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NULLIPORE RESERVOIR ZONATION AND EVALUATION USING SPECIAL CORE ANALYSIS, CORALLINE ALGAE AND WELL LOGGING DATA, RAS FANAR FIELD, GULF OF SUEZ, EGYPT

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تقسيم و تقييم خزان النلليبور بإستخدام التحليل الخاص بالعينات اللبية والطحالب المرجانية وبيانات تسجيلات الآبار بحقل رأس فنار– خليج السويس– مصر

الخلاصة: تهتم هذه الدراسة بعمل تقسيم و تقييم لشعاب حقل رأس فنار كواحدة من أشهر الشعاب المرجانية فى منطقة الشرق الأوسط و شمال أفريقيا.و يتراوح سمك الخزان (صخور النلليبورالكربوناتية) فى هذا الحقل ما بين٤٠٠ قدم الى ٩٨٠ قدماً و يتكون من الحجر الجيرى الدولوميتى الغنى بأجزاء من الطحالب التى تقع غير متوافقة فوق تكوين طيبة الأيوسينى السفلى، كما تسفل تكوين جنوب غارب من عصر الميوسين الأوسط إلى الأعلى.
و قد تم فى هذه الدراسة إستخدام تسجيلات الآبار لعدد ١٤ بئراً فى منطقة رأس فنار وكذلك بيانات الضغط الشعرى و التحليلات الخاصة بالعينات الصخرية اللبية المتاحة لبعض الآبار بالاضافة الى الطحاب المرجانية. وقد أمكن تقسيم خزان النلليبورحيث وجد أنه يتكون من ٣ نطاقات كهروليثوسحنية (نطاقات I و II و III) كل منها له خواصه البتروفيزيائية المميزة ، ويعد نطاق II من أهم النطاقات فى منطقة الدراسة حيث أنه يتميز بمسامية عالية متصلة و يحتوى على تشبعات عالية من الهيدروكربونات إذا ما قورن بالنطاقات الأخرى. كما تم عمل تقييم للجهود الهيدروكربونية (توزيعات المسامية و التشبع بالموائع و معاملات القطع) لصخور خزان النلليبور، كما أمكن التعامل مع المعاملات المختلفة التى تم إستنتاجها فى أنشاء مجموعة من الاشكال البتروفيزيائية الرأسية وخرائط التوزيعات الجانبية وكذلك توقعات لمعامل القطع. و قد أظهرت الدراسة أن صخور خزان النلليبور تتكون من تجمعين (A , B) يمتدان فى إتجاة شمال غرب و جنوب شرق و يزداد تركيز الهيدروكربونات تدريجيا إلى داخل هذه التجمعات حيث يتميز تجمع (B) بخواص خزانية أفضل، كما وجد أن معاملات القطع الفعلية لخزان النلليبور هى ١٤% (مسامية فعالة) و ٦٤% (تشبع بالمياه).

ABSTRACT: *The present study deals with zonation and evaluation of Ras Fanar reefs as one of the most prominent reefs in the Middle East and North Africa. The thickness of the target reservoir (Nullipore carbonate rocks) in this field ranges between 400 ft-980 ft. It consists of dolomitic limestone rich in algal fragments and unconformably overlies the Lower Eocene Thebes Formation and underlies the Middle to Upper Miocene South Gharib Formation. Wireline logs of 14 wells (KK84-1, KK84-11, KK84-12, KK84-4A, KK84-8, RF-A1, RF-A1A, RF-A2, RF-A2A, RF-A3, RF-A4, RF-B2, RF-B3 and RF-B4), capillary pressure data (Brine and Mercury Injection) and special core analyses of some cored intervals in these wells were used in this study. Furthermore, coralline algae was also incorporated together with other logging data and used for Nullipore reservoir zonation. It is found that Nullipore reservoir consists of 3 electro-lithofacies (zones I, II and III) each of which exhibits its own petrophysical characters. Zone (II) is considered the most important and mostly characterized by high well connected pore-space system and high hydrocarbon saturation as compared with the other zones.*
Hydrocarbons potentialities (pore space distribution, fluid saturation and pay cutoffs) of the Nullipore reservoir rocks are evaluated and the different deduced parameters are represented in a number of vertical analogs, lateral distribution maps and pay cutoff plots. Based on petrophysical analyses, it is found that Nullipore reservoir rocks consist of two lobes (A and B) extending in a northwest-southeast direction. Inside these lobes, the hydrocarbon saturation increases gradually towards the center. However, the (B) lobe was found to be of better reservoir quality than the (A) lobe. Porosity and water saturation values of 14 % and 64 %, respectively, are used as the net pay cutoffs in Nullipore reservoir rocks.

INTRODUCTION

In the Middle East and North Africa areas of more than 14 million square kilometers, shallow water carbonates are very common both in outcrops and stratigraphic sequences. More than two-thirds of all the world's oil reserves are found in this area. Reef deposits are of great economic significance, because of their porosity; they often make good hydrocarbon reservoirs when suitably sealed. So, considerable attention has been given to methods of locating oil fields in ancient reefs and petroleum exploration has already revealed a number of significant reefs, and related oil and gas reservoirs in these areas.

The term "Nullipore Carbonate" was first used by Moon and Sadek (1923) to describe the sequence that underlies the Evaporite Group (Ras Malaab Group) of Middle to Late Miocene in the Gulf of Suez. The National Stratigraphic Sub-Committee (1974) considered this "Nullipore" rock as being equivalent to the

Hammam Faraun Member of the Belayim Formation which was deposited under shallow marine warm water conditions favourable for reefal development with slight changes to shallow neritic and/or littoral environments. The "Nullipore" name was given for these rocks because of their richness in algal nodules and fragments.

GEOLOGIC SETTING

Ras Fanar area is located offshore of the western side of the Gulf of Suez, 3.5 km east of Ras Gharib shoreline (Fig. 1). The area is geologically located in the eastern part of the Gharib horst block, which is characterized by a northeast dip direction (Meshref and Abu El Karamat, 1988 and Salem et al. 1994). It is characterized by intensive faulting and unconformities and the cross faults of Aqaba trend may shift or terminate these blocks (Moustafa, 1977; Sultan and Moftah, 1985). Therefore, the Miocene carbonate strata are highly faulted to narrow elongated rectangular blocks aligned mainly in a NW-SE direction (Fig. 2). Ras Fanar area is exposed as a high land during the Lower Miocene time with continuous erosion acting over the high relief; meanwhile thick organic rich shale was deposited in the adjacent troughs (Moustafa, 1977). During the Middle Miocene time the area was submerged and became suitable for reefal growth of the Nullipore facies. More arid environment has dominated in the latter part of the Middle Miocene thus leading to the deposition of evaporites of the South Gharib and Zeit Formations.

Kulke (1982), Chowdhary and Taha (1986) and El-Naggar (1988) had studied the Miocene carbonate oil-bearing sequence in the Ras Fanar field. They emphasized that the sequence attains a maximum thickness of about 1000 ft in KK 84-11 well and accumulates unconformably over the Pre-Miocene eroded surface (Figs. 3 and 4). In some wells (KK 84-4A and KK 84-11), the Nullipore rock is underlain by what is so called the "Basal Bed" that consists of brecciated limestone (about 40 ft thick in KK 84-4A well). The subsurface sedimentary sequence in Ras Fanar area ranges in age from the Paleozoic to Recent (El-Naggar, 1988; Darwish and Saleh, 1990). Several erosional and/or non-depositional hiatus are recorded. Nullipore rocks in Ras Fanar field consist mainly of algal reefal dolomitic limestone and massive limestone buildup, which is anhydritic in some parts. The generalized stratigraphic column of Ras Fanar field is presented in Fig. 5. This sequence resembles, to a great extent, its counterparts in most of the Gulf of Suez province (Beats, 1948; Abdallah and El Adindani 1963b; Chowdhary and Taha, 1986; El-Naggar, 1988 and Said, 1990).

MATERIALS AND METHODS

The different well logging data of 14 wells available in Ras Fanar field were interpreted. These wells are KK84-1, KK84-11, KK84-12, KK84-4A, KK84-8, RF-A1, RF-A1A, RF-A2, RF-A2A, RF-A3, RF-A4, RF-B2, RF-B3 and RF-B4 (Fig. 6). Special core analyses of some intervals in these wells and coralline algae were incorporated together with other logging data and used for Nullipore reservoir zonation and evaluation. The laboratory measurements were covered through the core data measurements for some important parameters including porosity, permeability, fluid saturation and capillary pressure (Brine & Mercury Injection). These measurements were extensively carried out by Core Lab. and BP Research Center on some selected plugs and full diameter core samples from KK84-4A and KK84-8 (RF-B1) wells.

Although the Nullipore reservoir consists mainly of massive carbonate buildup, it is still possible to classify this reservoir into different zones; each of which has its own petrophysical characters and special different algal content. Therefore, it is very important to perform detailed reservoir zonation before going in the hydrocarbon potential evaluation. In this work, Nullipore reservoir zonation was carried out using different techniques including well log data, special core analysis and coralline algae. A comprehensive petrophysical analysis was carried out over the Nullipore carbonate rocks and several important parameters were deduced like uranium volume, porosities (total and effective), fluid saturations, and lithology volumes. Hydrocarbon potential (oil and/or gas) was evaluated and a number of vertical petrophysical analogs and petrophysical property distribution maps were constructed.

NULLIPORE RESERVOIR ZONATION

In multi-wells studies, the facies types and the depositional environments can be accurately recognized using correlation techniques. Additional information on the thickness of each facies or sequence of facies and on its evolution with depth and consequently, with time often allow discrimination between two or three possible environments (Schlumberger, 1984). In a sedimentary succession, the velocity of acoustic propagation depends on the properties of the rock matrix and the distribution, type and amount of porosity. The integration of different logging analyses has been applied to identify and clarify some of the important properties of certain zones in the reservoir, which may otherwise have been missed by using one of them alone. So, velocity parameters associated with synthetic seismic traces are used along with other logs to correlate and identify the different reservoir zones.

Detailed examination of the electrical logs in Ras Fanar field and correlation with the core description, coralline algae and the sedimentological analysis of the carbonates reveal that Nullipore carbonates consist of three zones. The followings are the different methods used in Nullipore reservoir zonation.

1. Log Correlation

The most common wireline logs used in the identification, correlation and interpretation of facies are

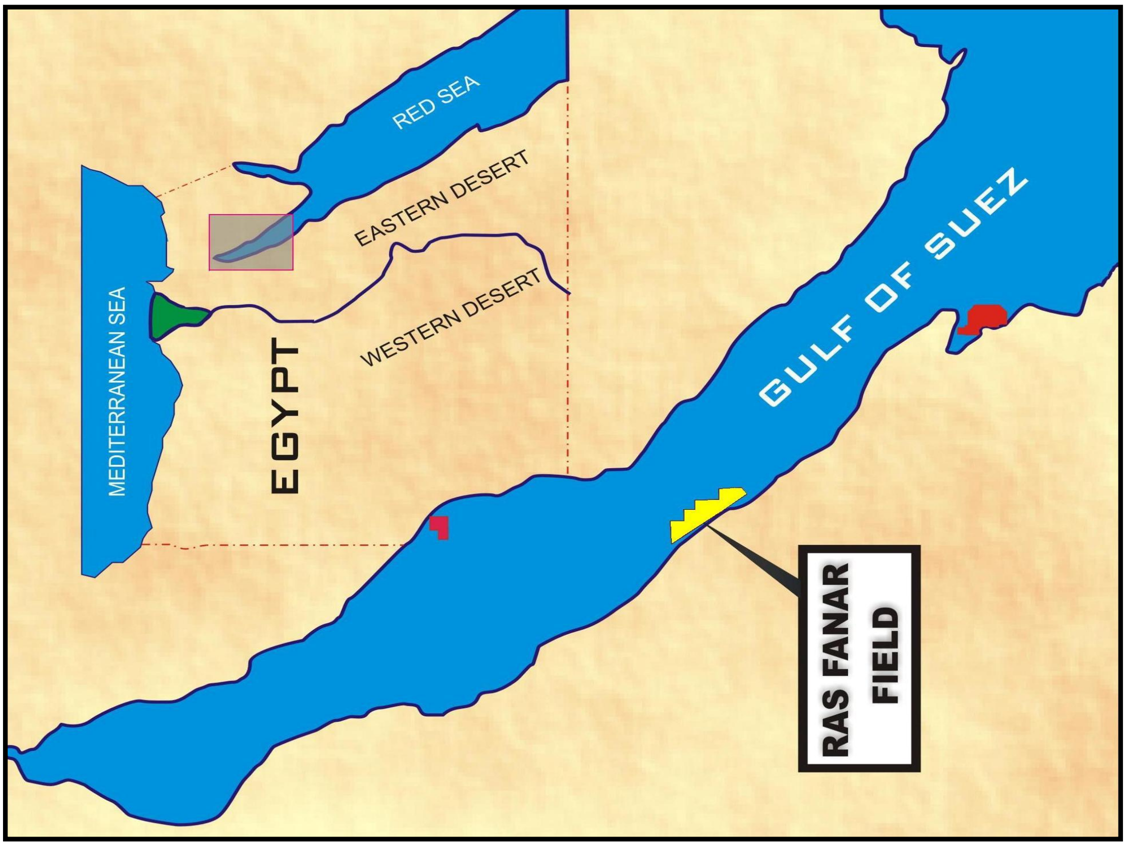


Fig. (1): Location map of Ras Fanar field, Gulf of Suez.

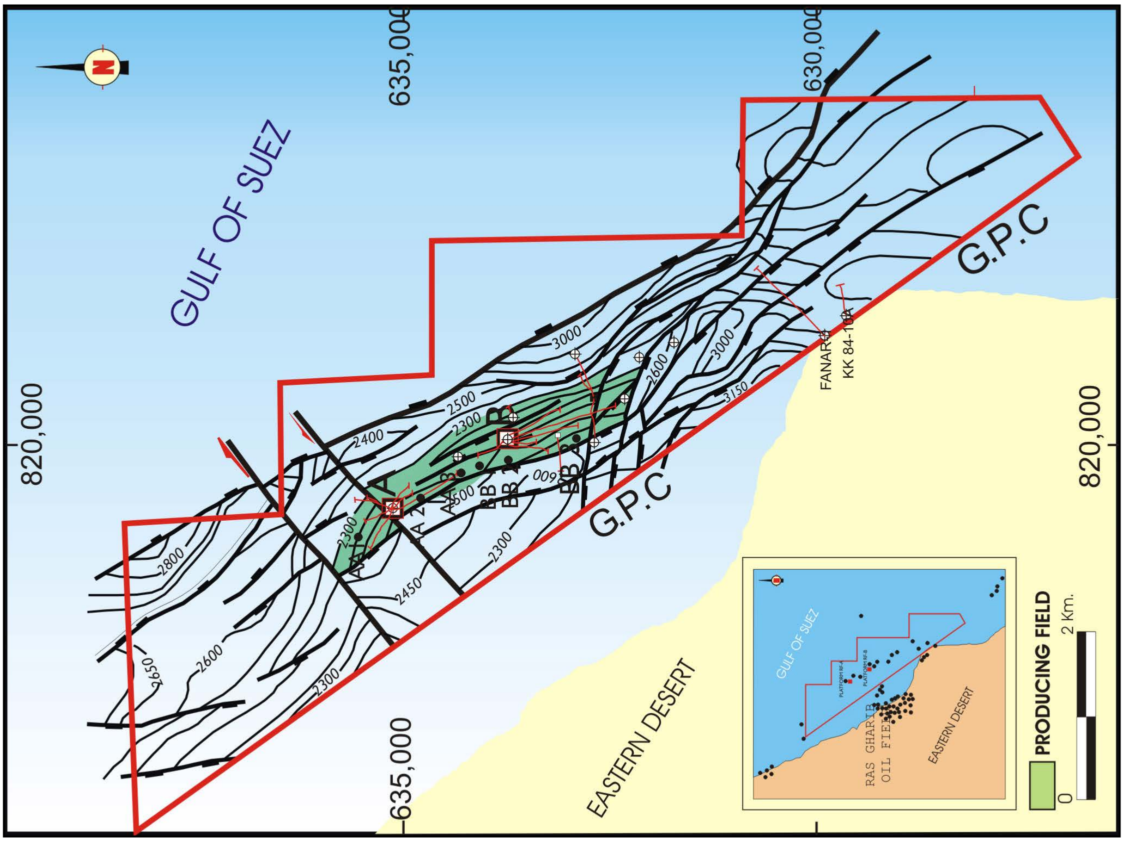


Fig. (2): Structure contour map on top of Nullipore carbonate rocks, Ras Fanar field.

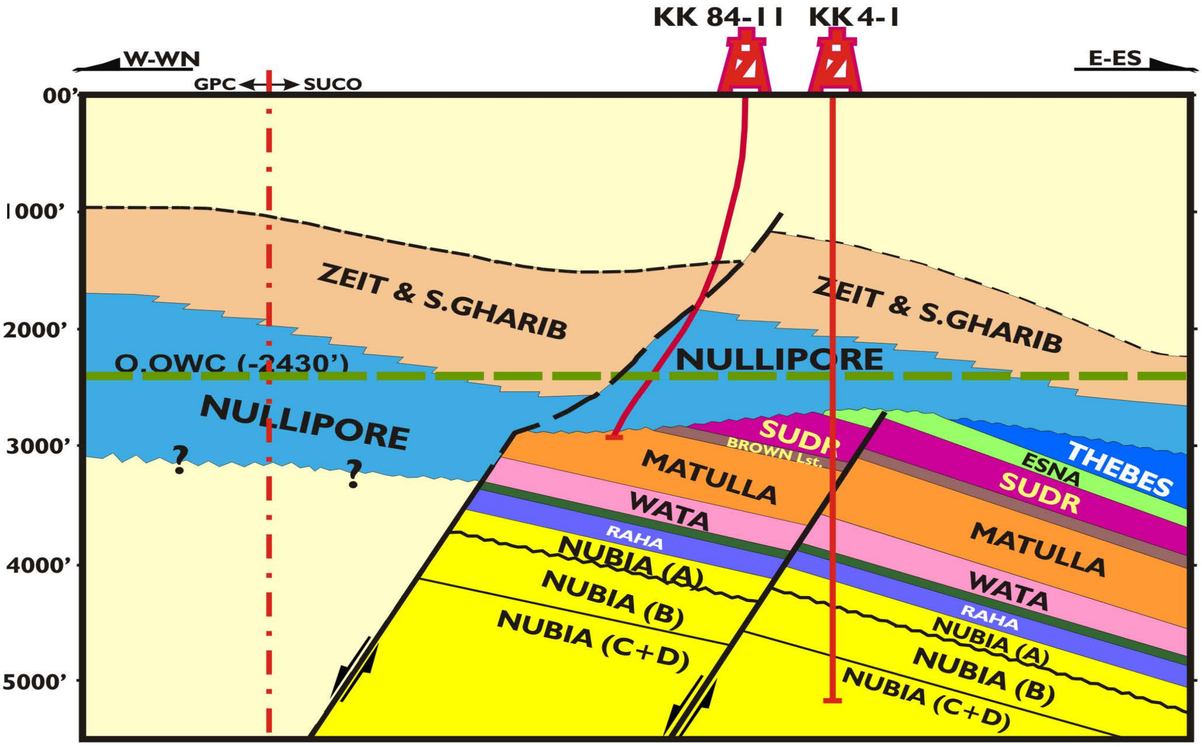


Fig. (3): Geologic cross section along KK 84-1 and KK 84-11 wells in Ras Fanar field, Gulf of Suez.

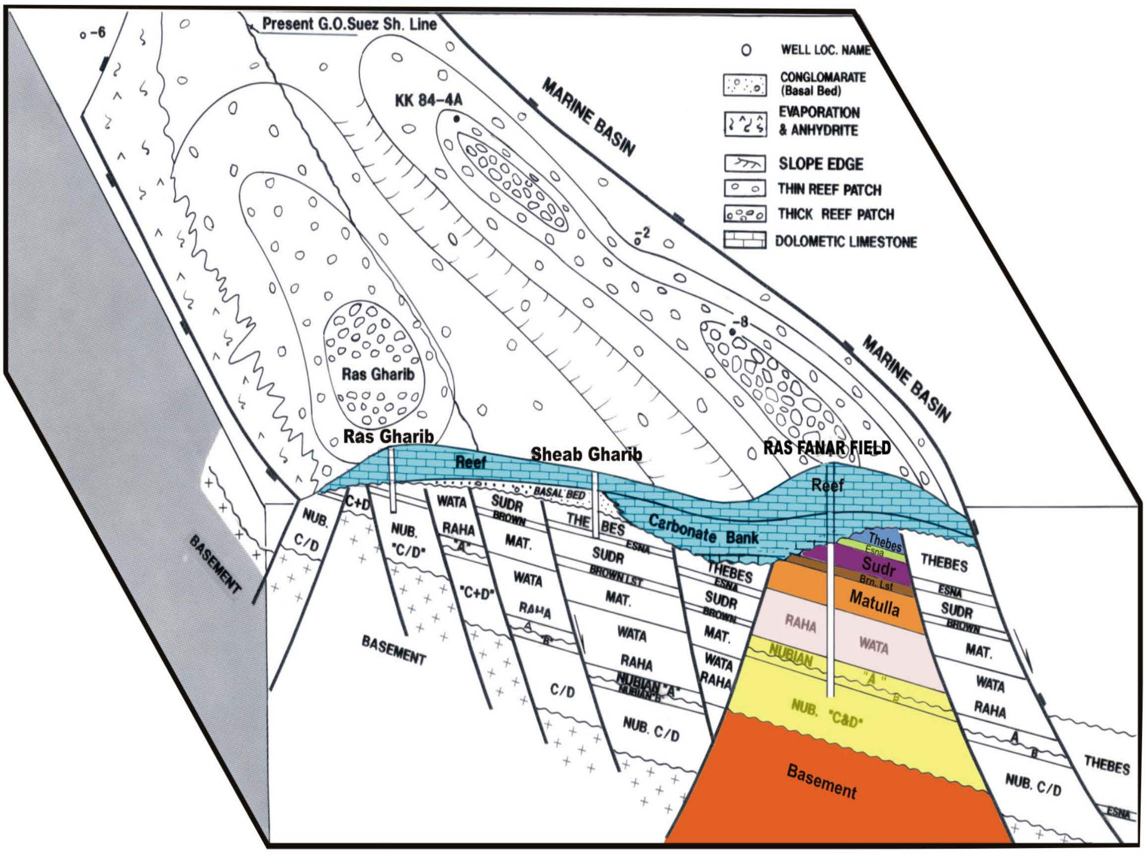


Fig. (4): Diagrammatic facies section across the Nullipore carbonate of Ras Gharib and Ras Fanar fields (after Chowdhary and Taha , 1986).

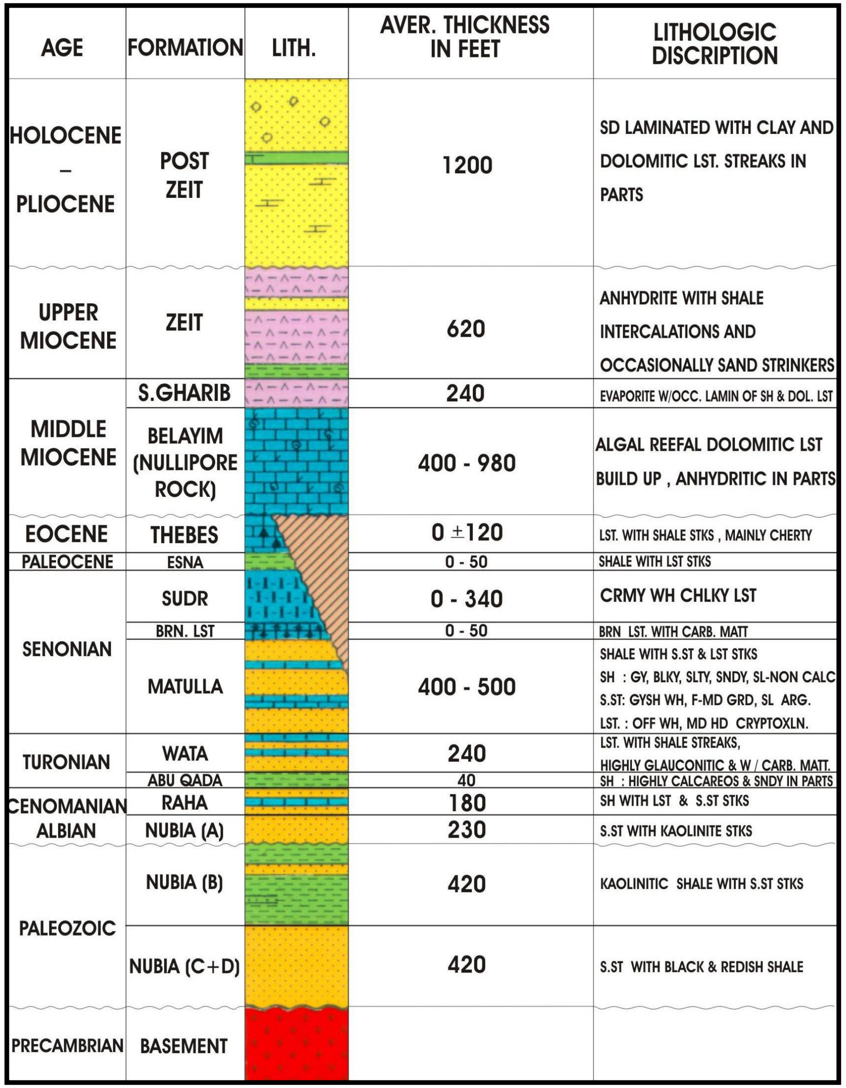


Fig. (5): Generalized stratigraphic column of Ras Fanar field (after El-Naggar, 1988).

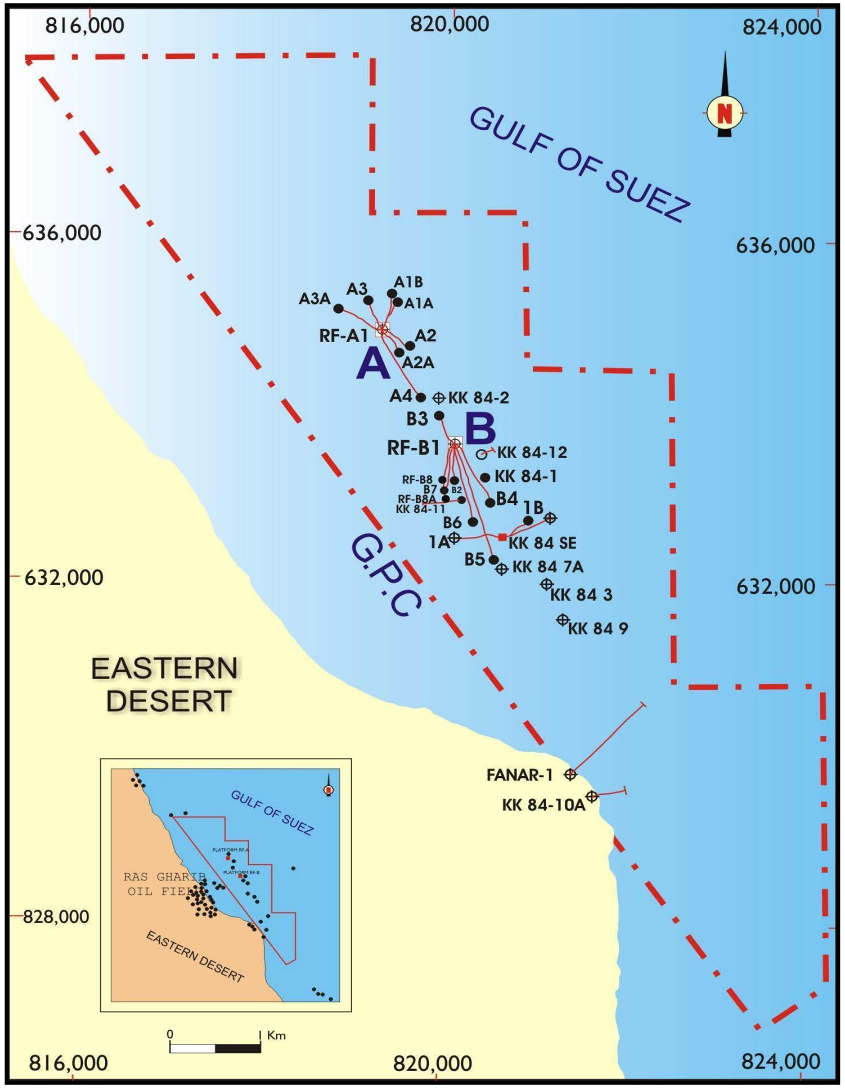


Fig. (6): Location map of the study wells, Ras Fanar field.

Gamma Ray, Sonic, Density and Neutron logs. Based on log correlation, three electro-lithofacies zones that could be fully correlated across the field (Fig. 7) are recognized in the Nullipore rocks. Each of these zones is found nearly at the same stratigraphic level with similar petrophysical characters and is characterized by certain log responses which are different from those displayed by the overlying and underlying ones in all studied wells. Zones (I) and (II) correspond to what was previously known as Nullipore Reef, meanwhile zone (III) corresponds to the Carbonate Bank or Platform.

Reservoir Zone (I)

This zone comprises the uppermost part of the Nullipore reservoir. The upper boundary is taken at a characteristic increase in the Gamma Ray response below the anhydrite of the South Gharib Formation. The rock facies in this zone are mostly characterized by a relatively low porosity (anhydritic) as compared with the lower zone.

Reservoir Zone (II)

The top of this zone exhibits a high Gamma Ray response, which is readily correlated throughout the field. The base of this zone is taken at the abrupt shift in the Sonic and Density-Neutron log readings, which generally reflects a change to tighter carbonates in the underlying zone. The rock facies in this zone are mostly characterized by very high porosity with well-connected pore system as compared with the other zones.

Reservoir Zone (III)

It underlies zone (II) and is composed mainly of carbonate rocks, which are tight, uniform in character, and of poor reservoir quality as compared with the overlying reservoir rocks. This zone is of subordinate importance as a hydrocarbon-bearing reservoir due to its limited petrophysical properties and the fact that it generally occurs below the oil-water contact of the field.

Furthermore, Fig. (8 A and B) shows the constructed synthetic seismograms of two wells (KK84-4A and KK84-11), selected as examples to demonstrate the presence of different zones in Nullipore carbonate rocks. The constructed model (velocity, acoustic impedance and synthetic seismic traces) reveals the presence of three zones with different petrophysical characters. The upper boundary of Nullipore rocks is characterized by velocity inversion due to transfer of velocity from the overlying high velocity rock salt of South Gharib Formation to the underlying low velocity Nullipore carbonate rocks. Furthermore, the synthetic seismograms traces indicate that these rocks attain moderate regular velocity and can be easily recognized by the presence of two bounding troughs at the top (high amplitude trough) and the bottom (low amplitude trough) of the formation.

2. Special Core Analysis

Air-brine capillary pressure and mercury injection tests are used to determine the pore-to-pore throat sizes relationship in the different zones constituting the Nullipore rocks. Air-brine (wetting phase) pressure measurements were performed on 9 core samples (5 samples from KK 84-4A well and 4 from KK 84-8 well) by Core Lab. (1982). The fully saturated samples were de-saturated in a porous plate cell by introducing of humidified nitrogen at increasing incremental pressures up to 30 psi. Figure (9) illustrates the air-brine capillary pressure (Cp) curves established in KK84-4A and KK 84-8 wells. It reflects the effect of cement on capillary pressure curves and indicates the presence of well-identified three petrophysical zones (A, B and C) in the Nullipore rocks. Air-mercury injection tests were carried out by BP Research Center (1987) on some selected core plugs. Four mercury injection tests were made to determine pore size distribution data for typical core plugs extracted from KK 84-4A and KK 84-8 wells (Fig. 10). From the capillary pressure curves it is evident that, for the used range of injected pressure (3 to 5000 psi), mercury will invade pores with radii ranging between 0.002 and 30 microns.

In terms of pore size distributions, Fig. (10) shows that Nullipore rocks exhibit three different petrophysical ranges of throat radius as follows; 1) pores of throat radius greater than 4 microns are considered to comprise the very lightly cemented pore system, 2) pores between 0.4 to 4 microns throat radius are considered to be of secondary porosity formed by the leaching out of the granular material in the reservoir formation which is partly filled with filling minerals, and 3) pores of less than 0.4 microns throat radius are considered to be of secondary porosity type, formed by the infill (completely or partly) of original primary or secondary pores with the post depositional anhydrite.

3. Coralline Algae Content

The coralline algae content has a direct significance of the environment and depth of deposition. Researches by Adey (1979) on tropical coralline algal floras (classified as red algae) indicate that some of the genera are restricted to certain depth zones. Bosence (1990) sampled in-situ coralline algae from the Miocene reefal facies in Esh El Mellaha, Egypt and correlated them with other Late Miocene coralline algal facies in Mallorca, Spain. He found that these Miocene reefal facies preserve some algal crusts with measurable Miocene water depths which could be further used in reefal zonation. Table (1) shows the classification of the Nullipore facies in Ras Fanar field, where four depth indicative coralline algal genera are common. These are *Lithophyllum*, *Archaolithothamnium*, *Lithothamnium and Lithoporella.*

Table (1): Classification of Nullipore facies in Ras Fanar field.

PERITIDAL	
(P-S)	**Sabkha:** Mottled or brecciated peloidal dolomicrites, +/- anhydrite nodules.
(P-I)	**Intertidal -** Peloidal dolomicrites with cryptalgal laminae.
INNER RAMP	
(IR-L)	**Lagoonal:** Peloidal mud-wackestones with molluscs and coralline fragments.
(IR-RM)	**Restricted Marine:** Mollusc, coralline foram, pack-grainstone with *Lithophyllum* and *Archaolithothamnium.*
(IR-OM)	**Open Marine < 30m:** Coralline coral, mollusc, foram, bryozoan, echinoid, pack-grainstone with *Lithophyllum* and *Archaolithothamnium.*
MID RAMP	
(MR-OM)	**Open Marine > 30m:** Coralline, coral, mollusc, foram, bryozoan, echinoid, pack-grainstone with *Lithothamnium.*

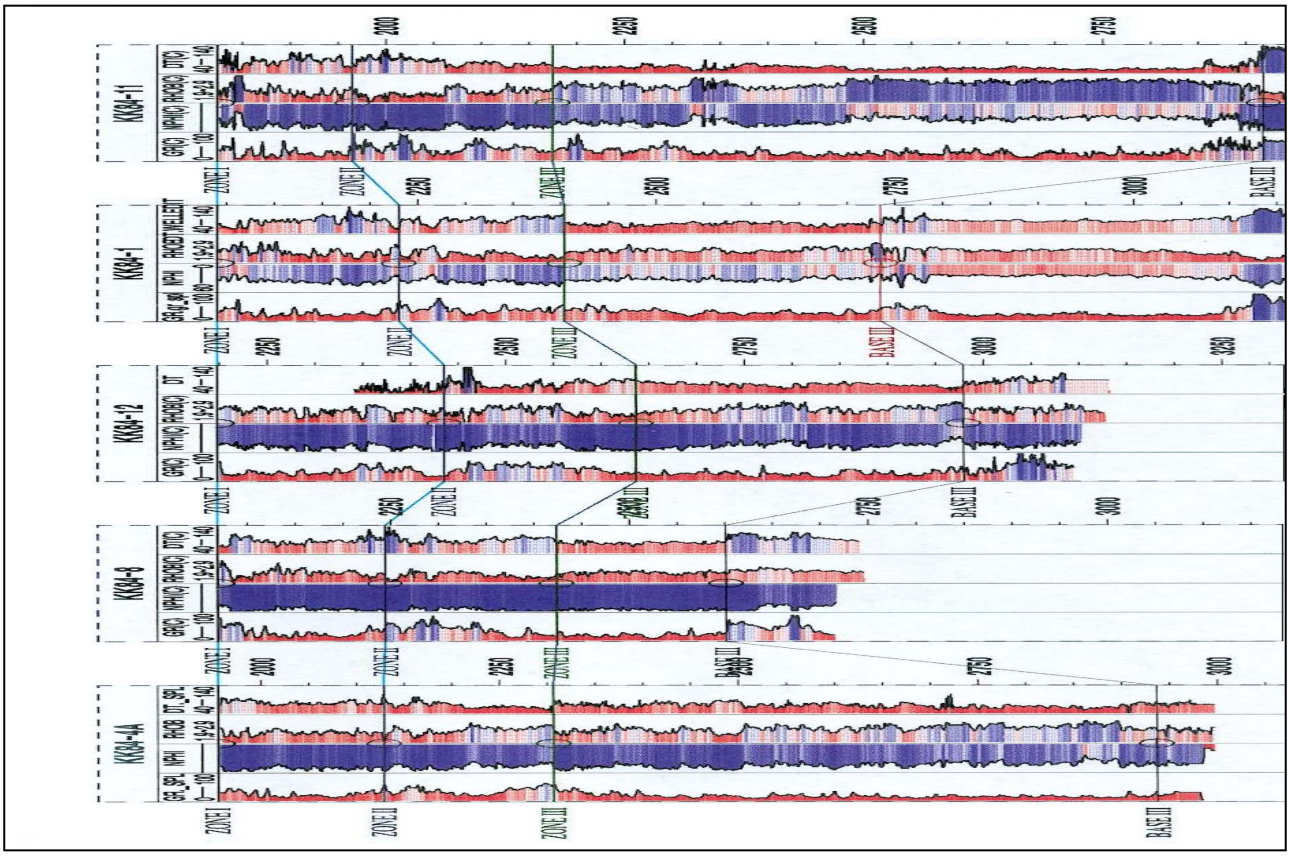


Fig. (7): Correlation chart inferring the presence of three different electro-lithofacies (zones I, II, & III) in Nullipore reservoir rocks, Ras Fanar field.

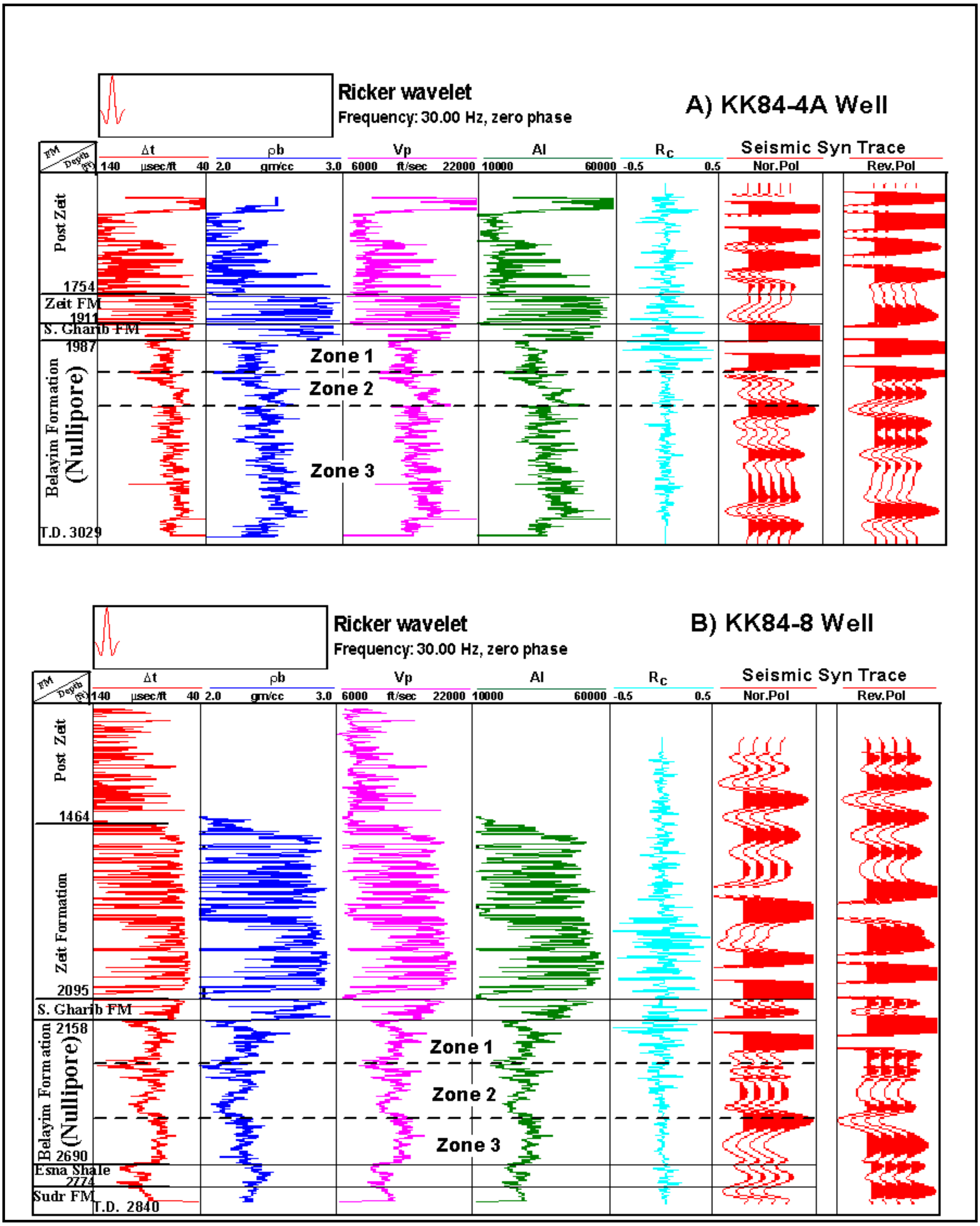
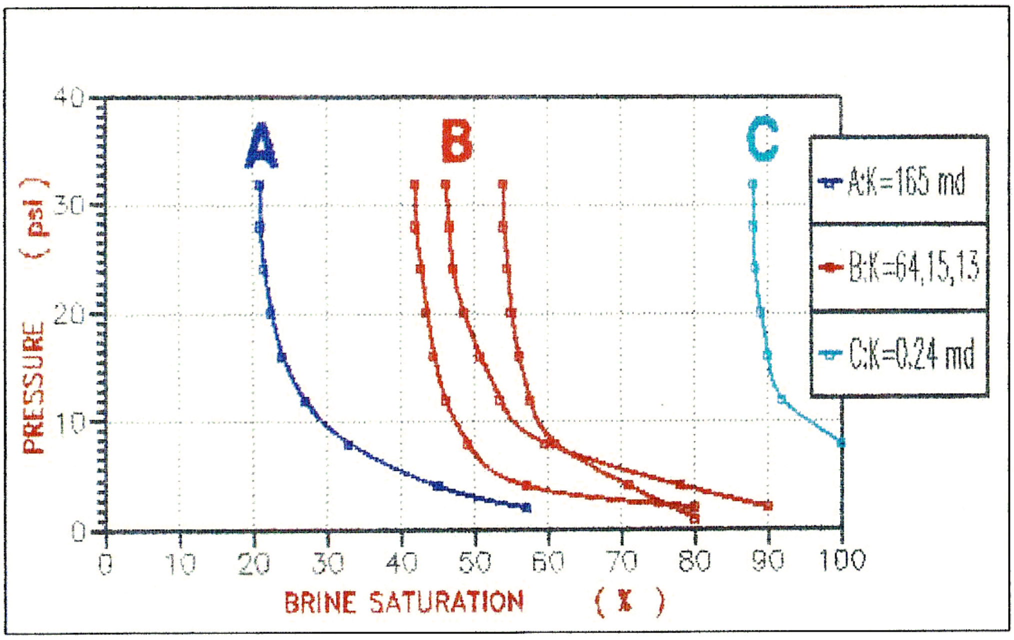


Fig. (8): Synthetic seismograms of KK84-4A and KK84-11 wells, Ras Fanar field.



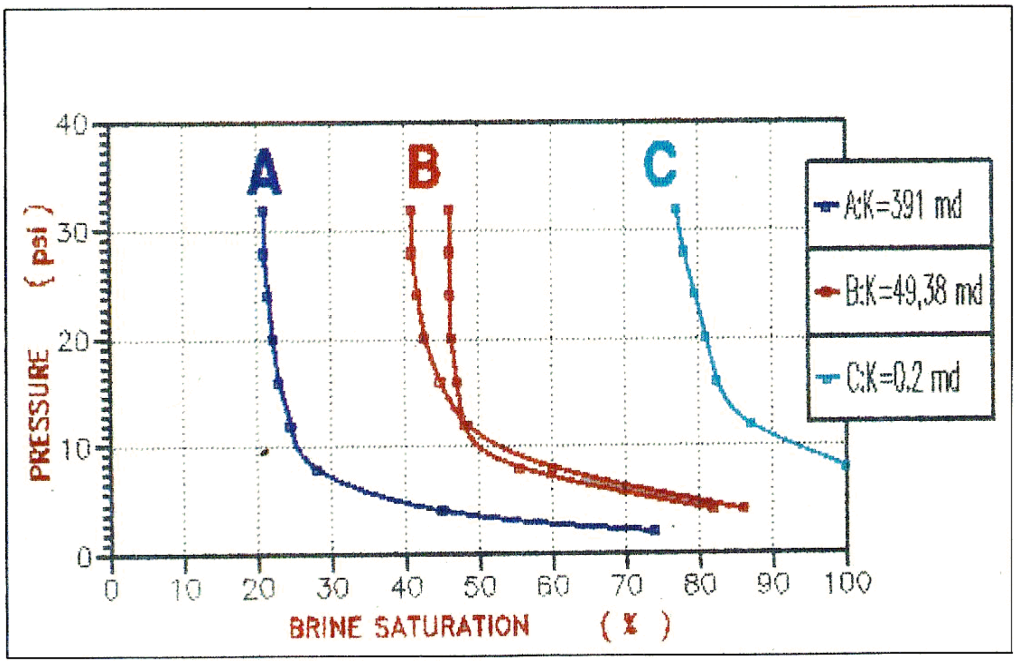


Fig. (9): Capillary pressure curves reflecting the presence of three petrophysical zones (A=II, B=III and C=I) in Nullipore reservoir rocks, Ras Fanar field.

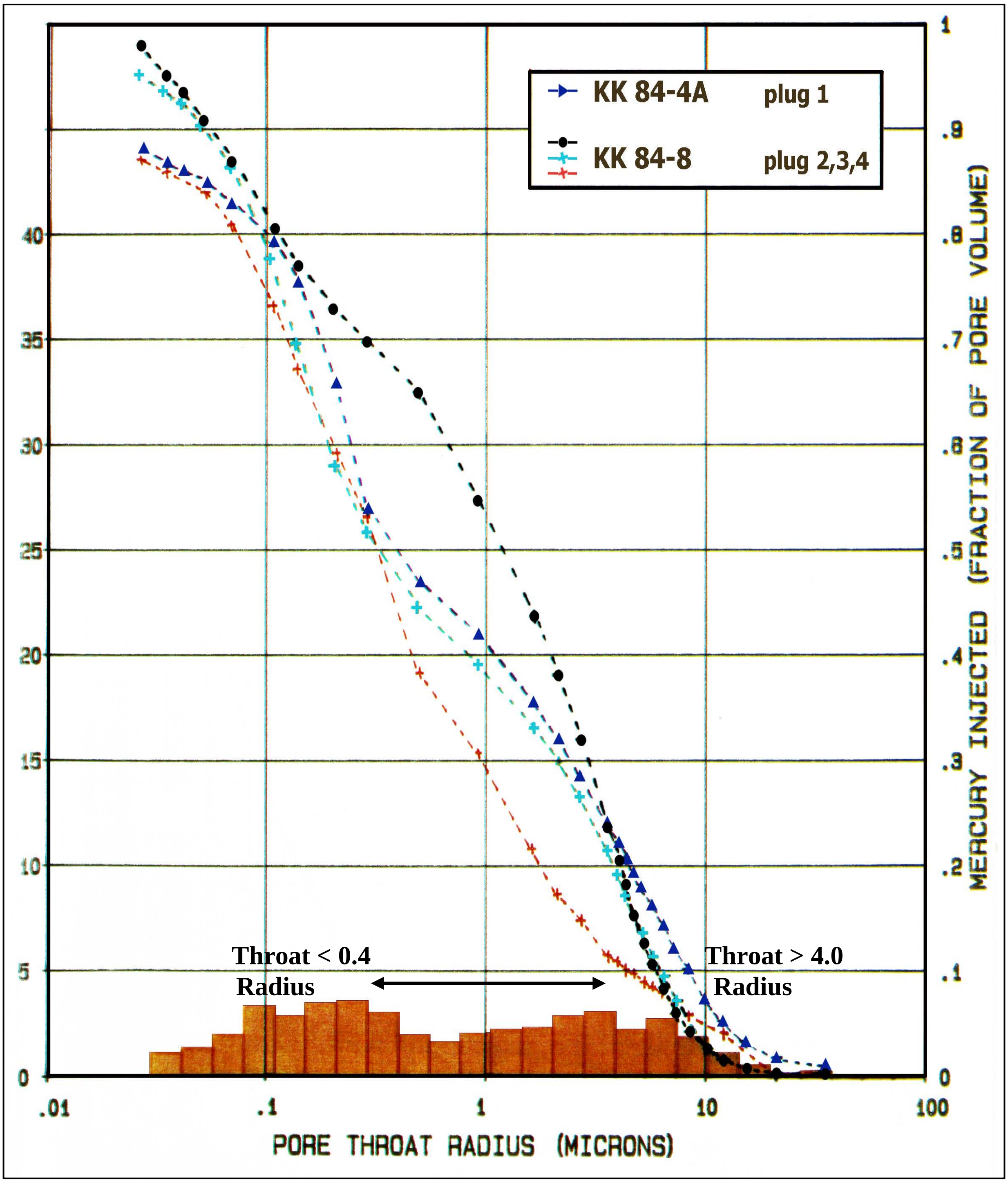


Fig. (10): Pore size distribution in Nullipore reservoir rocks exhibiting three different petrophysical ranges of throat radius, Ras Fanar field.

Facies characteristics and coralline algae content of the Nullipore succession indicate that it can be broadly divided into three regressive sequences. The main recognized facies are Peritidal (P), Inner Ramp (IR) and Mid Ramp (MR). Figure (11) ties the electro-lithofacies zones with these regressive sequences and shows a remarkably close fitting with the boundaries. The top of Zone (III) coincides with the top of the lower regressive sequence (A), top of Zone (II) matches with the top of the middle regressive sequence (B) and the top of the uppermost Zone (I) presumably correlates with the top of the regressive sequence (C). The sedimentologic evolution of the Nullipore carbonates of Ras Fanar can be summarized as follows (from bottom to top):

Sequence A (Zone III)

This sequence was penetrated by two vertical wells KK 84-4A and KK 84-8 (RF-B1). It starts with an inner-ramp packstone and passes upward into a restricted inner ramp with rare *Lithophyllum* sp.

Sequence B (Zone II)

It is penetrated in all the cored wells except for well RF-A3. KK 84-4A well shows a relatively slower subsidence rate as indicated by the presence of Halmides and some crustose algae. The deviated well RF-A2 shows a persistent open marine (inner-neritic) environment having a water depth less than 30 m as indicated by the presence of *Lithophyllum* sp.

The sequence increases in thickness whilst maintaining its open marine facies into wells KK 84-8 (RF-B1) and KK 84-2 (*Lithophyllum* and *Archeolithothamnium*). RF-B3 well shows a complete regressive sequence of inner to mid-ramp which is characterized by the presence of *Lithophyllum* at the bottom and *Lithothamnium* with rare *Lithophyllum* sp. in the uppermost part of the sequence.

Sequence C (Zone I)

This sequence is penetrated in RF-A3, KK 84-4A, KK 84-2, RF-B3 and KK 84-8 (RF-B1) wells. *Archeolithothamnium* sp. characterizes this sequence in RF-A3 and KK84-4A wells with *Lithophyllum* and rare *Lithoporella* suggesting an inner-ramp environment.

In the southern part of the field, RF-B3 well shows the repetition of the regressive sequence from mid-ramp packstone to boundstone (rich in *Lithophyllum*, *Archeolithothamnium*, some *Lithothamnium* and rare *Lithoporella* sp.) and then to mudstone facies in the uppermost part of the Nullipore sequence which is followed by a lagoonal environment.

NULLIPORE RESERVOIR EVALUATION

Nullipore reservoir characteristics had been evaluated using different analytical techniques and the different deduced petrophysical parameters, fluid saturations and pay-cutoffs were estimated and represented in a number of vertical analogs, lateral distribution maps and pay optimization plots. Based on well logging and core sample analyses, it is found that the petrophysical characteristics of Nullipore rocks in the different studied wells are nearly similar to a large extent with some relative differences in the percentages of pore spaces, fluid content and the lithological components.

Hydrocarbon Potentialities

Hydrocarbon potentialities regarding the study wells in Ras Fanar field were represented vertically in a number of analogs (litho-saturation crossplots). These analogs are the final layout, which collects the different deduced petrophysical parameters, of prime interest, together and allows their interpretation vertically with depth. In the majority of analogs, water saturation increases with depth and hydrocarbon content is represented only by oil. Only one exception is found in KK84-11 well, where little saturations of secondary gases are detected. The following is a detailed description of the analogs of four wells (KK84-4A, KK84-11, KK84-12 and RF-A2 wells) selected as examples to demonstrate the presence of different types of hydrocarbons (oil and/or gas).

Figure (12) shows the petrophysical analog of KK84-4A well. It indicates that the lithology of Nullipore reservoir is uniform and mainly dolomitic in composition. The pore spaces range between 22% and 30% and exhibit regular distribution allover the Nullipore section with some remarked increasing in the uppermost and lowermost parts. The fluid content is mainly water and hydrocarbon. Going down, the water saturation (43%) shows a general trend to increase. Therefore hydrocarbons are concentrated in the middle and upper parts of Nullipore rock. In this well, hydrocarbons are differentiated into movable and residual, and the oil-water contact is found in zone (III) at depth 2434 ft. The petrophysical analog of KK84-11 well is represented in Fig. (13). Like in KK84-4A well, the lithological content is mainly dolomitic, with little percent of limestone lithology. The pore spaces are uniform allover the whole section except in the upper and lower parts of the rock. They range from 17% (zone III) to 23% (zone II). Water saturation increases remarkably in the lowermost parts of the rock. An average water saturation value of 37% is given for Nullipore rocks in this well. Hydrocarbon content is represented by oil with little saturations of secondary gases occupied in the whole of zone (I) and the uppermost part of zone (II). Depth of 2185 ft is considered the gas-oil contact in this well.

On the other hand, high anhydrite content associated with low reduced porosity is shown in the upper part of the Nullipore rocks in KK84-12 well (Fig. 14). Pore spaces range between 21% to 27% and the lithology is mainly dolomitic in composition. High uranium content is detected in this well especially in the lower part of the Nullipore rock which is mainly saturated with water. Oil-water contact is detected in zone (II) at depth 2480ft and an average water saturation value of 45% is given for the Nullipore reservoir rocks in this well. Hydrocarbon content (55%) is mainly represented by oil.

Figure (15) exhibits the petrophysical analog of RF-A2 well. In the upper part of the Nullipore rock (zone I), the Neutron-Density overlay shows very low Neutron porosity and high-recorded Density readings which is the normal response of the presence of anhydrite as a major lithological component. This zone is filled mainly with water and is characterized by irregular pore space distribution. Below this zone, the dolomite lithology dominates, pore spaces (24%) are more uniform and hydrocarbon becomes the main fluid component (75%).

Property Distribution Maps

As previously mentioned, Ras Fanar field is an elongated horst block trending NW-SE direction, bounded by east and west clysmic faults. The geometry of the different petrophysical parameters was controlled by the geological setting of the Nullipore reservoir rock. A number of iso-parametric distribution maps for the Nullipore rocks are established, especially for those parameters concerned with the hydrocarbon potentialities (porosity, water and hydrocarbon saturations). In this respect, three porosity distribution maps are constructed for the three different zones constituting the Nullipore carbonate reservoir. Meanwhile only two average water and hydrocarbon saturation maps were enhanced due to the unrestricted occurrences of hydrocarbons to a certain zone in the Nullipore reservoir.

Fig. 16 (A, B and C) shows the porosity distribution maps of the Nullipore reservoir zones (I), (II) and (III). In the three maps, a characteristic low porosity semi-closure is well recognized between another two high porosity lobes (A and B lobes). This low porosity semi-closure attains the lowest porosity distributions and occurs in the central part of the map bounded by RF-A4 and RF-B3 wells. Porosity values are found in an increasing order to the northwest (A lobe) and southeast (B lobe) directions. Furthermore, the porosity values given for B lobe in zone II (Fig. 16B) are much higher than the other comparable values recorded for zones III and I. However, the maximum attained porosity value (31 %) is detected in zone III (Fig. 16C). It is recorded in KK 84-8 (RF-B1) well and represents the highest porosity closure in the field (B lobe).

Water and hydrocarbon saturation distribution maps (Figs. 17 and 18) reveal that two low water saturation closures (high hydrocarbon saturation) directed along a northwest-southeast axis are found in the study area. They are represented by (A) lobe in the northwestern part and (B) lobe in the southeastern part of the field. Outgoing of these lobes, hydrocarbon saturation decreases towards the eastern and western boundaries of the field. The maximum hydrocarbon saturation (S_H = 85 %) is detected in RF-B2 well at the central part of (B) lobe, meanwhile minimum values of 55 % and 57 % are recorded in KK 84-12 and KK 84-4A wells, respectively.

In general, (B) lobe (RF-B2, RF-B3, KK 84-8, KK 84-1, KK 84-11 and KK 84-12 wells) attains higher porosity, hydrocarbon saturations and better reservoir quality than (A) lobe (RF-A2, RF-A3, and KK 84-4A wells).

Nullipore Reservoir Cutoffs

Most reservoirs exhibit wide variations in lithology, porosity, permeability and water saturation. These rock properties are inter-related and could be used together in forming basis for estimating hydrocarbon reserves (Keeplinger, 1981). There are certain limits of shale volume, porosity and permeability that can be established as net pay cutoff. All formation footage having porosity and permeability values that fall below these limits is considered to have a negligible effect of recovery and can be excluded from subsequent reserve estimates. The main problem in a cutoff study is the definition of the starting (base) permeability value that adequately represents the threshold between producible and non-producible rocks. A porosity cutoff value of 14 %, corresponds to a permeability of approximately 1md, has been chosen to define net reservoir rock. So, the permeability of one millidarcy (based on core analysis) is the net pay cutoff of the Nullipore carbonate reservoir encountered in the study area.

The Nullipore reservoir cutoff has been further examined by plotting equivalent hydrocarbon column against a varying porosity cutoff for KK 84-4A and KK 84-8 wells (Figs. 19A and 20A). The plots indicate that a 14 % porosity cutoff will reduce the equivalent hydrocarbon column by approximately 2% (i.e., only 2% of the oil are contained in the Nullipore rock with porosity less than 14 %). Moreover, the plots of equivalent hydrocarbon column against varying water saturation (Sw) cutoff (Figs. 19B and 20B) show that a cutoff of 36 % hydrocarbon saturation (64 % water saturation) will discount approximately the same amount of oil as the 14 % porosity cutoff (2 %).

Table (2) summarizes the net reservoir and net pay cutoffs parameters for Nullipore Reservoir rocks in some selected wells, in Ras Fanar field.

SUMMARY AND CONCLUSIONS

Nullipore reservoir rocks consist mainly of algal rich dolomitic limestone rocks. These rocks are considered the main oil-bearing reservoirs in Ras Fanar field. The petrophysical characteristics of these rocks are evaluated through integrated well logging data, special core analysis and the algal content of 14 wells in the field. Three distinguished electro-lithofacies zones

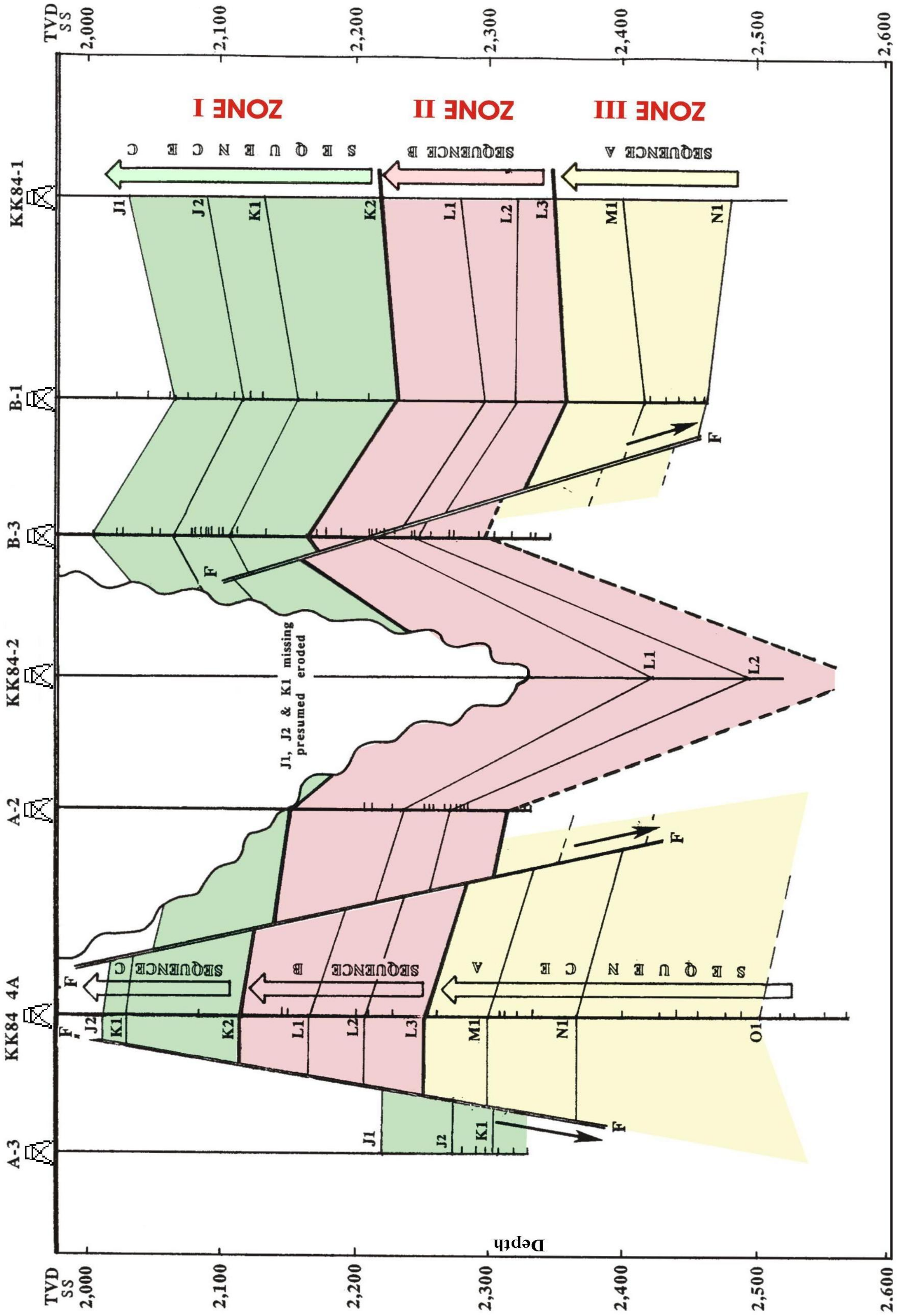


Fig. (11): Ting of Nullipore electrozones (I, II & II) with the regressive sequences (A, B and C) in Ras Fanar field.

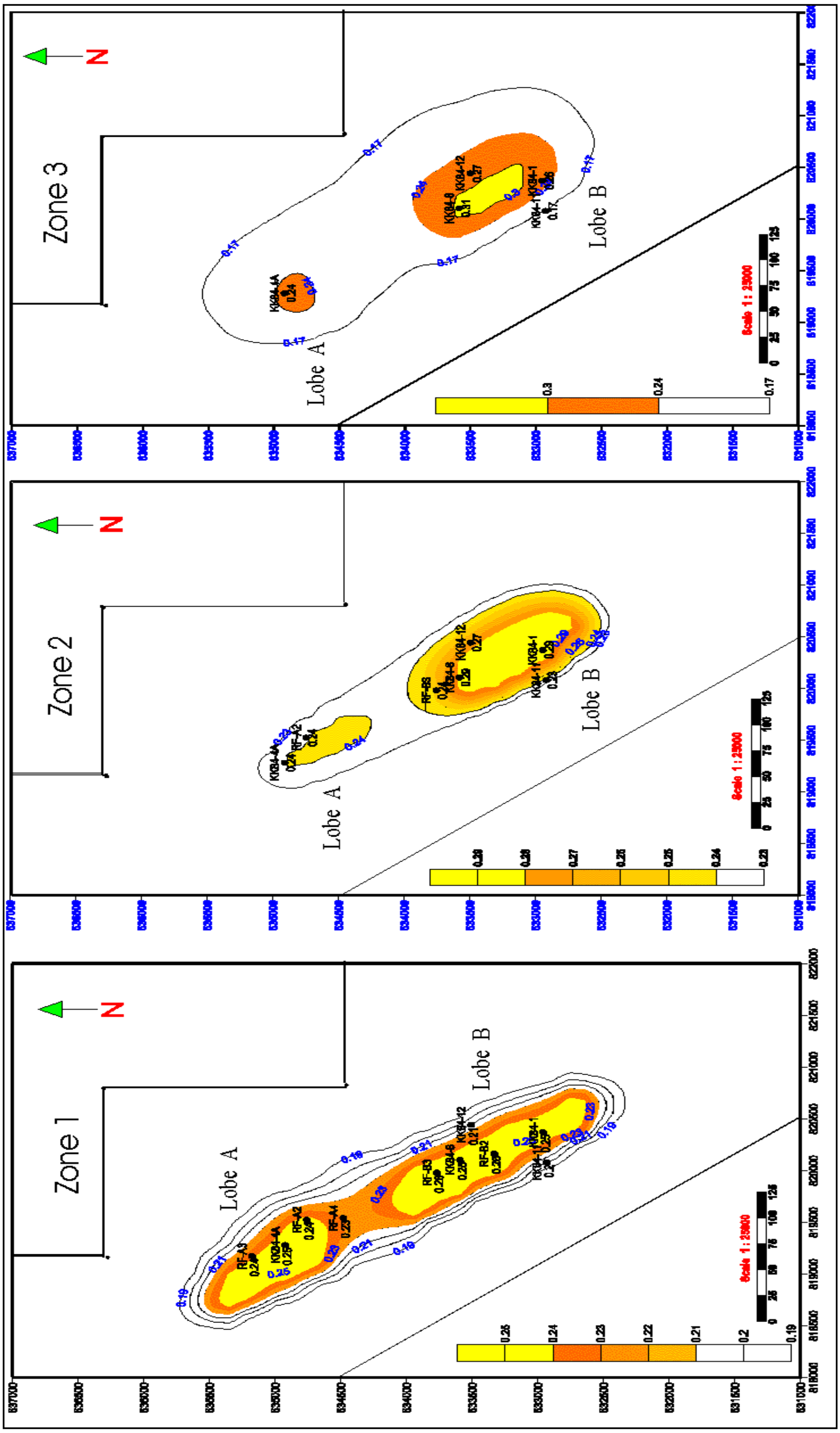


Fig. (16): Porosity distribution maps of Nullipore reservoir zones (I, II and III), Ras Fanar field.

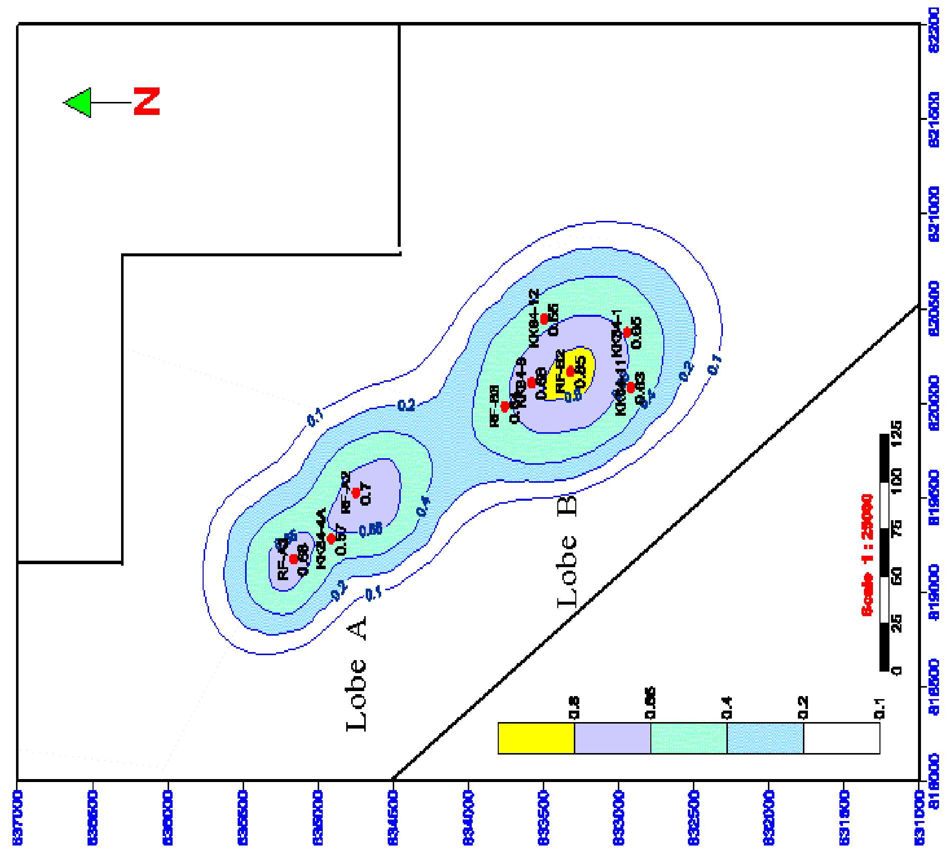


Fig. (18): Hydrocarbon saturation distribution maps of Nullipore reservoir rocks, Ras Fanar field.

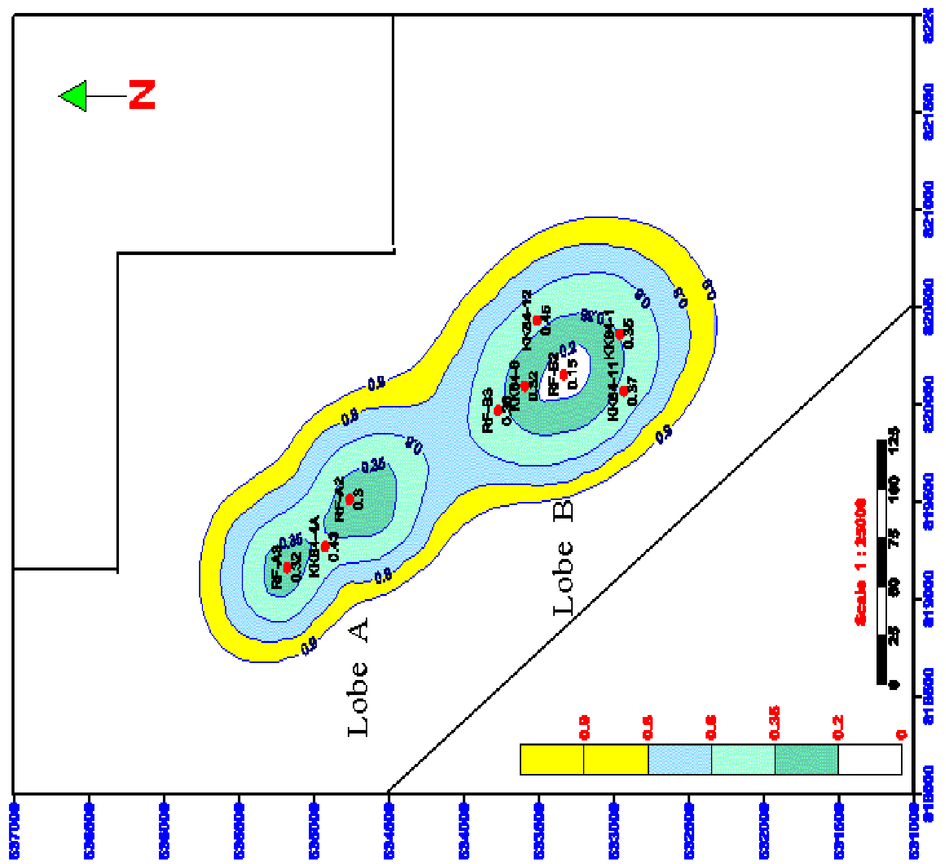
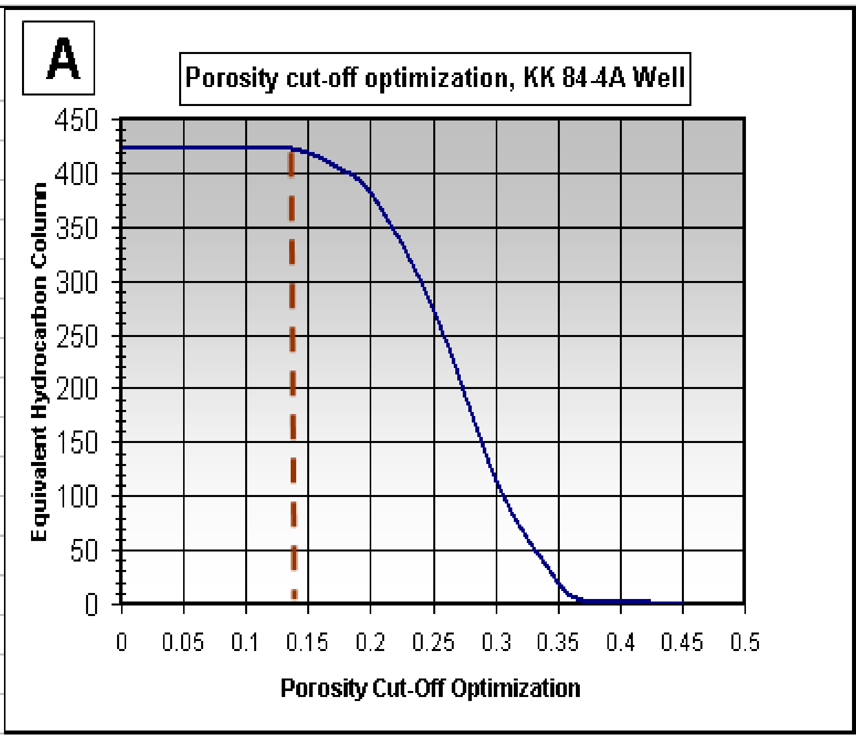


Fig. (17): Water saturation distribution maps of Nullipore reservoir rocks, Ras Fanar field.

Porosity Cut-Off	Equivalent Hydrocarbon Column
0	423
0.02	423
0.05	423
0.08	423
0.1	423
0.13	423
0.14	421
0.15	420
0.17	407
0.2	382
0.25	272
0.3	113
0.35	20
0.37	4
0.4	1.75
0.45	0



Sw Cut-Off	Equivalent Hydrocarbon Column
1	446.5
0.9	443.5
0.8	441
0.7	432
0.65	423
0.6	405
0.55	388
0.52	370
0.51	365
0.5	360
0.4	214
0.3	60
0.2	6
0.1	0
0	0

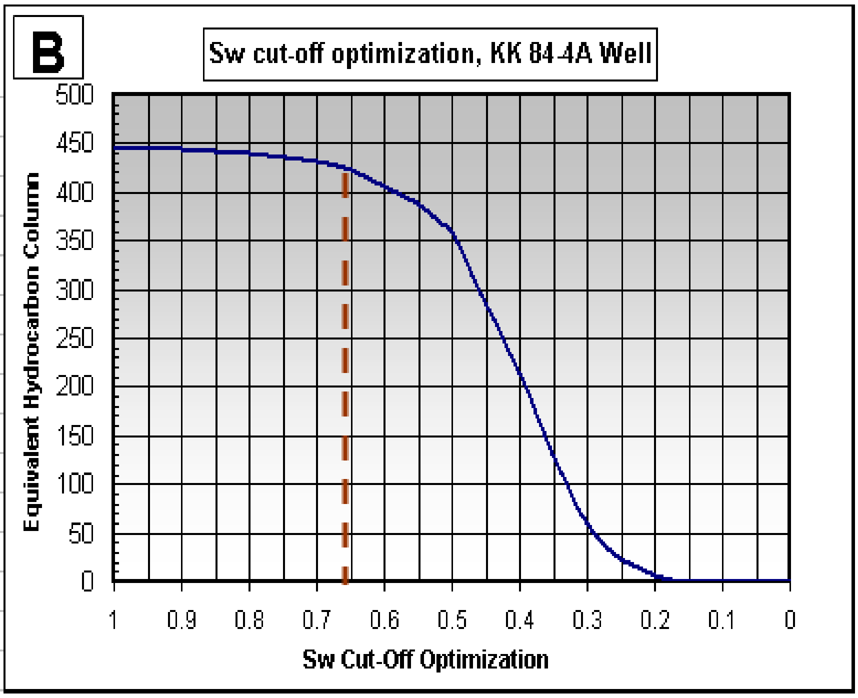
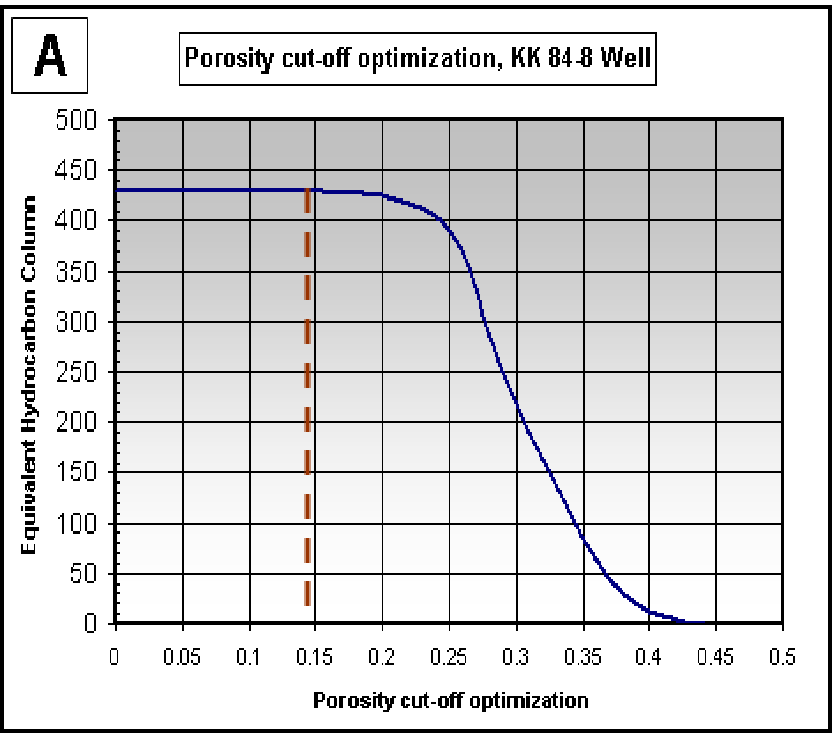


Fig. (19): Pay cutoffs optimization of Nullipore reservoir rocks in KK84-4A well, Ras Fanar field.

Porosity Cut-Off	Equivalent Hydrocarbon Column
0	430.5
0.06	430.5
0.1	430.5
0.12	430.5
0.14	430.5
0.145	430
0.15	429.5
0.17	428.5
0.18	427.5
0.2	426.5
0.22	418
0.26	367.5
0.28	286
0.3	218.5
0.32	163.5
0.36	65
0.4	12.5
0.43	1
0.44	0



Sw Cut-Off	Equivalent Hydrocarbon Column
1	430.5
0.95	430.5
0.85	430.5
0.8	430.5
0.7	430.5
0.65	430.5
0.64	430
0.62	429
0.6	425
0.5	383
0.4	350
0.3	325
0.2	259
0.1	71
0.05	9
0.03	0

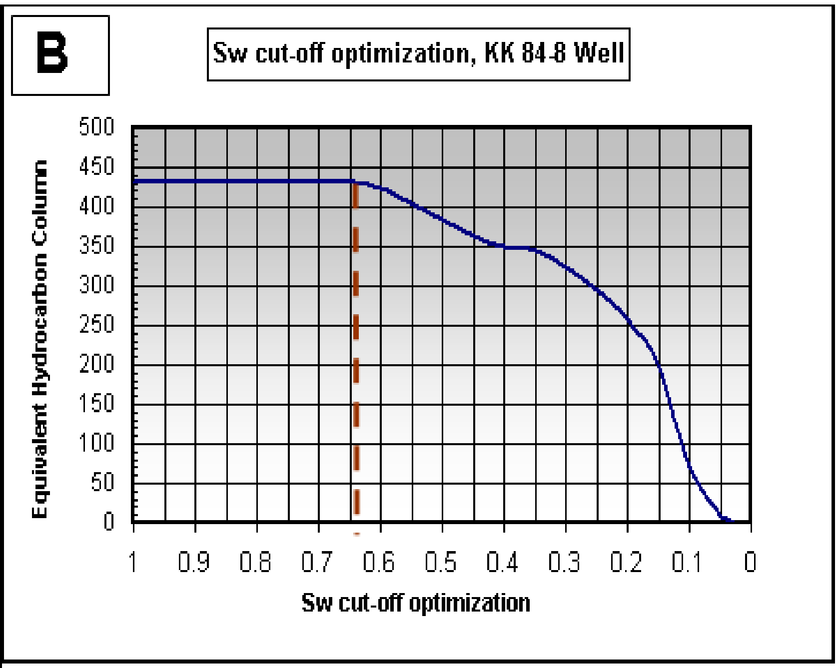


Fig. (20): Pay cutoffs optimization of Nullipore reservoir rocks in KK84-8 well, Ras Fanar field.

WELL	ZONE	Interval		GROSS Thick (Ft)	Net Reservoir				Net Pay					N/G Ratio
		TOP Ft MD	BTM Ft MD		Thick (Ft)	Avg PHI	PHI * Thick	Avg Clay Vol	Thick (Ft)	Avg PHI	PHI * Thick	Avg SW	SH * PHI Thick	
KK 84 - 1	ZONE I	2074.00	2265.00	191.00	187.00	0.272	50.89	0.00	186.25	0.250	50.75	0.29	35.86	0.98
	ZONE II	2265.00	2438.00	173.00	171.00	0.312	53.38	0.00	171.00	0.290	53.38	0.38	33.10	1.00
	ZONE III	2438.00	2770.00	332.00	124.25	0.267	33.21	0.00	9.25	0.260	2.78	0.58	1.17	0.07
KK 84 - 11	ZONE I	1986.00	2144.00	158.00	144.00	0.200	37.35	0.00	139.50	0.200	36.59	0.34	24.57	0.88
	ZONE II	2144.00	2380.00	236.00	234.50	0.234	64.52	0.00	229.00	0.230	63.36	0.32	43.09	0.97
	ZONE III	2380.00	2680.00	300.00	246.00	0.191	47.01	0.00	182.25	0.170	34.75	0.44	19.57	0.61
	ZONE III (Water)	2680.00	3210.00	530.00	20.75	0.174	3.61	0.00	6.00	0.170	1.00	0.54	0.46	0.29
KK 84 - 12	ZONE I	2322.00	2480.00	158.00	158.00	0.265	41.90	0.00	157.00	0.270	41.69	0.34	27.43	0.70
	ZONE I (Water)	2480.00	2564.00	84.00	80.00	0.259	20.75	0.00	11.75	0.310	6.68	0.50	1.82	0.08
	ZONE II	2564.00	2768.00	204.00	29.75	0.329	9.80	0.00	17.00	0.370	6.27	0.55	4.08	0.08
	ZONE III	2768.00	3116.00	348.00	-	-	-	-	-	-	-	-	-	-
KK 84 - 8 (RF-B1)	ZONE I	2158.00	2334.00	176.00	164.25	0.290	47.64	0.00	164.25	0.290	47.64	0.14	0.29	1.00
	ZONE II	2334.00	2514.00	180.00	180.00	0.326	60.02	0.00	180.00	0.330	49.74	0.17	0.66	1.00
	ZONE III	2514.00	2692.00	178.00	120.00	0.292	24.01	0.00	120.00	0.290	9.41	0.51	0.29	0.67
KK 84 - 4A	ZONE I	1987.00	2161.00	174.00	174.00	0.293	51.03	0.00	173.75	0.250	50.97	0.32	34.89	1.00
	ZONE II	2161.00	2339.00	178.00	178.00	0.245	43.56	0.00	178.00	0.240	43.56	0.34	28.73	1.00
	ZONE III	2339.00	2434.00	95.00	94.50	0.250	23.63	0.00	88.50	0.240	22.31	0.45	13.92	0.93
	ZONE III (Water)	2434.00	2970.00	536.00	160.75	0.256	41.23	0.00	17.75	0.240	4.65	0.58	1.93	0.17
RF - A2	ZONE I	2527.00	2762.00	235.00	199.25	0.245	48.90	0.00	199.25	0.250	48.90	0.28	35.22	0.98
	ZONE II	-	-	-	-	-	-	-	-		-		-	-
	ZONE III	-	-	-	-	-	-	-	-		-		-	-
RF - A3	ZONE I	2558.00	2724.00	166.00	138.25	0.272	37.62	0.00	131.75	0.280	36.39	0.28	26.33	0.79
	ZONE II	-	-	-	-	-	-	-	-		-		-	-
	ZONE III	-	-	-	-	-	-	-	-		-		-	-
RF - B2	ZONE I	2519.00	2810.00	291.00	251.75	0.311	78.21	0.00	249.25	0.310	77.58	0.14	66.86	0.97
	ZONE II	-	-	-	-	-	-	-	-		-		-	-
	ZONE III	-	-	-	-	-	-	-	-		-		-	-
RF - B3	ZONE I	2297.00	2521.00	224.00	219.25	0.260	57.04	0.01	218.25	0.260	56.91	0.27	41.49	0.97
	ZONE II	2521.00	2640.00	119.00	112.25	0.250	28.09	0.02	112.25	0.250	28.09	0.29	19.95	1.00
	ZONE III	-	-	-	-	-	-	-	-		-		-	-

Table (2): The net reservoir and net pay cutoffs for the Nullipore reservoir rocks in some selected wells in Ras Fanar field.

(zones I, II and III) are well recognized based on the integrated data of wireline log suites (log correlation and synthetic seismic traces) with the special core analysis of some selected core plugs (air-brine and mercury injection). Furthermore, the study of the coralline algae content reveals the presence of three main facies (Peritidal, P, Inner Ramp, IR and Mid Ramp, MR) in the Nullipore succession. These facies are found in good matching and close fitting with the three electro-lithofacies zones.

Complete petrophysical analysis was preformed over Nullipore carbonate rocks and various parameters were deduced like uranium volume (V_U), porosities (ϕ_t and ϕ_{eff}), fluid saturations, lithology volumes and pay cutoffs. Hydrocarbon potentialities were evaluated and number of vertical analogs and lateral distribution maps were constructed. The analogs show that Nullipore carbonate rocks consist mainly of dolomitic limestone lithology, which exhibits nearly regular distribution allover the entire rock. Going down, water saturation usually increases in the lower parts of the section. Hydrocarbons are represented mainly by oil, while some secondary gases are detected in KK84-11 well.

The lateral distribution maps of pore spaces, water and hydrocarbon saturations were also constructed. These maps indicate that Nullipore reservoir rocks in Ras Fanar field are distinguished petrophysically into two lobes (A and B) oriented along a northwest-southeast axis. The hydrocarbon saturation increases towards the center of these lobes. The maximum porosity value of 31 % is recorded in KK 84-8 (RF-B1) well, which represent the highest porosity closure in the field (B lobe).

Lobe (B) is considered better in reservoir quality than lobe (A) as it exhibits high pore spaces and the maximum hydrocarbon saturation (S_H = 85 % in Rf-B2 well). Cutoff values of 14% porosity and 64% water saturation are considered the net pay evaluation of Nullipore reservoir rocks.

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