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Geological characterization and reservoir evaluation for Mishrif formation in Nasiriyah oilfield

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Abstract

Hydrocarbon estimation is a vital step for formation evaluation and development plans, significantly impacting the decision-making process. Well logs data from 40 wells in the Nasiriyah oilfield was utilised to characterise the Mishrif formation and construct a 3D static model. This model illustrates the spatial distribution of petrophysical properties and calculates the Original Oil in Place volume (OOIP) using a volumetric approach.

The model incorporates water saturation, effective porosity, permeability, and a 2D structural, which is discretized by 317130 grids. These petrophysical properties are populated in 3D dimensions using the geostatistical method SGS. At the same time, the difference in depths of OWC is captured and represented by three regions of initialization for accurate characterization of the reservoir. The geological modeling identified unit MB1 as the main reservoir in the Mishrif formation, characterized by an average porosity of 21.5%, permeability up to 500 md, and water saturation of 27%. However, unit MB2 exhibits similar petrophysical properties but with significantly higher water saturation above 70%, making it a water-bearing zone. The total OOIP volume for the studied reservoir was calculated to be 8535 MMSTB, mainly accumulated in units MB1 and MB2. Unit MB1 holds approximately 73% of the total oil in place, establishing it as the major reservoir in the Mishrif formation, while unit MB2 contains the remaining 27%.

Keywords: geological characterization; reservoir evaluation; Nasiriyah oilfield; hydrocarbon estimation; petrophysical modeling.

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1- Introduction

Designing a static model is a vital process in the petroleum sector, especially since it can be considered the initial step for oil and gas field development [1]. Static modeling is the most efficient method for accurately capturing the structural and stratigraphic hydrocarbon traps and geological features in the fields, which lead to representative hydrocarbon in place [2]. 3D modeling can be defined by a mathematical representation process of a 3D group of surfaces and blocks of any 3-dimensional item [3]. Estimating hydrocarbon in place is a decisive factor in the decision-making process, as it eventually determines the profitability of a discovered reservoir [4]. The most frequently used method for evaluating resources is the volumetric approach, which depends on the properties of rocks (porosity and permeability) and reservoir fluids (water, oil, and gas saturations). Despite its simplicity, this approach is prone to various uncertainties [5- 6]. To reduce this unreliability, skilled modelers with expertise in the study area and access to high-quality static and dynamic data are required [7- 8]. However, it is noteworthy to mention that geological modeling's key function is not only to estimate the (OOIP), but also to provide a qualitative and quantitative description of the reservoir's heterogeneity and, more importantly, to predict the hydrocarbon volume distribution along the reservoir area [9]. In another way, 3D static modelling selects the best approach to building structure surfaces, grid blocks, and distribution of petrophysical properties [10 - 11]. Abdullah et al. included 25 wells in the geological model of the Nasiryiah field [12]. Al-Mozan also used 25 wells to build the static model for the reservoir simulation [13]. While Rashid and Hamad-Allah have included 40 wells for geologic characterization [14]. This study aims to build a 3D geologic model for the Mishrif formation in the Nasiriyah oilfield by including 40 wells, which makes it able to cover all of the field's areas. The model aims to depict the spatial distribution of petrophysical properties accurately. The main outcomes include evaluating oil reserves and determining the modeled oil-water contact (OWC) depth.

1.1. Area of study

The studied oil field is situated within the Mesopotamian Area, which extends in a northwest-to-southeast direction, spanning the plains of the Euphrates and Tigris valleys. It is located approximately 38 km NW of the Thi-Qar governorate, as depicted in Fig. 1.

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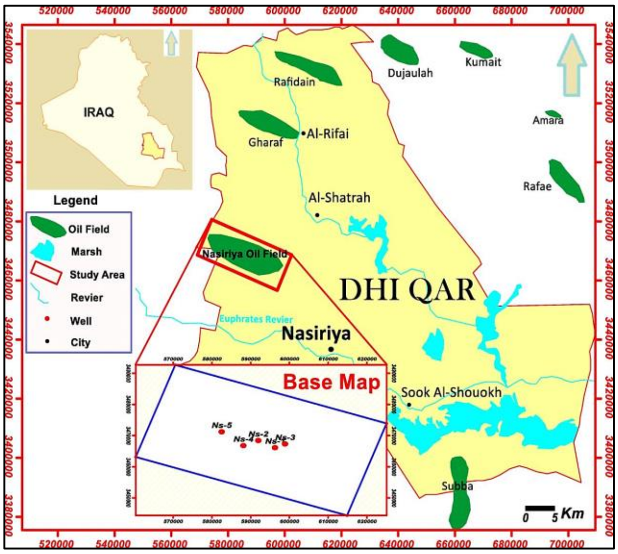


Fig. 1. Location of the studied area [15]

The dimensions for the studied field (34 km by 13 km) exhibit a gentle inclination towards the northeast-southwest direction, with an angle of around 1 to 2 degrees. The Iraqi National Oil Company initiated a seismic survey operation in 1975, which led to the field's discovery. In 1978, Ns-1, the first exploration well, was drilled, confirming the presence of oil in the Mishrif, Nahr-Umr, and Yamama formations. Furthermore, there were indications of limited oil presence in the Zubair Formation. The field's oil production commenced in August 2009, with initial operations utilizing three wells [16].

1.2. Geological overview

Mishrif Formation, which belongs to the Early Cretaceous period, is mainly a varied limestone formation consisting of organic detrital deposits. Within this formation, there are several layers of rudist, algal, and coral-reef structures, with freshwater limestones capping the formation [17]. Fig. 2 depicts each formation’s lithology.

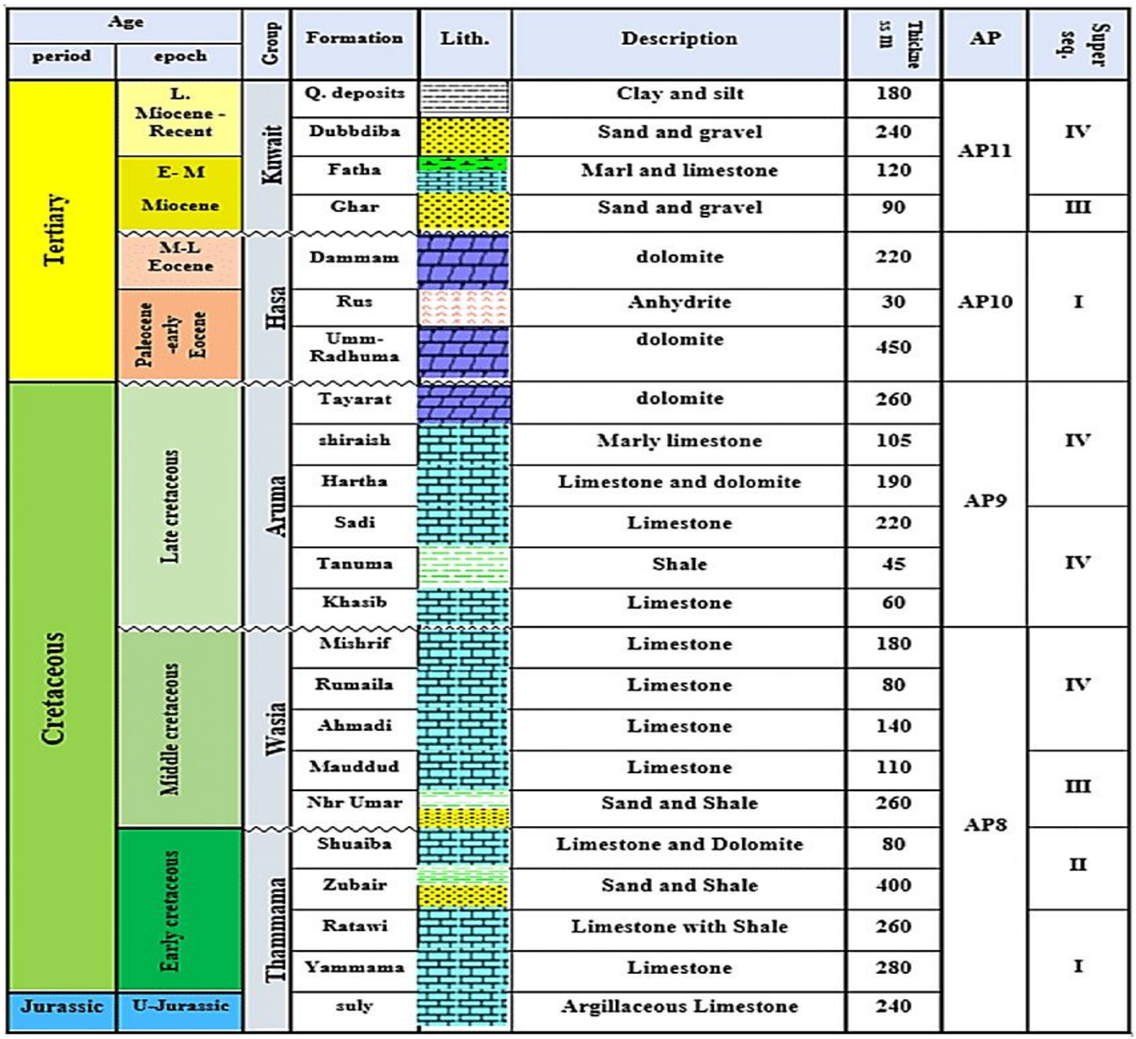


Fig. 2. Stratigraphic column for the southern part of Iraq [18]

In the Nasiriyah oil field, the average thickness of the Mishrif formation is around 180 meters, with depths ranging from 1902 to 2100 meters below sea level. It is distinguished by a wide range of grain sizes, from very coarse to fine bioclastic limestone buried in a shallow environment. The formation is divided into two main units: MA, which is considered the upper part, and the lower unit, known as MB. These units are separated by a shale layer approximately 10 to 12 meters thick. The MB unit, which is approximately 110 meters thick, is the main pay of the reservoir that contains oil[19]. Furthermore, the Mishrif reservoir can be subdivided into three main units and two barrier units, as listed from the most recent to the oldest:

a. Cap rock (CR. I)

The upper section of the Mishrif formation essentially consists of clay-limestone and acts as an effective seal. It acts as a caprock due to its extremely low porosity and permeability, making it an efficient barrier.

b. Upper Mishrif (MA)

In the southern oil fields of Iraq, this reservoir unit holds significant importance, except for in Nasiriyah where it is water-saturated. Despite having a favorable porosity level of 17%, its permeability is limited due to the degraded facies it possesses.

c. Continental shale unit (CR. II)

located beneath the MA unit. This particular unit is identifiable by its distinctive response in Gamma Ray (GR) and sonic logs, which show high levels. It serves as a barrier between the lower and upper sections of the Mishrif reservoir. In the Nasiriyah oil field, the average thickness of this barrier measures approximately 11 meters [14].

d. MB1

It is the most important unit in the reservoir as it exhibits excellent reservoir properties, with 21.5% average porosity. The upper portion of this unit primarily contains fossilized bioclastic limestone abundant in mollusks, algae, rudists, and a few corals [14].

e. MB2

This unit is considered an intermediate zone between (Rumaila-Mishrif) formations, where oil exists only in the upper section. It shows characteristics of a shallow organic lagoon, resulting in unfavorable petrophysical properties, particularly in the lower section. MB1 and MB2 units are interconnected, as there is no barrier layer separating them[14].

2- Methodology

The approach employed in this study uses Petrel 2018 software, which follows a similar procedure to Suhail et al. [20], as illustrated in Fig. 3.

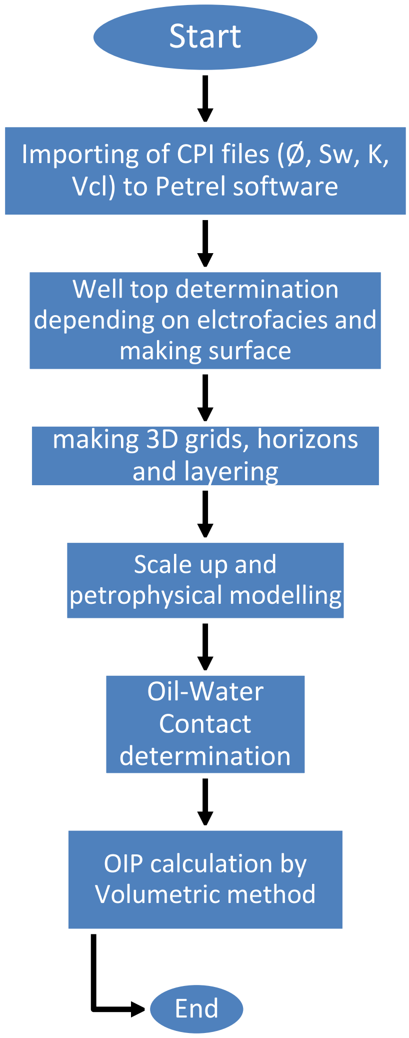


Fig. 3. Workflow of the study

The model is built by dividing the region depicted in 2D structural maps into discrete sections and incorporating petrophysical properties derived from interpreting well-log data using Techlog 2015 software. Gamma-ray logs are used mainly for shale volume calculation, while neutron and density logs have been combined and utilized to determine total porosity. Meanwhile, the Archie equation determines water saturation. Table 1 presents all parameters for calculating Conventional Petrophysical Interpretation (CPI) properties.

Eq. 1 explains the calculation of effective porosity as follows:

$$\varphi e = \varphi t \times (1 - Vsh) \quad (1)$$

In the equation above, the effective porosity is represented by φe, and the total porosity is represented by φt. Shale volume ($V sh$) is estimated using an empirical equation designed for older rocks [21]. Igr represents the index for gamma-ray, as shown in Eq. 2.

$$Vsh = (22 * Igr - 1) \times 0.33 \quad (2)$$

Table 1. Formation evaluation parameters

Rw (Ω.m)	m	n	a	Grmax (API)	Grmin (API)	ΦNsh (%)	ρmatrix (g/cc)
0.02189	2.058	2.4291	1	70-90	5.3-9.8	40.31-45.503	2.71

This study uses the arithmetic average method among the geometric and harmonic averaging methods to upscale water saturation and effective porosity. In contrast, harmonic averaging is used for the permeability calculation [22]. This choice is made to keep the vertical variation of petrophysical properties during 3D modeling by averaging the values of porosity or permeability within each layer. The upscaled properties are then populated in three dimensions (3D) using SGS. The calculation of the NTG ratio is performed for each grid by determining the cutoff values for water saturation and porosity logs. This study used the applied values (φcutoff=7%, Swcutoff=65%). Subsequently, it is upscaled to the 3D model layers and populated in the 3D structure of grids by SGS, with a bias towards porosity and water saturation. Finally, the OWC is modeled to calculate the Original Oil in Place (OOIP) for all the grids of the model.

3- Results and discussion

Every step outlined in the previous section generates specific outcomes that play a role in the volumetric calculations of oil reserves. The subsequent sections present the outcomes from every step in building the geological model and estimating OOIP.

3.1. Structural modeling

The first step in the workflow includes modeling the reservoir structure, which is most important for accurately representing the field's large-scale geology [23]. This study's step depends on a structural map of the reservoir derived from updated well tops and the primary information available from seismic data. The structural depth map in Fig. 4 clarifies the top of the studied reservoir, and Fig. 5 presents a correlation for the well section.

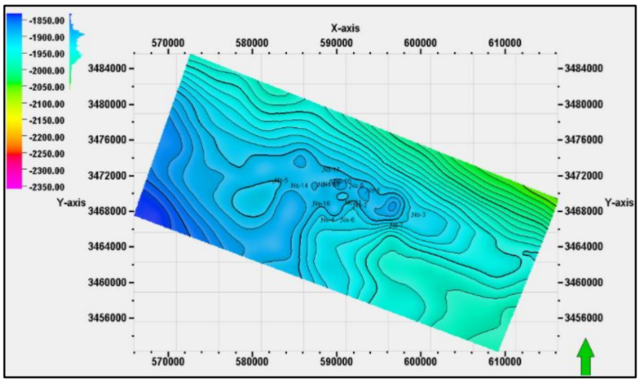


Fig. 4. Structural map for the top of the Mishrif formation

3.2. Skeleton and layering

A reservoir model, which includes 317130 grid blocks with dimensions of 165x62x31, is instructed to represent the reservoir. The grid size of the reservoir varies, with finer grids implemented within specific areas of interest where wells are concentrated. This allows and facilitates the computation for reservoir simulation (dynamic modeling). Fig. 6 illustrates the 3-D gridding of the model, and the size of its grid blocks are stated below:

1. X-axis: is divided into 165 grids; 145 grids are (150x150 m) scales for the area of interest, which developed by 40 wells, while the area outside the development region has a scale of (300X300m)
 (8*300,145*150,12*300).
2. Y-axis: is divided by 62 grids, 62 are 150 x150 m for the area developed with available wells
3. Z-axis: divided into 31 layers; Fig. 7 displays the upscaled petrophysical properties layers versus the CPI logs.

3.3. Petrophysical modeling

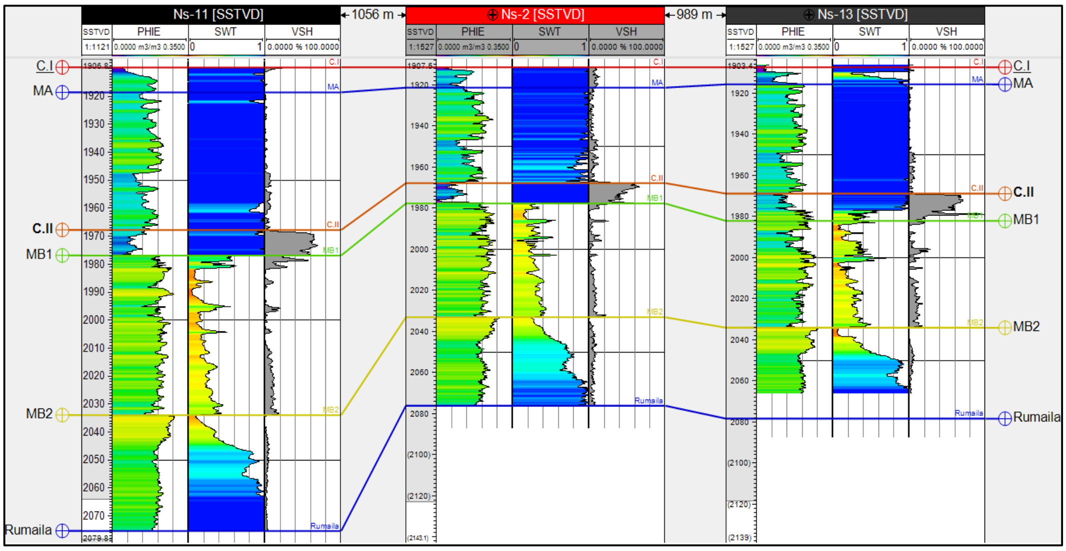
The 3D property modeling method maintains the vertical variation of properties and uses geostatistical algorithms to distribute the volume between wells horizontally [24]. In the current study, the Sequential Gaussian Simulation (SGS) method has been utilized for modeling purposes due to its simplicity, efficiency, and flexibility [25]. The focus of 3D reservoir characterization is mainly on effective porosity and water saturation, other than the other important petrophysical properties [26]. The following sections display the modeling outcomes of these properties and an explanation of the Net-to-Gross (NTG) parameter, as stated in Section 2.

3.3.1 Porosity

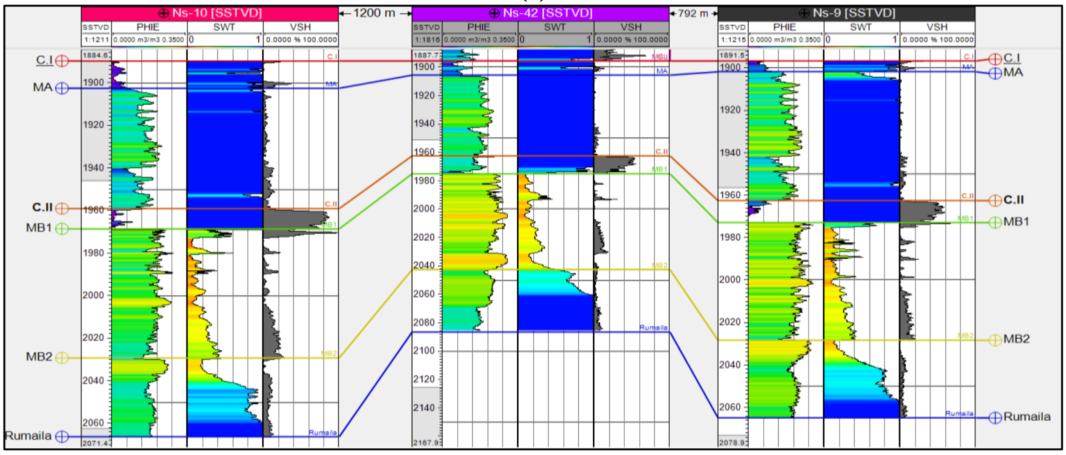
As mentioned, the arithmetically average upscaled properties have been distributed horizontally using the SGS algorithm, specifically porosity in the MB1 unit. Its distribution in the MB1 follows a normal distribution, as explained in Fig. 8, with an excellent value of 21.53% on average. Fig. 9 shows the major spatial trend of porosity in the MB1 unit, which decreases in quality from the northwest (NW) to the northeast (NE) .The MB2 unit reveals a similar trend to the MB1 unit. However, a slight difference with greater values for porosity distribution. The average value for the MB2 unit is 22%, slightly greater than that of the MB1 unit, as shown in Fig. 10 and Fig. 11.

3.3.2. Water saturation (Sw)

Water saturation is modeled in 3D for each unit. According to the statistics, MB1 shows the values for oil saturation, indicating the presence of the oil resource, as shown in Fig. 12 and Fig. 13. On the other hand, MB2 is predominantly saturated with water, as depicted in Fig. 14 and Fig. 15. The geological description of the formation and interpretations of well logs reveal that two units are considered non-reservoir.



(a)



(b)

Fig. 5. Well correlation section for wells (a) Ns-11, Ns-2, and Ns-13 and (b) Ns-10, Ns-42, and Ns-9

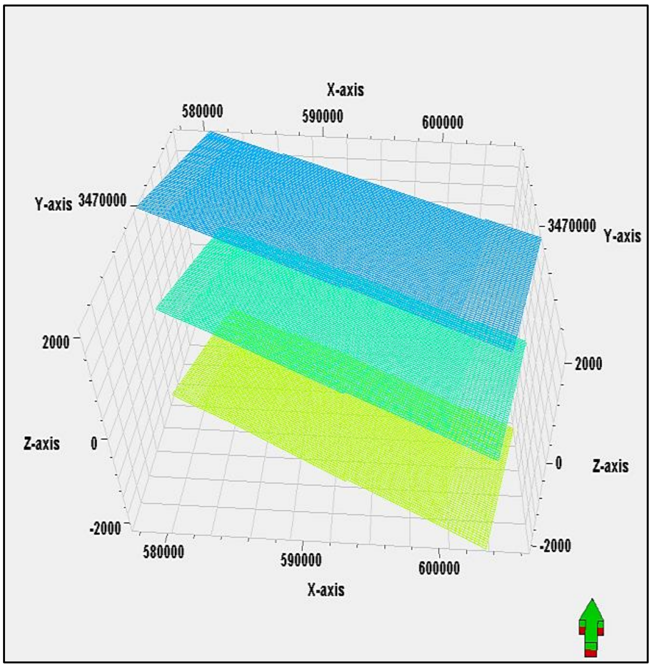


Fig. 6. Skeleton (Reservoir gridding)

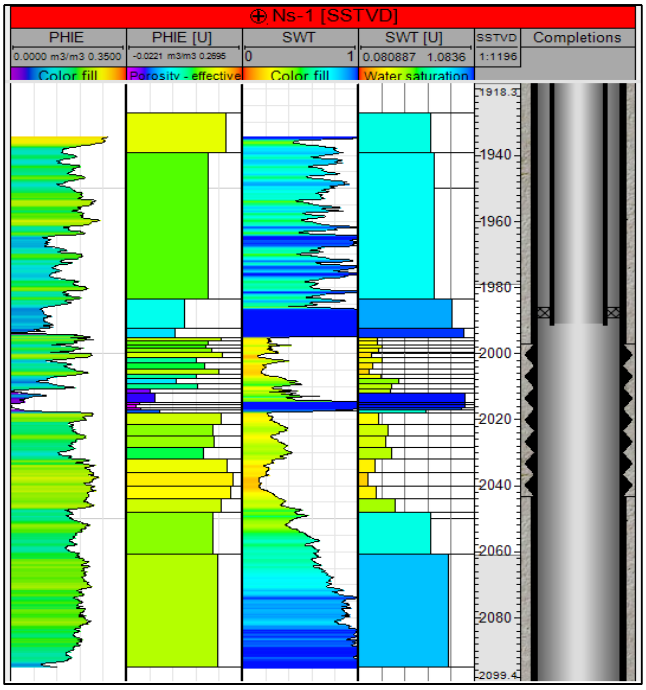


Fig. 7. Comparison between CPI and upscaled CPI for well Ns-1

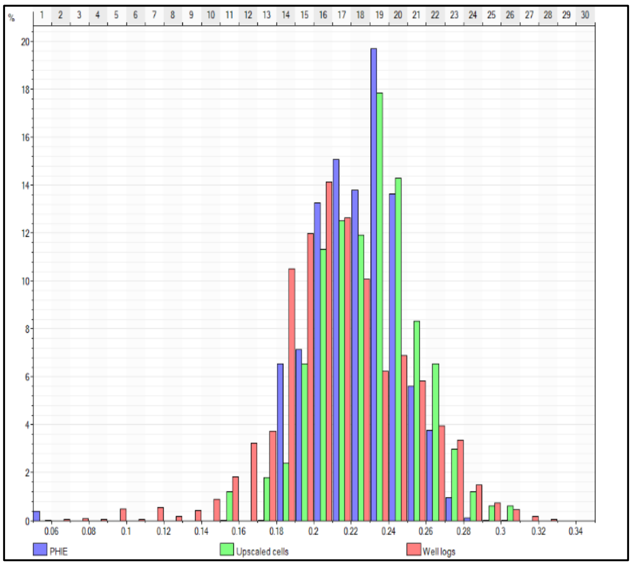


Fig. 8. Porosity histogram for MB1 unit

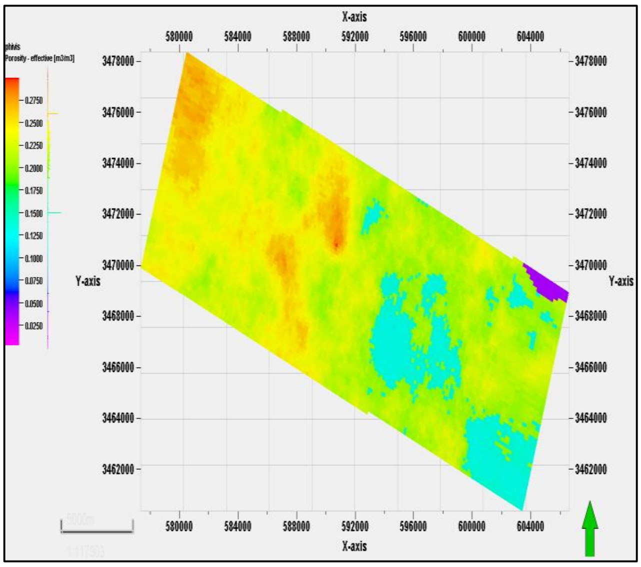


Fig. 11. Porosity modeling- top of MB2 unit

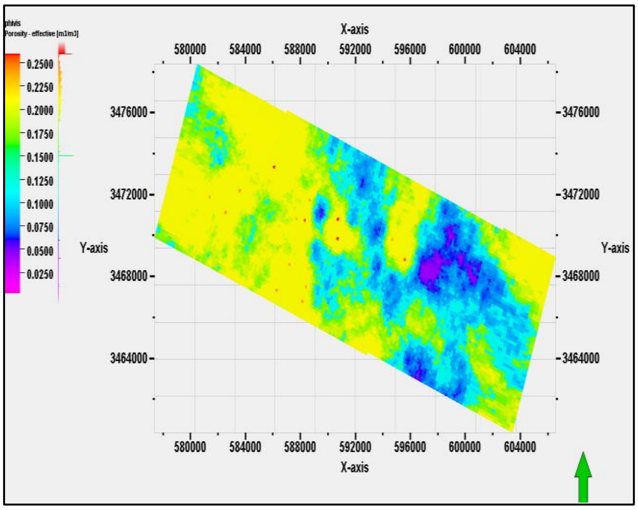


Fig. 9. Porosity distribution of top MB1

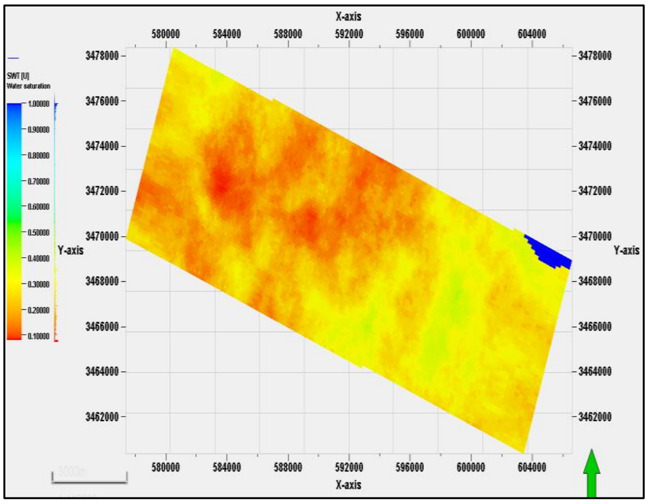


Fig. 12. Distribution of water saturation for the top of MB1

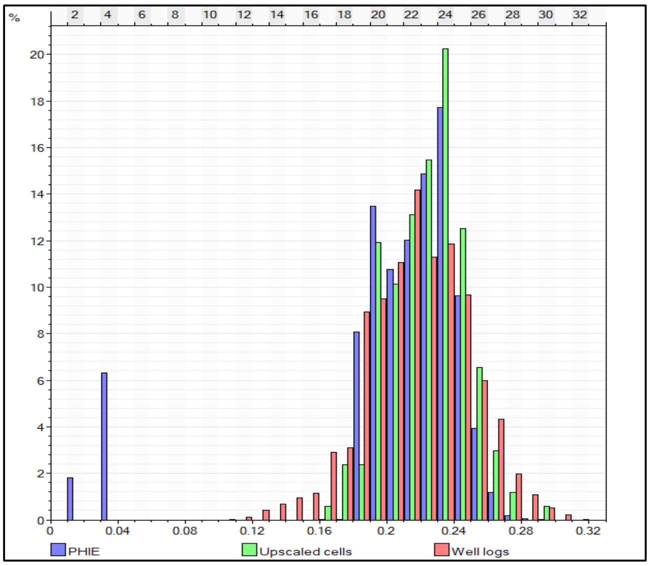


Fig. 10. Porosity histogram- MB2 unit

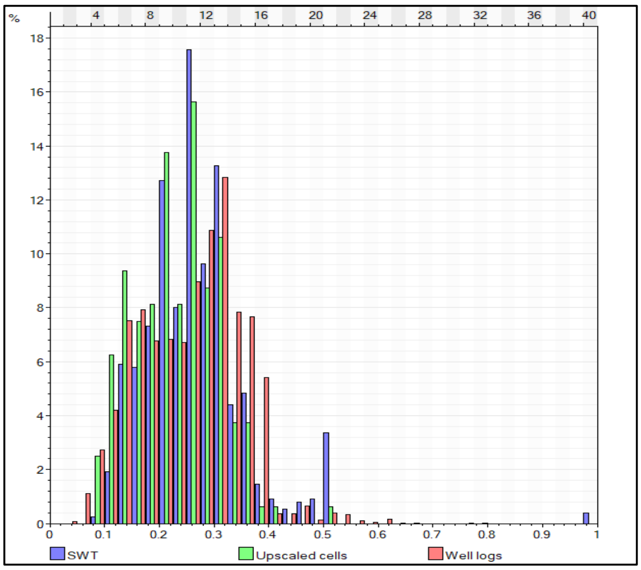


Fig. 13. Water saturation histogram in MB1

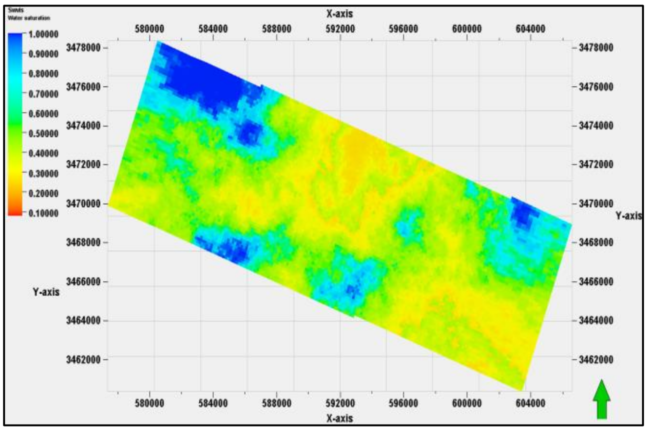


Fig. 14. Water saturation distribution for MB2 unit

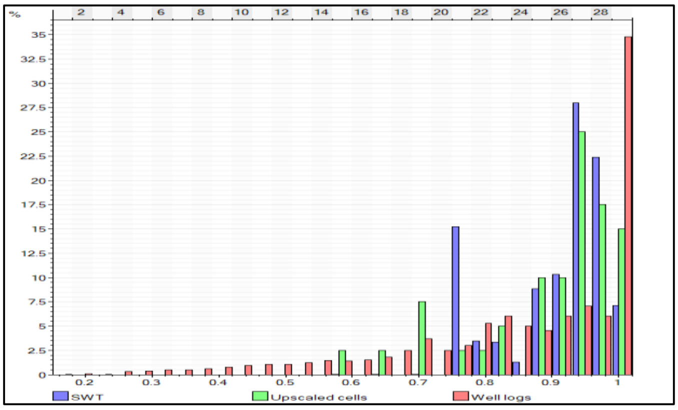


Fig. 15. Water saturation histogram for MB2

3.3.3. Permeability

Permeability has been calculated for uncored intervals based on porosity-permeability relations (using the FZI method) for each rock type that exists in the reservoir[27]As shown in Fig. 16, it’s highly noted that permeability is not distributed statistically by SGS as porosity; however, the distribution trend is based on rock-type distribution. The harmonically averaged upscaled property is distributed horizontally by calculating permeability from the porosity at each rock type; Fig. 17 clearly shows that the permeability histogram for MB1 follows a log-normal distribution with an average value of 493 md, while Fig. 18 shows the areal distribution for it. The MB2 unit is similar to the lognormal distribution of MB1 with fewer permeability values of 97 md, which is the average permeability for this unit, as depicted in Fig. 19 and Fig. 20, respectively, make it a preferable production zone, especially since it is characterized by high oil saturation, as mentioned in the previous section.

3.3.4. Net to gross (NTG)

As described in Section 2, Fig. 21 through Fig. 24 represent the three-dimensional (3D) distribution of the NTG property and show statistical insights. The observed distribution effectively recognizes the oil zones within the Mishrif reservoir, specifically MB1 and MB2. This distinction is critical in building a representative model for the reservoir.

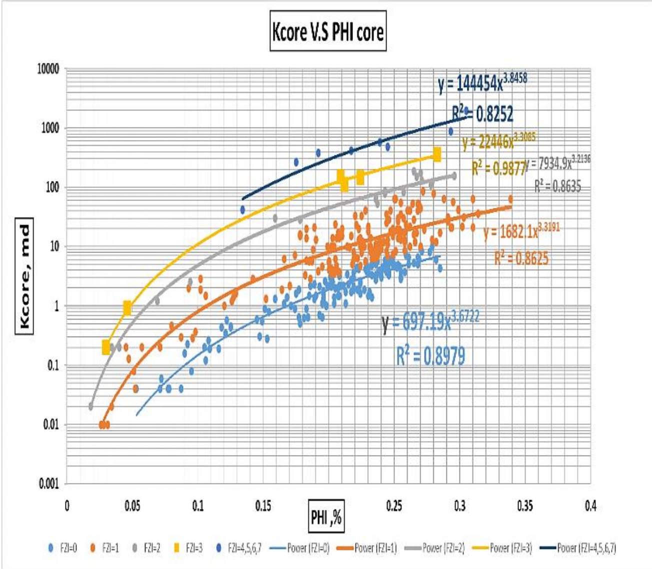


Fig. 16. Permeability- porosity relation at the cored intervals

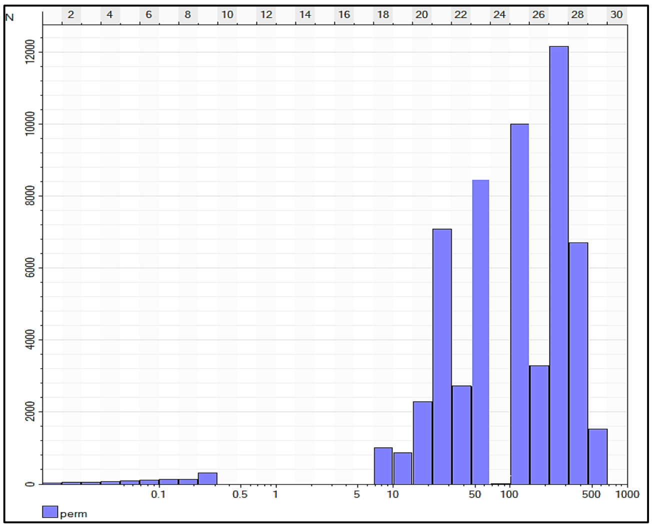


Fig. 17. Permeability Histogram for MB1

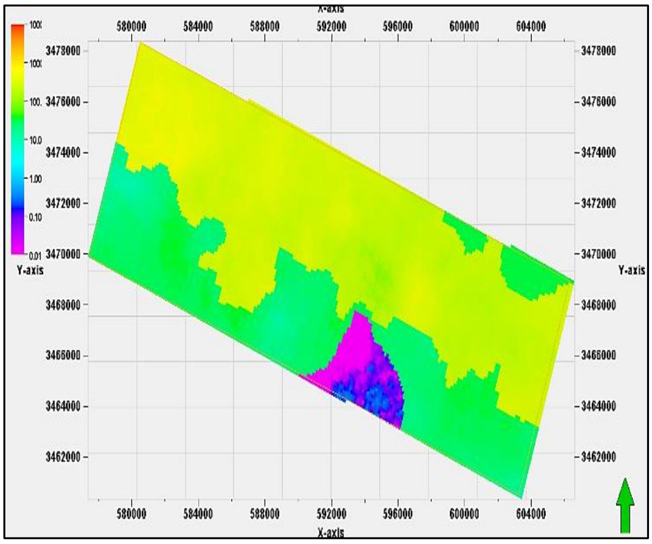


Fig. 18. Permeability distribution for MB1

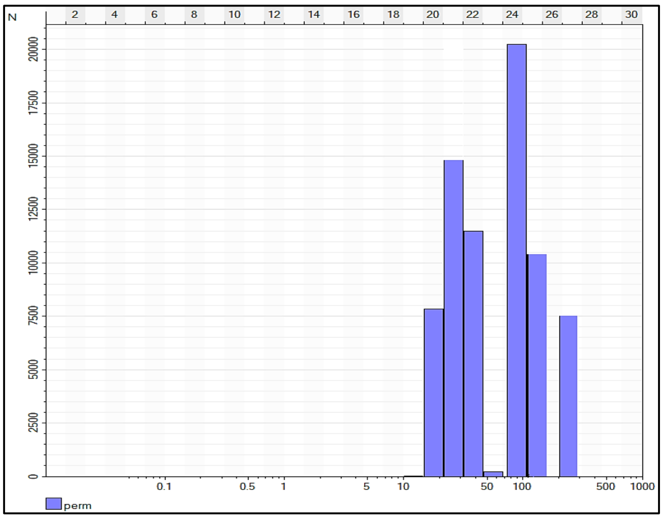


Fig. 19. Permeability histogram for MB2

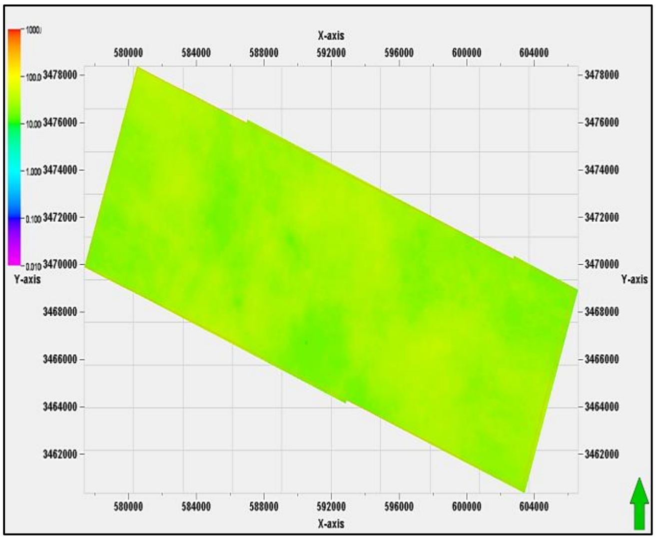


Fig. 20. Permeability distribution for MB2

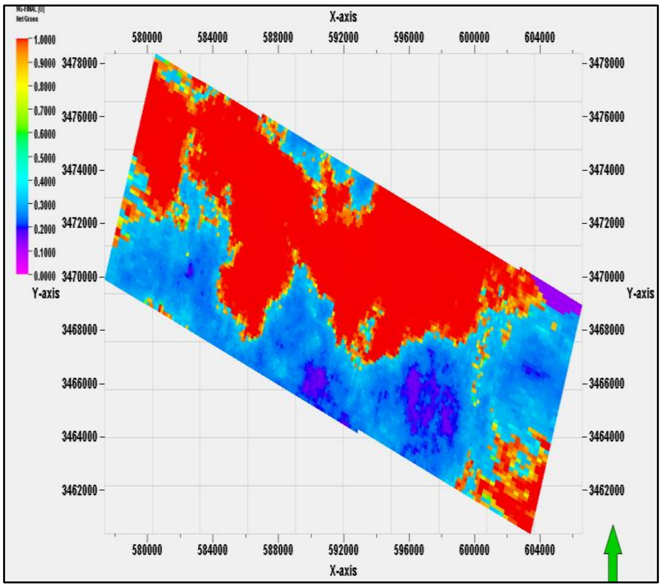


Fig. 21. The NTG distribution for the top of MB1

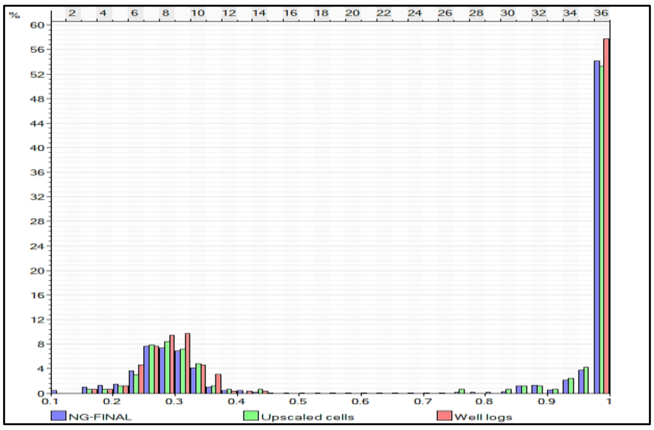


Fig. 22. The NTG histogram for MB1

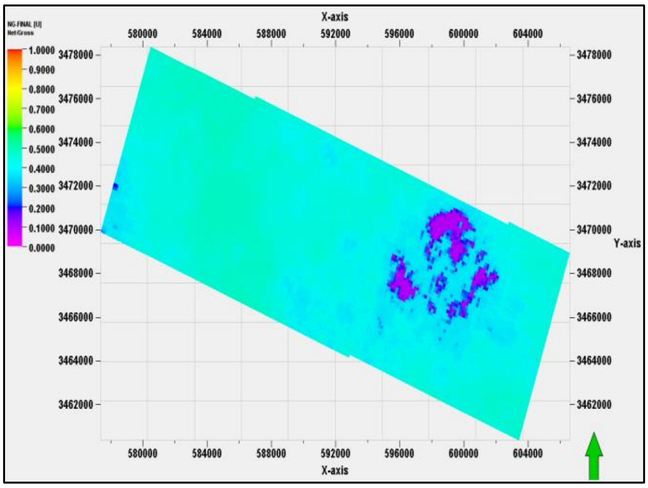


Fig. 23. The NTG histogram for MB2

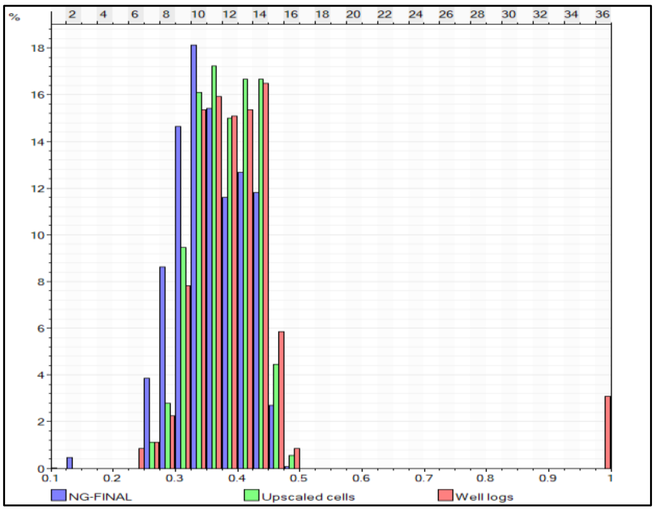


Fig. 24. The NTG histogram of MB2

3.4. Modeling of the OWC

The well log interpretations for the 40 wells in the Nasriyah oilfield showed a considerable difference in OWC depths from one well to another; Fig. 25 displays the depths of the Oil-Water Contact (OWC) measured from sea level for 40 wells that have corresponding data for (CPI). In OWC, three initial regions have been designated within the reservoir to capture and simulate the variation accurately. Fig. 26 illustrates the OWC values and shows the depths of OWC for wells located within that region. These values range from 2060m and 2050m to 2046m from northwest to southeast.

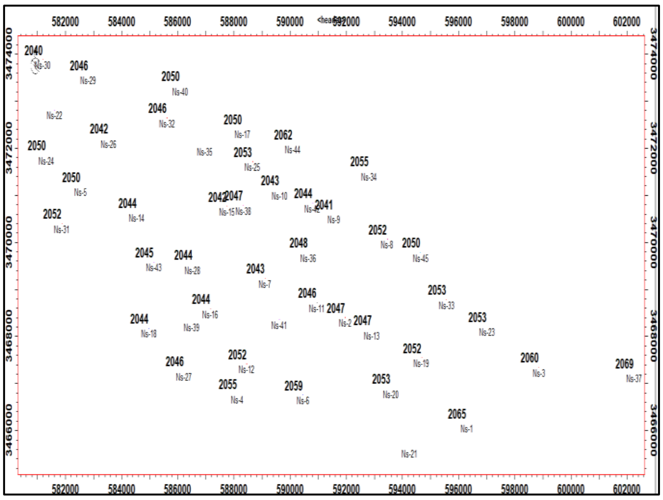


Fig. 25. OWC depth (m) distribution in the drilled wells measured from sea level

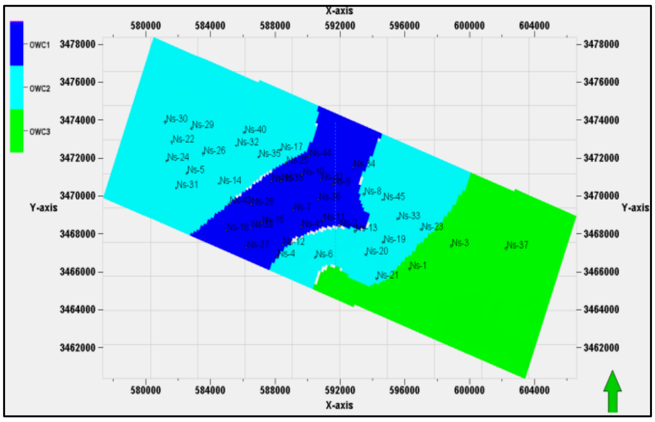


Fig. 26. Average OWC values proposed in the model

3.5. Hydrocarbon volume calculations

After applying the geologic characterization approach for the reservoir, OOIP calculation is performed by employing the volumetric method for the Mishrif reservoir in the Nasiriyah oilfield, where the total OOIP is estimated to be equal to 8535.5 MMSTB. With MB1 unit accounting for 73% (6195 MMSTB) and MB2 holding 27% of the total OOIP. The current study includes a significantly larger number of wells compared to previous studies, which has allowed for a more comprehensive geologic model. This model encompasses almost the entire area of the field and has led to an updated structural map of the reservoir. Table 2 compares OOIP calculated in the current and previous studies[18]

Table 2. Comparison of OOIP values with previous studies

Study	STOOIP (MMSTB)
SOC 2003	14779
ENI 2007	7518.7
NIPPON 2008	6756
S.Wali 2020	7945
Current Study	8535.5

4- Conclusions

The study involved constructing a representative 3D geologic model to characterize the spatial distribution of petrophysical properties and estimate the Original Oil in Place (OOIP) for the Mishrif reservoir in the Nasiriyah oilfield. The major outcomes of this study are outlined below:

1. The calculated overall OOIP for the Mishrif formation in the Nasiriyah oilfield is 8535 million stock tank barrels (MMSTB). The discrepancy in the volume of the current study compared to previous studies can be attributed to the inclusion of a significant number of wells involved in the geological model, which covers nearly the entire area of the field and has resulted in an updated structural map for the reservoir, enhancing the accuracy of the characterization. The model specified that most oil reserves are in the MB1 unit, accounting for approximately 73% of the total reserves. The remaining 27% of the reserves are found in the MB2 unit.
2. Due to the significant heterogeneity and varying sizes of pore throats, the OWC depths vary from one well to another. This phenomenon is characterized by three equilibrium regions or three regions of initialization, where each region maintains the average OWC depth for wells within this region.

Nomenclature

a	tortuosity
IGr	index of Gamma-ray
m	factor for Cementation
n	Saturation exponent
Vsh	Shale volume

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التقييم المكمني والتوصيف الجيولوجي لتكوين المشرف في حقل الناصرية النفطي

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الخلاصة

عملية تقييم الخزين الهيدروكاربوني في المكامن هي خطوة بالغه ألاهميه في خطط تطوير الحقول النفطية والغازية والتي تؤثر بشكل كبير على اتخاذ القرارات في خطط تطوير الحقول والحكم عليه فيما اذا كان مجديا اقتصاديا ام لا. تم جمع بيانات جس الابار في هذه الدراسه من ٤٠ بئرا في حقل الناصرية لكي يتم استخدامها لتفسير خواص الصخور البتروفيزيائيه وبالتالي تساعد في عمليه بناء الموديل الجيولوجي ثلاثي الابعاد الذي يستخدم لوصف التوزيع المكاني لخواص الصخور البتروفيزياوية وحساب الخزين النفطي باستخدام الطريقة الحجمية. تم استخدام خارطه عمقية ثنائيه الابعاد لتحديد طبغرافية التكوين بالاضافه الى نتائج تفسير المجسات والتي تتضمن (المساميه الفعالة، النفاذية، تشبع الماء) لغرض بناء الموديل الجيولوجي وقد احتوى الموديل الصمم على ٣١٧١٣٠ خلية. ان هذه الخواص البتروفيزياويه تم توزيعها بالاتجاهات الثلاثة في الموديل عن طريق طرق احصائية تدعى (SGS) كذلك تم تمثيل الاختلاف في مستويات تماس الموائع (ماء/نفط) عن طريق تقسيم المكمن الى ثلاث مناطق توازن هيدروليكي لغرض وصف المكمن بشكل دقيق حيث تم حساب الخزين النفطي للمكمن في هذه الدراسة وقد بلغ ٨٥٣٥ مليون برميل حاليا والذي يتركز في طبقتين اساسيتين وهما MB2 , MB1 حيث ان الوحده الاولى تحتوي على ٧٣% من الخزين الحالي وتعتبر المكمن الرئيسي في تكوين المشرف.

الكلمات الدالة: التوصيف الجيولوجي، التقييم المكمني، تقييم الخزين النفطي، حقل الناصرية، نمذجة الخواص البتروفيزياوية.