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Petrophysical Properties and Reservoir Assessment of Mishrif Formation in Eridu oil field, Southern Iraq

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Abstract

This study is achieved in the local area of the Eridu oil field, where the Mishrif Formation is considered the main productive reservoir. The Mishrif Formation was deposited during the Cretaceous period in the secondary sedimentary cycle (Cenomanian-Early Turonian as a part of the Wasia Group, a carbonate succession widespread throughout the Arabian Plate.

The Mishrif Formation already have been evaluated in terms of depositional environments and their diagenetic processes. Here, it will test the previous conclusions with petrophysical properties delineated by using well logging. The results show there is a fully matching with two reservoir units (MA and MB). Dissolution and primary porosity are responsible for forming a variety of large porosity types. These porosity types have preserved the hydrocarbons in commercial quantities. MA and MB reservoir units show low gamma ray and high to moderate total and effective porosities values. The water saturation Sw in the upper unit (MA) is very high in generally to become water-bearing zone. This appears in all studied wells except in the E-NE part, characterized by patches area of moderate water saturation. In contrast, the lower unit (MB) is characterized by high values of hydrocarbon saturation (Sh) except for some areas in the middle of the studied field.

Cap rocks (CR1 and CR2) represents rock unit with low porosity and permeability due to the main components of these units. It contains lime mudstone with log response of this cap rocks indicates high gamma-ray peak value. Compaction and dolomitization are responsible for low porosity and permeability in this type of rock unit.

Keywords: Petrophysical properties, Reservoir assessment, Mishrif Formation, Eridu oil field

الخصائص البتروفيزيائية والتقييم المكمني لتكوين مشرف في حقل إريدو النفطي ، جنوب العراق

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الخلاصة

تمت هذه الدراسة في المنطقة المحلية في حقل إريدو النفطي ، حيث يعتبر تكوين مشرف الخزان الإنتاجي الرئيسي. ترسب تكوين مشرف خلال العصر الطباشيري في الدورة الرسوبية الثانوية من السينوماني الى التوروني المبكر كجزء من مجموعة الوسيعة الصخرية وهي عبارة عن تتابع كربوني واسع الانتشار في

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جميع أنحاء الصفيحة العربية. تم بالفعل تقييم تكوين مشرف من حيث البيئات الترسيبية وعملياتها التحويرية. هنا ، سيتم اختبار الاستنتاجات السابقة مع تحديد الخصائص البتروفيزيائية باستخدام بيانات الجس البئري. حيث اظهرت النتائج أن هناك تطابق كامل مع وحدتين مكمنين مشرف (أ) و مشرف (ب). الاذابة بالإضافة إلى المسامية الأولية مسؤولان عن تكوين مجموعة متنوعة من أنواع المسامية الكبيرة. يتم الاحتفاظ بالهيدروكربونات في هذه الأنواع من المسامية بكميات تجارية. تُظهر وحدات مكمن مشرف (أ) و مشرف (ب) أشعة جاما منخفضة وقيمة مسامية كلية وفعالة عالية إلى متوسطة. التشبع بالماء في الوحدة العلوية (مشرف – أ) مرتفع جدًا بشكل عام ليصبح منطقة تحمل الماء ، ويظهر هذا في جميع الآبار المدروسة باستثناء الجزء الشرقي والشمالي الشرقي الذي يتميز بمناطق متفرقة ذات تشبع معتدل بالماء. بينما تتميز الوحدة السفلية (مشرف – ب) بقيم عالية من التشبع الهيدروكربوني باستثناء بعض المناطق في وسط الحقل المدروس.

تمثل صخور الغطاء (CR1) و (CR2) كوحدة صخرية ذات مسامية ونفاذية منخفضة بسبب المكونات الرئيسية لهذه الوحدات. إنه يحتوي على صخور الجير الطيني مع استجابة بيانات الجس البئري لصخور الغطاء حيث تشير إلى ارتفاع قيمة أشعة جاما. يعتبر الاحكام و الدلمتة مسؤولين عن انخفاض المسامية والنفاذية في هذا النوع من الوحدات الصخرية.

1. Introduction

Mishrif Formation is regarded as one of the most important reservoirs throughout the Middle East. The Mishrif Formation comprises 30% of the total Iraqi oil reserves. The Mishrif Formation was deposited during the Cretaceous period in the secondary sedimentary cycle (Cenomanian-Early Turonian) as a part of the Wasia Group, a carbonate succession and widespread throughout the Arabian Plate.

The Mishrif Formation is an important stratigraphic unit as it has oil productivity in the southern oil fields in Iraq, such as Rumaila, Zubair, Nahr Umr, and Majnoon Abu Amood fields and considers the main productive reservoir in the Eridu oil field. The Mishrif Formation was firstly described by Bellen et al. in 1959 [1]. It belongs to Late Tithonian-Early Turonian tectonostratigraphic megasequence AP8. It is a part of the Waisa Group (Albian-Early Turonian Sequence) [2]. The formation was deposited as shoals and reefs above actively growing structures within a relatively deeper shelf and represents a heterogeneous formation originally described as organic detrital limestones, with algal, rudist, and coral-reef limestones, capped by limonitic freshwater limestones [1]. The lower contact of the formation is usually conformable with underlying formations (Rumaila Formation) in the S and the W area, and the upper boundary is unconformable within over formations (Khasib Formation).

This study is achieved in the local area of the Eridu oil field, where the Mishrif Formation is considered the main productive reservoir. This oil field is located in Al-Muthanna governorate, some (35 km) southeast of Samawa city and (60 km) to the west of Nasiriya city, as shown in the location map (Figure 1).

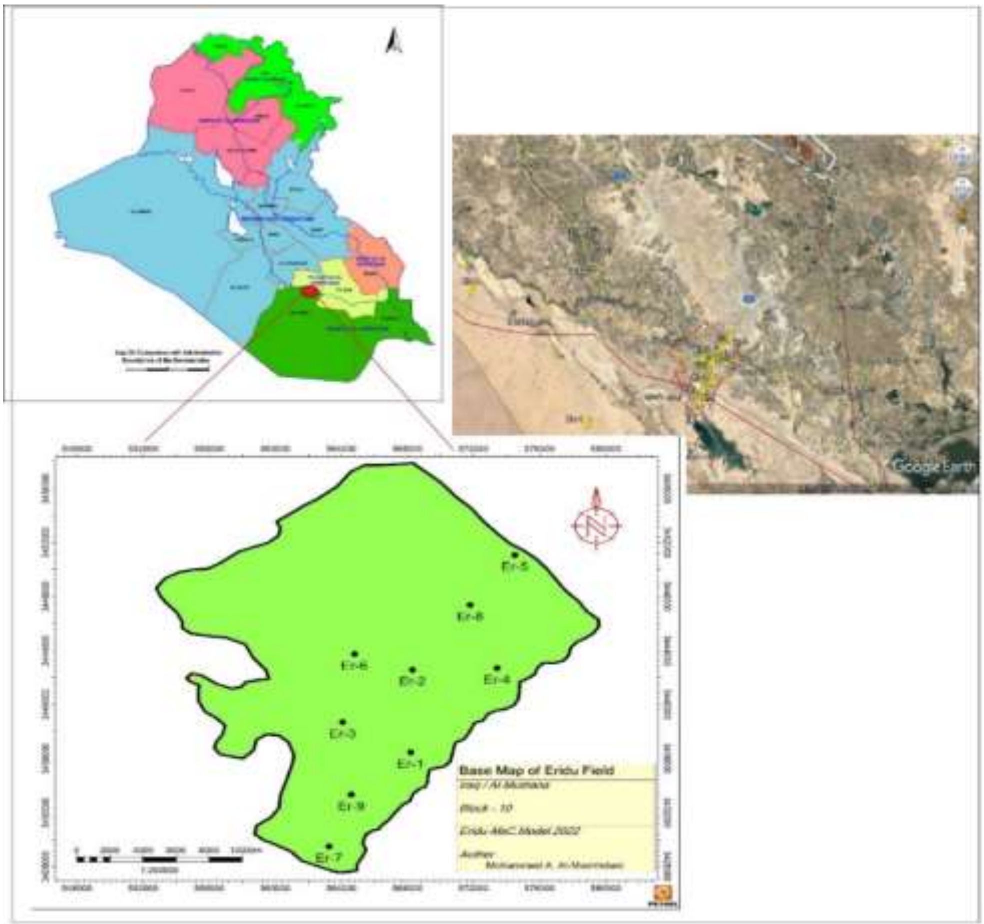

Figure 1: Location Map with administrative governorates boundary according to wells coordinates.

Eridu oil field is located in the Mesopotamian Foredeep. The terrestrial remnant of the Zagros foreland basin extends southeast to its marine counterpart (the Arabian Plate. It is located between the stable continental part (i.e., Inner Platform) and the Zagros Mountains front to the northeast.

Petrophysical properties by well logs analysis and microfacies are described and interpreted to capture their vertical and lateral variations and heterogeneity, in addition to using a modelling approach to determine Stratigraphic Framework.

Altameemi and Al-Zaidy [3] explained the formation evaluation by using well logging of Mishrif Formation in the Noor oil field. The Mishrif Formation, in terms of reservoir units, consist of several reservoir units. Major reservoir units are divided into three; these are MA, MB and MC. These major units are divided into minor reservoirs units (MB11, MB12, MC2 & MC3). The MB major reservoir units represent the best reservoir unit. These reservoir units are separated by cap rocks (mainly tight limestone) (CR1, CR2, CR3, CR4, CR5, CR6, and CR7).

Al-Zaidy and Al-Shwaliay [4] studied the Cenomanian - Early Turonian Cycle sequence in selected wells within Southeastern Iraq. Another study by Al-Zaidy [5] described the microfacies analysis and basin development of the Cenomanian - Early Turonian Sequence in the Rafai, Noor and Halfaya oil fields. In this study, The Cenomanian- Early Turonian sequence was divided into three cycles displaying coarsening upward cycles: Mishrif A, Mishrif B, and Mishrif C; which comprises a highest and system tract dominated by rudistid packstone to grainstone or rudistid biostrome facies separated by transgressive units (CR I and CR II).

The aim of this study is petrophysical properties and the reservoir characteristics used to assess the Cenomanian-Early Turonian (Mishrif Formation) in the Eridu oil field in southeastern Iraq.

2. Methodology:

- **Field Work**

1-Collected data for five wells in the Eridu oil field. It consists of (Parts of final Geological reports, Full set logs) and raw data as conventional open hole logs (Table 1).

- **Laboratory Work**

1-Made Quality-check (QC) for the primary data, including (processing and arranging it according to the formats required in the software.
2-Study the available well logs and relate the log response to petrophysical property changes.
3-Calculate the petrophysical properties (Logs Interpretation) from the collected well logs by Techlog software and suggest the electro facies to correlate with limited core data.
4-Preparing 2D geological models for the Mishrif reservoir, including (Horizon mapping as depth and thickness for reservoir units and petrophysical characteristics distribution) by using Petrel software (Schlumberger Technology).

Table 1: List of available wireline open hole logs in Mishrif Formation of Eridu oil field wells

Well No.	Coordinate system UTM-WGS84		Tops (m)		Well logs
	Easting (m)	Northing (m)	TVDSS	MD	
Eridu-X	568188	3436483	1677.6	1695.5	CAL, DT, GR, NPHI, RHOB, SP
Eridu-X	568294	3442598	1725.3	1744.2	CAL, DT, GR, NPHI, RHOB, SP
Eridu-X	564069	3438718	1699.4	1717.9	CAL, DT, GR, NPHI, RHOB, SP
Eridu-X	573411	3442721	1743	1761.5	CAL, DT, GR, NPHI, RHOB, SP
Eridu-X	574487	3451090	1788	1806	CAL, DT, GR, NPHI, RHOB, SP

3. Stratigraphic and tectonic settings

Mishrif Formation represents a heterogeneous formation originally described as organic detrital limestones, with beds of algal, rudist, and coral-reef limestones, capped by limonitic freshwater limestones.

The Mishrif Formation is considered one of the main important reservoirs in southern Iraq. The formation was deposited in the early part of the Late Cretaceous period [1], and it is considered with the Kifl, Rumaila, and Ahmadi formations a major sedimentary cycle representing the age (Cenomanian- E. Turonian), where the upper boundary of the Mishrif formation represents a conformable surface with the Kifl Formation, and the lower boundary also represents a conformable surface with the Rumaila formation. Due to the importance of the formation, this study focused on its stratigraphic and reservoir phenomena in it, as it represents the most important exploratory goal in this sedimentary cycle [2].

The Mishrif Formation is a regressive sequence of deposition within the secondary cycle of Cenomanian-Early Turonian sedimentary, which began with the interruption of the deposition of the Mauddud Formation and the emergence of a regional unconformity surface for the top formation [6], in which the Rutbah Formation was deposited in the western parts from the basin. The Ahmadi and Rumaila formations were deposited in the eastern parts in the marine inundation conditions during the Transgressive conditions, consisting of limestone, calcareous clay and shale rocks with the presence of planktonic foraminifera and calcispheres fossils. The sediments of this phase adopt the depositional pattern known as retrogradation sequence. The deposition of the Mishrif Formation followed this in shallow marine environments. In the later stages of this cycle, the evaporative Kifl Formation was deposited in the shallower parts of the basin, as it formed a cover of evaporite rocks above the Rumaila Formation and sometimes above the Mishrif Formation. This sedimentary cycle ended with the emergence of a Middle Turonian surface separating the Khasib Formation from the Kifl Formation or the Mishrif Formation.

The Arabian Plate period, extending from the middle of the Cretaceous until the end of Maastrichtian, represents a transitional stage and transformation from a tectonic tension system to a compressional tectonic system as a result of the convergence between the Arabian Plate and the adjacent plates with it. This convergence resulted in the subduction of the Oceanic Crust of the Arabian Plate under the marine crust of the two neighboring blocks (Iranian and Turkish), and these two blocks together formed the Eurasian Plate. Burchett & Wright [7] indicated that the subduction of the marine crust under the Eurasian Plate was accompanied by the emergence of a structural rise (Uplift) along the southeastern edge of the Arabian Plate, which contributed to the formation of a developed platform (the Mishrif Formation platform) (Figure 2).

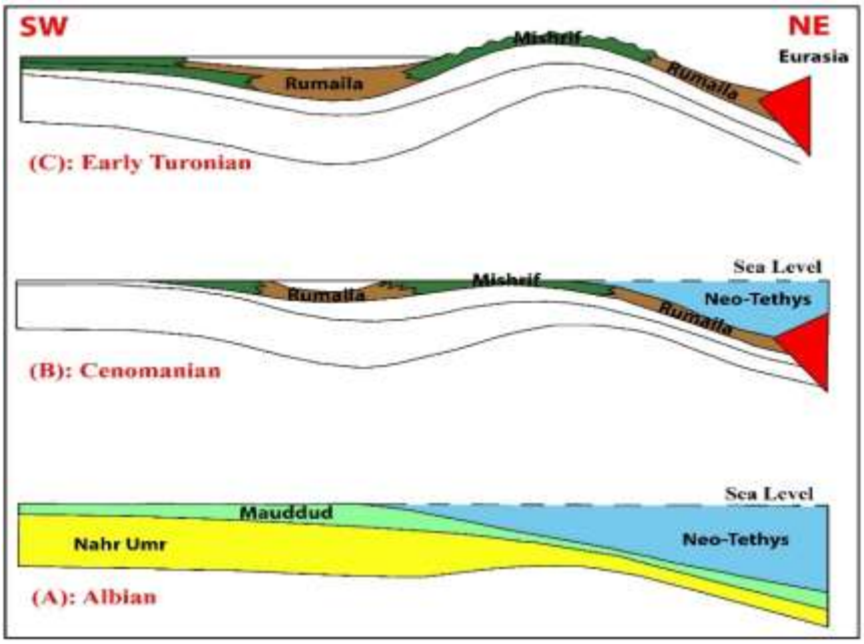

Figure 2: Depositional stages during the development of the Arabian plate according to [7]

The structural factor contributed to the beginning of the Cenomanian age through the subduction of the Arabian Plate oceanic crust, below the oceanic crust of the Eurasian Plate, to the emergence of a structural uplift along the southeastern edge of the Arabian Plate, which contributed to the formation of the Mishrif Formation platform in the form of an arch, on which facies were distributed of the Mishrif Formation, which formed the rudist barrier under Highstand conditions [7].

The Mishrif Formation carbonates are heterogeneous [8] and include Rudistid, bioclastic, algal and foraminiferal-rich facies deposited in setting ranging from deep marine to lagoonal. Division of the formation into two long-term regressive cycles (or sequences) was proposed by Reulet [9] and Aqrawi *et al.*, [10]. This division was based on facies evolution and identifying a regional-scale intra-formational disconformity surface separating the two sequences. The formation is dated from foraminiferal studies as middle Cenomanian-Early Turonian [11, 12, 13 and 14]. Regional stratigraphic and sedimentological studies e.g. [14, 15, 10, 16 and 2] indicate that the Mishrif Formation deposits formed a carbonate platform extending throughout the Mesopotamian Basin in southern and central Iraq.

4. Petrophysical Evaluation

Petrophysics means the study of the physical properties of rocks and their (contained) fluids, particularly for the detection and evaluation of hydrocarbon deposits penetrated by a borehole (according to Archie's Definition, 1950) [17]. The principal goal of reservoir characterization is to construct three-dimensional images of petrophysical properties. through measurements of the properties such as shale volume, porosity, permeability, and saturation which calculate directly or indicated by three types of well logs data of wireline open-hole tools.

4.1 Classification of Mishrif Formation into units:

Based on the stratigraphic boundaries, logs and the shale volume, the Mishrif Formation was divided into four units, two layers (MA, MB) as reservoir units and CR-1 and CR-2 as barriers meaning cap rocks units (Table 2 and Figure 3).

A histogram displays a comparison of the reading ranges of the gamma-ray log (GR) in the five wells of the Eridu oil field (Figures 4 and 5) to diagnose the thicknesses of the log units preliminarily, and it was noted that the logs reading rate and ranges of the barrier units (CR1, CR2) are more than they are in the reservoir units (Mishrif-A, Mishrif-B).

Table 2: Mishrif rock units in studied wells with their coordinates and thickness.

Wells	Formation	Coordinate system UTM-WGS84		Tops (m)		Thickness (m)
		Easting (m)	Northing (m)	TVDSS	MD	
Eridu-X	CR1	568188	3436483	1677.6	1695.5	19.2
Eridu-X	Mishrif A	568188	3436483	1696.8	1714.7	34.3
Eridu-X	CR2	568188	3436483	1731.1	1749	13.8
Eridu-X	Mishrif B	568188	3436483	1744.9	1762.8	122.2
Eridu-X	Rumaila	568188	3436483	1867.1	1885	
Eridu-X	CR1	568294	3442598	1725.3	1744.2	2.8
Eridu-X	Mishrif A	568294	3442598	1728.1	1747	68
Eridu-X	CR2	568294	3442598	1796.1	1815	14
Eridu-X	Mishrif B	568294	3442598	1810.1	1829	79
Eridu-X	Rumaila	568294	3442598	1889.1	1908	
Eridu-X	CR1	564069	3438718	1699.4	1717.9	10.6
Eridu-X	Mishrif A	564069	3438718	1710	1728.5	72.2
Eridu-X	CR2	564069	3438718	1782.2	1800.7	16.6
Eridu-X	Mishrif B	564069	3438718	1798.8	1817.3	63.7
Eridu-X	Rumaila	564069	3438718	1862.5	1881	

Eridu-X	CR1	573411	3442721	1743	1761.5	7.5
Eridu-X	Mishrif A	573411	3442721	1750.5	1769	51
Eridu-X	CR2	573411	3442721	1801.5	1820	12.7
Eridu-X	Mishrif B	573411	3442721	1814.2	1832.7	108.3
Eridu-X	Rumaila	573411	3442721	1922.5	1941	
Eridu-X	CR1	574487	3451090	1788	1806	3
Eridu-X	Mishrif A	574487	3451090	1791	1809	65.7
Eridu-X	CR2	574487	3451090	1856.7	1874.7	13.3
Eridu-X	Mishrif B	574487	3451090	1870	1888	85
Eridu-X	Rumaila	574487	3451090	1955	1973	

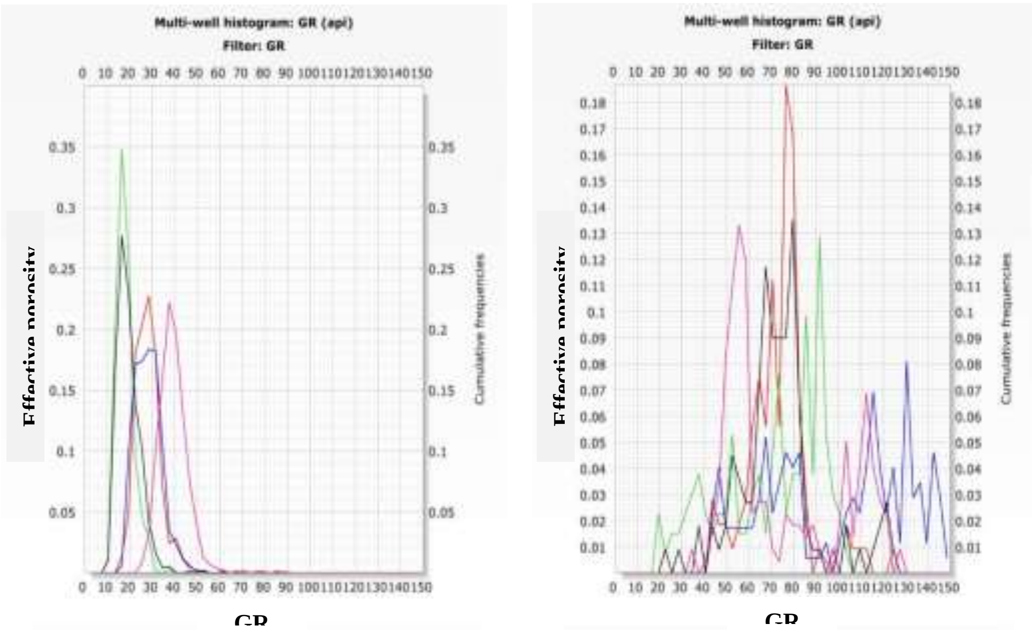

Figure 3: Histogram of the Gamma Ray – Effective porosity readings for **A.** reservoir units **B.** barrier units in Eridu oil field wells

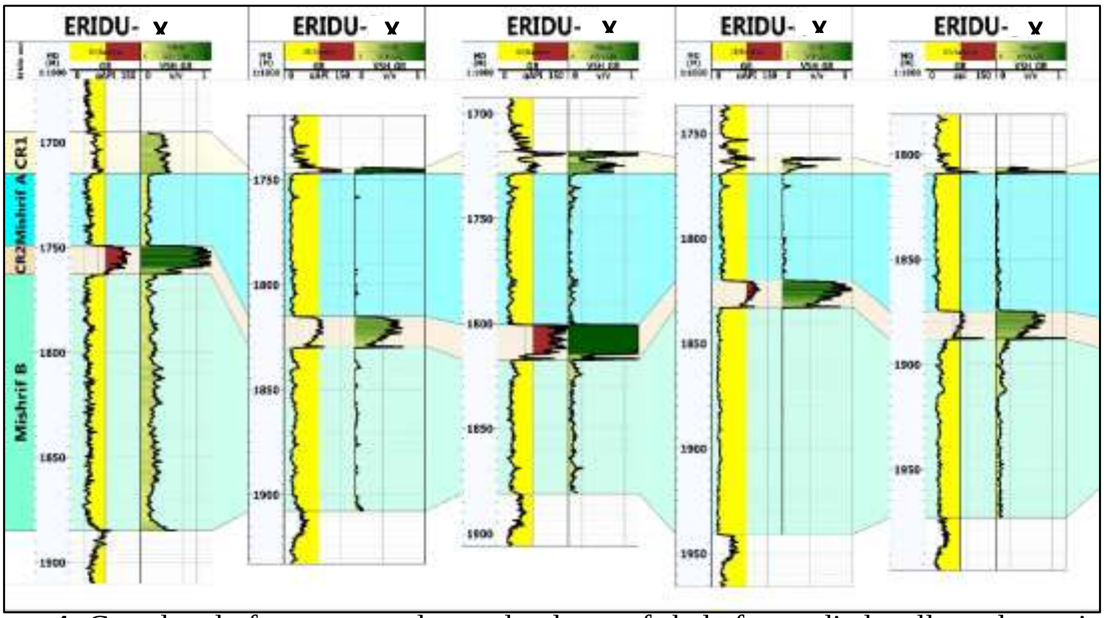

Figure 4: Correlated of gamma ray log and volume of shale for studied wells to determine the rock units.

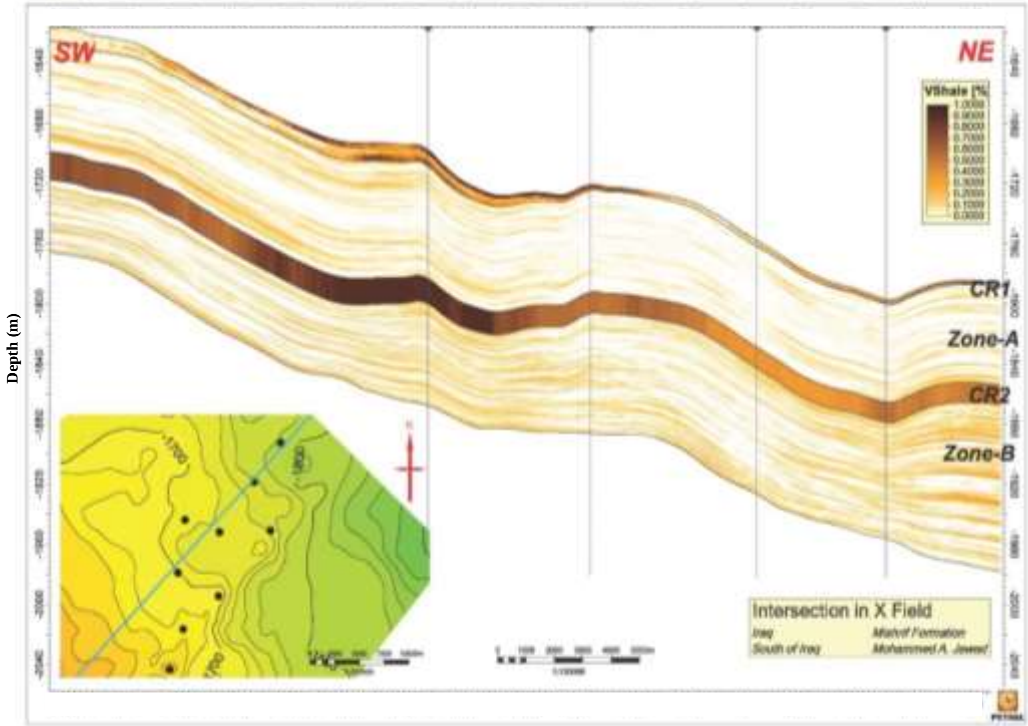

Figure 5: Cross section shows the shale volume through the rock units in the studied wells.

4.2 Total and effective porosity

- Total porosity is defined as a volume ratio of pores to the bulk volume of rocks, regardless of whether connected or nonconnected [18].

The following equation was used to calculate the total porosity:

$$\phi t = \frac{\phi N + \phi D}{2}$$

Where:

ϕ t: Total porosity

ϕ_N: Neutron porosity

ϕ_D: Density porosity

- Effective porosity is defined as the percentage of the volume of the connected pores in reservoir rocks to the total volume of reservoir rocks, [18] and it was called by this name because it is effective in the movement of fluids and passing them through the rock as it expresses the number of pores connected. The effective porosity is calculated from the equation [19] after total porosity is corrected from shale volume:

$\phi_e = \phi_t \times (1-V_{sh})$

Where:

ϕ_e: Effective porosity

ϕ_t: Total porosity ($\phi_{N,D}$) : Average porosity

V_{sh}: Volume of shale

It is also possible to use the equation of [18] to obtain the effective porosity corrected from the effect of the gas content, as the equation below is used when ($\phi_N < \phi_D$) as:

$$\emptyset \boldsymbol{N}.\boldsymbol{D} = \sqrt{\frac{(\emptyset \boldsymbol{N})^2 + (\emptyset \boldsymbol{D})^2}{2}}$$

The porosity in Mishrif Formation was calculated using the density log and the direct measurement provided by the neutron log. The total porosity (PHIT) was derived from the response of these two logs, and then the effective porosity (PHIE) was calculated after subtracting the volume of clays by using (Quanti-Elan) application in TechLog software and based on the three porosity Logs (acoustic, density, and neutron).

The sonic log was adopted to correct the porosity reading for the depth intervals which have bad hole conditions because this log is the least affected by the irregularity of the borehole.
Noticeable increases in porosity were observed at the lower part of the formation (Mishrif-B Unit). This pattern is also observed at different, shallower depths and is attributed to porous limestone units characterized by shoal and shallow open marine facies associations.

Figures (6) and (7) illustrate the calculations of the total and effective porosity values and their comparison with porosity values was measured from core analyzes of the wells of the Eridu field and distributed on the basis of the reservoir units for Mishrif Formation.

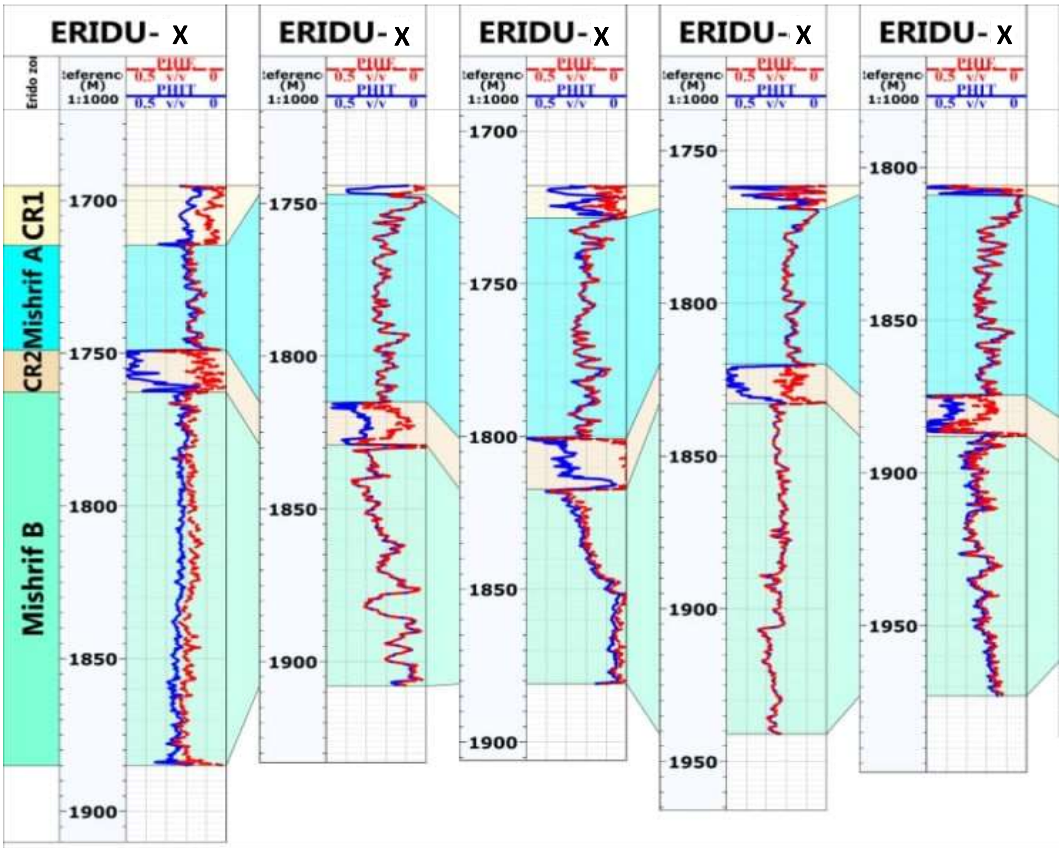

Figure 6: Correlated of total porosity and effective porosity for the rock units in studied wells.

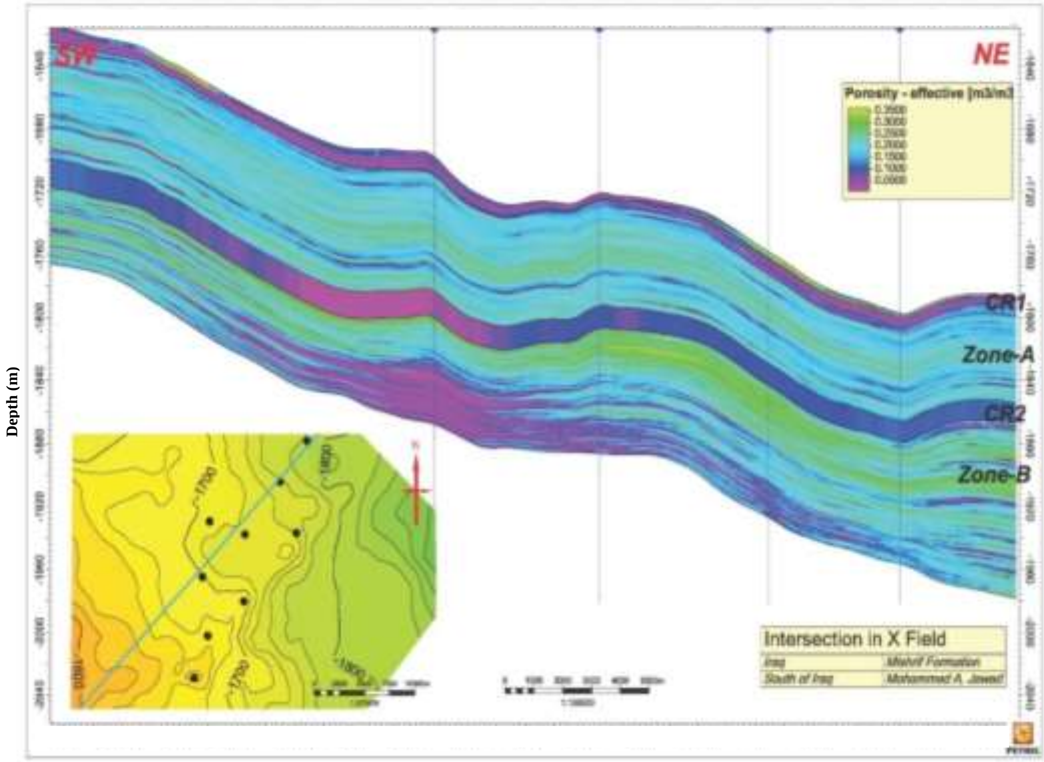

Figure 7: Cross section showing effective porosity through the rock units in studied wells.

4.3 Determination of formation water resistivity (Rw)

Formation water Resistivity (Rw) is an important parameter in estimating the water saturation of reservoirs.

There are several methods for calculating the formation water resistance (RW). In this study, the Pickett plot method was adopted for the relationship between the effective porosity and the deep resistivity log (Figure 8). The current results from the Mishrif Formation is compatible with the wells in other nearby fields, according to previous studies. Table 3 shows this value with the rest of the values of the calculated coefficients.

Table 3: Values of the calculated petrophysical parameters.

	Parameters	Value
1	a	1.0
2	Cementation exponent, m	2.1
3	Saturation exponent, n	2
4	RW	0.027 Ω

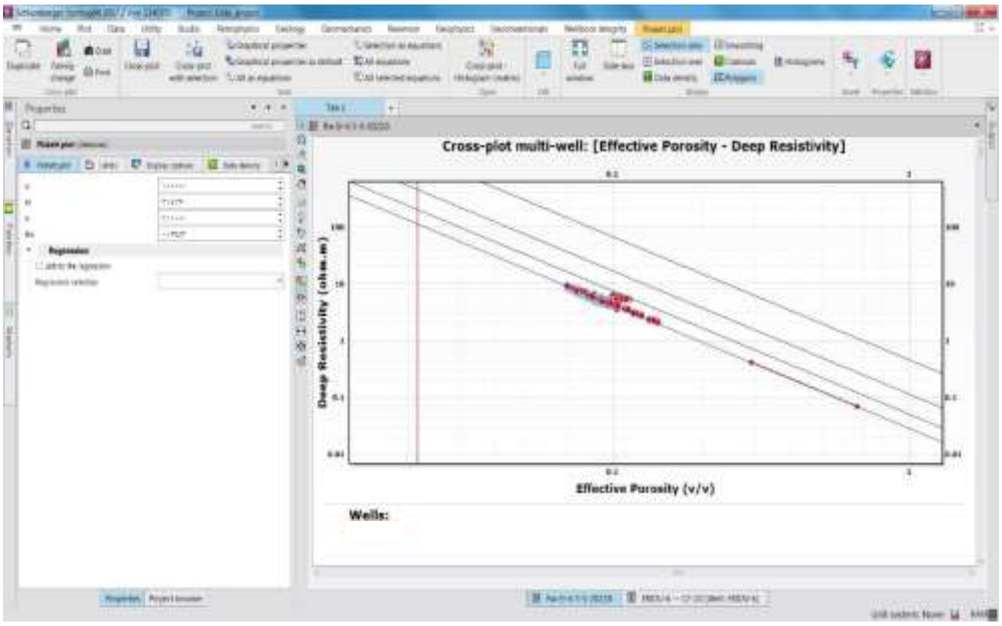

Figure 8 Pickett plot shows the formation resistivity of water (Rw) for the Mishrif Formation in well Eridu-5.

4.3.1 Calculation of the Formation Factor (F)

According to the Archie equation, the formation coefficient is important in calculating water saturation.

F is usually obtained from the measured porosity of the formation according to the relationship: [20].

$$F = \frac{a}{\emptyset^{m}}$$

Where:
a = is a constant = 1 for Carbonate rocks.
ϕ = Porosity
m = Cementation factor
It was calculated within the processors' mechanism of the Techlog software in calculating water saturation.

4.3.2 Water Saturation Calculation (SW)

It is defined as the measure of pore volume in a rock that is filled by the formation water. It is signified as a decimal portion or percentage and has the symbol (SW). Water saturation (SW) of the reservoir for the uninvaded interval is calculated through Archie's equation [20]: as given by [21].

$$SW = \left(\frac{F * Rw}{Rt}\right)^{1/n}$$

Where:
Rw = formation water resistivity.
Rt = True formation resistivity.
F = Formation resistivity factor.
n = Saturation exponent.

In the current study, Archie's method was used to calculate the saturation of the reservoir units for the Mishrif Formation in the Eridu oil field with water (SW), because these units were not polluted by the shale, which was adopted in calculating the hydrocarbon content (SH = 1-Sw) using the Quanti-Elan in Techlog software for Schlumberger company. Figure 9 shows the water saturation for the studied wells in the Eridu oil field.

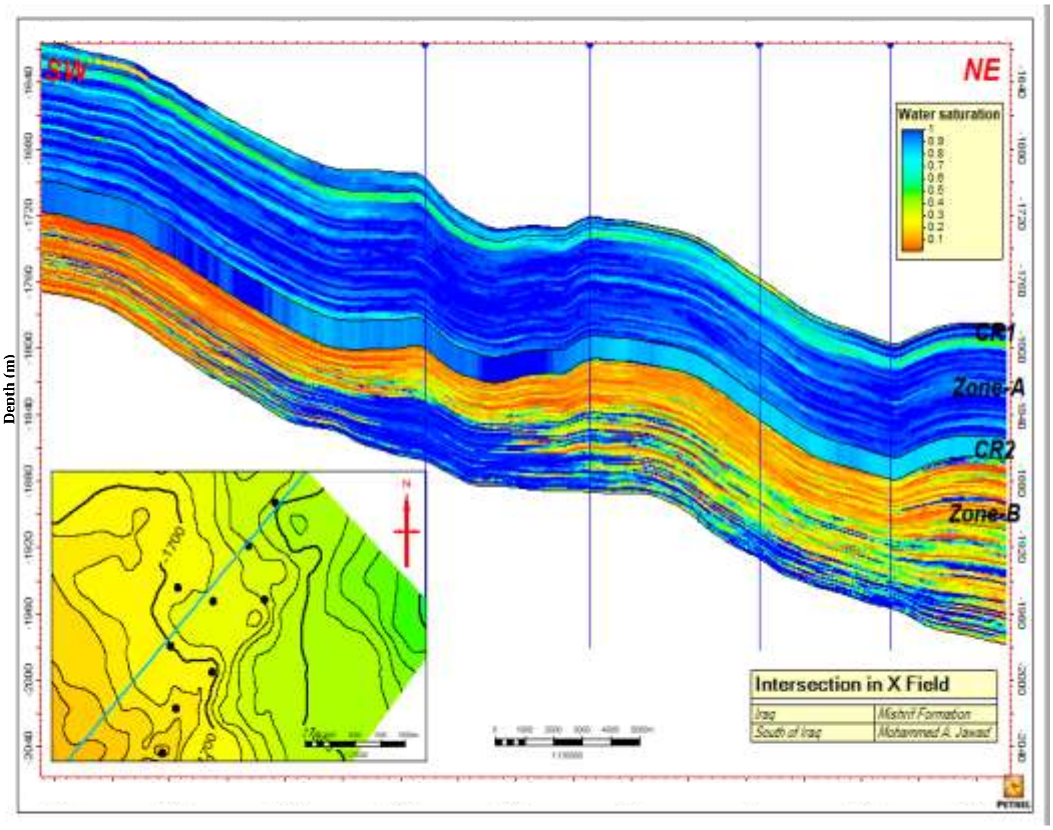

Figure 9: Cross section shows water saturation through the rock units in studied wells.

5. Conclusions

Mishrif Formation has already been evaluated regarding depositional environments and their diagenetic processes. Currently, it will test the previous conclusions with petrophysical properties delineated by using well logging. The results fully match two reservoir units (MA and MB). Secondary porosity and primary porosity, is responsible for forming a variety of large porosity types. These porosity types have preserved the hydrocarbons within the rock units. MA and MB reservoir units show low gamma ray and high to moderate total and effective porosities values. The water saturation Sw in the upper unit (MA) is very high in generally to become water-bearing zone. This appears in all studied wells except in the E-NE part, which is characterized by patches area of moderate water saturation. At the same time, the lower unit (MB) is characterized by high values of hydrocarbon saturation (Sh) except for some areas in the middle of the studied field (Figures 10, 11, 12 and 13).

Cap rocks (CR1 and CR2) represent rock unit with low porosity and permeability due to the main components of these units. It contains lime mudstone with log response of this cap rocks indicates high gamma ray peak value. The reduction of diagenetic processes are responsible for low porosity and permeability in this type of rock unit (Figures 10, 11, 12 and 13).

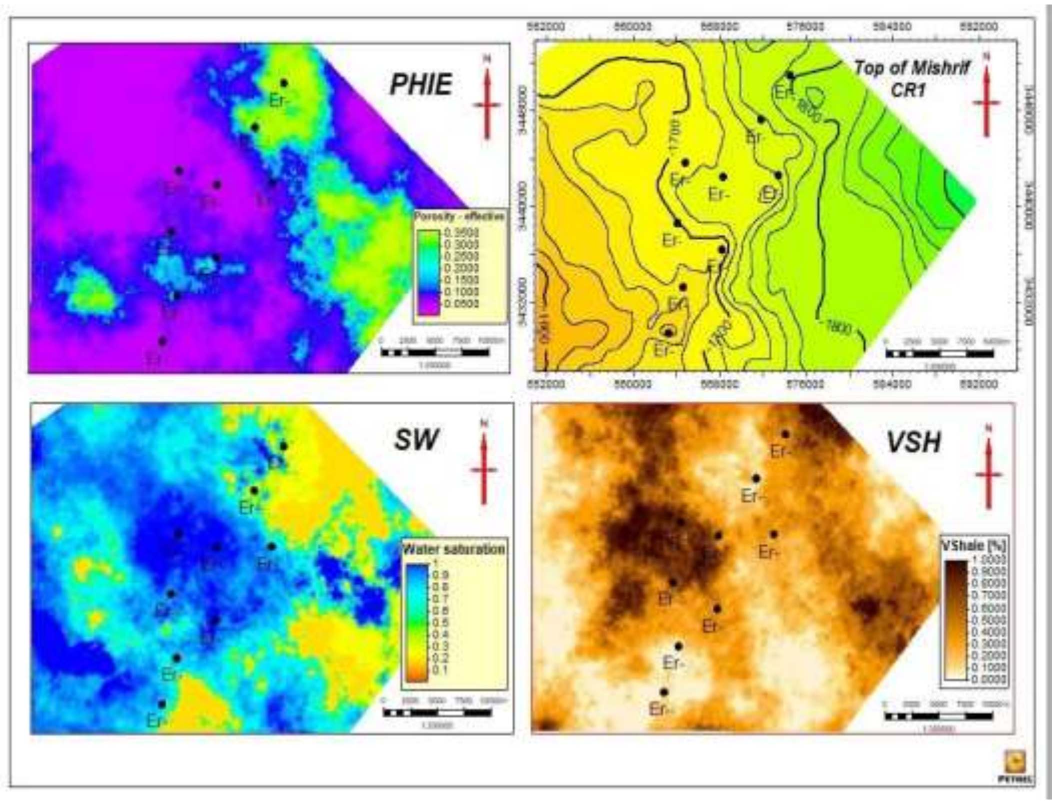

Figure 10: Integrated assessment for Mishrif cup rock units (CR1) in studied area.

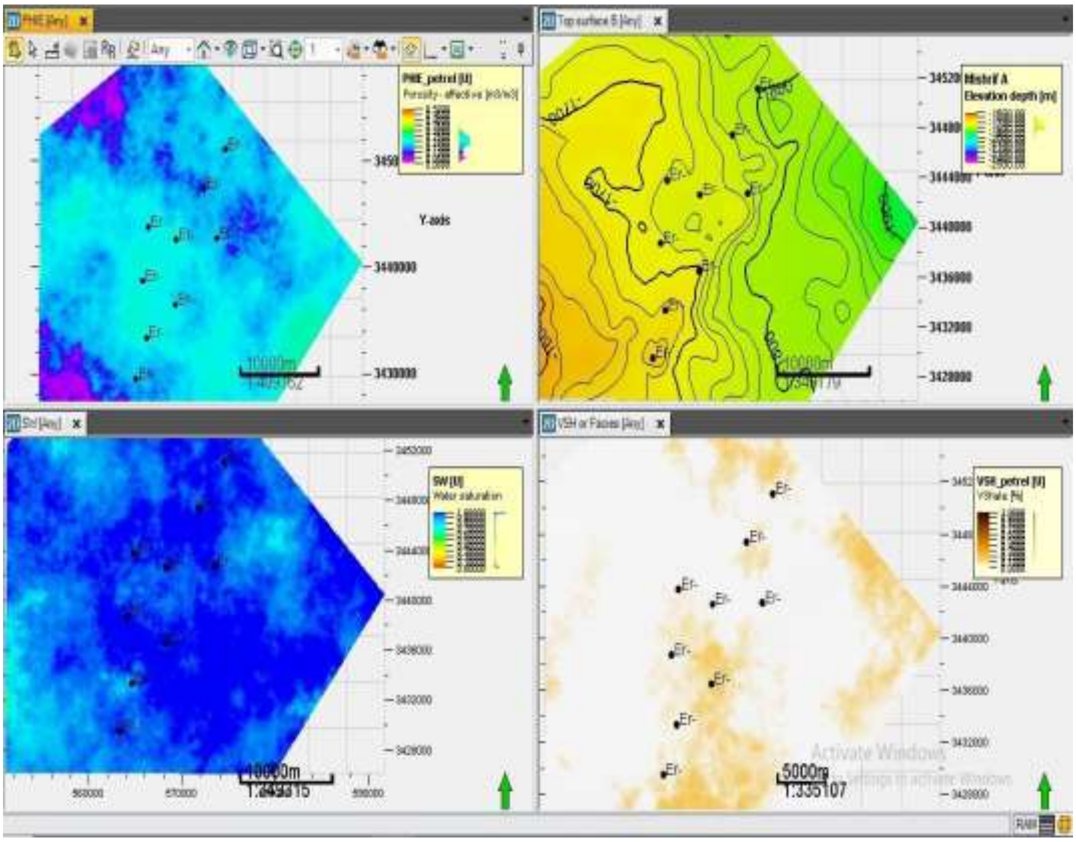

Figure 11: Integrated assessment for Mishrif reservoir rock units (MA) in the studied area.

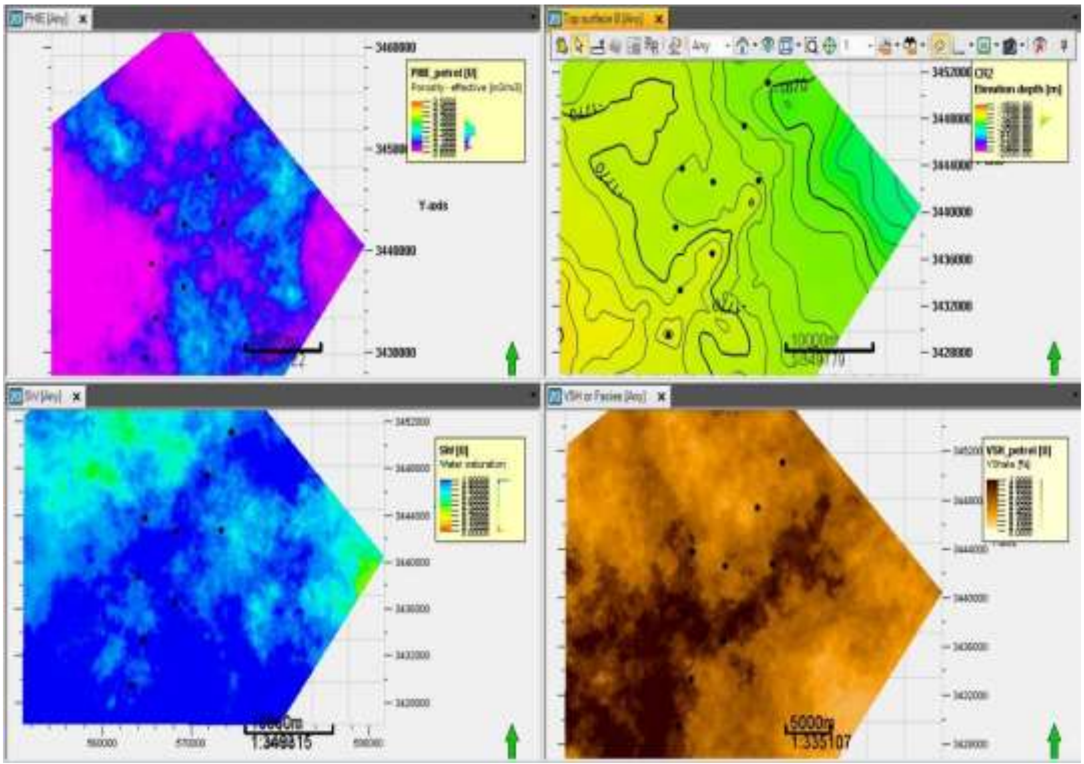

Figure 12: Integrated assessment for Mishrif cup rock units (CR2) in the studied area.

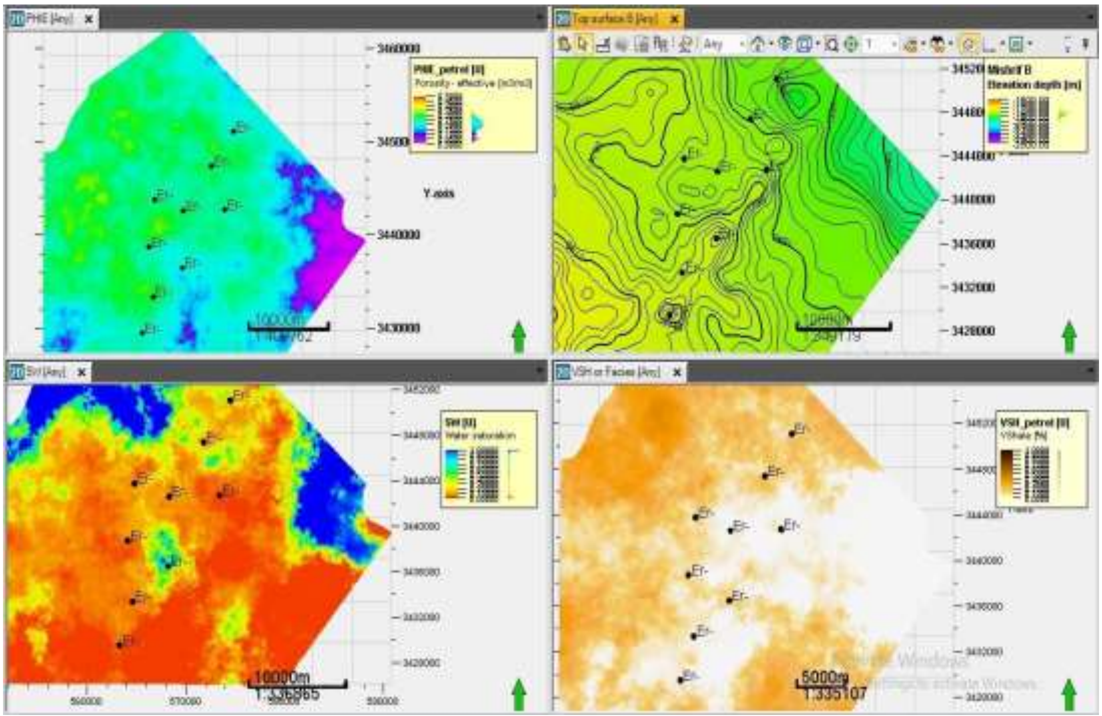

Figure 13: Integrated assessment for Mishrif reservoir rock units (MB) in the studied area.

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