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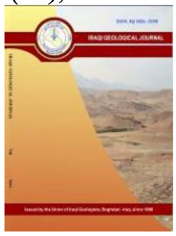

# Development of 3D Geological Model and Analysis of the Uncertainty in a Tight Oil Reservoir in the Halfaya Oil Field

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## Abstract

A geological model was built for the Sadi reservoir, located at the Halfaya oil field. It is regarded as one of the most significant oilfields in Iraq. The study includes several steps, the most essential of which was importing well logs from six oil wells to the Interactive Petrophysics software for conducting interpretation and analysis to calculate the petrophysical properties such as permeability, porosity, shale volume, water saturation, and NTG and then importing maps and the well tops to the Petrel software to build the 3D-Geological model and to calculate the value of the original oil in place. Three geological surfaces were produced for all Sadi units based on well-top data and the top Sadi structural map. The reservoir has been divided into 85 sublayers in the vertical direction and 170*143 grid cells in the x-y direction, totalling 2,066,350 grid cells. The Sequential Gaussian Simulation technique is used to fill 3D grid cells with property values in locations far from wells after upscaling the well log data, then distributed across all reservoir zones. The standard original oil in place has been calculated, uncertainty evaluation was used to obtain more accurate results. Model Risk Analysis employs Monte Carlo Simulation to generate the pessimistic, most likely, and optimistic reserve values (P90, P50, and P10). The uncertainty was affected by the oil formation volume factor, oil depth, petrophysical model (porosity, water saturation, and NTG), and reservoir geometric structure (horizons and zones).

**Keywords:** Sadi reservoir; Halfaya oil field; Static model; Reservoir characterization; Carbonate reservoir; Uncertainty analysis

## 1. Introduction

Tight oil reservoirs have received substantial interest for exploration and development worldwide as a critical unconventional resource. Tight oil reservoir are complex and highly heterogeneous in both lateral and vertical directions, with extremely low porosity and permeability. Single wells have no natural production capacity, necessitating horizontal drilling and hydraulic fracturing to achieve economic flow. To maximize resource utilization, several features of such reservoirs must be evaluated. However, macroscopic petrophysical metrics like porosity, permeability, and saturation cannot provide an acceptable appraisal of the efficacy of tight oil reservoirs. Pore structures, which determine reservoir storage capacity and control rock transportation characteristics, represent microscopic rock properties. As a result, the characterization and prediction of rock pore structure in wells is an essential challenge

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in studying tight oil reservoirs (Xu , 2018). Oil reserves in conventional reservoirs are consistent decline, resulting in complexities and advancements in hydrocarbon exploration and characterization technology.One possible alternative to maintaining present output levels is the development of difficult-to-recover reserves, such as low-permeable (tight) carbonate reservoirs. Despite a rise in interest in developing such formations and deposits, determining the optimal reservoir parameters for the situation remains challenging for oil and gas companies. Porosity and permeability contribute considerably to a target asset's resource evaluation and reserve estimation (Mukhametdinova et al., 2020)(Sha, 2019). The tight oil reservoirs, like the Sadi B formation, have a porosity of less than 10% and a permeability of less than 0.01 MD, which leads to poor injectivity for either water or gas. Sadi B oil is light, has a high solution gas-to-oil ratio, and a high bubble point pressure to give solution gas drive more power(Sadi, 2012)(Farouk and Al-Haleem, 2022).

## 2. Geological Background

Sadi reservoir/Halfaya oil field was discovered in 1976 and is located 35 km from Amara city(Fig. 1) southern Iraq, towards the Iraqi/Iranian boundaries. It is one of the largest oil fields in Maysan region, south-west Iraq. The Sadi B formation is 31 km long and 11.5 km wide, with a gentle elongated anticline trending NW-SE to NWW-SEE. The Sadi B reservoir covers an area of 288 km$^2$. The lithology of the Sadi Formation is mainly limestone, and its significant mineral content is calcite. The average formation thickness of the Sadi Formation ranges from 120 to 130 m, with a trend toward the east. with a height of 121 to 158 m. Sadi-A and Sadi-B are the two layers that compose their division. The contract area and oil-bearing layer are continuously distributed with Sadi-B, including B1, B2, and B3. According to variations in lithology, electricity, and petrophysical properties, Sadi-B3 is divided vertically into four sublayers: Sadi-B3-U1, Sadi-B3-U2, Sadi-B3-U3, and Sadi-B3-U4.

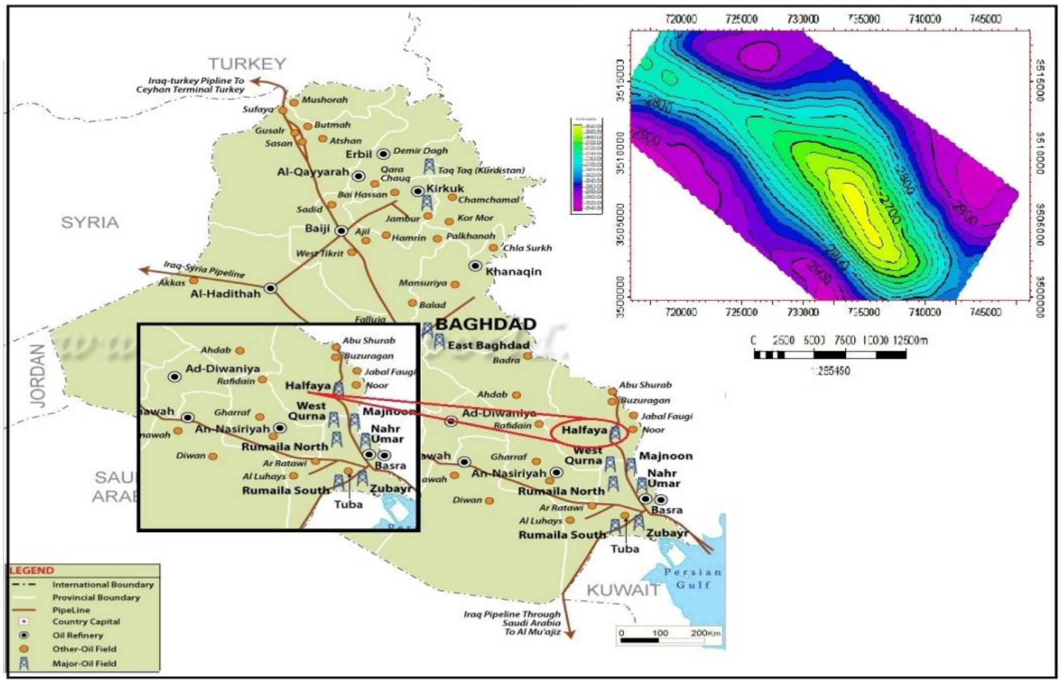


**Fig. 1.** The location of the Halfaya oilfield (Iraq Oil Pipelines Map, 2022)

The evaluation indicates each layer's thickness: Sadi-A is about 51m; Sadi-B1 is 28m; Sadi-B2 is 30m; and Sadi-B3 is 20m. The Sadi Formation represents a third-order depositional cycle; Sadi B3, Sadi B2, and Sadi B1 represent transgressive units; Sadi A represents a regressive unit; and the top of Sadi A is believed to have been eroded under the uplifted tectonic movements. Sadi A comprises grey limestone in the upper part and dark grey marlstones and mudstones in the lower part. Sadi B1 is composed of alternating bioturbated planktonic foraminifera packstones and argillaceous wackestones, and bioturbated planktonic foraminifera packstones dominate Sadi B2 with thin skeletal packstone intervals. Sadi B3 is composed of packstones and grainstones interbedded with thin muddy limestone and dolomitic mudstone. Oil occupies Sadi B1, Sadi B2, and Sadi B3; no oil occurs in Sadi A (Team, 2014) and (Sadi, 2012).

## 3. Materials and Methods

The Sadi reservoir's 3D geological model was created using the Petrel (2017) program. Numerous steps are involved in building this type of model, starting with importing the data into Petrel (counter map, wellheads, well tops, and well logs, including reservoir properties (Porosity,permeability, water saturation), and CPI value, which is obtained from IP). Fig. 2. show the process flow diagram for creating a 3D geological model in Petrel software. To build this kind of model, there are numerous steps that start with gathering the data. They are as follows:

- counter map
  A contour map with lines that include points of equal value and separate points of higher and lower value. Which displays the elevation or depth of a formation.
- Well tops
  Measured depth in each well and clarified each reservoir zone or structure in the Sadi formation.
- Well heads
  The wellheads of six boreholes in the Halfaya field are imported by the Petrel software. This includes the location (eastern, northern) and "Rotary Table Kelly Bosh" (RTKB), as well as the total depth of each well.
- Well logs
  Importing well logs (Porosity, Water saturation, Shale volume, Permeability.Net to gross) for each of the six studied wells was part of the process.

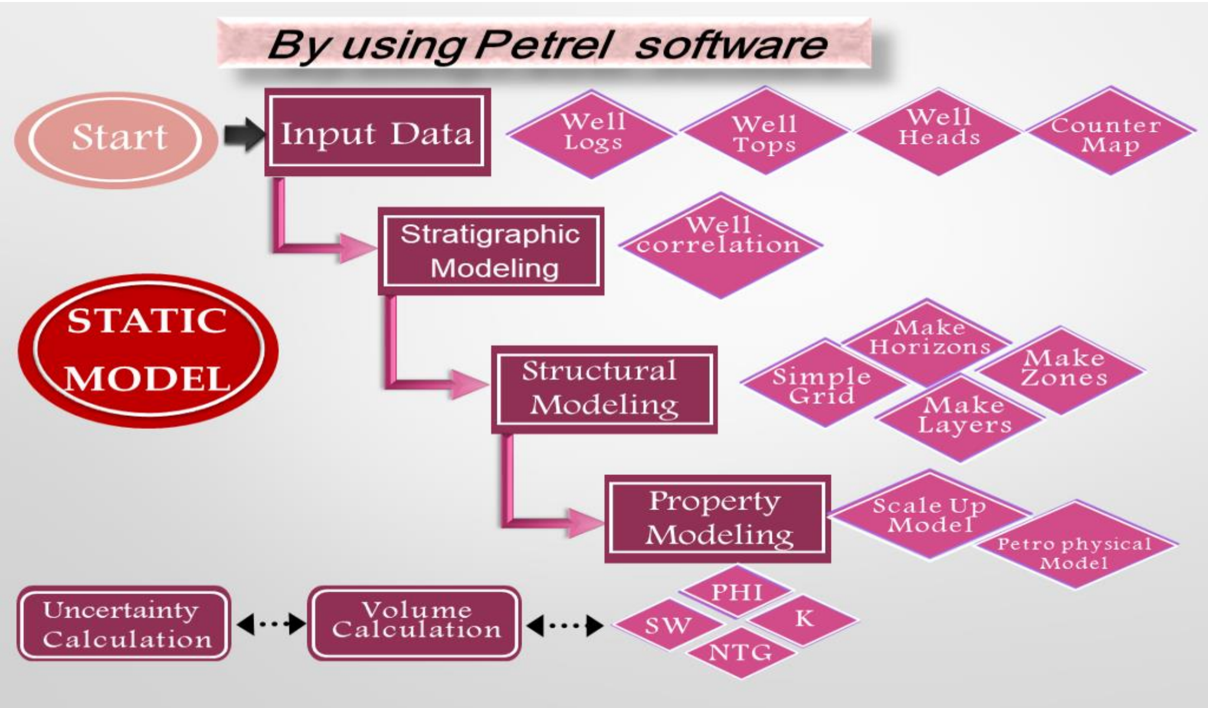


**Fig. 2.** The workflow of constructing a 3D geological model by using Petrel software.

### 3.1. Well Correlation

In Petrel, well correlation makes it possible to compare several wells in a well section, create well tops, and compare newly discovered wells to those that have already been correlated (Technoguide, 2010). Well correlation was used in this study because it is a quick and convenient way to get an overview of the differences in thickness between Sadi units and the differences in petrophysical properties (like porosity, permeability, and SW) between the various Sadi reservoir units. After entering data into Petrel, we were able to generate correlation sections for the Sadi wells (Fig.3).

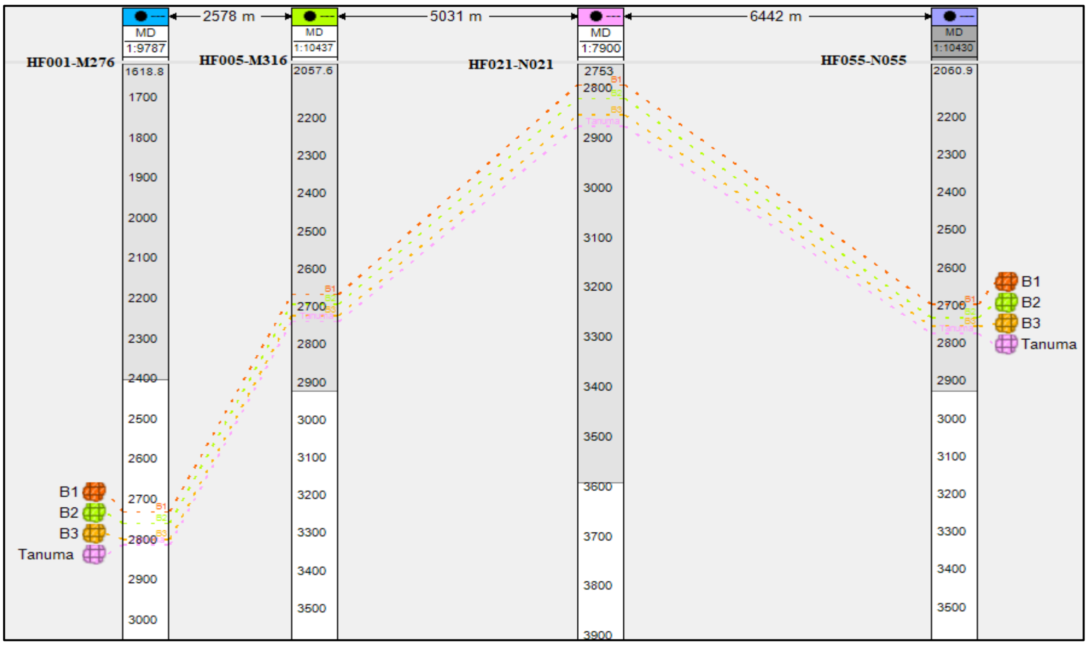


**Fig. 3.** A well correlation with well tops and surface correlations in vertical Sadi wells

### 3.2. Static Model (Geological Model)

*3.2.1. Structural modeling*

Structural modeling can be divided into four different operations: simple grid, Horizon, zonation, and layering. All of the mentioned steps were done one after the other to create a single data model. A structure contour map is an important tool for three-dimensional interpretation because it shows the complete three-dimensional shape of the map horizon in a clear way. The way the structure was modeled was a good representation of how the formation was made. A structure contour map is important for figuring out what is going on in 3D because it shows how the map horizon looks in all three dimensions(Rassas, 2020). All Sadi formation wells were built with a three-dimensional base at the top. There are four sub-layers in the Sadi formation: Sadi A, Sadi B1, Sadi B2, and Sadi B3. One of the sublayers, Sadi A, was not included in the geological modeling because it lacked hydrocarbon. The fundamental building block for modeling structures is known as the horizon model. Limestone makes up the three zones. Based on the structural map above the Sadi B formation, the model generates structural maps for each unit, which are then modified to account for well tops. The Sadi formation has a single dome structure, according to the structural diagrams that were produced (Figs. 4 and 5).

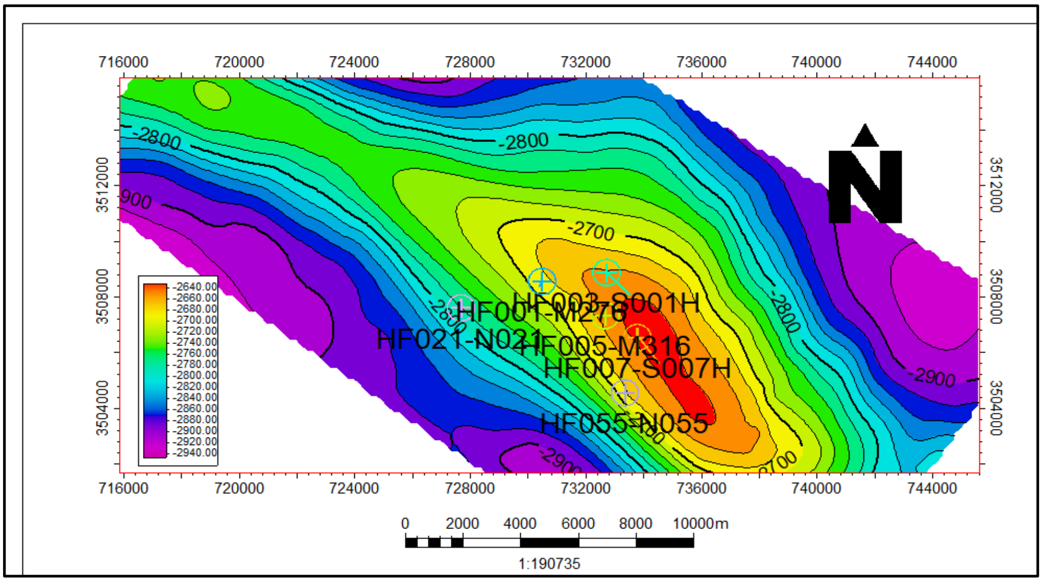


**Fig. 4.** 2D Structural contour map on the Top of Sadi B unit

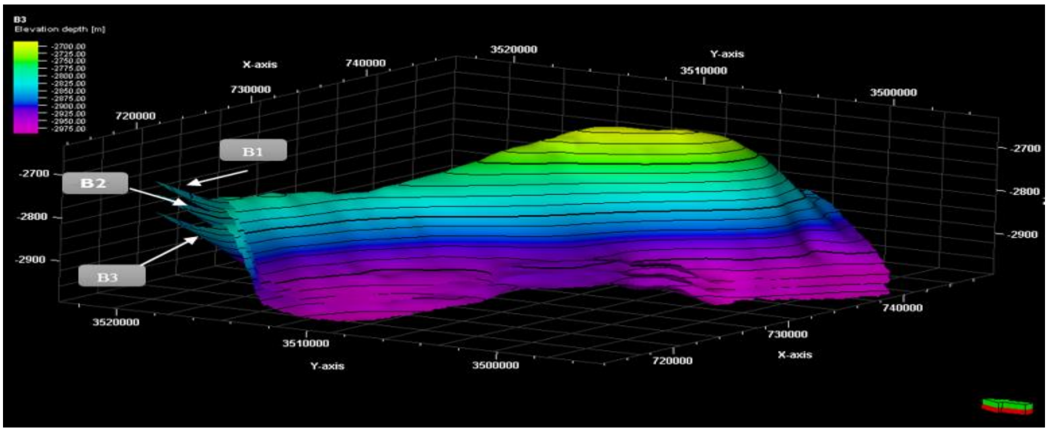


**Fig. 5.** The three different surfaces that comprise the Sadi units

### *3.2.2.3. D Grid Construction*

The modeling of reservoir properties and numerical simulation based on geostatistics depend heavily on the results of the preceding step, the construction of a 3D reservoir grid model. The gridding process in geostatistical reservoir modeling decides how to characterize the reservoir's macroscopic homogeneity. In addition, the grid's shape and resolution influence the simulation's accuracy and speed when applied to a reservoir (Zhang, 2022). The three-dimensional grid system of the Sadi formation has 85 vertical sublayers (z-axis), and (x-y) axis grid cells of (170*143). There are 2,066,350 grid cells. The dimensions of the lateral grid were set to (200 & 200) m on the (x-y) axis. Fig. 6. Depicts the three-dimensional grid system of the Sadi geological model. Six well data are incorporated into the geological model. The structural map vertically constrained the model's top and bottom to the Sadi formation.

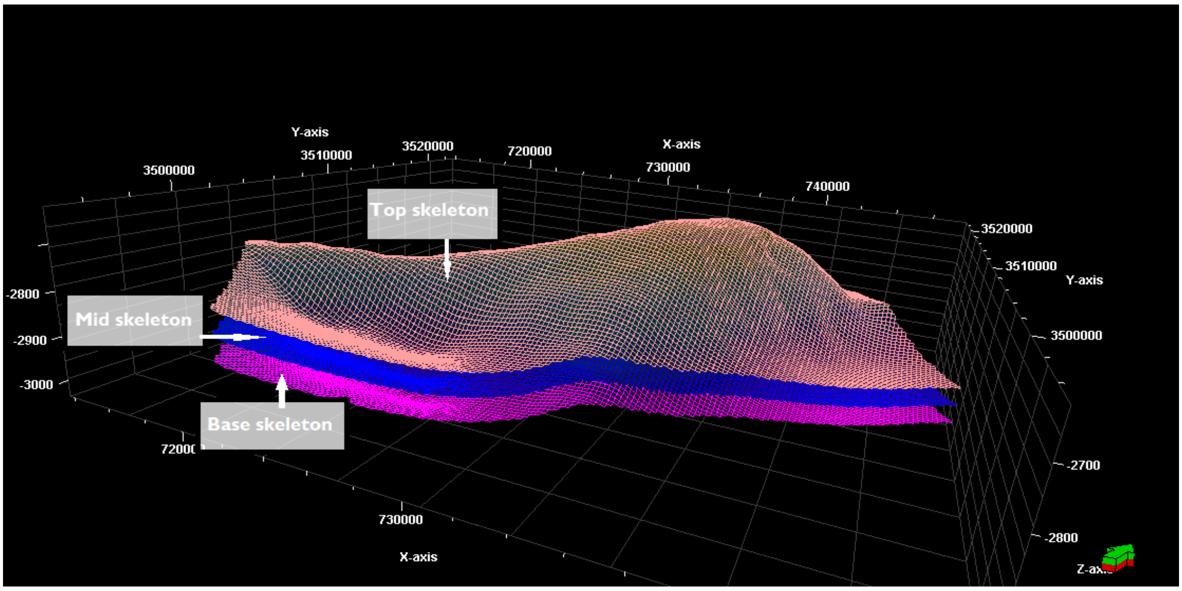


**Fig. 6.** 3D gridding system for the geological model

### *3.2.3. Make horizon*

The horizon process is a step in the definition of vertical layering. It begins with the main reservoir layers obtained from seismic interpretations and zonation from geological reports and ends with the final vertical resolution determined by the number of cell layers. Due to the hydrocarbon content in the Sadi reservoir's B units (B1, B2, and B1), we depend on them in the current study; Sadi A was not filled with hydrocarbons and was therefore not included in the geological modeling.

### *3.2.4. Zonation and layering*

The structural model of Sadi consists of three zones (Sadi-B1, Sadi-B2, and Sadi-B3), as well as four main horizons), which are Sadi-B1, Sadi-B2, Sadi-B3, and Tanuma. The geological surface map of Sadi-B served as the foundation for all horizon creation; consequently, well tops data derived from petrophysical core data and lithological descriptions were used in addition to the surface map to generate reservoir zones, and each created zone was subdivided into many layers. Among the 85 sublayers that make up the three zones, Sadi-B1 has 30 layers, Sadi-B2 has 35 layers, and Sadi-B3 has 20 layers. As shown in table 1, the reservoir characteristics and the amount of hydrocarbon content in the tertiary units of the Sadi formation have caused these units to be subdivided into many layers.

**Table 1.** Different layers of sadi formation zones

| ZONE | Thickness(m) | No .of layers |
|---|---|---|
| SADI B1 | 26.1 | 30 |
| SADI B2 | 31.8 | 35 |
| SADI B3 | 20 | 20 |

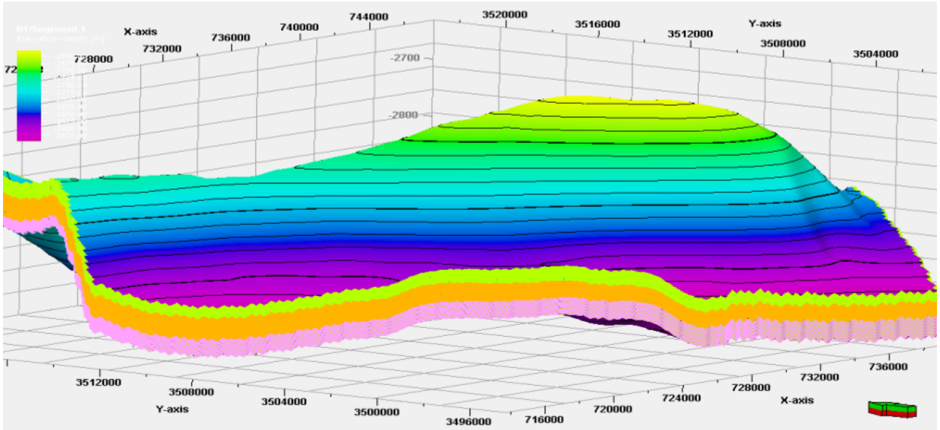


**Fig. 7.** The three zones

### 3.3. Oil Water Contact (OWC)

The estimation of oil-water contact (OWC) and knowledge of the capillary behavior of hydrocarbon reservoirs are essential for optimal reservoir characterization, hydrocarbon exploration, and production. Consequently, the height of oil-water contact above the level of free water has increased (Okolie and Ujanbi, 2008). Up to a high reservoir, oil and water are generated until the relative permeability to water is significantly low, at which point just oil will flow.This level represents the lowest level of producible oil. The well logs for the Sadi formation have been looked at, the value of O.W.C. equals to -2845 m.

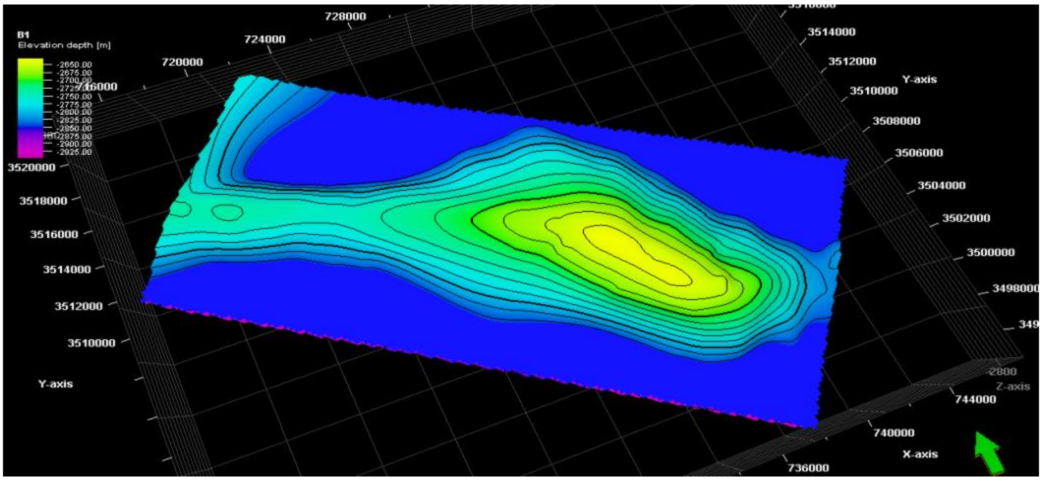


**Fig. 8.** Well cross section showing the critical wells for OWC.

### 3.4. Property Model

#### *3.4.1.Scale up well logs*

Well log upscaling was used to add well data to the model and get an average value for each cell in the 3-D grid that the wells pass through. The volume of a region is represented by a three-dimensional grid cell structure in petrophysical property modeling. In statistics, the geometric method, the arithmetic average, and the harmonic method are all ways to upscale. The average arithmetic method was used to scale up the porosity, water saturation,and NTG. While scaling up the permeability was done with the help of the harmonic mean algorithm.

### *3.4.2. Petrophysical model*

Petrel uses a stochastic technique based on Sequential Gaussian Simulation to create models of petrophysical properties. There is no easier way to generate multivariable Gaussian field evolutions than with this algorithm(Jasim et al., 2020). This process involves making educated guesses about reservoir rock properties and fluid saturations outside of the wellbore and in regions for which data is lacking. Sequential Gaussian Simulation (SGS) is a statistical method for predicting and managing properties such as (porosity, SW, permeability, and NTG) at great distances from wells. Petrophysical modeling can interpolate and simulate reservoir data as porosity, and permeability throughout the model grids and, ultimately, continuously provide the distribution of these properties in a reservoir model. According to the statistics of petrophysical properties, the average porosity of the Sadi B formation is 11.5%-18.4% and the average permeability is 0.1 – 3.1 MD. Figs. 9&12 Shows that the Sadi B2 reservoir has the highest average porosity of 18.4%; the layers of Sadi B1 and Sadi B3 have low porosity values of 15.3% and 11.5%, respectively. Figs. 10 and13. Shows that the layer Sadi-B2 has a high permeability region that allows it to reach 3.1 MD, whereas the other layers have lower values (0.1 MD in Sadi-B1 and 0.6 MD in Sadi-B3). It is shown that a high water saturation region appears in the Sadi-B1 and Sadi-B3 layers, where the water content is between 85% and 100%. In contrast, the Sadi-B2 layer has a low water saturation region of only 46% (Figs. 11 and 14).

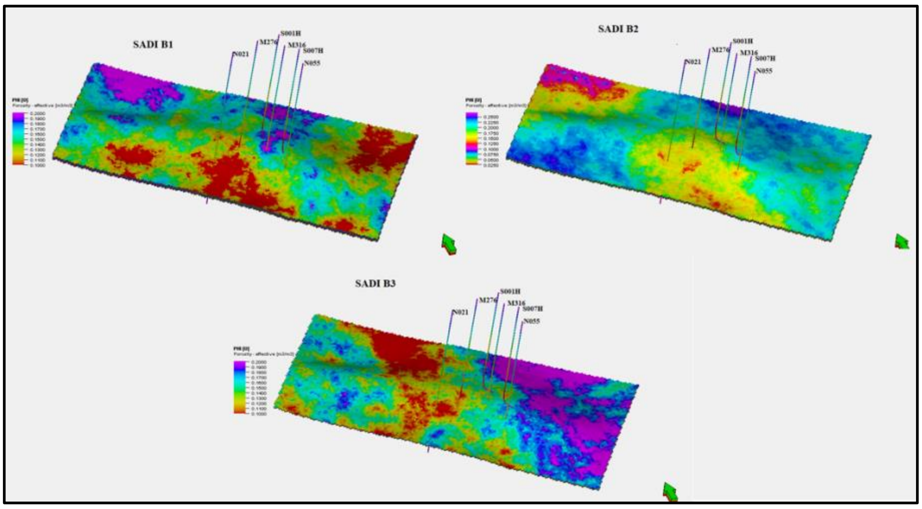


**Fig. 9.** 3D map of porosity distribution for all Sadi formation units

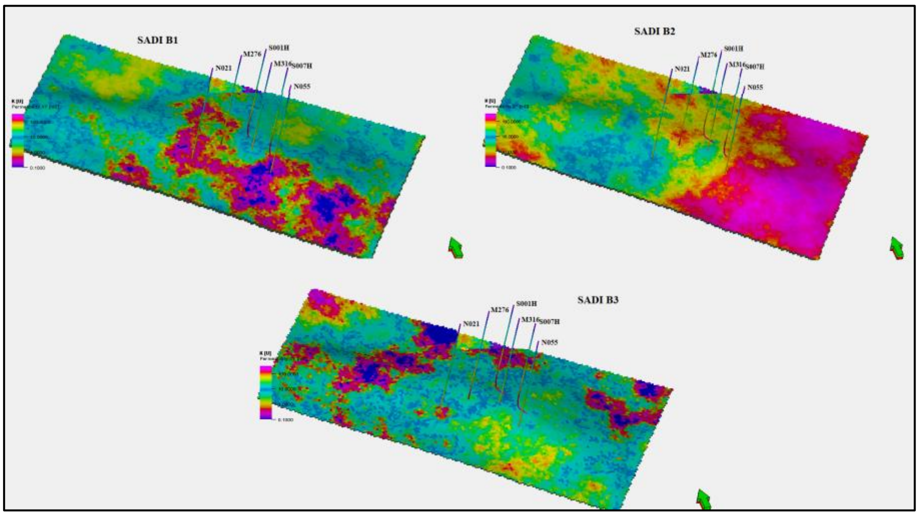


**Fig. 10.** 3D map of permeability distribution of all Sadi formation units.

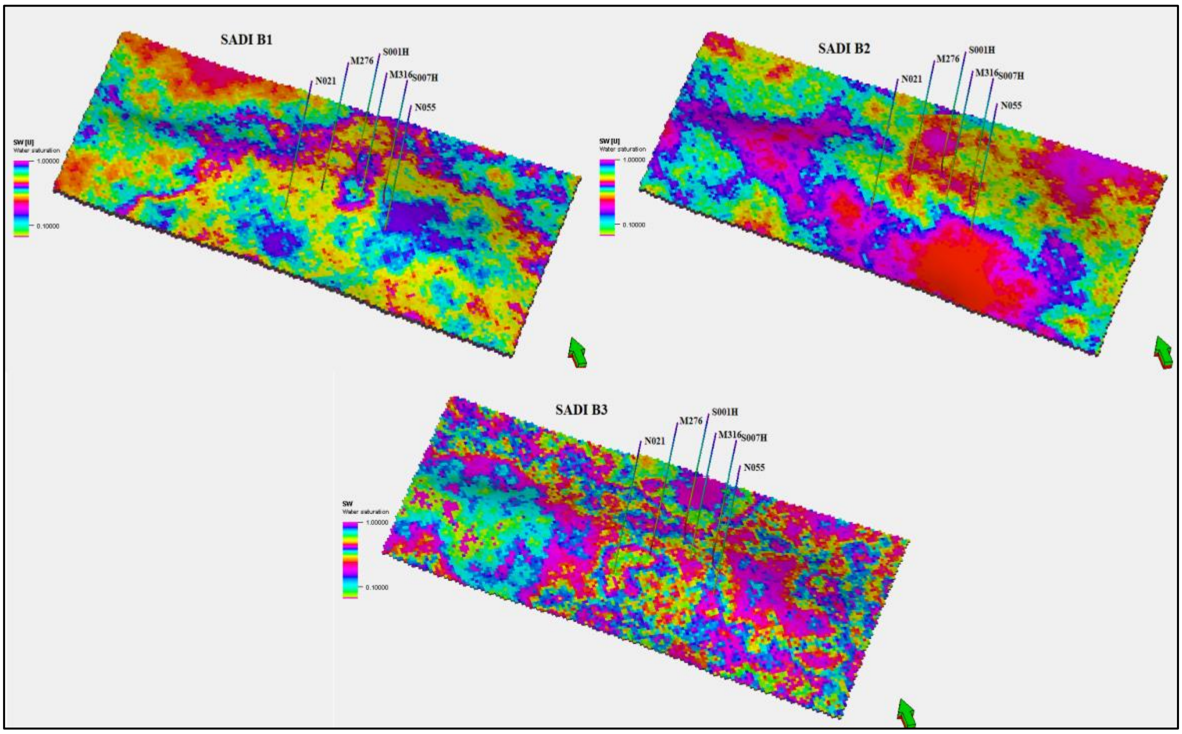


**Fig. 11.** 3D map of water saturation distribution model for all Sadi formation units.

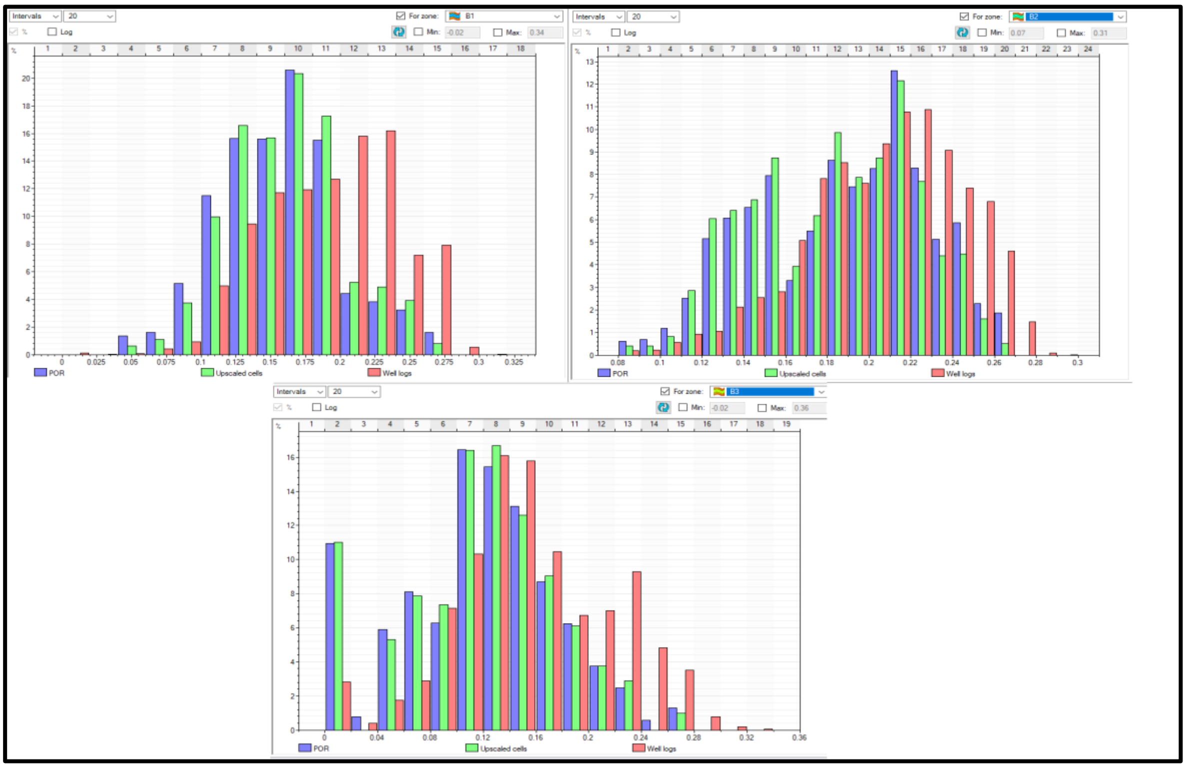

**Fig. 12.** Statistical comparison of modeled, log and upscaled porosity for all Sadi B1, B2, and B3 units

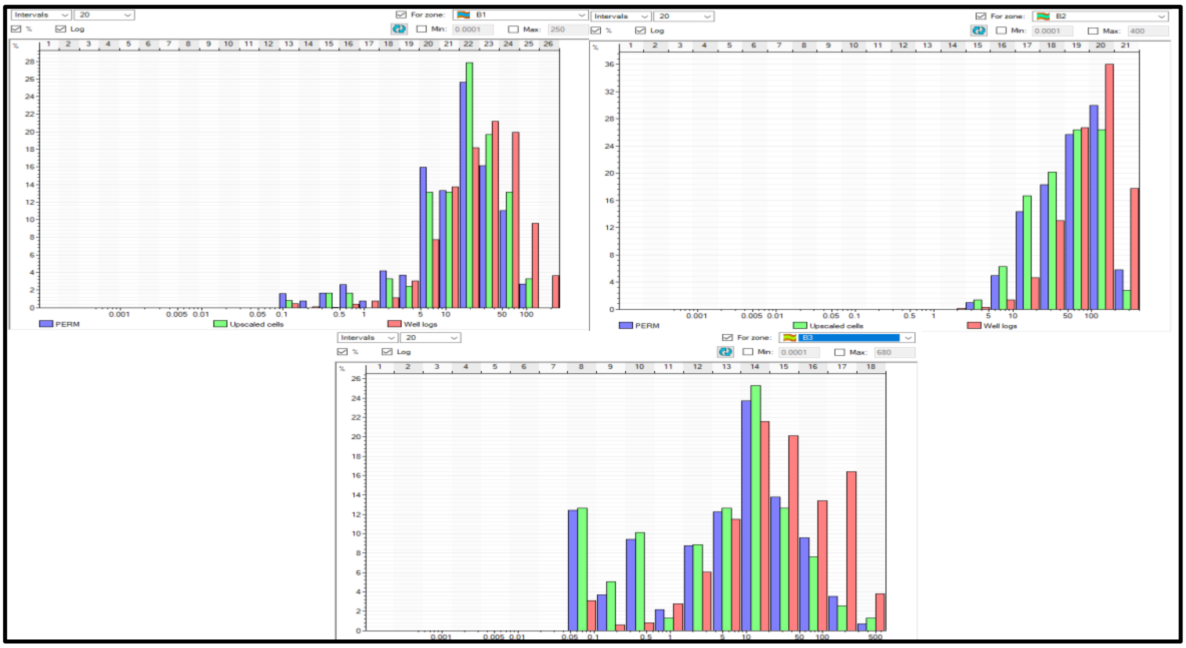


**Fig. 13.** Statistical comparison of modeled, log and upscaled permeability for Sadi B1, B2, and B3 units

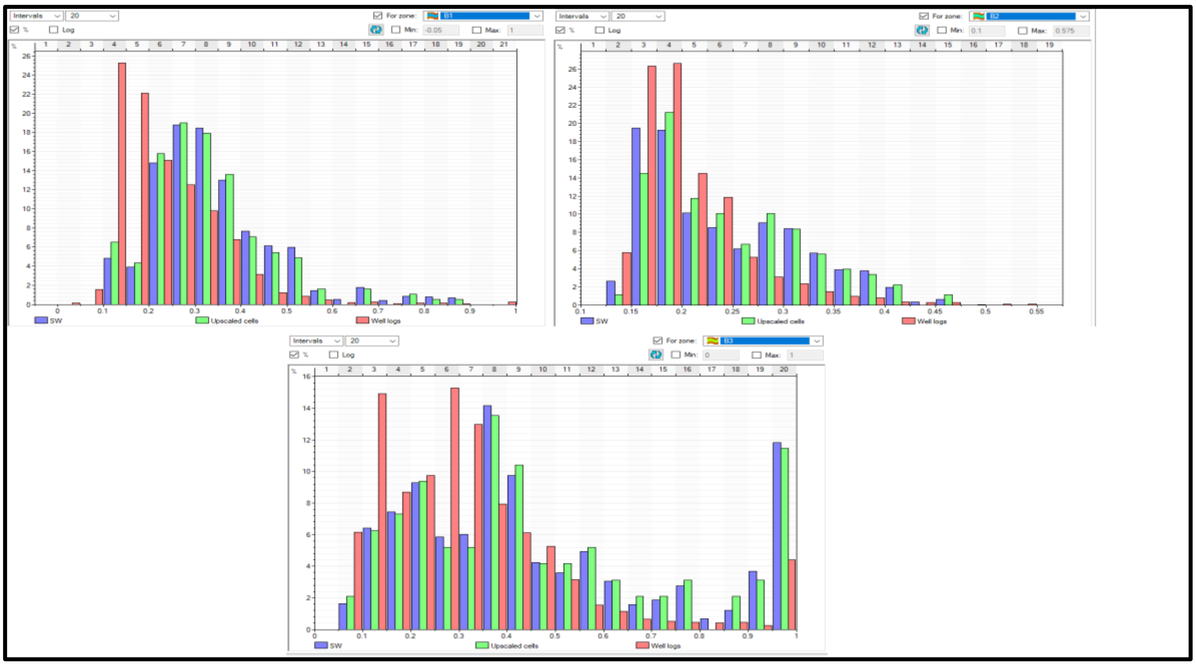


**Fig. 14.** Statistical Comparison of modeled, log and upscaled water saturation for Sadi B1, B2, and B3 units

### 3.5. Net to Gross Model

The goal of the net/gross ratio is to represent the proportion of the reservoir rock that is credited with contributing to production. Net pay also known as the producible thicknes is determined by taking the total thickness of the formation and multiplying it by a ratio based on appropriate cut-offs on the log curves(Cosentina, 2001). In addition, Net to gross was used to calculate the volumetric. The Sequential Gaussian Simulation method was used to build the Net to Gross model of the Sadi formation. This method was used to scale up the well logs. The N/G of the Sadi formation is mostly between 0.21 and 1.00, with an average of 0.64. Table 2. shows the N/G value (Fig. 16).

**Table 2.** Represents the outcome result of N/G

| **Type of Data** | **Continuous %** |
|---|---|
| Min | 0.21 |
| Max | 1 |
| Mean | 0.64 |
| Std.Dev | 0.23 |

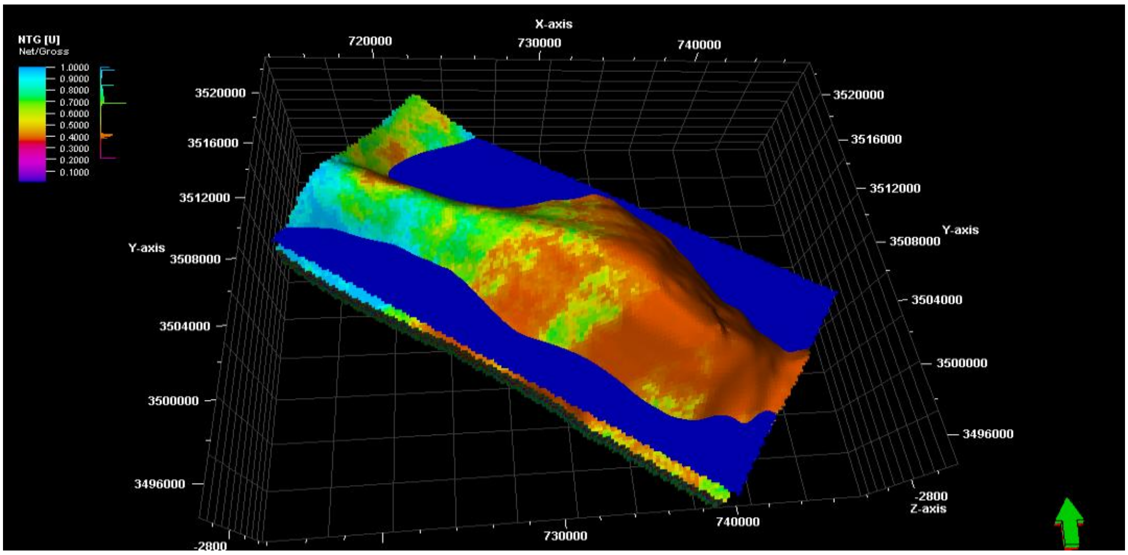


**Fig. 15.** Net to gross model Sadi formation.

## 4. Result and Discussions

### 4.1.OOIP Calculation

The 3D geological reservoir model was used to calculate the OOIP. This estimate is based on the fluid contacts in the reservoir mapping and net pay cut-offs of PHI=12%, Vsh=25%, and SW=50%.
The OIIP is calculated using the following equation (Thai, 2017):

$$OOIP(STB) = \frac{BRV*NTG*PHI*(1-SW)}{BO}*C \quad (1)$$

Where the Petrel static model was created by first creating a structural contour map for each unit of the Sadi formation, then importing well log data using IP software, and finally upscaling, layering, and distributing reservoir properties using the Sequential Gaussian simulation(SGS) statistical method to complete the estimates the volumetric calculation to be(4.277 MMM STB).

**Table 3.** Estimated IOIP from a static model

| Layer | OOIP, MM STB | Percentage |
|---|---|---|
| Sadi-B1 | 1792 | 41.89% |
| Sadi-B2 | 1950 | 45.59% |
| Sadi-B3 | 535 | 12.5% |
| Total | 4277 | 100% |

According to the estimated OOIP values, layer Sadi-B1 accounts for 41.89% of total OOIP. In contrast, layer Sadi-B2, which contains the largest reserve of the Sadi reservoir, accounts for 45.59% of total OOIP, which is related to the layer's good petrophysical property distribution. The Sadi-B3 layer has the lowest OOIP value of 12.5%. Table.3. illustrates this.

### 4.2. Sensitivity Analysis

A sensitivity analysis was conducted to identify and rank the uncertain parameters with a substantial impact on the field production forecast. The only goal of the sensitivity analysis was to find the most critical parameters that could be used to do a more in-depth risk analysis. The factors, such as OWC, Seed Variables (Seed NTG), (Seed POR), (Seed SW), and the oil formation volume factor (Bo), are essential for how successfully an oilfield is developed. The randomness of the value that initiates the random number sequence for each process in the model is maintained using the global variable $SEED. When editing a stochastic process, the variable $SEED is automatically entered into the appropriate text box when the Seed check box is selected in the Uncertainty and optimization process workflow window. Like other variables, $SEED will be listed in the Variables tab(Seismic and Optimize, 2010). The aforementioned five factors were analyzed for their impact on the OOIP. As a result, it can be concluded that OWC depth is the most influencing factor in calculations OOIP. OWC was chosen as the most uncertain parameter for OOIP estimation, where it was treated as a horizontal plane surface at -2845 m. The reason for that the available geological and field data were not sufficient to demonstrate OWC conclusively. Out of the total of 6 wells, only one well has reached the Sadi formation's water zone, as shown in Fig. 16. The data is displayed using a Tornado chart, which makes it easy to see how large of an effect each input variable has on the overall error of the results. The "Tornado Plot" displays the outliers across all output parameters. All of the chosen input parameters are plotted in descending order along the Y-axis from most significant to least significant (Fig.17). In addition, Seed NTG is second only to the OWC in terms of its impact on the uncertainty surrounding OOIP. The SeedPOR variable is the third most influential after the SeedNTG, followed by SeedSW, which has insignificant effect. Finally, the oil formation volume factor (Bo) variable, where the formation volume factor ranges from 1.6 to 1.66 (bbl/stb) according to the case value is (1.63 bbl/stb). The PHI, SW, and Bo values significantly impacted the OOIP calculations because they directly affect the OOIP calculation's equation.

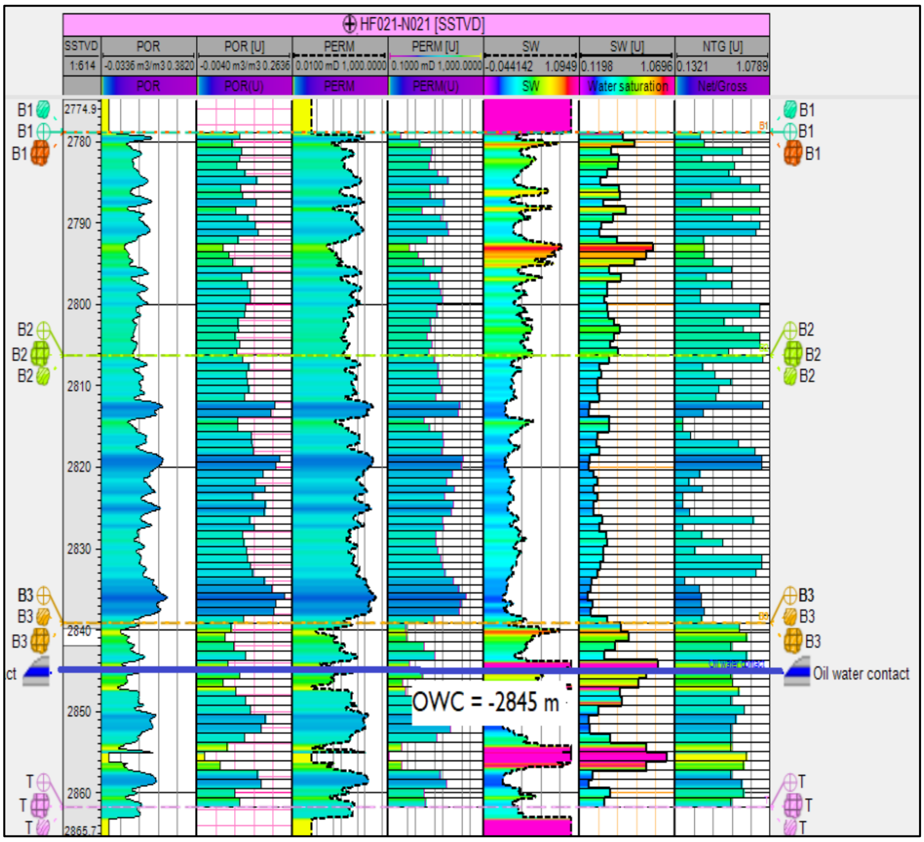


**Fig. 16**. The oil water-contact boundaries from one of the wells in a Sadi reservoir

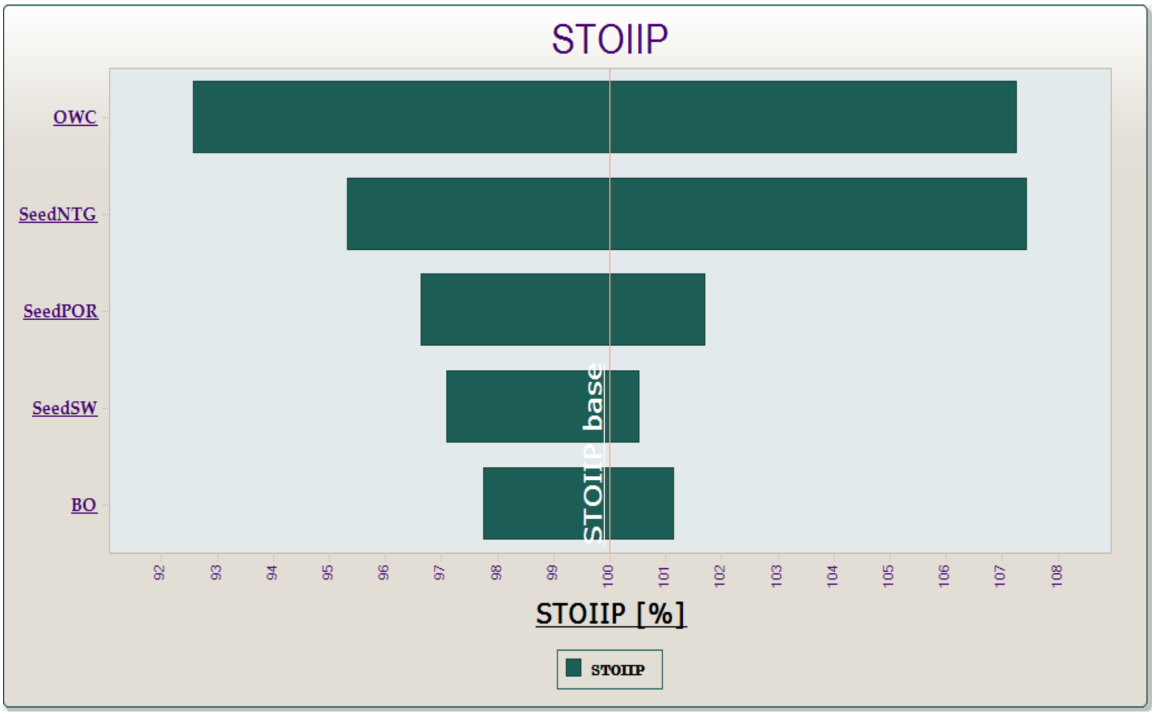


**Fig. 17.** Illustration of a sensitivity analysis using a tornado diagram.

### 4.3. Uncertainty Analysis Using the Monte Carlo Method

When using the Monte Carlo sampling technique, a large sampling number of N is required for an accurate estimation. The algorithm uses a random number function (between 0 and 1) to relate and control the uncertainty distributions of the individual parameters by performing numerous random iterations for each distribution. To statistically approximate the solution of any mathematical or physical problem, the Monte Carlo simulation procedure relies on a large number of probabilities for selected samples. To be effective, a simulation model must accurately depict the underlying geological structure (reservoir) being investigated. Therefore, the simulation algorithm takes in a mix of stochastically correlated parameters and geological data subject to constraints(Lashin, 2002). The sampler makes calculations using thousands of sampling values. Every calculation generates a potential outcome. A probability distribution curve is created after combining all the findings. The probability methods can assist figure out which factors are the most important and how much the OOIP could be (P10, P50, and P90). Table 4, and Fig. 18 show provides the volumetrics and OOIP of the Sadi formation as a percentage of P10, P50, and P90 cases.

The following are the definitions of the definitions P90, P50, and P10(Mahmood and Al-Fatlawi, 2021):

- The P10 is defined as the high case, where the confidence level is 10%, and the error is 90%.
- The P90 is defined as the low case, there is a 90% confidence level of 10% error.
- The P50 is considered an optimal case, there is a 50% confidence level, and a 50% error.

**Table 4.** The probabilities of uncertainty analysis results

| Probability | OWC (-2845 m) | BO (1.63bbl/STB) | OOIP (MMM STB) | Confidence % |
|---|---|---|---|---|
| P90 | -2852 | 1.6 | 3.962 | 10% error |
| P50 | -2844 | 1.62 | 4.251 | 50% error |
| P10 | -2836 | 1.65 | 4.516 | 90% error |

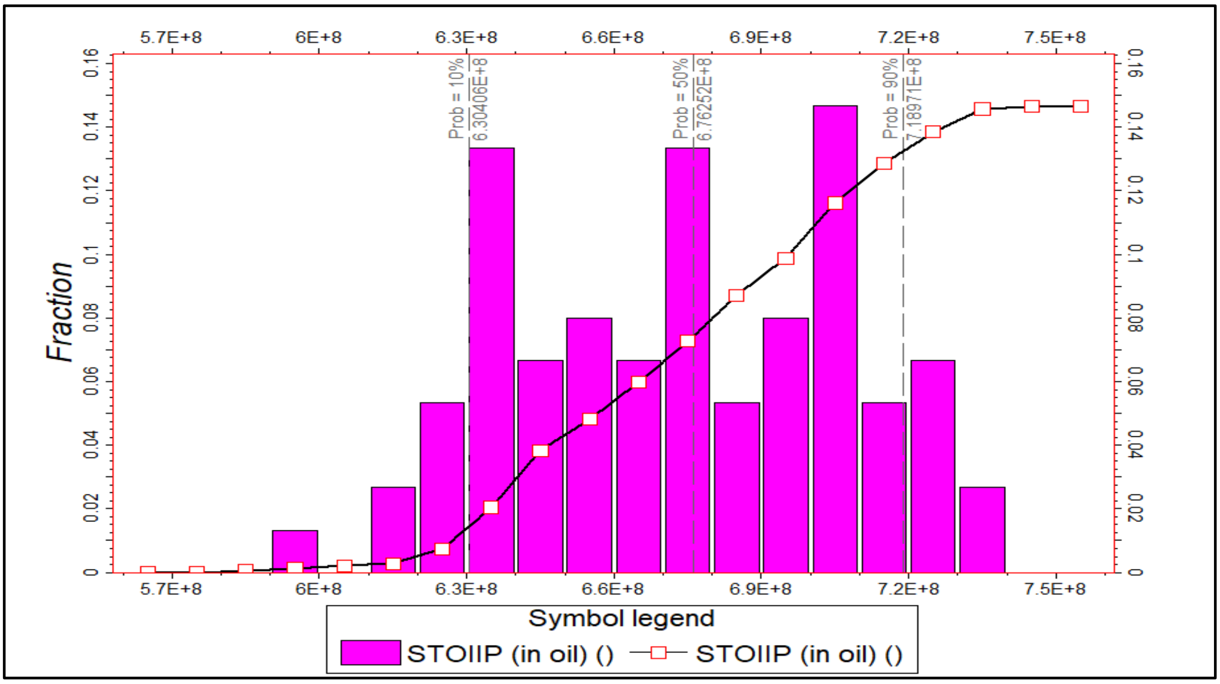


**Fig. 18.** View the histograms of parametric uncertainties from a Monte Carlo Analysis

## 5. Conclusions

- Carbonate reservoirs have low porosity and permeability and are highly heterogeneous in addition to complexity.
- Based on the structural map, creating a 3D geological model of the Sadi reservoir with three zones and four horizons on top of the Sadi B formation. The Sadi formation petrophysical model (porosity, permeability, Water saturation, and Net to Gross) was created using the SGS statistical technique. These models show that unit B2 is the best unit in the Sadi Formation compared to units B1 and B3.
- The geological model estimates the OOIP in these Sadi B reservoirs to be around 4.277 MMMSTB. Sadi-B2 has the largest reserve, accounting for 45.59% of total OOIP, due to the layer's good petrophysical property distribution. As a result, Sadi B2 has the largest oil-bearing area, the thickest net pay, and the highest average porosity compared to Sadi B1 and B3 units.
- Sensitivity analysis and uncertainty were performed to identify and rank the uncertain parameters that significantly impact the field production forecast. The objective is to determine the most crucial variables that can be applied to carry out a more thorough risk analysis. OWC, Seed Variables of (Seed NTG), (Seed POR), (Seed SW), and the oil formation volume factor (Bo) are critical for the successful development of an oilfield where it can be concluded that OWC depth has the most significant influence on STOIIP estimations, which was treated as a horizontal plane surface at -2845 m.

## References

Cosentina, L. 2001.Integrated reservoir studies (fundamentals of exploration and production), 53(9),1–310.

Farouk, A.K., and Al-Haleem, A.A., 2022.Integrating Petrophysical and geomechanical rock properties for determination of fracability of the Iraqi Tight Oil Reservoir. Iraqi Geological Journal, 55(1F), 81–94.

Iraq Oil Pipelines Map, 2022.

Jasim, N., Hamd-Allah, S.M., and Abass, H., 2020. Specifying quality of a tight oil reservoir through 3-d reservoir modeling. Iraqi Journal of Science, 61(12), 3252–3265.

Lashin, A., 2002. Reservoir characterization using Monte Carlo simulation and Stochastic analysis,1–19.

Mahmood, H. and Al-Fatlawi, O. 2021. Construction of comprehensive geological model for an Iraqi Oil Reservoir. Iraqi Geological Journal, 54 (2F), 22–35.

Mukhametdinova, A., Kazak, A. and Cheremisin, A. 2020. Reservoir Properties of Low-Permeable Carbonate Rocks : Experimental Features.

Okolie, E. and Ujanbi, O. 2008. Estimation of height of oil -water contact above free water level using capillary pressure method for effective classification of reservoirs in the Niger Delta.Nigerian, Journal of Physics, 19(2), 303–311.

Rassas, A., 2020. Application of 3D Reservoir geological model on Es1 Formation, Block Nv32, Shenvsi Oilfield, China. Open Journal of Yangtze Oil and Gas, 05(02),54–72.

Sadi, B. 2012. Development plan P2-3-Sadi-Tanuma.

Seismic, P., and Optimize, S.S., 2010.Welcome to the Petrel, help manual, Design.

Sha, F., 2019.Petrophysical characterization and fractal analysis of carbonate reservoirs of the eastern margin of the pre-caspian basin. Energies, 12(1).

Team, T.S., 2014. Sadi-Tanuma Favorable Reservoir Prediction and Well Location Proposal Technical Support Team.

Thai, N.B., 2017.Applying the evaluation results of porosity-permeability distribution characteristics based on hydraulic flow units (HFU) to improve the reliability in building a 3D geological model, GD field, Cuu Long Basin. Journal of Petroleum Exploration and Production Technology, 7(3),687–697.

Xu, Z., 2018.Characterization and Consecutive Prediction of Pore.

Zhang, X., 2022 .3D Geological Property Modeling Methods.