Distribution of Petrophysical Properties Based on Conceptual Facies Model, Mishrif Reservoir/South of Iraq

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Abstract

A 3D geological model is an essential step to reveal reservoir heterogeneity and reservoir properties distribution. In the present study, a three-dimensional geological model for the Mishrif reservoir was set-up based on data obtained from seven wells and core data. The methodology includes setting up a 3D grid and preparing it with petrophysical properties such as (facies, porosity, water saturation, and net to gross ratio). The structural model was built based on a base contour map obtained from 2D seismic interpretation along with well tops from seven wells. A simple grid method was used to build the structural framework with 234x278x91 grid cells in the X, Y, and Z directions, respectively, with lengths equal to 150 meters. The total number of grids is (5919732) in the geological model. CPI (computer-processed interpretation) for 7 wells contain (facies, porosity, water saturation, and NTG) was imported to Petrel 2016 software. Facies log was upscaled and distributed along the 3D grid. Truncated Gaussian with trend method was used to distribute the facies taking into account the conceptual facies model of the Mishrif formation. The result shows that the trend of sedimentation suggests a retrogradation pattern from NW to SE. Facies1 (Reservoir), dominated by Limestone brown to light brown, with oil shows has well distribution within the area and thinning towards the NW. The petrophysical properties (porosity, water saturation, NTG, and permeability) were distributed using the Sequential Gaussian Simulation (SIS) method and the facies model as a guide for distribution.

The results show that petrophysical properties obvious in the southeast area, representing the reef region compared to the northwest side of the study area. The unit Mishrif B had the highest porosity value and lower water saturation value along the entire field. While the units Mishrif B1, B2, and B3 show gradual decrease in reservoir properties ahead towards southeast side of the field. The results also show that conceptual facies model has great benefit in constructing

the 3D geological model, which reflects the geological knowledge used to distribute the reservoir properties (porosity and water saturation) correctly.

Keywords: Facies model, 3-D Geological model, reservoir heterogeneity.

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توزيع الخصائص البتروفيزيائية بناءا على نموذج مفهوم السحنات
مكمن المشرف/ جنوب العراق

الخلاصة

يعد الموديل الجيولوجي ثلاثي الأبعاد واحد من اهم الخطوات الاساسية للكشف عن درجة تجانس المكمن النفطي وتوزيع الخصائص البتروفيزيائية للمكمن. في هذه الدراسة، تم بناء الموديل الجيولوجي ثلاثي الأبعاد لمكمن المشرف بناءً على البيانات التي تم الحصول عليها من سبع آبار وبيانات اللباب الصخري المقطوع. تتضمن طريقة العمل بناء الهيكل التركيبي ثلاثي الأبعاد وملؤها بالخصائص البتروفيزيائية (السحنات، المسامية، التشبع المائي، نسبة العطاء الصافي الى السمك الكلي). حيث تم بناء الهيكل التركيبي لمكمن المشرف بناءً على خريطة تركيبية عمقية تم الحصول عليها من التفسير السيزمي ثنائي الأبعاد جنبًا إلى جنب مع قمم وحدات تكوين المشرف من سبع آبار. تم استخدام طريقة الشبكة البسيطة لبناء الإطار الهيكلي بخلايا شبكية 234 × 278 × 91 في اتجاهات X وY وZ، على التوالي، بطول يساوي 150 مترًا. وكان إجمالي عدد خلايا الموديل الجيولوجي (5919732).

التفسيرات البتروفيزيائية لـ 7 آبار تحتوي على (السحنات، المسامية، التشبع المائي، ونسبة العطاء الصافي الى الكلي) تم استيرادها إلى برنامج Petrel 2016، و استخدام طريقة (Truncated Gaussian with trend) لتوزيع السحنات مع الأخذ في الاعتبار موديل السحنات المفاهيمي لتكوين المشرف. اظهر الموديل السحني أن اتجاه الترسيب يشير إلى نمط تراجع بحري من اتجاه الشمال الغربي الى الجنوب الشرقي. كذلك بين الموديل السحني ان السحنة الجيدة التي يغلب عليها الحجر الجيري البني إلى البني الفاتح، المشبعة بالنفط قد توزعت جيدا داخل المنطقة وتقل تدريجيا باتجاه الشمال الغربي لتحل محلها السحنة ذات المواصفات السيئة. تم توزيع الخواص البتروفيزيائية (المسامية، تشبع الماء، نسبة العطاء الصافي الى السمك الكلي) باستخدام طريقة Sequential Gaussian simulation (SIS) مع استخدام الموديل السحني كدليل موجه للتوزيع. بينت نتائج الموديل البتروفيزيائي أن الخواص البتروفيزيائية جيدة وتتحسن في المنطقة الجنوبية الشرقية التي تمثل منطقة الشعاب المرجانية مقارنة بالجانب الشمالي الغربي من منطقة الدراسة.

الوحدة مشرف B تمتاز بمسامية عالية وتشبع قليل بينما الوحدات B1, B2, B3 اظهرت نقصان متدرج بالخواص البتروفيزيائية باتجاه الجنوب الشرقي من الحقل. النتائج ايضا بينت ان اعتماد نموذج السحنات مفيد جدا لبناء الموديل الجيولوجي والذي يعكس المعرفة الجيولوجية لتوزيع الخواص المكمنية (مسامية تشبع بصورة مضبوطة).

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1. Introduction

One of the standard tools currently used to generate production forecasts of any oil and gas field is three-dimensional reservoir modeling and flow-simulation studies. A significant challenge has been facing geologists in constructing 3D geological modeling. Facies distribution in lateral and vertical directions and between different flow units in the defined 3D grid is one of these challenges [1]. Also, the proper and acceptable mapping of reservoir

characterization is one of the significant challenges. Therefore, integration and incorporation of all quantitative field studies with all available data are required. Building 3D stochastic models based on the conceptual geological model had great benefit to reflect the geological knowledge and proper distribution of reservoir properties [2]. The main objective of conceptual geological model is its using as a guide to build the 3D reservoir model, and representing the geological knowledge based on real and or conceptual geological objects [3].

Porosity, water saturation, and permeability have an essential impact on hydrocarbon reservoir and reservoir modelling. The petrophysical properties and reservoir characterization are used to generate petrophysical models. The petrophysical model predicts future performance and estimates reserves [4]. The Mishrif formation in X-field is the main hydrocarbon reservoir, which is the subject of our study. The Mishrif formation is a heterogeneous reservoir. Consequently, a critical petrophysical analysis and model development is required to ensure optimal enhancement of oil recovery using a 3D petrophysical model. The Mishrif Formation in central and southern Iraq was a subject for many studies [5- 10]. It is considered one of the important reservoirs in the south Iraq region; approximately 30% of the total Iraqi oil reserves were found in this formation [8, 11].

The Mishrif Formation was first described by [12] in southern Iraq. The formation consists of sub basinal, shelf limestone, and restricted shelf facies [5]. Mishrif formation belongs to the middle Cenomanian – early Turonian age and is deposited on a basin-wide shallow-water platform [13].

Few studies have been carried out on the Mishrif formation to distribute petrophysical properties using the facies model as a guide for distributions. Therefore, the primary purpose of this paper is to build a 3D static geological model for Mishrif Formation in X-field, south Iraq, and build the 3D petrophysical model based on the conceptual facies model. The study also aims to understand better the lateral and vertical distribution of petrophysical properties (Porosity, water saturation, and NTG) of the Mishrif reservoir.

2. **The study area**

The X-field is situated in the south-eastern part of Iraq. It is located above the suture structure at the junction of the inner part of the Arabian plate and the western part of the Mesopotamian

foredeep. The western part of the Mesopotamian foredeep is defined by northeasterly strike folds of low amplitude (30-40 m). The field lies on the Euphrates subzone, Mesopotamian Basin of the unstable shelf. The structural depth maps (Figure 1) of the Mishrif Formation show that the field is a stratigraphic trap with a general NW - SE trend, 30 km long, 12 km width. The drilling of exploration wells shows that the oil is accumulated mainly in the Mishrif Formation.

The super sequence Albian – lower Turonian represents a transition from onlap margin to the basin [14]. This super sequence consists of Wara, Ahmadi, Rumaila, and Mishrif formation. Mishrif formation belongs to the middle Cenomanian – Early Turonian age, and it is considered one of the important reservoirs in this sequence. The formation consists of two third-order sequences [8], consisting of bioclastic limestone rock and chalky Limestone.

The Mishrif formation in X-field consists of upper Mishrif (MA) and lower Mishrif (MB), which differ one from another by reservoir properties of sediments, and are separated by shale (CR-II) and marls. The average thickness of the formation is about 186 m.

3. **Data set and Methods**

The data used in this paper consists of CPI (computer-processed interpretation) for 7 wells. The CPI contains (Facies, Porosity, Water saturation, and NTG), base contour map for Mishrif Formation from the last interpretation of 2D seismic. Collecting and quality check of the data and preliminary information from the final geological reports and previous reservoir studies is the first step in the workflow of geological modeling.

Schlumberger's Petrel 2016 software was used for 3D geological modeling. Modeling software presents a 3D view for all reservoir properties and helps geologists distribute the petrophysical properties models and design new wells [15].
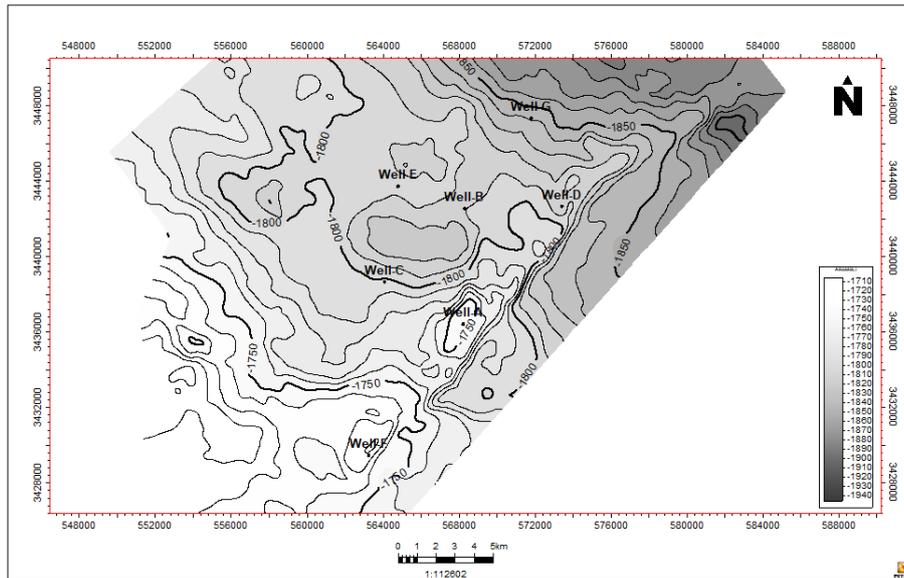
Fig. (1): Base structural depth map obtained from 2D seismic interpretation

The geological model for Mishrif formation was constructed using the regular modeling workflow (Figure 2). This model was built with three main steps, which are:

- The first step is building a structural model using the surface contour map taken from 2D seismic interpretation for the top of Mishrif formation as a base surface, then using the well tops with this map to build the reservoir unit surface maps. A simple grid method without any fault was used to build the structural model for Mishrif formation in X-field.

- The second step is constructing the conceptual facies model from seismic interpretation and core study. This conceptual model will be used as a guide for the final 3D facies model.

- The last step is upscaling and distributing the petrophysical properties over geological model cell using facies model as a guide for the distribution. The sequential Gaussian Simulation (SGS) method was used in petrophysical model distribution.

In the following, the workflow of geological model construction is discussed in more detail.
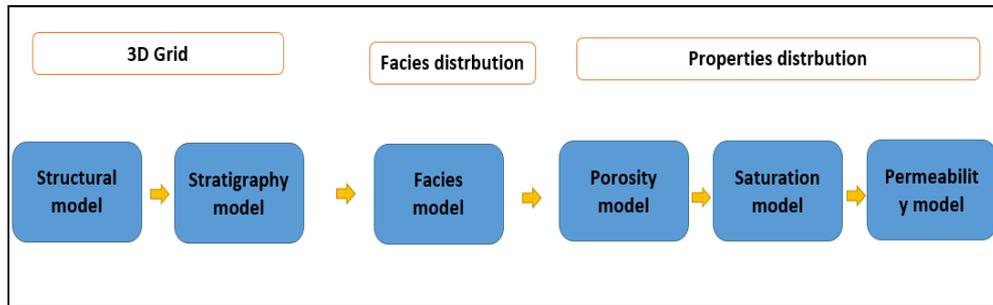
Fig. (2): 3D geological model workflow [16]

3.1 Stratigraphic model (Well correlation)

The concept of well correlation may enhance the distribution of petrophysical properties variation and thickness of different lithological units in the reservoir; it was applied to give an idea and allow simple visualization of the changes in the thickness within Mishrif units and the change of the petrophysical properties [16]. After data were loaded into Petrel Software, two well correlation sections were made. The two well correlation sections are shown in the map (Figure 3) show the direction of correlation between wells. A green line represents the first one in the NE-SW direction through three wells (Well-F, Well-A, Well-D). The second represents the red line in the E-W direction pass by three wells (Well-D, Well-B, and Well-E). The correlation was performed by comparing the well logs and petrophysical interpretation logs (PHI, Sw, Facies) with indicated marker horizons. There are two marker horizons identified in the studied area based on the standard logs: claystone of CR-II layer and the top of argillaceous limestones of the Rumaila formation.
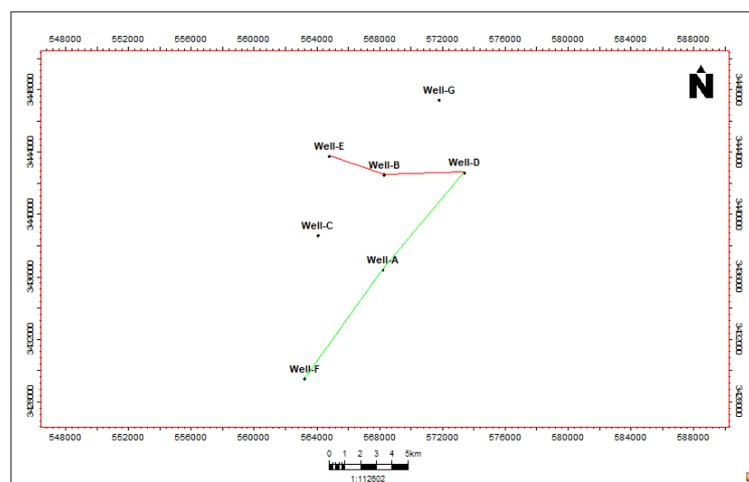
Fig. (3): Lateral (Redline) and Longitudinal (Green line) well Correlation of Mishrif Formation in X- Oilfield

3.2 Structural Modeling

The structural model represents the main and the first stage for constructing a 3D geological model, which divides the model into grid cells. Each cell will take one value of porosity, one value of water saturation. The primary input for this model is a structure contour map and fault information, which represents one of the most critical steps to create a three-dimensional structural interpretation. The Structural modeling was subdivided into four processes: make edit polygon, make edit surface, make sample grid, and vertical layering. All three operations were performed one after the other to form one single data model.

The Structural surfaces maps were built based on a base map obtained by 2D seismic data interpretation results (taking into account the locations of the drilled wells). The base map was used as reference surfaces in order to build the structural model. In the model, a surfaces map for each unit of Mishrif formation was created based on the structural map taken from 2D seismic interpretation, and these maps have been adapted to well tops.

A simple grid method was used to build the structural framework of X-field with 234x278x91 grid cells in the X, Y, and Z directions, respectively. The grid was depicted as a square; its side length is equal to 150 meters. The grid dimensions were relatively large to preventing grid upscaling problem when exported into the simulation model. Figure (4) shows the skeleton of the geological model.
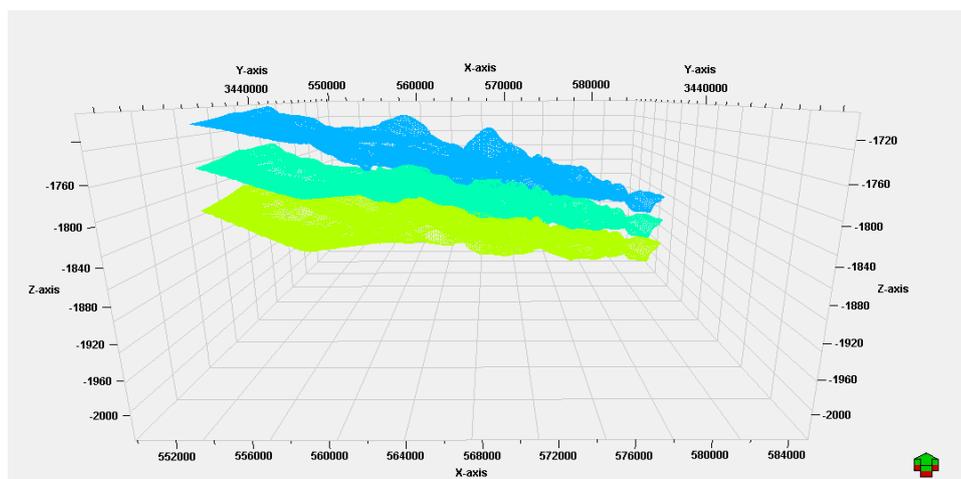
Fig. (4): Structural constraint for geological model

After grids construction, layering and zoning is the final step in constructing the structural framework. It is essential to define the thickness and orientation of the layers between horizons of the 3D grid. To ensure the best upscaling values for petrophysical properties in the geological model cell, we should define the grid thickness properly. It is normal to modify the layering after upscaling is done to compare input data and upscaled data better.

Each Mishrif unit in X-field has been divided into many layers depending on petrophysical properties. CR11 zone consists of one layer in the uppermost of the formation because it represents the seal rock of Mishrif formation. Table (1) illustrates the number of layers of each unit in Mishrif formation.

Table (1) Mishrif unit and number of layers in each unit

Zone	No. of Layers
CR_II - Mishrif B	1
Mishrif B -Mishrif B1	20
Mishrif B1 - Mishrif B2	25
Mishrif B2 - Mishrif B3	25
Mishrif B3 -Rumaila	20

The scale-up well logs are making averages for the values to the cells in the 3D grid penetrated by the wells. An excessively large considerable model will cause PETREL's simulation to take more significant amounts of time. During the process of upscaling well data into the model, we have to ensure that once in the model; the data is representative of the original well data. Too few layers will result in data loss, and too many layers will result in slow modeling in the future. Comparison between well data and upscaled data is a primary process in static modeling and needs to be thorough [17]. In geological models, facies and petrophysical properties (porosity (Ø), permeability (K), and water saturation (Sw)) have been scaled up. Many statistical methods are used to scale up, such as (arithmetic, harmonic, and geometric method). The facies log was upscaled using most methods, while the current model's porosity, water saturation, and permeability values were scaled up using the arithmetic average. Figure 5 showing the Scale-up of facies, porosity, and water saturation logs for well-B.

3.3 Property Modelling

Property modeling is the process of filling the grid cells with discrete (facies) or continuous properties (porosity and water saturation). It is used to distribute petrophysical properties laterally and vertically in the 3D grid cells.
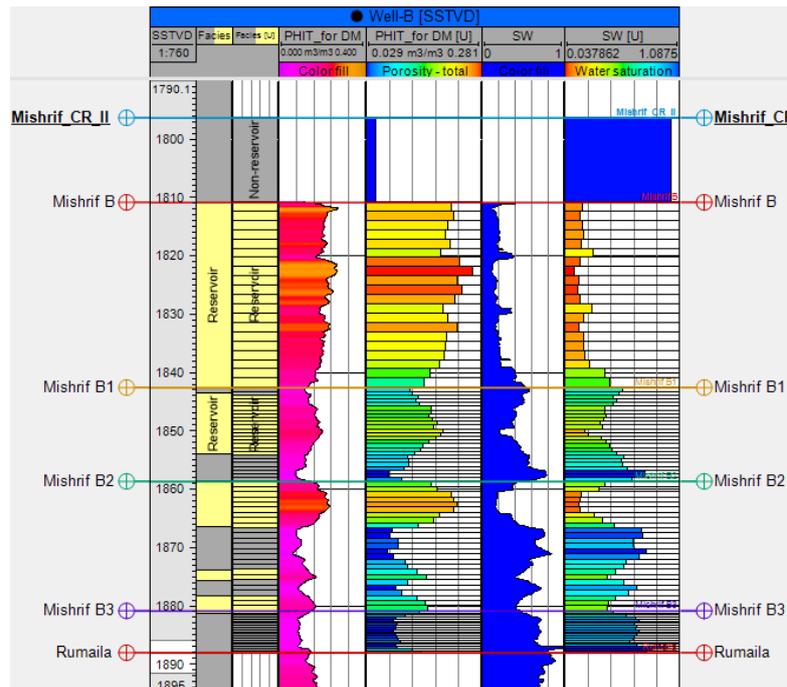
Fig. (5): Scale-up of facies, porosity, and water saturation logs for well-B

3.3.1 Facies modeling

Facies log from CPI was upscaled and distributed along the 3D grid. The Truncated Gaussian with trend method was used to distribute the upscale facies log, this method was used to honour the carbonate build-up deposit of Mishrif formation. The model was built based on the result of conceptual geological model. The conceptual facies model for Mishrif formation in X-field was built by integration data from 2D/3D seismic interpretation, well data, and core analysis (Figure 6). In order to generate the conceptual facies model, three genetic rock types were identified in the Mishrif B unit; carbonate build-up deposits, shoal deposits, and enclosing Lagoon rocks. According to the core study results, Wells A, D, and F penetrated reef deposits, while Wells B and G penetrated back-reef Grainstones at the top of the MB unit. These rocks are replaced by bioclastic sediments north eastwards in Wells C and E.

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The facies log contains two codes which are (Reservoir and non-reservoir). The reservoirs are determined by porosity cut-off values using porosity – permeability cross plot. The porosity cut-off values used are; 10% for petro type-1 Reef area, 13% for petro type-2, and 15.5% for petro type-3. The Facies model of unit Mishrif B, B1, B2, and B3 were built using Truncated Gaussian Simulation with Trend method.
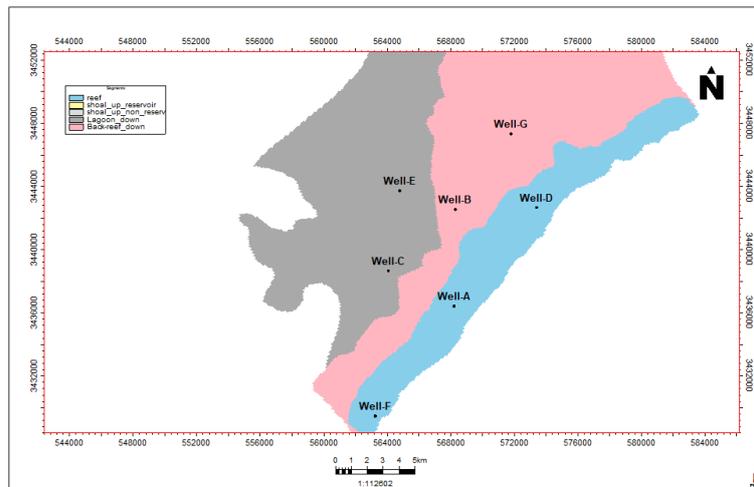
Fig. (6): Conceptual Facies model based on seismic and core study for X-field

3.3.2 Petrophysical model

The distribution of the petrophysical properties on a 3D grid is the primary purpose of this paper. The reservoir petrophysical modelling can be done by deterministic and stochastic methods. Sequential Gaussian simulation is a stochastic method, and it was widely used in petrophysical modeling because of the flexibility of this method (Deutsch, 2014[18]).

The porosity, water saturation, and net to gross logs from Computer Processed Interpretation results (CPI) for seven wells were scaled up into a cellular model using the arithmetic method. The porosity model was built using the Sequential Gaussian Simulation (SGS) method and the facies model as a guide for distribution. The same geostatistical method used in the porosity models was also used in the water saturation and NTG model.

4. Results and Discussion

Well, correlations (lateral and longitudinal) were made for Mishrif Formation in X- field to take an initial idea about the subsurface geological layers and check the thickness of subunit of

Mishrif formation (Figure (7 and 8)). Figure (8) shows that well-D stratigraphically higher than other wells. The thickness of the Mishrif unit is slightly decreasing toward the southeast of the field, and a decrease in petrophysical properties is observed in the west of the field (well-E). The petrophysical properties are very good with high net pay and NE-SW direction, which presents the reef environment in X-field (Figure 7).

From the facies model, we can see the trend of sedimentation, which suggests a retrogradation pattern from NW to SE. Facies 1 (Reservoir), dominated by Limestone brown to light brown, and with oil shows has well distribution within the area and thinning towards the NW. The facies model for units Mishrif B1 and B2 shows that oil shows disappear in the Lagoon region and are dominated by (non-reservoir) facies. In contrast, the back reef alteration between reservoirs facies at the top of these units and non-reservoir at the bottom. High oil shows still dominated the reef area in these units while reservoir facies in the Reef region dominate Mishrif B3. The following Figures (9, 10) show the facies model with different geological layers, while (Figure 11) shows intersection for facies model through wells (F, A, B, and E).
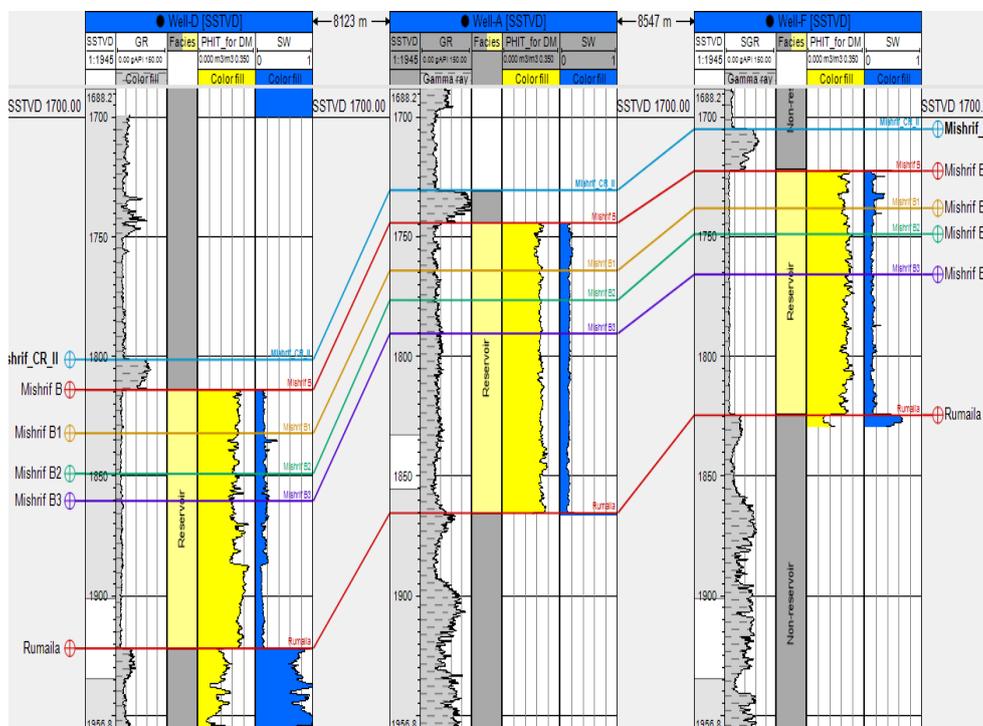
Fig. (7): Well Correlation of Wells (D, A, F)
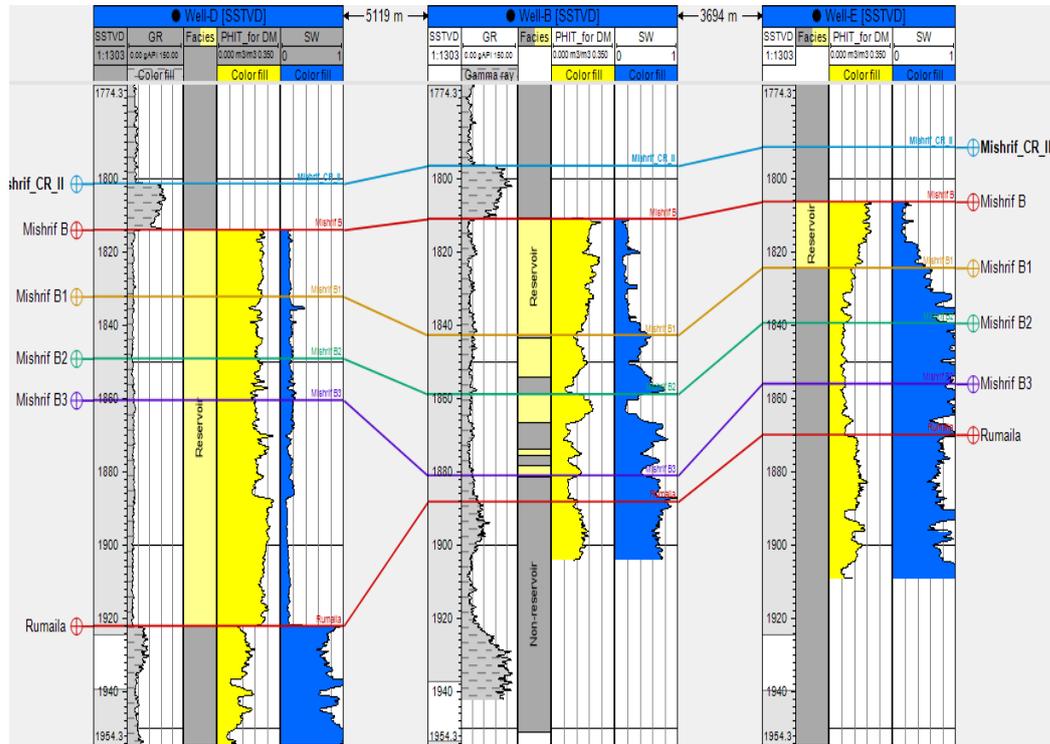
Fig. (8): Well Correlation of Wells (D, B, E)
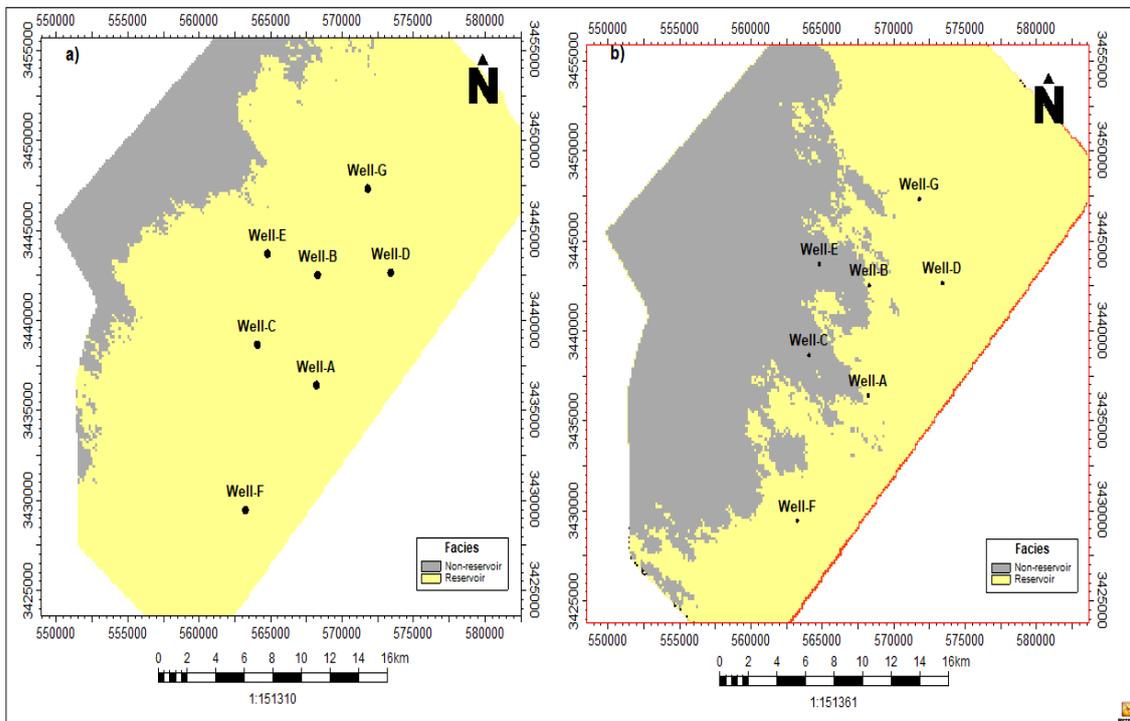
**Fig. (9): Facies model for Mishrif formation, a) unit Mishrif B, layer 19,
b) unit Mishrif B1 at layer 27**
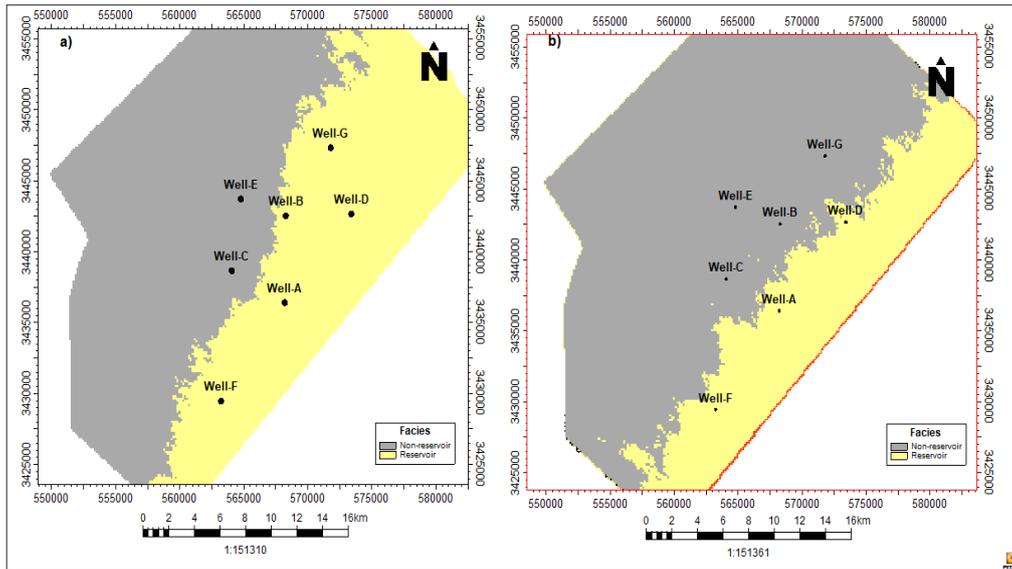
Fig. (10): Facies model for Mishrif formation, a) unit Mishrif B2, layer 50, b) unit Mishrif B3 at layer 89
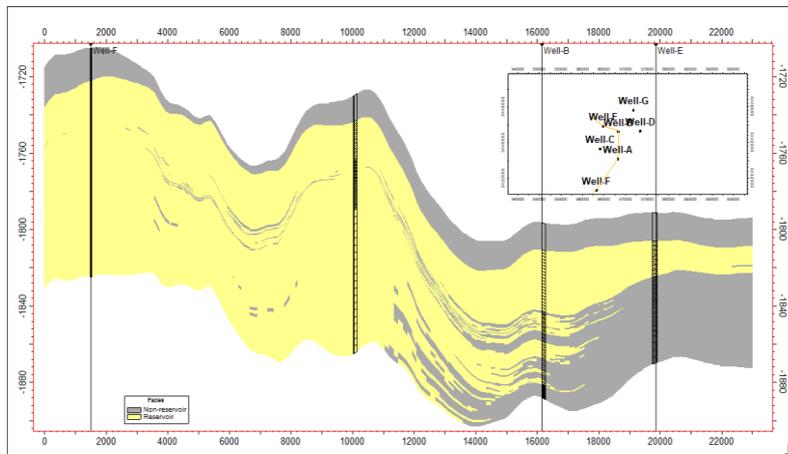
Fig. (11): Cross section for Facies model throw wells (F, A, B, and E)

The porosity model shows, in general, the south east area, which represents the reef region, is high compared to the North West side of the study area. The porosity range in the reef region is between (14%-27%) especially in the wells F, A, D. These wells are characterized by high porosity in all the Mishrif units. In contrast, C and E wells show that the porosity increases in unit Mishrif B and gradually decreases in other units. The wells B and G show good to medium porosity in all units except unit Mishrif B3. Figures (12, 13) show the average porosity model of each Mishrif reservoir unit. The cross-sections in the S-N direction for porosity models were

built to illustrate the vertical porosity distribution in each well understudy, as shown in Figure (14).

The water saturation model shows that the unit Mishrif B has the lowest value across the field, the Sw values starting a decrease in the northeast of the field. The water saturation also shows that (F, A, and D wells) have the lowest water saturation reading. The unit Mishrif B3 shows the highest Sw value on the northeast side of the field. Figures (15, 16) show the average Sw model of each Mishrif reservoir unit. In contrast, figure (17) shows the cross-sections in the S-N direction for Sw models built to illustrate the vertical distribution of Sw in each well under study.

The NTG model shows that unit Mishrif B has the highest NTG with a range from (1-0.6), then gradually decreasing toward the SE direction of the field. The unit Mishrif B3 has high NTG along the reef area. Figures (18, 19) show the NTG model in each reservoir unit of Mishrif formation.
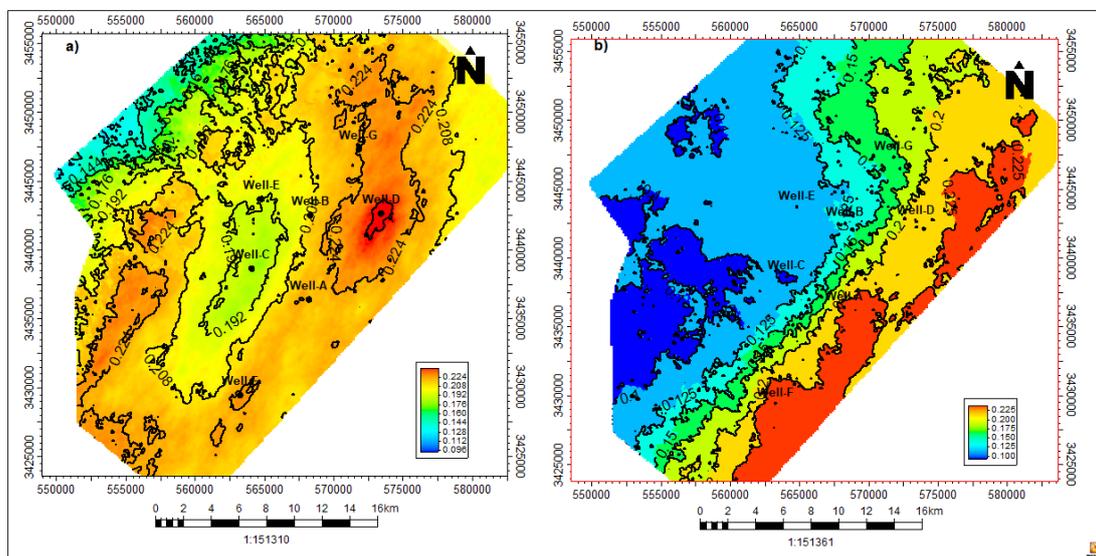
Fig. (12): Average porosity model, a) average porosity for unit Mishrif B,
b) average porosity for unit Mishrif B1.
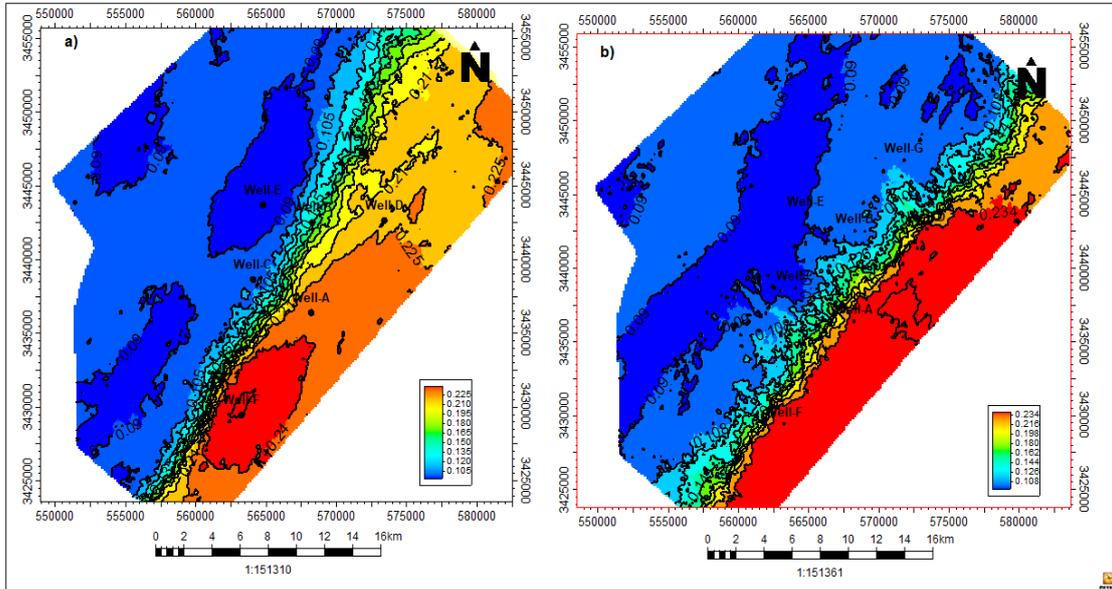
Fig. (13): Average porosity model, a) average porosity for unit Mishrif B2, b) average porosity for unit Mishrif B3.
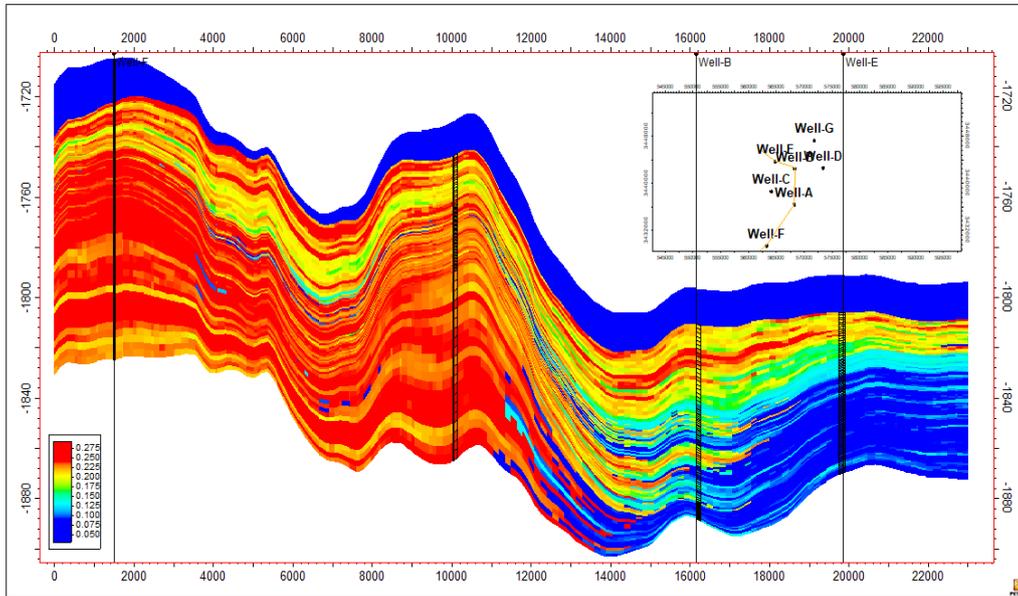
Fig. (14): Intersection for porosity model through wells (F, A, B, and E)
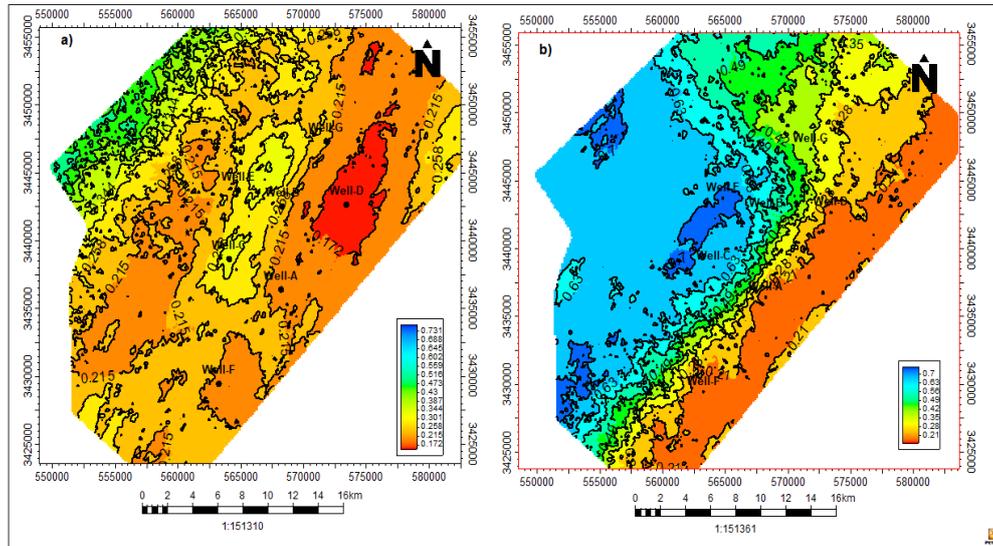
**Fig. (15): Average water saturation model, a) average Sw for unit Mishrif B,
b) average Sw for unit Mishrif B1.**
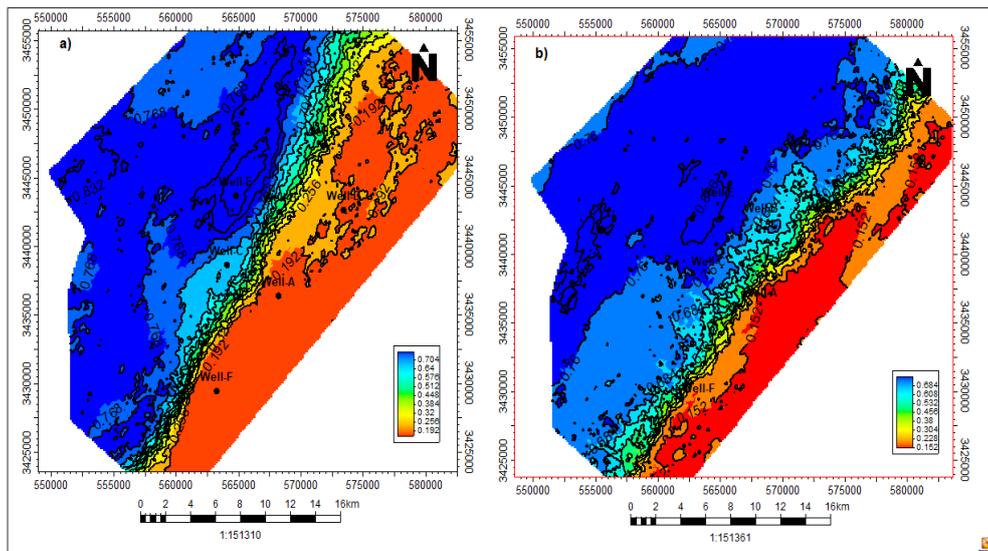
**Fig. (16): Average water saturation model, a) average Sw for unit Mishrif B2,
b) average Sw for unit Mishrif B3.**
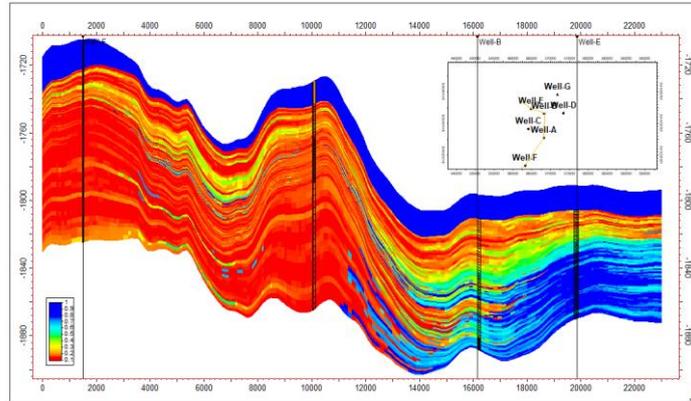
Fig. (17): Intersection for water saturation model through wells (F, A, B, and E)
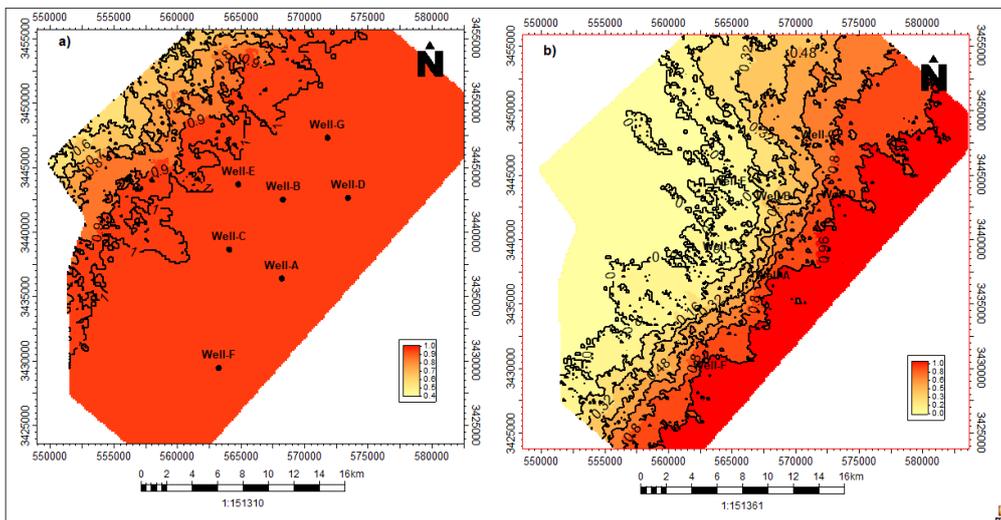
Fig. (18): NTG map, a) NTG for unit Mishrif B, b) NTG for unit Mishrif B1.
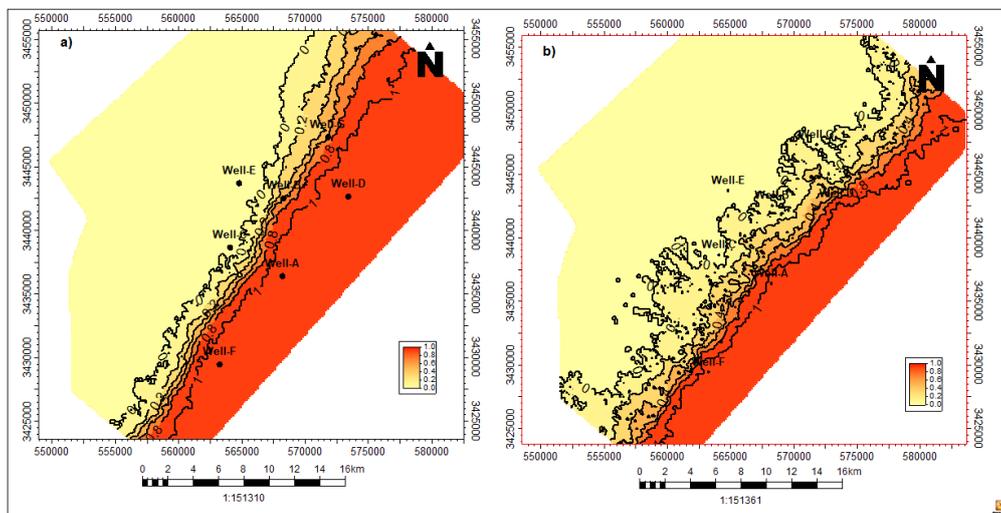
Fig. (19): NTG map, a) NTG for unit Mishrif B2, b) NTG for unit Mishrif B3

5. <u>Conclusions</u>

The study aimed to distribute the reservoir properties in the framework of 3D geological modelling for Mishrif Formation using Petrel software. It can be concluded that:

1- The stratigraphic model shows that the SE part of the field is stratigraphically more arisen than the NW part, with the thickness of the Mishrif unit slightly decreasing toward the southeast of the field. The Mishrif reservoir was subdivided into four units according to logs and petrophysical interpretation.

2- The Mishrif reservoir is a structural and stratigraphic trap. This conclusion was observed from the structural depth map and the petrophysical interpretation.

3- The sedimentation pattern is retrograded from NW to SE. The presence of oil shows a slight disappearance in the Lagoon region in units Mishrif B1, B2, and B3. Large oil shows dominated reef area in these units while Mishrif B3 is dominated by reservoir facies in Reef region only.

4- The porosity model shows that the southeast part of the field is large compared to the northwest part of the study area. The porosity ranges between (14%-27%) in the SE part of the field. The NW part shows good porosity in-unit Mishrif B only and gradually decreases in other units.

5- The water saturation model shows that unit Mishrif B3 shows the largest Sw value in the northeast side of the field while unit Mishrif B shows the lowest water saturation value in the entire field.

6- The NTG model shows that unit Mishrif B has the largest NTG with a range from (1-0.6), and then gradually decreases toward the SE direction of the field.

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