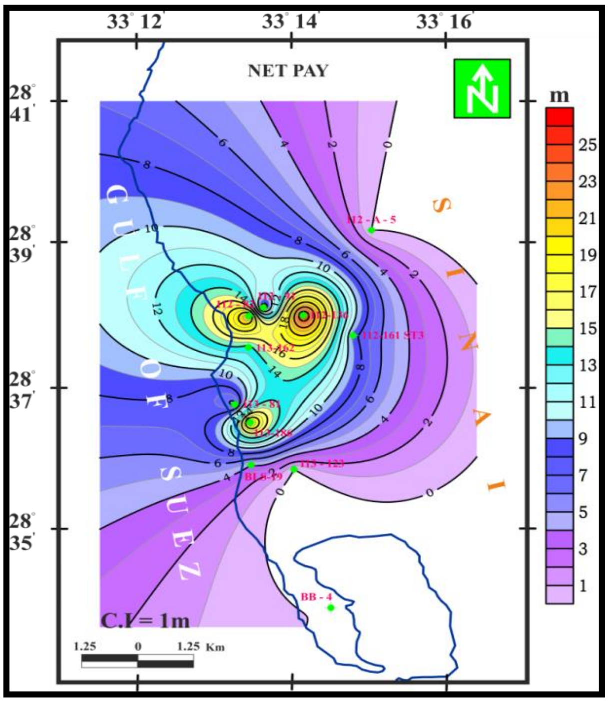

Fig. (14): Net-Pay distribution map of Hammam Faraun Member in the study area.

6. CROSS-PLOTTING

Whereas, the identification of lithology is of a particular importance in formation evaluation process, therefor, cross-plot technique represents another effective method for visualizing petrophysical data, which can be used in identify lithology and clay minerals types and form. For this purpose different types of cross-plots have been constructed for lithology identification as Neutron-Density, Density-PEF, M - N and Umaa - ρmaa cross-plot, also identifying clay minerals types and form as NGS Cross-Plot and Thomas-Stieber Plot.

6.1. Lithological Identification Cross-Plots:

6.1.1. Neutron-Density Cross-Plot:

Neutron versus Density cross-plot becomes the best available indicator for identifying pure matrix and the related porosity. It has been applied for two wells (112-82 and 112-161 ST3), which showed that Hammam Faraun Member is mainly composed of shale and sandstone as illustrated in (Fig. 15, 16).

6.1.2. Density-PEF Cross-Plot:

The bulk density versus photoelectric cross section index cross-plot is useful to identify the mineral composition in a single or two mineral matrixes where the minerals are known. Density-PEF cross-plots have been constructed for two wells (112-82 and 112-161 ST3). The results point out the presence of sandstone and shale as the main components of Hammam Faraun Member, whereas the shale points are shifted towards the dolomite and anhydrite base line that means that the shale to be dolomitic as obvious in (Fig. 17, 18), and this is well matched with cutting samples descriptions of Hammam Faraun Member on mud log.

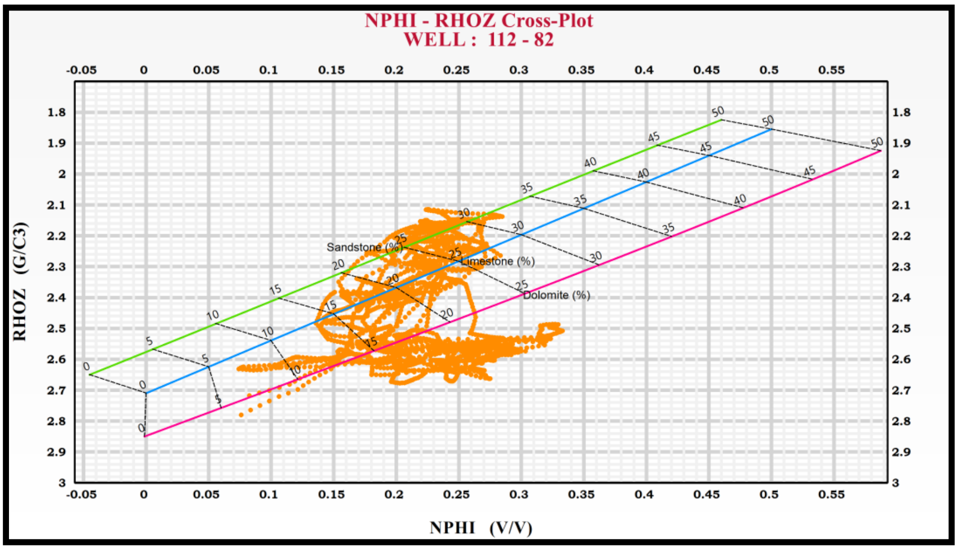

Fig. (15): Neutron-Density cross-plot of well (112-82).

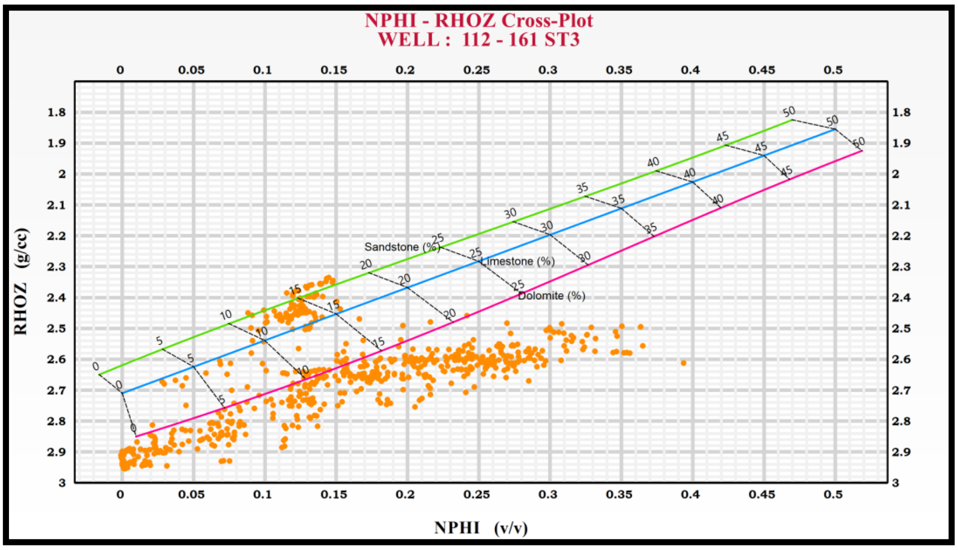

Fig. (16): Neutron-Density cross-plot of well (112-161 ST3).

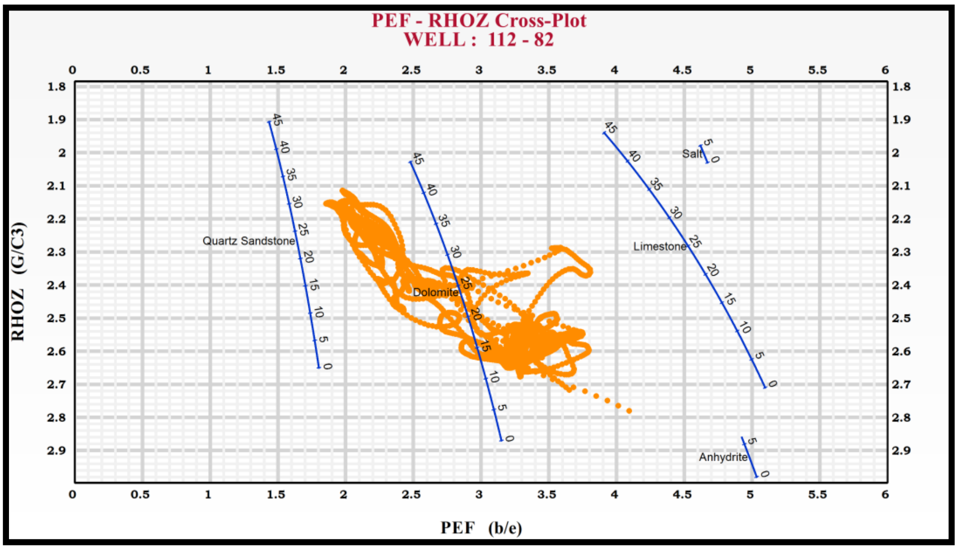

Fig. (17): Density-PEF cross-plot of well (112-82).

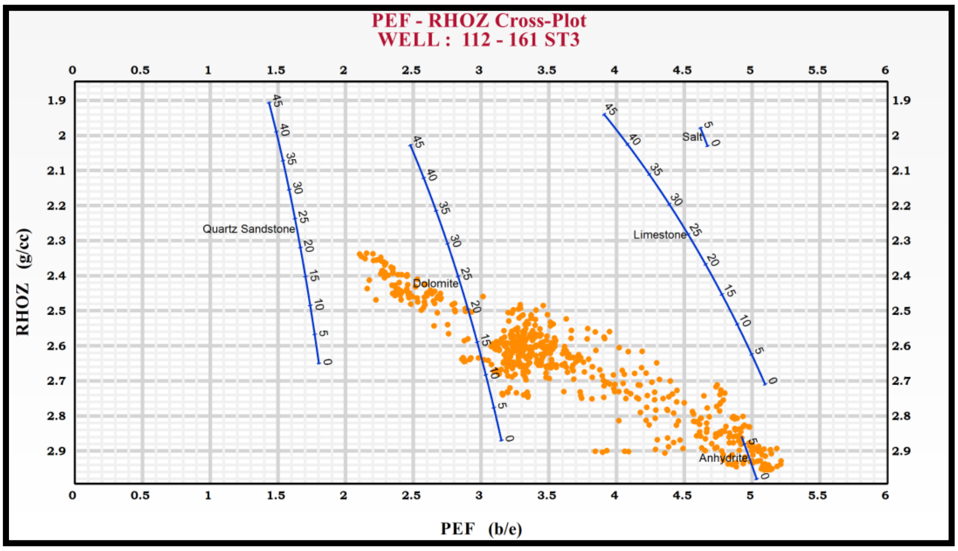

Fig. (18): Density-PEF cross-plot of well (112-161 ST3).

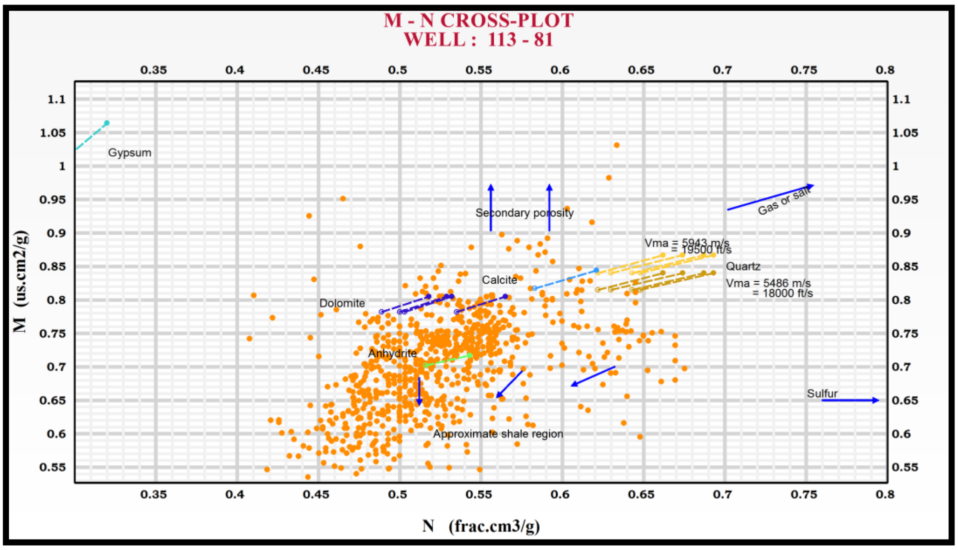

Fig. (19): M-N cross-plot of well (113-81).

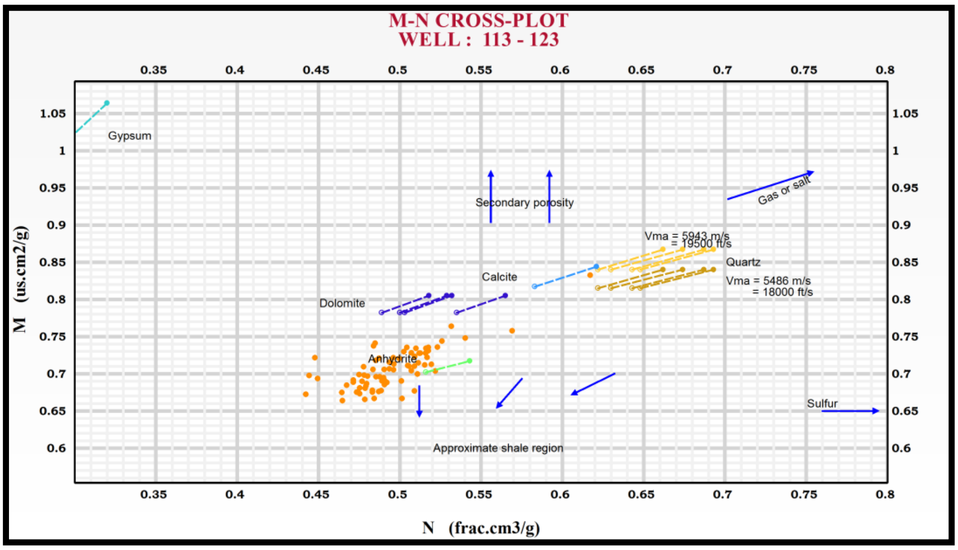

Fig. (20): M-N cross-plot of well (113-123).

6.1.3. M - N Cross-Plot:

M-N cross-plot is a three porosity (sonic, neutron and density logs) cross-plot that useful to identify the complex mineral mixtures and lithology contents. It was applied for two wells (113-81 and 113-123), which are obvious in (Fig. 19, 20). M-N cross-plot in well 113-123 reflects the shale as the dominant component, whereas in well 113-81, it illustrates of the presence of quartz besides shale, where the points are shifted vicinity of calcite and anhydrite minerals giving indication for the shale to be calcareous.

6.1.4. Umaa - ρma Cross-Plot:

The apparent matrix grain density (ρ_{ma}) vs. the apparent matrix volumetric cross section (U_{maa}) is another cross-plot technique for identifying lithology using data from the Litho-Density log. It was applied also for wells (113-81 and 113-123) as illustrated in (Fig. 21, 22).

6.2. Determination of Shale Minerals Type Cross-Plot:

NGS cross-plots were constructed for well (113-81), represents by two cross-plots, potassium versus thorium concentration, that used (Schlumberger, LITH-2, Thorium vs. Potassium) chart and potassium concentration versus photoelectric cross section index (PEF) using (Schlumberger, LITH-1A, K concentration vs. PEF) chart. It shows that the shale in reservoir is composed of different minerals types as chlorite, montmorillonite, illite, and mixed layer clays (Fig. 23, 24).

Also, Thomas-Stieber's plot was constructed for well (112-161 ST3) to determine the distribution modes of shale in sand bodies, which show that both laminated and dispersed types are represented within the reservoir (Fig. 25).

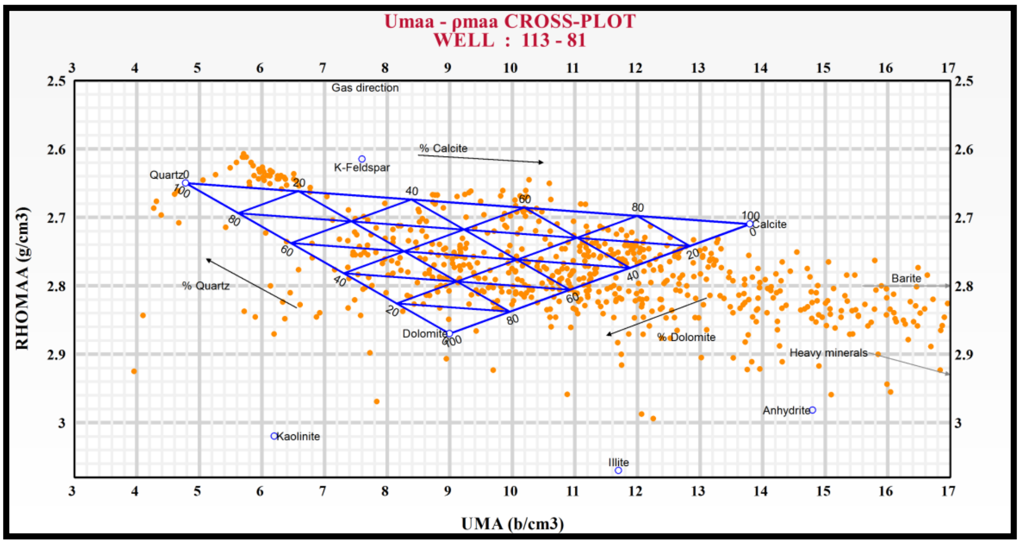

Fig. (21): Umaa - ρmaa cross-plot of well (113-81).

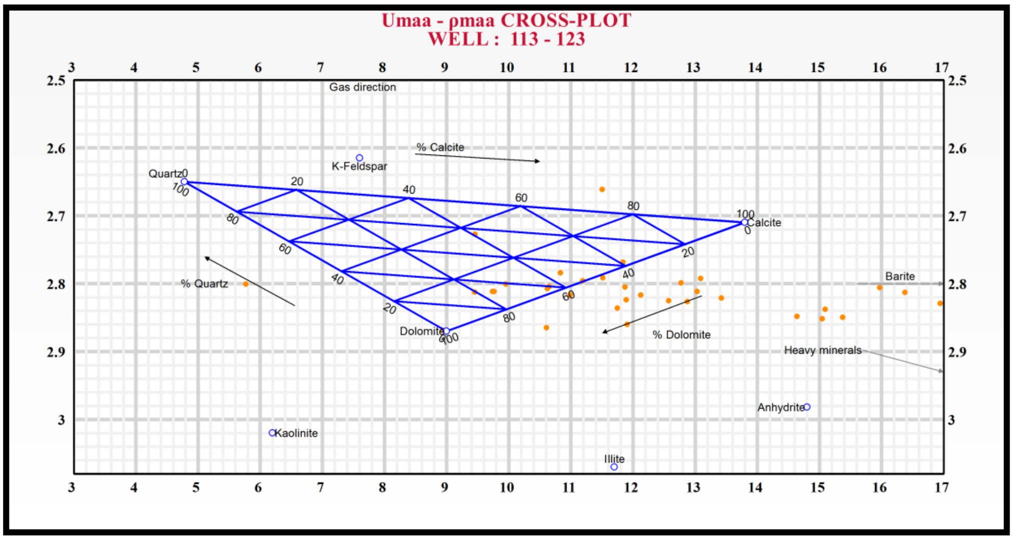

Fig. (22): Umaa - ρmaa cross-plot of well (113-123).

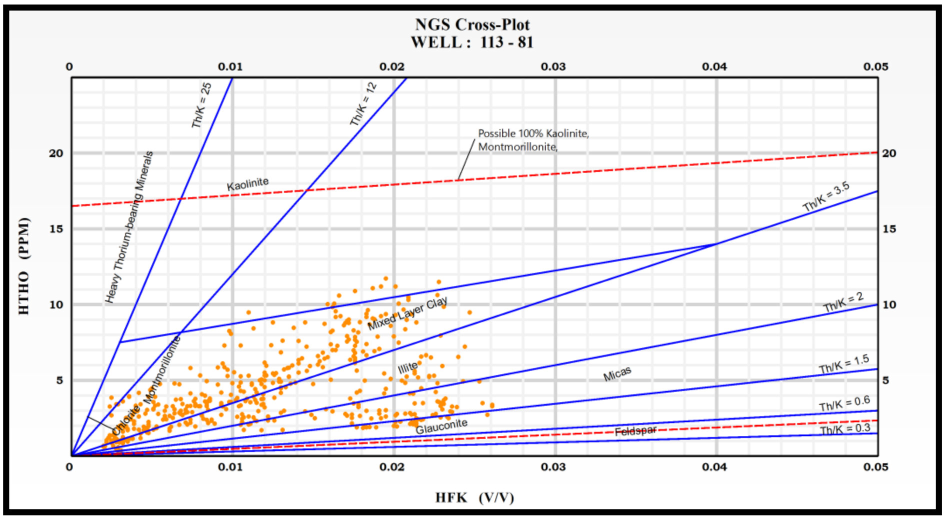

Fig. (23): Potassium - Thorium cross-plot of well (113-81).

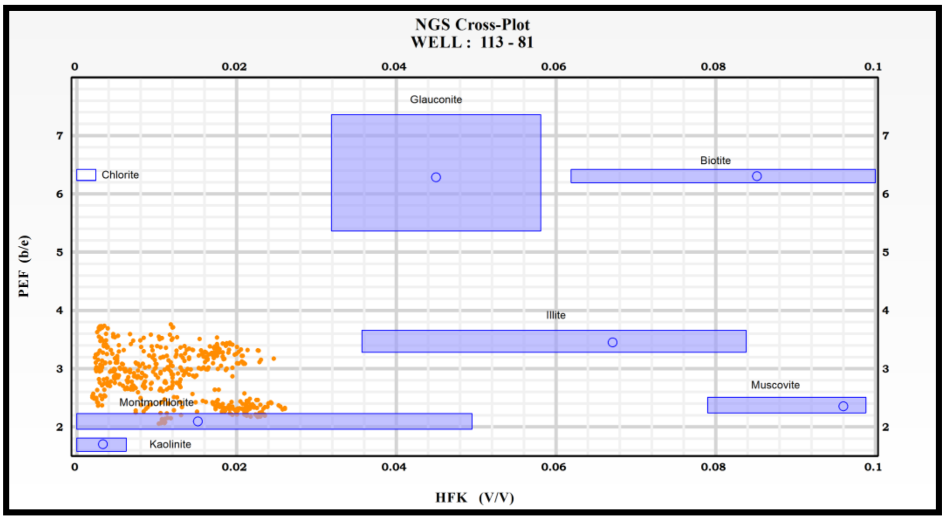

Fig. (24): Potassium - PEF cross-plot of well (113-81).

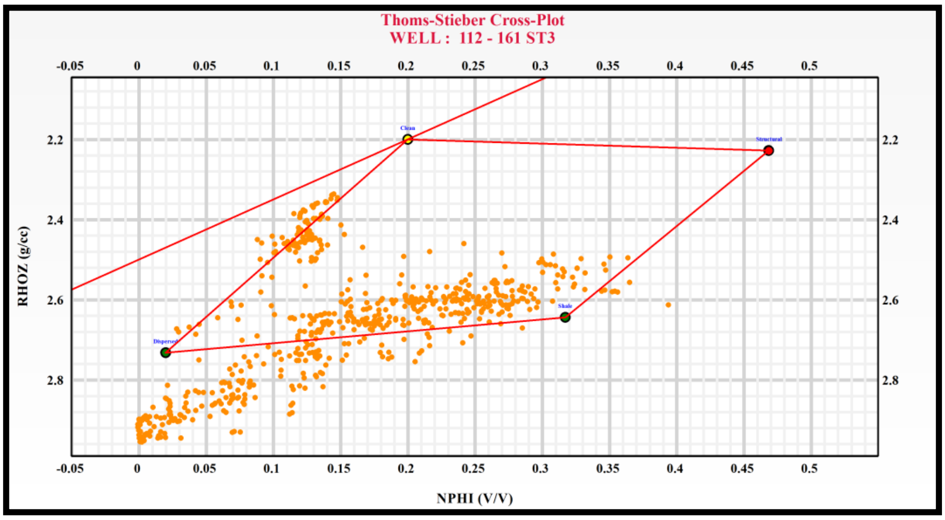

Fig. (25): Thomas-Stieber cross-plot of well (112-161 ST3).

7. CONCLUSIONS

The comprehensive well log analysis of Hammam Faraun Member in Belayim land oil field indicate that, it is composed of calcareous shale intercalated with sandstone cemented with calcite and dolomite, whereas the sandstone thickness increases in the central and northern parts of the study area with average thickness 38m in well 112-82 while, the net pay is around 5.5m In well 113-81 to 22.5m in well 112-82, that characterized by shale volume ranges from 6% at 112-82 well to 12% in well 113-81, The effective porosity ranges from 9% in well 113-123 to 23% in well 112-82, the water saturation ranges from 16% in well 112-161 ST3 to 70 % at 113-123 well, and hydrocarbon saturation ranges from 30% in well 113-123 to 85% at 112-161 ST3 well; also the presence of shale minerals is chlorite, montmorillonite, illite, and mixed layer clays with laminated and dispersed form.

As a result of using petrophysical parameters distribution maps and petrophysical evaluation, Hammam Faraun Member is considered a good reservoir, which can delineate more fluids with high porosity, especially the central part of the study area that characterized by high hydrocarbon saturation and high net pay thickness with low shale volume and high effective porosity.

Acknowledgements:

We would like to acknowledge the Egyptian General Petroleum Corporation (EGPC) and Belayim Petroleum Company (Petrobel) for providing the well log and core data for this study and permission for data processing, interpretation and publication.

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