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Electro-Facies and Petrophysical Properties of the Hartha Formation in Selected Wells of East Baghdad Oil Field

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Abstract

The Hartha Formation is a major carbonate succession deposited during the Late Campanian period. The current study depends on four selected wells (EB 1, 2, 4 and 30) within the East Baghdad oil field to study electrofacies and petrophysical properties related to the reservoir characterization.

The Hartha Formation is divided into three electro-facies units using GR and SP logs in Petrel software. The upper unit of the Hartha Formation is composed mainly of limestone. The middle unit is composing of thick layers of shale. The lower unit is composed mainly of limestone with few shale layers. The three units are divided into three types of rocks in relation to the total porosity: 1. High-moderate active porosity rocks (type I). 2. Moderate active porosity rocks (type II). 3. Low-non pores rocks (type III).

The lower unit represents the shale–dominated part of the Hartha Formation, with low to non-pores rocks (type III). This zone is revealed in all studied wells. These are limit presences for the high to moderate active porosity type (I) within the shale bands lithofacies appear in the studied wells.

The middle unit is divided into two subzones. The upper part of this zone is characterized by high to moderate active porosity (type I), while the lower one shows moderate active porosity (type II) and low to non-pores rocks (type III) due to the high ratio content of shale.

Upper rock-unit is expressed by high-moderate active porosity rocks (type I), which shale content is very low. This porosity type is identified through the upper unit at the East Baghdad oil field. These characteristic features are highly consistent with the low to moderate shale value rock unit.

Keywords: Hartha Formation, Electro-facies, Petrophysical Properties, East Baghdad Oil Field

الخواص البتروفيزيائية والسحنات الكهربائية لتكوين الهارثة في عدة آبار مختارة ضمن حقل شرق بغداد النفطي

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الخلاصة

تكوين الهارثة هو عبارة عن تتابع كربوني تم ترسيبه خلال الفترة الكامبانين المتأخر. ترتكز الدراسة الحالية

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على أربعة آبار محفورة ضمن حقل نفط شرق بغداد وهي (1، 2، 4، 30) وذلك لدراسة الخصائص الكهربائية والبتروفيزيائية المتعلقة بوصف المكمن الصخري بشكل عام.
ينقسم تكوين الهارثة اعتمادا على مجسات اشعة كاما (GR) والجهد الذاتي (SP) وباستخدام برنامج Petrel إلى ثلاث وحدات للسحنات الكهربائية. تتكون الوحدة العليا من تكوين الهارثة في الغالب من الحجر الجيري. وتتكون الوحدة الوسطى من طبقات سميكة من صخور الشيل (الطفل). تتكون الوحدة السفلية بشكل أساسي من الحجر الجيري مع طبقات أقل من صخور الشيل (الطفل). تنقسم الوحدات الثلاث إلى ثلاثة أنواع من الصخور حسب المسامية الكلية الى: 1. صخور ذات مسامية فعالة عالية ومتوسطة المسامية (النوع الأول). 2. صخور معتدلة المسامية الفعالة (النوع الثاني). 3. صخور منخفضة الى عديمة المسامية (النوع الثالث).
تمثل الوحدة السفلية الجزء الذي يهيمن عليه صخور الشيل (الطفل) من تكوين الهارثة، مع صخور منخفضة إلى عديمة المسامية (النوع الثالث). يظهر هذا النطاق تقريبا في جميع الآبار المدروسة. هذا بدوره حدد من وجود نوع المسامية الفعالة العالية إلى المتوسطة (نوع الاول)، داخل السحنات الطبقية من صخور الشيل والتي تظهر في جميع الآبار المدروسة.
الوحدة الوسطى مقسمة إلى منطقتين فرعيتين. يتميز الجزء العلوي من هذه المنطقة بمسامية فعالة عالية إلى متوسطة (النوع الأول)، بينما الجزء السفلي يظهر مسامية فعالة معتدلة (النوع الثاني)، وصخور منخفضة إلى غير مسامية (النوع الثالث)، بسبب النسبة العالية من محتوى صخور الشيل.
تتميز الوحدة العلوية بصخور مسامية فعالة عالية الى متوسطة (النوع الأول)، بسبب انخفاض محتوى صخور الشيل (الطفل). يتم التعرف على هذا النوع من المسامية من خلال الوحدة العلوية في حقل نفط شرق بغداد. تتوافق هذه الصفات الصخرية التي تم التعرف عليها مع وحدة الصخور ذات المحتوى الصخري المنخفض إلى المعتدل من صخور الشيل (الطفل).

1. Introduction

Carbonate reservoirs consist of more than 60% of the world's oil reserves and produce more than 30% of the daily oil word production. In comparison to most sandstone reservoirs, assessing petrophysical characteristics and understanding fluid flow mechanisms is more complicated in carbonate reservoirs. Fluid flow through heterogeneous carbonate reservoirs is a different and difficult process than fluid flow through homogeneous sandstone reservoirs, due to the more complex pore systems of carbonate rocks compared to the sandstone. In addition, the greater chemical reactivity of carbonate minerals, as carbonate rocks are mostly composed of calcite minerals, which are easily reactive to the formation brine [1].

The process of analyzing a mixture of various measurements which are mainly gathered from inside the well bore to characterize wells for a possible hydrocarbon containing rocks, which includes cores analysis, laboratory studies of fluid characteristics, and well logs, is known as a formation evaluation. Well logs are one of the most important data sources for geological and petrophysical parameters of reservoir formations; well logging is crucial in determining hydrocarbon reservoirs production potentials. The key petrophysical characteristics and lithology of the Hartha Formation in the south of the East Baghdad oil field are the objective of the current research. The field is still in the early stages of development. The goal of the study is to obtain a better understanding of the reservoir characteristics to develop tools for future field economic development plans.

The Hartha Formation is a major carbonate succession deposited during the Late Campanian period. By the intricacies of the sedimentary basin and the movements that shaped it, there is a significant heterogeneous from one location to the next. For most parts, Hartha formation was formed in marginal-marine, fore-reef, neritic, and shoal environments, and in locally parts back-reef facies can be found as well [2].

Rabanit 1952 [2], (in [3]) was the first to identify the Hartha formation at Zubair Field. The formation is comprised of bioclastic-detrital glauconitic limestone that is 200-250 meters thick (656-820 feet), with green or gray shaley interbeds.

East Baghdad is a super-giant oil field located 10 kilometers Eastern Baghdad capital city, in governorates of Baghdad and Diyala (Figure 1a). The contract area for the East Baghdad field is 65 kilometers long and 11 kilometers wide, and it encompasses the area North-West of the Diyala River.

The purpose of this research is to conduct a petrophysical analysis of the Hartha Formation to identify and interpret the reservoir characterization. This will assist to a large extent in the assessment of this important reservoir and give a reservoir evaluation for future works.

2. Methodology

For correction and interpretation, Interactive Petrophysics software (IP V3.5, 2009) was utilized, and Petrel software. Potential spontaneous recordings (SP), gamma rays, density, sonic, neutrons, and resistivity logs were utilized from four well log records in the form of LAS-files. These selected wells are EB-1, EB-2, EB-4, and EB-30 (Figure 1b).

The environment corrections were performed using the Interactive Petrophysics software's environment correction module. Schlumberger Log Interpretation Charts (2000 Edition) was used, whereas Schlumberger oil field services provided the well log data. When gamma-ray measurements are corrected for mud characteristics i.e., mud kind and weight, and borehole condition, the findings show a considerable rise in gamma-ray readings. Whilst the well had no cavities, as shown by the caliper log, mud properties were the determining factor in this shift. Since induction resistivity showed no change in readings, the raw log data were not impacted by drilling mud in the invention zone. Because of the drilling mud and logging techniques utilized, the readings on the micro resistivity and density logs have changed slightly.

Neutron density log shifted significantly between readings, and the corrected readings were increased; the neutron log is influenced by various factors, including drilling mud, formation properties, and lithology contrast. Figure 2 displays log plots with corrections for the well EB-30, Southern the study area.

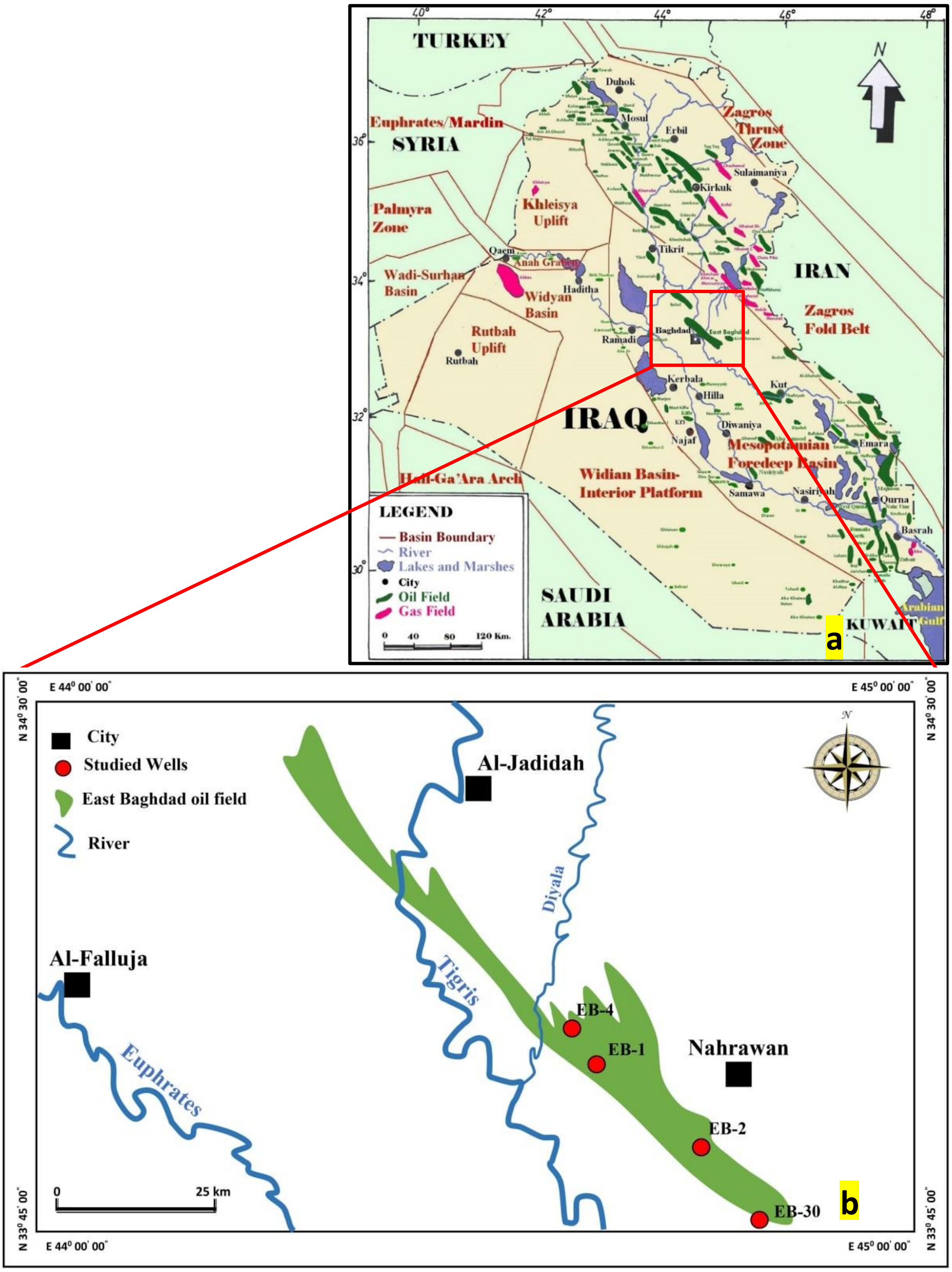

Figure 1- a) Map of Iraq showing the location of the East Baghdad oil field highlighted by red rectangle [4], b) Locations of four Wells used in the current study within the study area of East Baghdad oil field

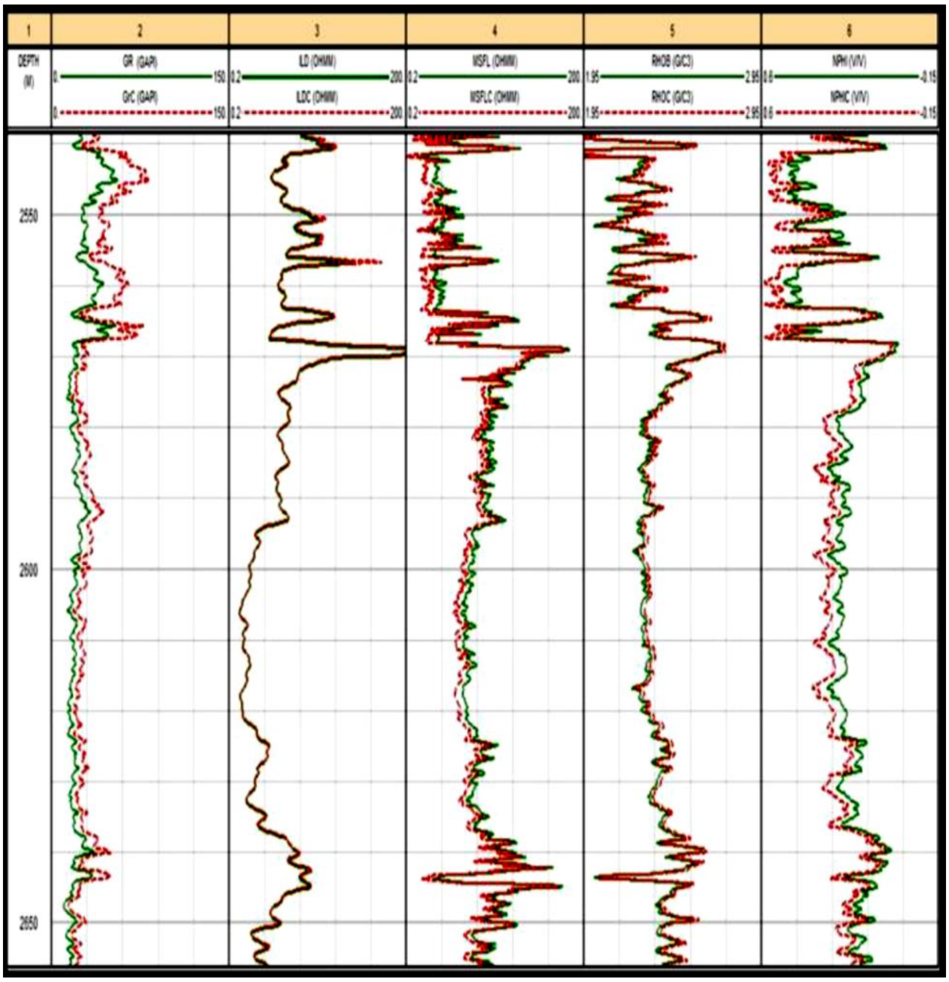

Figure 2- Plot of environmental correction log of EB-30 well, generated by IP software. The solid green lines reflect the well logs reading, while the dotted red lines represent the corrected readings

3. Stratigraphic Setting

In the geological development of Iraq territory, the Upper Campanian-Maastrichtian cycle contains significant geological formations. The deposition cycle starts with a widespread transgression that nearly covers the entire Iraqi territory, occurring after the sea-level rising [5].

Because of the importance of most formations for the oil productions and industry in both the Northern and Southern portions of the Iraq and neighboring countries, the Upper Campanian-Maastrichtian cycle rocks/sediments have been subjected to extensive scientific studies.

The cycles Formations are roughly contemporary and are replaced by one another. Within the Upper Campanian-Maastrichtian period, local changes in age occur mainly where facies bound structures inter-tongue.

Many scholarly attempts have been conducted to define rock units from this time based on their lithofacies and biofacies, as well as their paleogeographic depositional site. The most important attempts were conducted by Buday [6], which is in his division blended these unit rocks depending on similar facies and paleogeographic locations, and he was splitting them into groups based on their depositional environments (Figure 3).

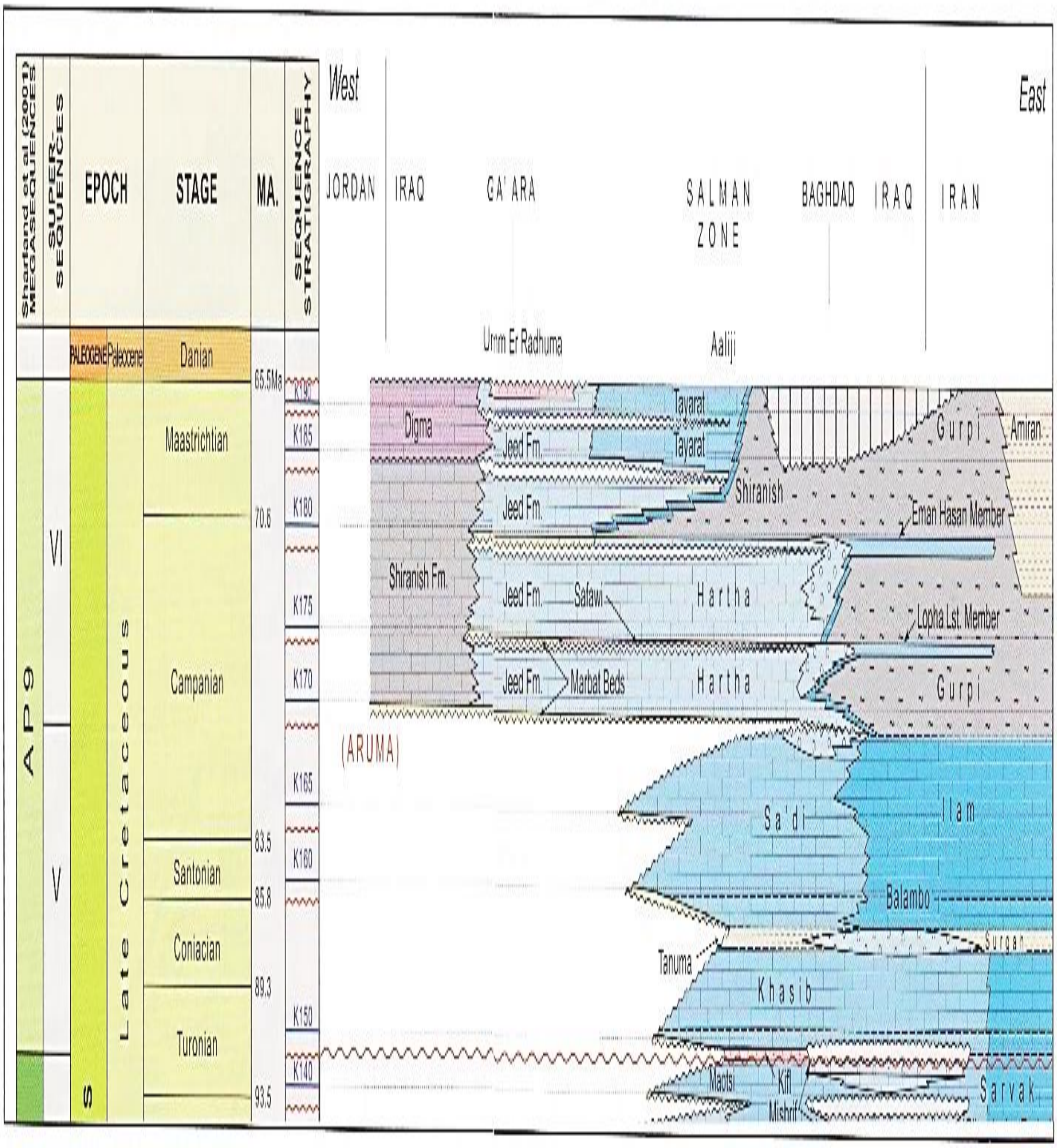

Figure 3- The figure represents the Early Cretaceous chronostratigraphic cross-section (After [6])

Between Ramadi and Makhual areas, the Hartha Formation contains anhydrite and oolitic limestone as layers and interbedded lenses. Oolitic limestone is found in North-eastern Iraq. These carbonate facies were deposited in a lagoon environment on the West side of the Mesopotamian Zone, in the Hartha carbonate setting platform [7].

The Hartha Formation in the Rutba area of Western Iraq consists of "Birdseye" textured marl and dolomite strata, which refer to deposition in the supratidal-subtidal environment. The Hartha Formation is thinning to the North of Rutba and is completely terminated underlying an unconformity with Tayarat Formation on the Ga'ara depression's Northern margin. In the West, at the Rutba city, the formation is mostly carbonates, whereas, in the east part, it consists mostly of marl rocks

Homadi and Al-Zaidy [8] studied the Hartha formation and suggested Four depositional environments that deposited this type of succession: shallow open marine, deep open marine, semi-restricted, and restricted. The distribution of these depositional environments led to the recognition of three major depositional stages in the Hartha succession in the East Baghdad oil field.

The Hartha formation is thick in Salman Zone (400 m), South of Ramadi city, while it is around 100-200 m thick in Mosul city. The Hartha Formation was formed in environments that ranged from fore-reef to shoal. Back reef (Lagoonal) facies are also found along the stable marginal shelf as evidenced by coral reef limestone as debris in detrital limestone strata in some parts of the Formation, while reef facies may be present near the Khlesia uplift [7].

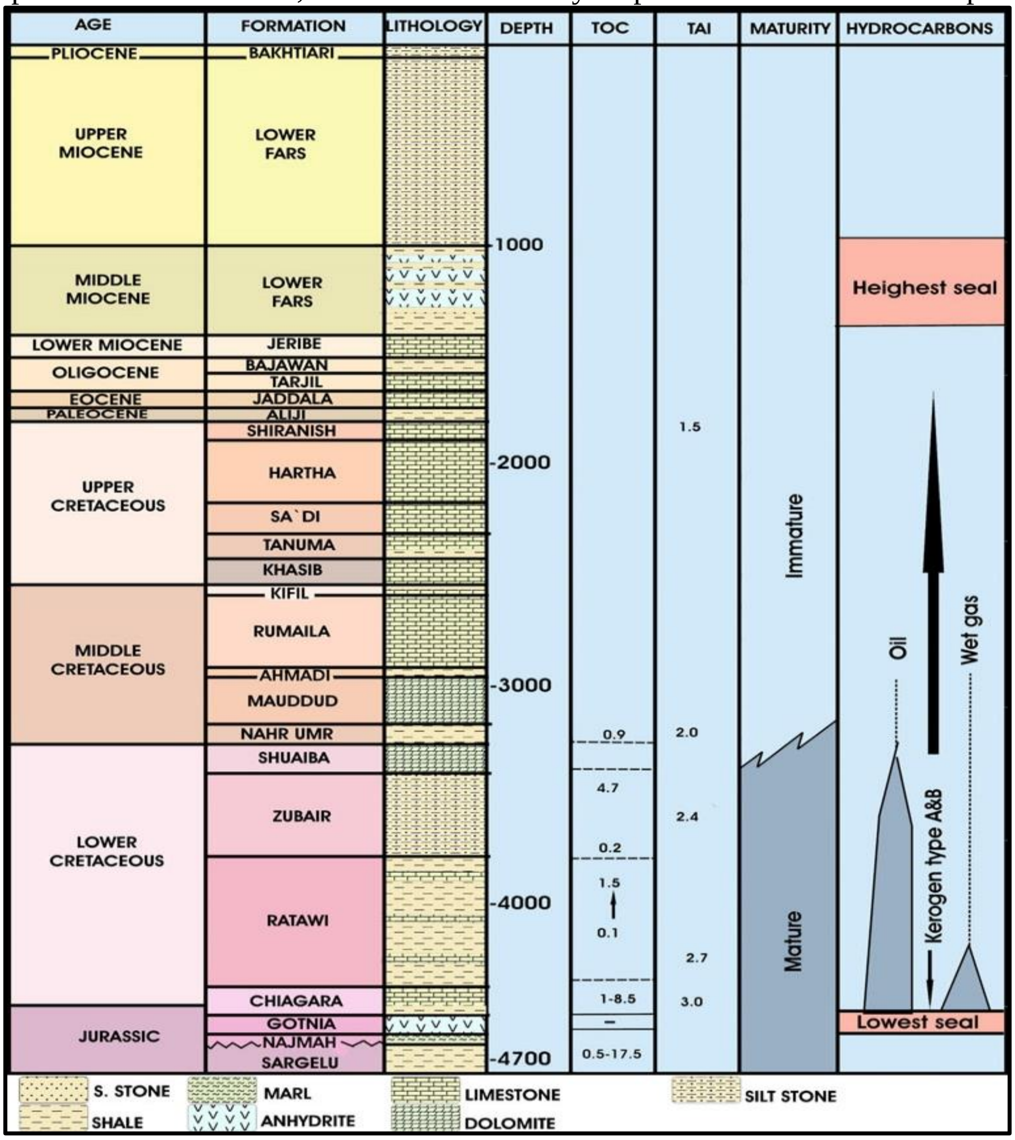

Figure 4- The Stratigraphic columnar section with formations thicknesses in meter for East Baghdad Oil Field with the generation of hydrocarbon parameters and seal property within the total petroleum system [9]

The study area was subjected to various tectonic events with regressive and transgressive cycles [10], which predominantly allowed high organic matters to be preserved, resulting in the advancement of the Arabian Region's largest oil and gas reserves. Many faults with NW-SE trending structures can be found in the field area, with hydrocarbon production coming from Tanuma Formation, fractured Khasib carbonates (Late Cretaceous), and Zubair Formation which represent Early Cretaceous sandstone.

The hydrocarbon has been successfully tested out in addition to the Cretaceous reservoirs such as Hartha, Mishrif/Rumaila carbonate successions, while clastics of Nahr Umr, and mixed clastic/carbonate of Ratawi formations [11] (Figure 5).

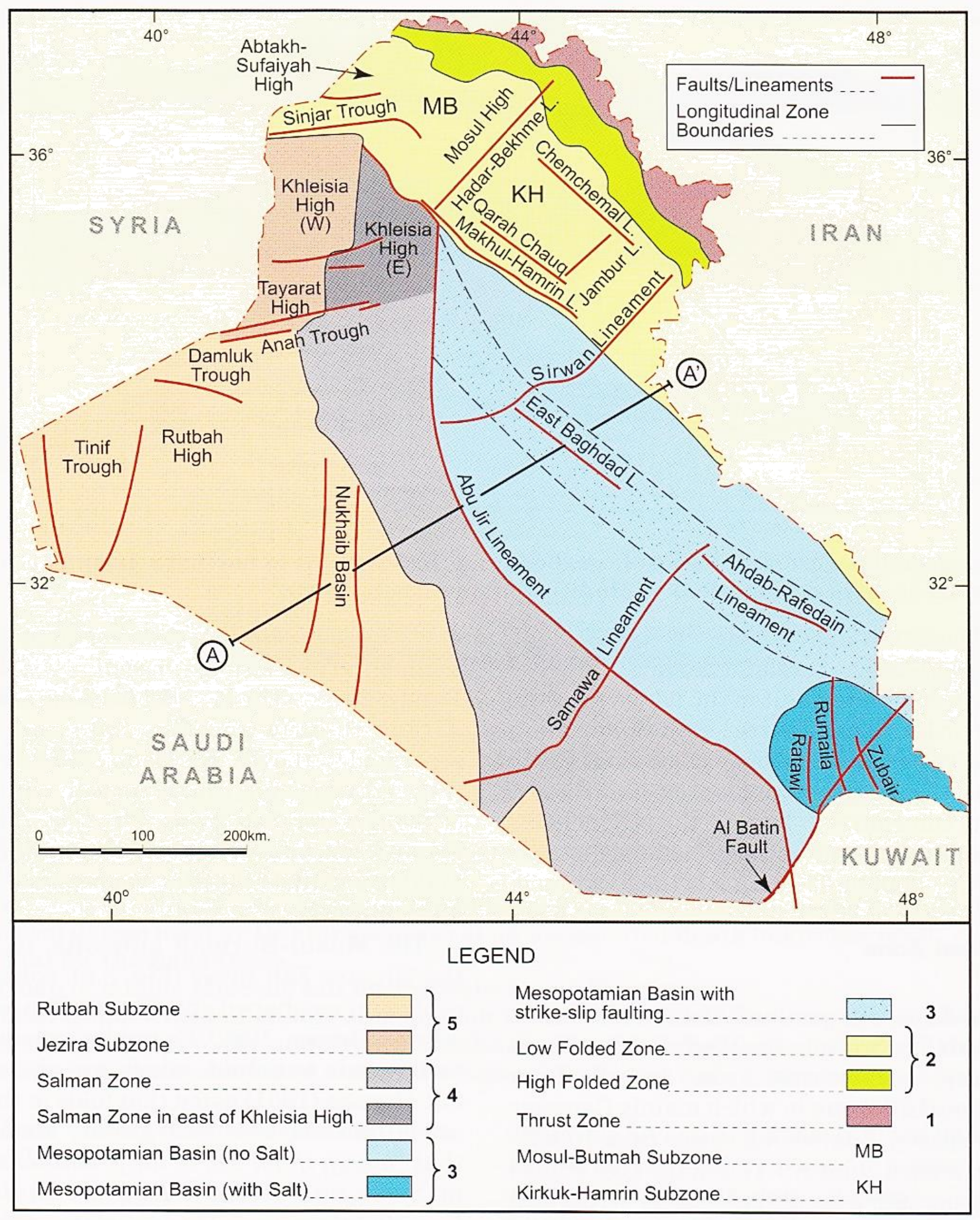

Figure 5- The Tectonic Map of Iraq showing the Mesopotamia Foredeep (Modified after [5])

6. Electrofacies Units of the Hartha Formation

The Hartha formation thickness in the current study area is approximately 225 m (Table 1). It is divided using GR & SP logs in Petrel Software into three lithofacies units (Figure 6). The upper member of the Hartha formation is mainly composed of limestone. The middle unit or member is composed of thick layers of shale. The lower unit consists mainly of limestone with less shale layers. Figures (6), (7), (8), (9), (10) and (11) are illustrated the depth and isopach maps of three stratigraphic zones of the Hartha formation in the study area.

Table 1- Showing the top, bottom and thickness (in meter) of the four studied wells

Well No	Hartha Formation		
	Top	**Bottom**	**Thickness (m)**
EB-1	1874 m	2194 m	320 m
EB-2	2003 m	2287 m	284 m
EB-4	1863.5 m	2172 m	308.5 m
EB-30	2111.5 m	2400 m	288.5 m

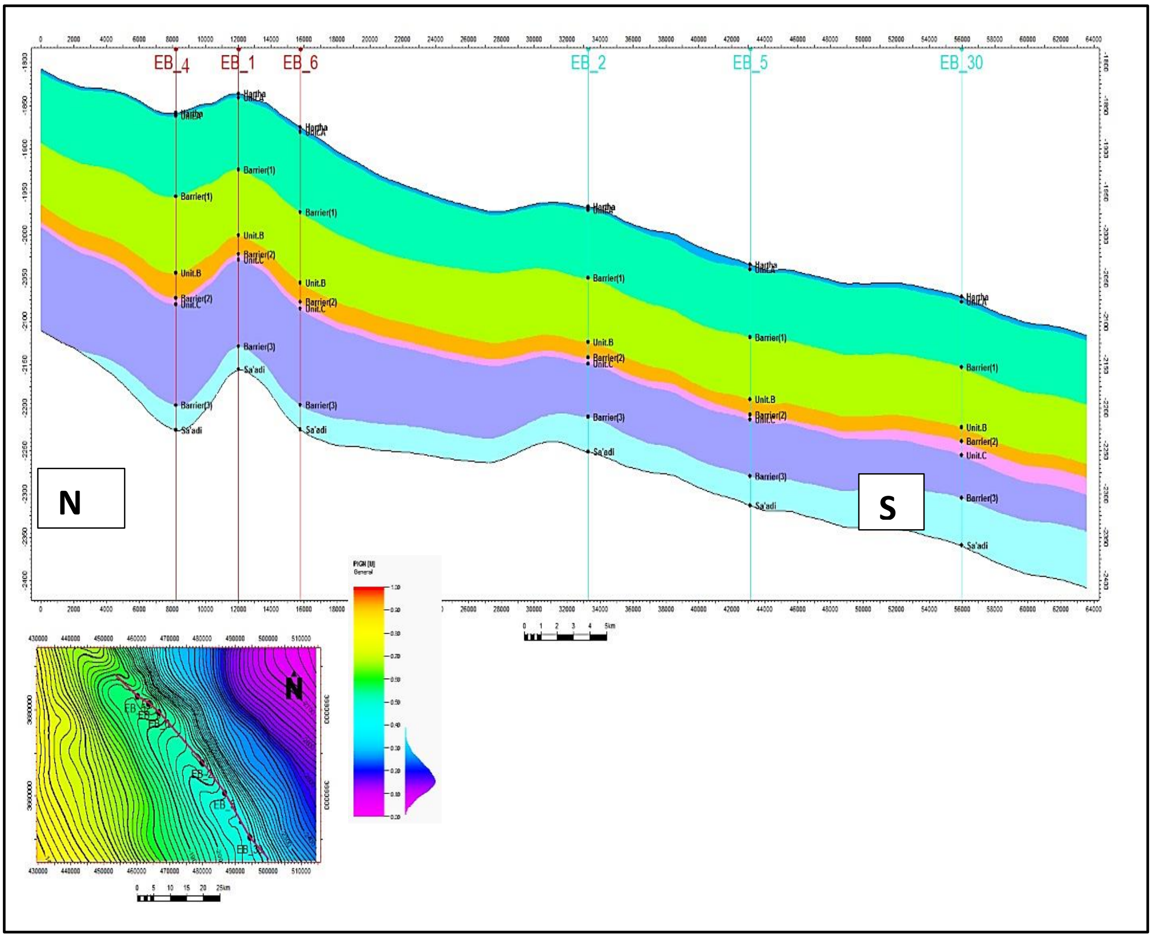

Figure 6- Cross-section showing main three units of the Hartha Formation (lower, middle and upper units) in East Baghdad Oil Field

- Upper unit

The upper unit is characterized by low gamma-ray well log values with many cycles as descending upward bell shape, and grain size increasing as a funnel shape pattern. This unit also has a bell and serrated shapes in the study area. The thickness of this rock unit is about 25 m in EB-4 and increases to about 50 m in the Northwest direction. Figure (7a) shows the facies distribution through this upper unit.

- Middle unit

This unit is distinguished by high Gamma Ray (GR) values with many cycles of fining upward as funnel shape of gamma well log pattern in the upper part of this unit, and fining upward as hour-glass shaped in some positions. The middle unit has a thickness of about 60 m in the East Baghdad oil field. Figure (7b) displays the distribution of thicknesses for this unit.

- Lower unit

This unit has shown low V-shale and the general gamma ray log pattern almost forms a serrated shape, which refers to relatively increasing and decreasing upward. The thickness of the lower unit is about 100 m in the East Baghdad oil field. Figure (7c) illustrates the thickness variation in the lower unit.

These three units are clearly shown in Figure (6), which mainly showed variations of facies along EB-1, EB-2, EB-5, EB-4 and EB-30 exploration wells.

7. Porosity distribution models

The above-mentioned is represented a petrographic testing and observations, which are in terms of rock-fabric units. These rock units can be most effectively converted into the petrophysical features and then into the reservoir model-characterizations.

The Hartha formation can be divided based on the gamma-ray patterns and shale value into three petrophysical zones: upper, middle, and lower zone, which match stratigraphic zones. Therefore, the logs-porosities and the porosity evaluation have been interpreted depending on these zones or divisions. The porosity well logs (sonic logs) in the studied wells show an approximate matching with these three identified divisions.

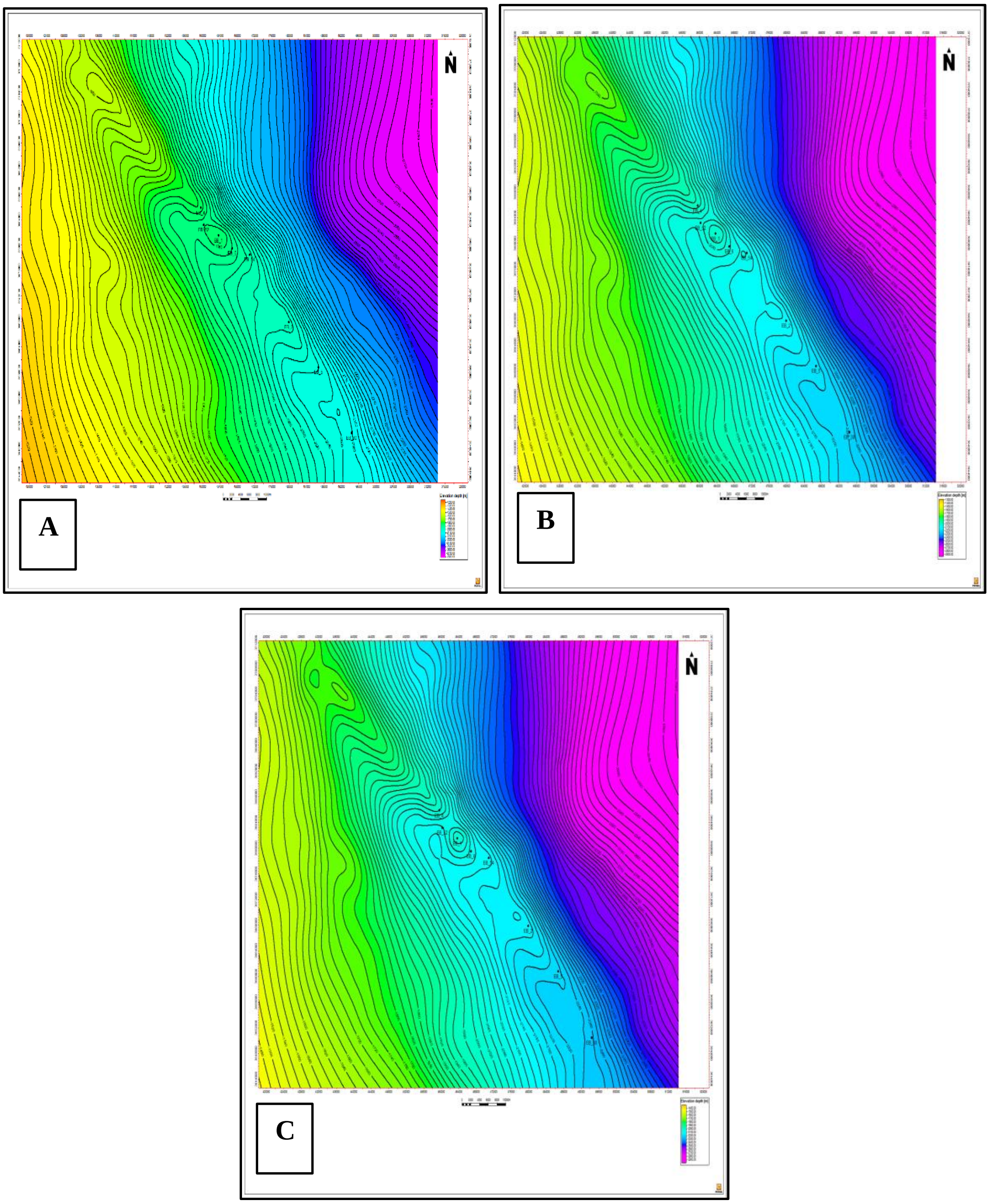

Figure 7- Isopach map for the: A. Lower unit, B. Middle unit and C. Upper unit of the Hartha Formation in East Baghdad Oil Field

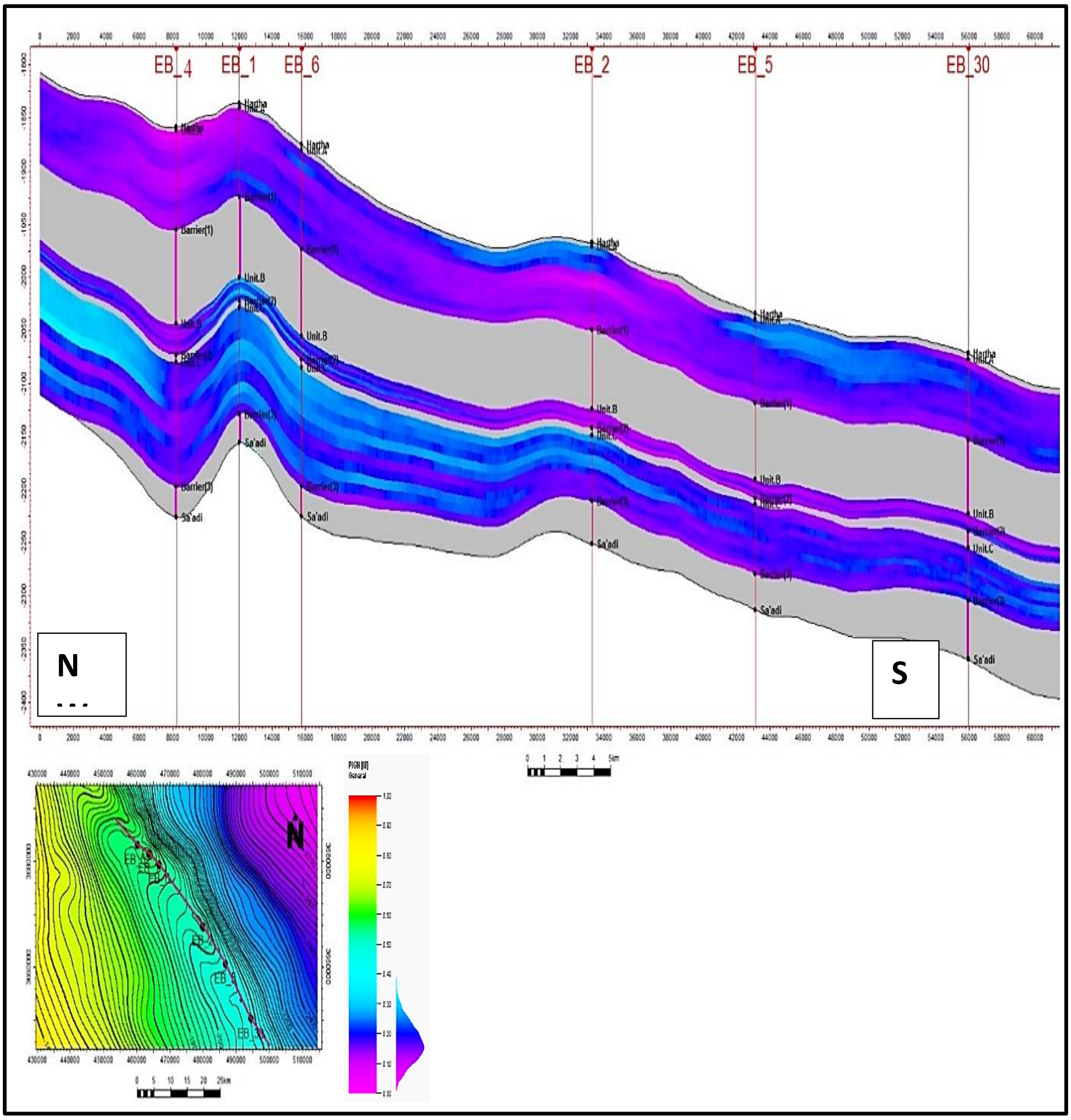

Figure 8- The figure of Cross section showing porosity distribution in three units of the Hartha formation in East Baghdad Oil Field

Depending on the Petrel software of sonic well logs of drawing the porosity-depth relationship for each selected wells rather than well logs reading with depth. The sonic (porosity) well logs are studied to detect and identify the interconnected petrophysical zones of voids space, thus transferring fluids therein, i.e., effective porosity in the Hartha formation. These petrophysical zones can be divided into three rock types depending on total porosity (Figure 8):

1. High values to moderate active porosity rocks (type I).
2. Moderate values of active porosity rocks (type II).
3. Low values and/or non-pores rocks (type III).

- *Lower zone*

The lower zone represents a shale–dominated rocks of the Hartha formation, with low porosity value to non-pores rock types (type III). This zone is identified in whole studied wells (Figure 9a). These are restricted presences for high to moderate values of active porosity type (I) within the shale bands lithofacies which appeared in the currently studied wells.

- Middle zone

This zone is classified into two subzones. The upper part of this zone is characterized by high to moderate values of active porosity (type I), while the lower part is showed moderate values of active porosity (type II), and low values to non-pores rock-types (type III), this due to the high-ratio shale volume (Figure 9b). This petrophysical zone is represented the middle part of Hartha formation within the shale-dominated unit.

- Upper zone

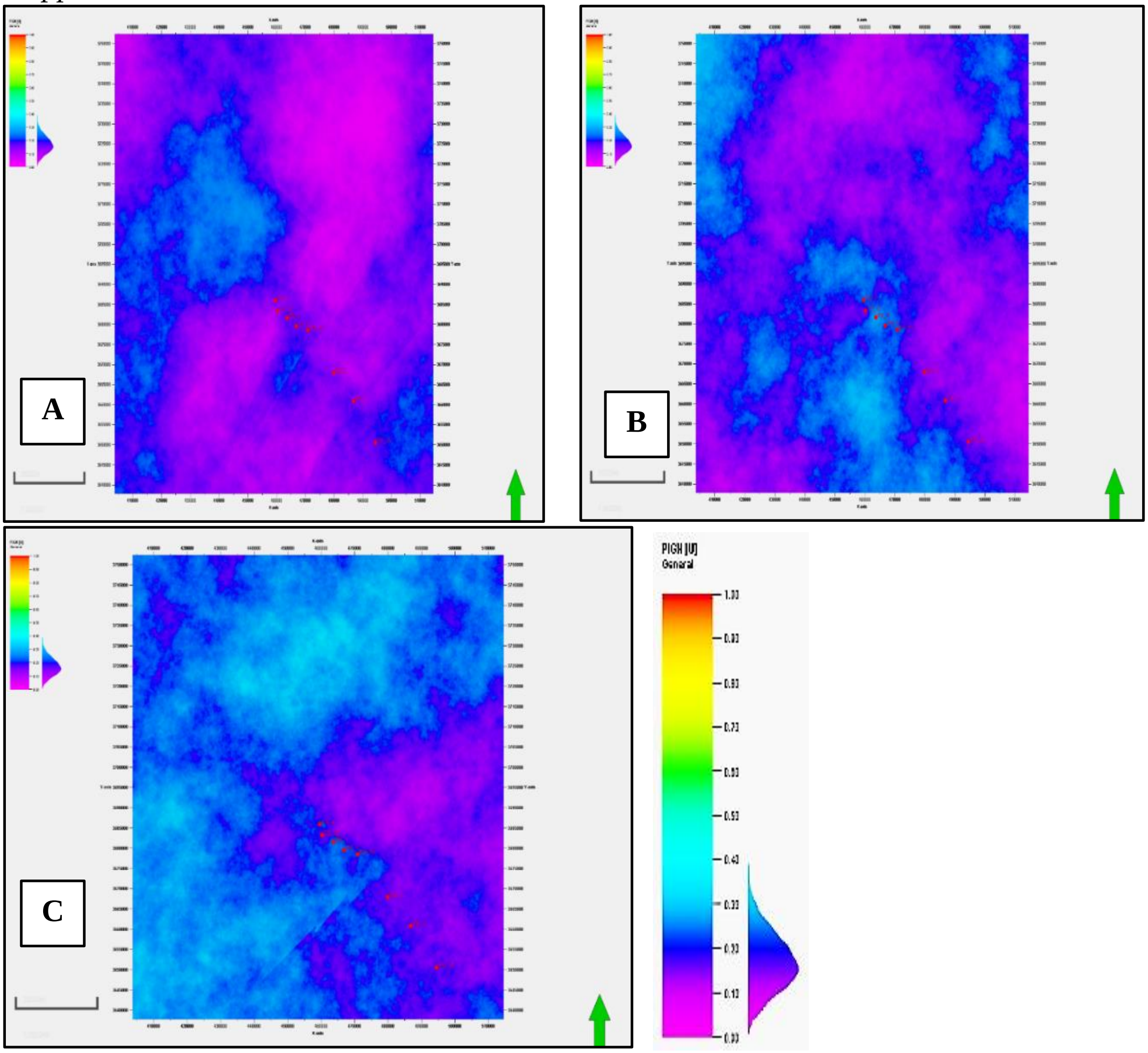

Figure 9- The figures show the Porosity distribution maps in the: A. lower unit, B. middle unit and C. Upper unit of the Hartha formation in East Baghdad Oil Field

This zone is characterized by a high to a moderate value of active porosity rocks (type I) due to the V-shale value is very low. This type of porosity is distinguished through the upper rock unit at the Hartha Formation in the studied area (Figure 9c). These characteristic features are matching with the low to moderate values of shale rock unit.

8. Computer Processing Interpretation (CPI) of four selected wells

8.1. Computer Processing Interpretation of Well EB-1

The results have been concluded of this well shoed that this well consists of one main petrophysics unit. This unit is characterized by a high resistivity and low Gamma-ray value and begins with a depth ranging from 2050-2125 m within lower electrofacies. This unit is characterized by high effective porosity and then high potential of hydrocarbon saturation as well (Figure 10).

8.2. Computer Processing Interpretation of Well EB-2

The Hartha Formation in Well EB-2 is divided into two main reservoir units. First rock unit is characterized by high values of resistivity and low gamma ray values in general. The effective porosity is high and then high hydrocarbon saturation. The depth of this unit is between 2000-2035 m within the upper electrofacies unit. The second rock unit is characterized by high to moderate resistivity values and low gamma ray values. Porosity was moderate with moderate of hydrocarbon saturation. This unit's depth ranges between 2200-2225 m (Figure 11).

8.3. Computer Processing Interpretation of Well EB-4

This well contains two major petrophysics units. The first petrophysics unit is characterized by moderate resistivity value and low gamma-ray values. Effective porosity is moderate with moderate of hydrocarbon saturation as well. The depth of this unit is between 2030-2050 m. While the second petrophysics unit is characterized by a high to moderate resistivity value with low gamma-ray values. Effective porosity is high to moderate with a high to moderate hydrocarbon saturation. The depth is between 2055-2105 m (Figure 12).

8.4. Computer Processing Interpretation of Well EB-30

This well does not show any specific petrophysics units. Where the electrofacies unit is characterized by low resistivity and high Gamma-ray values. Effective porosity is very low without the potential of hydrocarbon saturation (Figure 13).

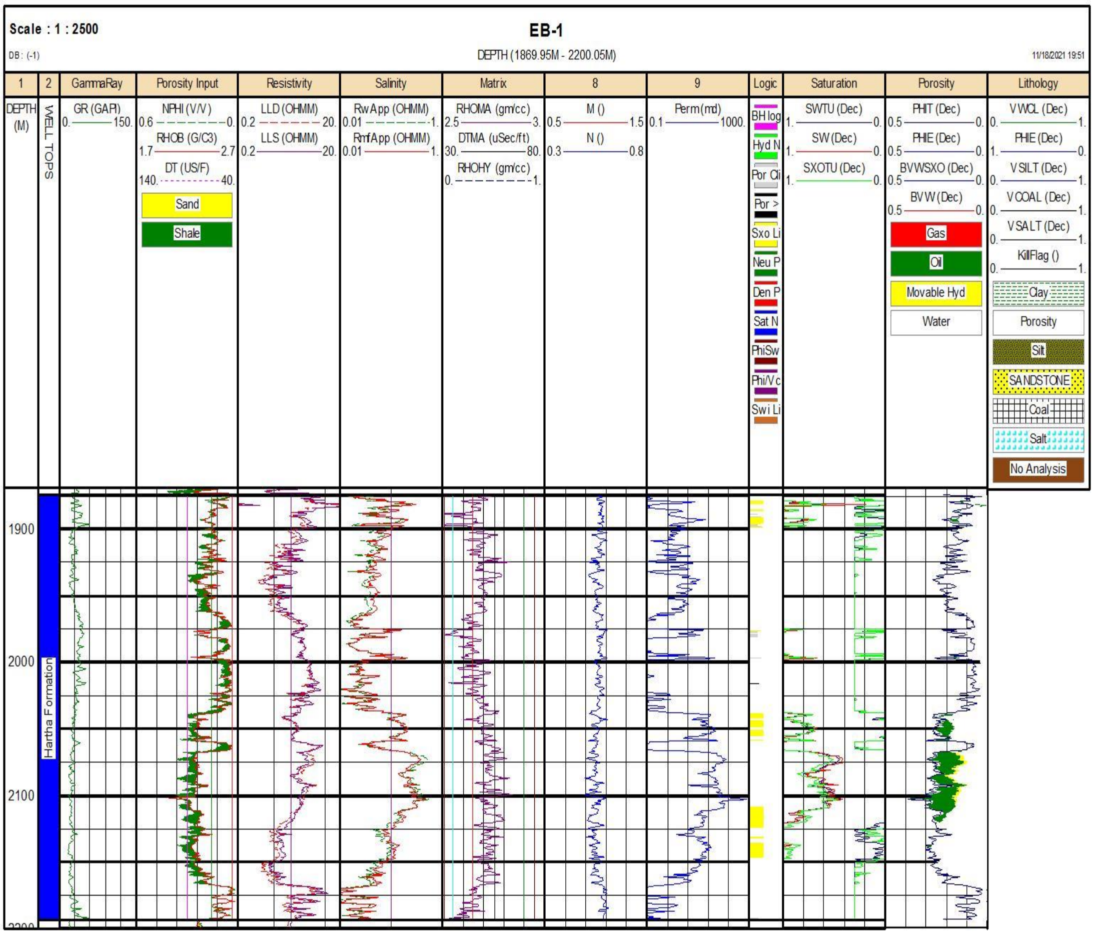

Figure 10- This figure depicts the Computer Pprocessing Interpretation (CPI) of the Hartha Formation at well EB-1

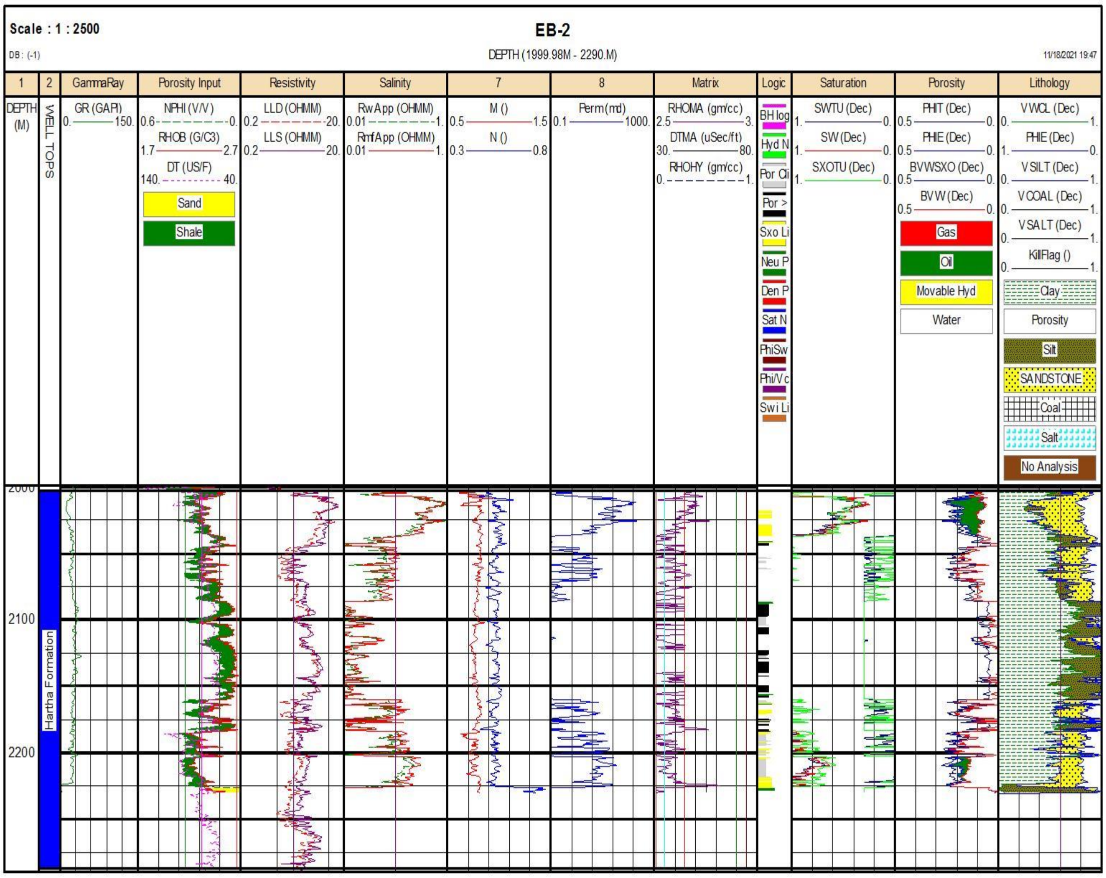

Figure 11- This figure depicts the Computer Pprocessing Interpretation (CPI) of the Hartha Formation at well EB-2

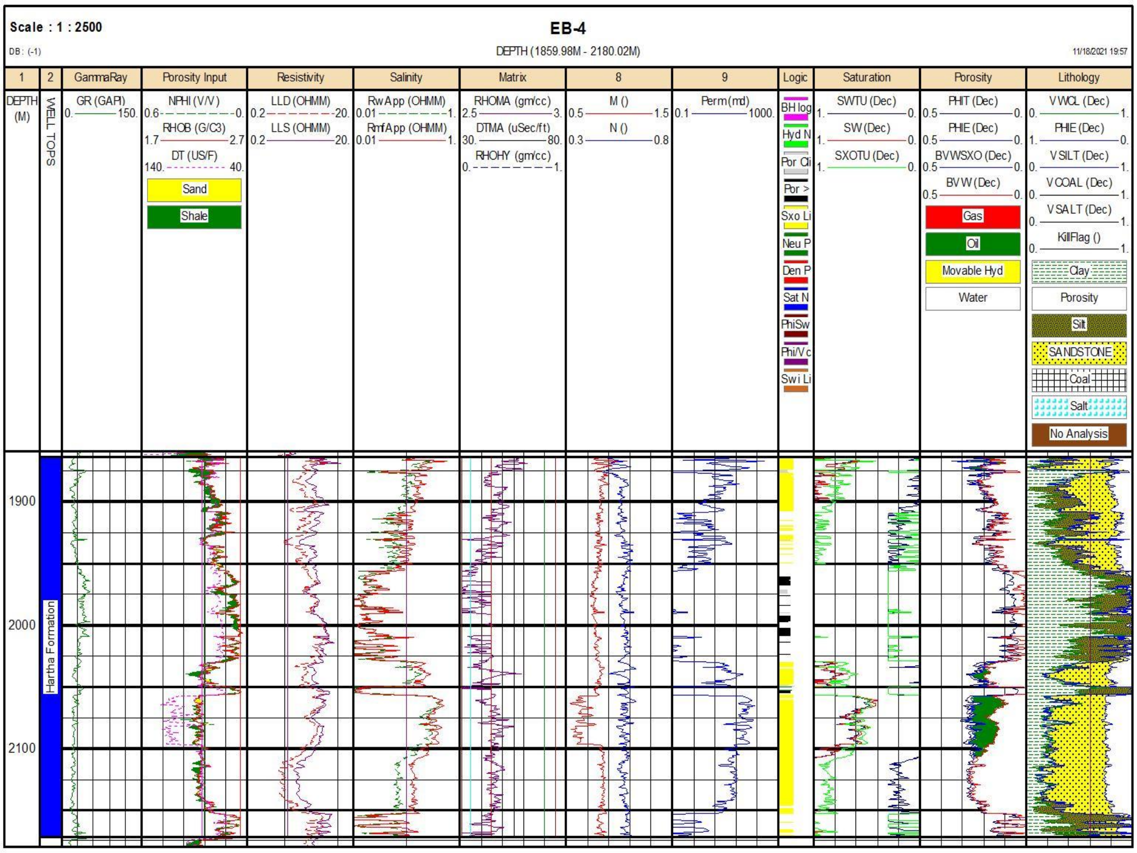

Figure 12- This figure depicts the Computer Pprocessing Interpretation (CPI) of the Hartha Formation at well EB-4

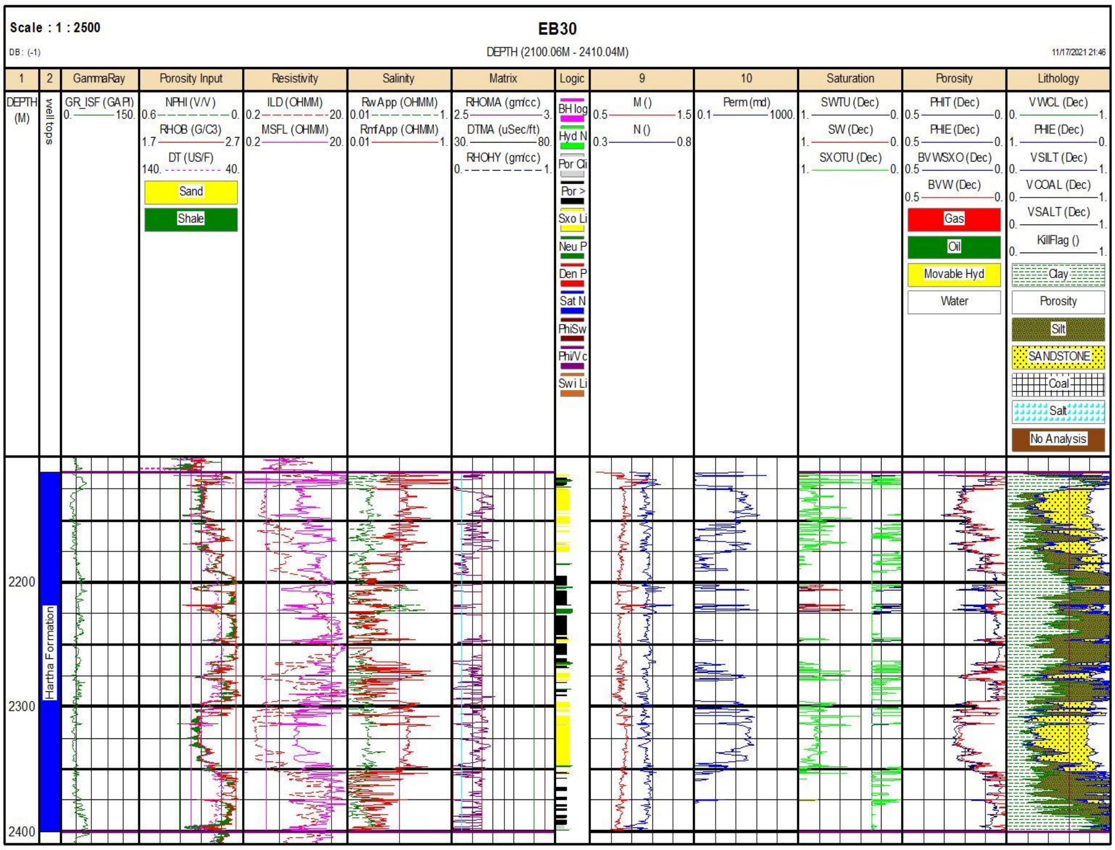

Figure 13- The Computer Pprocessing Interpretation (CPI) of the Hartha formation in well EB-30

9. Conclusions

GR and SP logs in Petrel Software were used to identify and then divide the Hartha formation into three electro-facies units. The limestone dominates the upper section of the Hartha formation. The middle section consists of thick shale layers. The limestone dominates is the lower unit, with less shale layers. According to the total porosity, the three units are divided into three different types of rocks: 1. Rocks with high to moderate values of active porosity (type I); 2. Rocks with moderate active porosity (type II); 3. non-porous rock-types with low-content pores (type III).

The lower rock unit represents the shale-dominated rock-type of the Hartha formation, with low porosity values to non-pores type-rocks (type III), and the general gamma ray well log is practically creating a pattern of serrated shape, indicating that gamma-ray values are increasing and decreasing upward. This zone can be found in all of the wells that have been analyzed. These are restricted the presences of high to moderate values of active porosity type (I) within the shale bands lithofacies, which is clearly shown in the studied wells.

High gamma-ray values with many cycles of fining upward as a funnel-shaped of gamma-ray well log pattern in the upper petrophysical zone of this unit, and fining upward as an hour-glass shaped in some spots describe mainly the middle unit. In the East Baghdad oil field, the thickness of this zone is around 60 meters. There are two subzones in this unit. Because of the high ratio presence of shale, the upper part of this zone has a high to a moderate value of active porosity (type I). In contrast, the bottom section has a moderate active porosity (type II) and low to non-pores rocks (type III). Low values of gamma-ray log with several cycles of a bell shape as decreasing upward pattern and grain size increasing describe the upper unit. In the study area, there are also bell and serrated shapes. This unit has a thickness of about 25 m in EB-4 and increases to ≈ 50 m in the Northwest, and high-moderate active porosity rocks (type I) with a very low shale component. The higher unit of the East Baghdad oil field identifies this type of porosity. These characteristics correspond to a shale rock unit with a low-moderate shale value.

By studying and analyzing Computer Processing Interpretation (CPI), the Hartha formation in East Baghdad oil field is divided into two main petrophysics units. The first petrophysics unit is characterized by moderate resistivity and low gamma ray values. The second rock unit has a high resistivity value with low gamma-Ray values. Both units begin with depths ranging from 2050-2125 m

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