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Advanced Geostatistical Techniques for Building 3D Geological Modeling: A Case Study from Cretaceous Reservoir in Bai Hassan Oil Field

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Abstract

A 3D Geological model was generated using an advanced geostatistical method for the Cretaceous reservoir in the Bai Hassan oil field. In this study, a 3D geological model was built based on data from four wells for the petrophysical property distribution of permeability, porosity, water saturation, and NTG by using Petrel 2021 software. The geological model was divided into a structural model and a property model. The geological structures of the cretaceous reservoir in the Bai Hassan oil field represent elongated anticline folds with two faults, which had been clarified in the 3D Structural model. Thirteen formations represent the Cretaceous reservoir which includes (Shiranish, Mashurah, U.kometan, Kometan Shale, L. Kometan, Gulneni, Dokan, Mauddud, Jawan/Mud, Batiwah, Shuaiba, Garagu, L.Sarmord). According to the property model, the model for each petrophysical property was constructed based on core data and CPI. By using the geostatistical method, the property model was constructed. The Mauddud Formation is considered one of the most promising hydrocarbon reservoirs in the Bai Hassan oil field based on the results of the property model, where the ratio of water saturation is around 30%, the porosity value is reaching up to 31%, and the net to gross ratio is averaging at 70%.

Keywords: Cretaceous; Mauddud Formation; Bai Hassan oil field; Petrophysical properties

1. Introduction

A 3D Geological model is a grid model. At this grid, the layers, faults, and reservoir properties are represented in the directions X, Y and Z. The cells of this grid can represent any reservoir properties such as water saturation, porosity and permeability, and each of these cells contains only one value for each of these properties. The 3D geological model used in many operations fields obtains the most accurate descriptions of subsurface reservoir attributes and quantities through data on reservoir characteristics. The majority of geological features, such as the petrophysical characteristics of the reservoir, the types of rocks present in the formation, faults, folds, and some subsurface data limits, must be understood and covered in order to determine the distribution of these features (Abdulmajeed, 2020). The four key processes that make up a geological model are stratigraphic modeling, lithological modeling, petrophysical modeling, and structural modeling. In general, the methods and applications are becoming increasingly intricate. Improved hydrocarbon-bearing zone quantification required high-resolution geological models and more accurate data collection (Boschetti et al., 2020). They were building a 3D petrophysical model of the Cretaceous

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reservoir in the Bai Hassan oil field (BH). In 3D geological models, fundamental data in terms of sources, types of data, sizes, and additional stages can typically be employed to clarify the conduct of geological modeling (Fertl, 1981; Al-Mimar et al., 2018). Several researchers studied the petrophysical properties of various types of reservoirs. Khaleel and Farouk Al-haleem (2022) and Awadh et al., (2018) studied the petrophysical properties of the tight Iraqi reservoir; in contrast,Tali and Farman(2021), Taher (2005), and Ali, Farman and Hafiz (2021) used statistical methods to improve carbonate reservoir characterization in both Abo -Amood oil field, Asmari oil field and Siba oil field. Hamdulla et al. (2018) built a 3D geological model and studied the petrophysical parameters for tertiary reservoirs in the Ismail oil field. Al-Qayim, Qadir and Albeyati (2010) evaluated the reservoir properties of a cretaceous reservoir in the Khabaz oil field. Mahdi and Farman (2023) and Awadh et al. (2014) studied the petrophysical properties of the shaly sand reservoir in south Iraq. Hashim and Farman (2023) studied how to estimate the major petrophysical properties. The study area is located in the BH oil field. The BH Oil Field was discovered in 1929. It is located in the northwest of the city of Kirkuk in the northern part of Iraq, parallel to the Avana dome in the Kirkuk oilfield. The field structurally falls within the range of low fold zones parallel to the Zagros mountain range (Dunnington, 1958) while according to the structural map of Iraq prepared by Buday it is within the Batma-Chamchamal range which is the northeastern part of the Foothill zone range located within the Unstable Shelf area (Buday, 1987). The BH oil field is approximately 13km northeast of Kirkuk field as shown in Fig.1. Compared to the wells in the Kirkuk field, the wells in the BH oil field are deeper. The structure of the BH oil field is approximately 34 km long and 3.8 km wide and trends from northwest to southeast. The structure consists of two domes: the Daoud Dome to the northwest and the Kithke Dome to the southeast. The Kithke Dome larger, more prolific and it has a significant surface expression in contrast with Daoud Dome. Consequently, it discovered and produced after several years Kithke Dome production started. The shahl saddle physically separates the two domes from each other and the deviation in it of the fold axis is noted by (10–30) degrees towards the west according to a North Oil Company study in 1992. Actually, four wells selected in this study to cover the cretaceous reservoir are (BH-1, BH-2, BH-3, BH-4). The first goal of this study is to build a structural model of the Cretaceous reservoir to calculate fault displacement, and the second goal is to build a 3D geological model of the Mauddud Formation using the Petrel 2021 software to comprehend the behavior and characteristics of the Mauddud reservoir, including its structural, petrophysical, and facies modeling.

2. Materials and Methods

The dataset used in this research includes wellheads, well logs, core data, well tops, and contour maps, organized and imported into folders or for each data folder by Petrel software to create 3D-geological models. The following is a brief description of various types of input data for the Petrel software:

- Well heads

Display the location of the wells, the name of the wells, the total depth measured along the actual well path, and their symbol. This data was obtained for four wells for the Mauddud Formation in the BH oil field.

- Well top

This type of input data is considered along the path of the well, which has thirteen geological formations. Well tops are typically necessary for the structure model because they are used to build a contour map for all formations in the Cretaceous reservoir.

- Structure contour map

From the surface and the correlated borehole, a contour map can be generated.

- Core data and well-log data

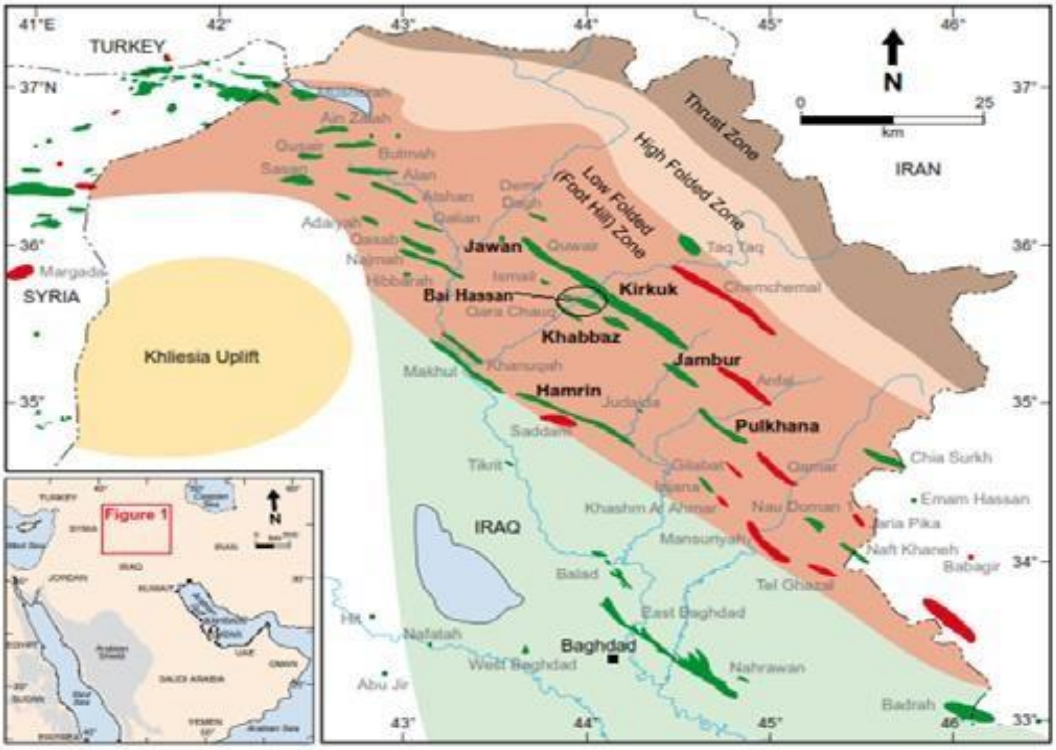

Fig .1. Location of Oil and gas fields in northern Iraq (Zeynalov and Ismail, 2016)

The well logs attached were available for four wells in the Mauddud Formation and contained information about the reservoir properties and the formation depth. Core data was available for three wells and includes the values of permeability and porosity from the core sample, along with the depth and name of the formation.

The methodology used for this study included input of necessary data for Petrel software, generation of boundary and surface for all units, and the construction of stratigraphic, structural, and property models for the Mauddud formation. Fig.2, clarify the methodology used for constructing 3D geological model for this study.

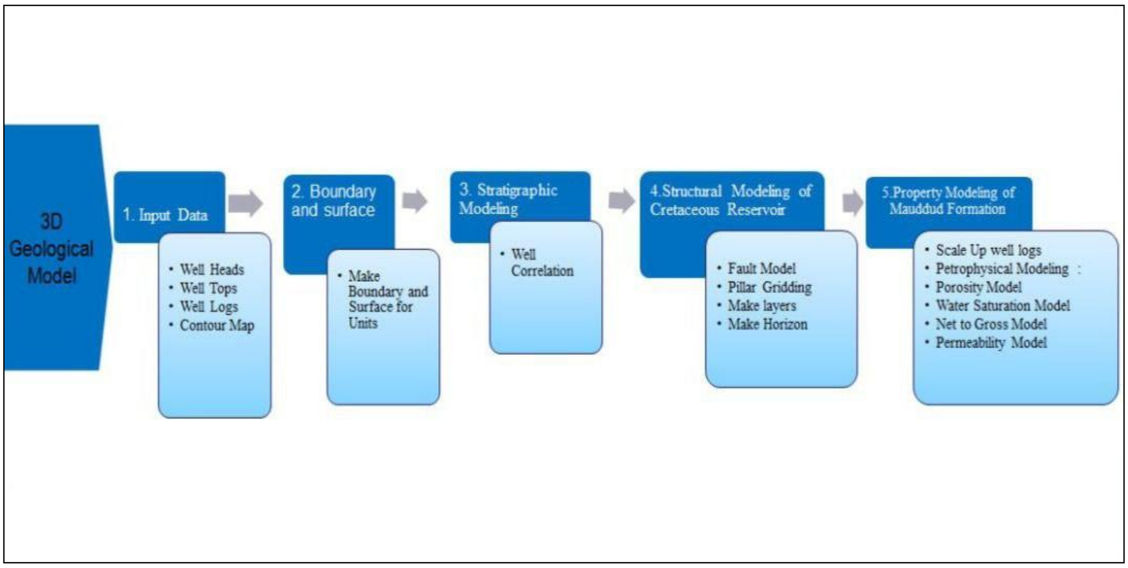

Fig.2. Workflow diagram for constructing a 3D geological model for this study

3. Results and Discussion

3.1. Well Correlation

One of the essential steps in the Petrel software for making the 3D geological model is well correlation. Well correlation was performed for many reasons such as: Shed light on variation in the distribution of petrophysical properties. Assure formation tops indicated in the final well reports. Have an idea about the behavior of the formations throughout the studied reservoirs. Categorize and organize well-log data as a simple 2D visualization. Compare newly drilled wells to wells that have already been correlated (Abdelmaksoud et al., 2019)

In this study, the well correlation was applied to show changes in important reservoir properties, which include porosity, water saturation (Sw), net to gross (NTG) permeability, and changes in thickness for different geological formations of the Cretaceous reservoir. After completing the information and data entry into the Petrel 2021 software, geological well correlations were made for each of the study wells.

The well correlation includes the information that was entered into the program with the depths and tops of layers for the cretaceous reservoir, through which the quality check (QC) was done for the information that was entered, and correcting the information resulting from some errors that occurred in the gathering or arranging of the information or through the stage of uploading the information to the petrel software. The objectives of well correlation are to know the position of the layers in the reservoir, the facies of the layers, and the thicknesses of different layers. The two cross-sections for creating the well correlation are shown in Figs.3 and 4, displaying that the Mauddud thickness increases toward wells BH-2 and BH-3, while decreasing toward wells BH-1 and BH-4.

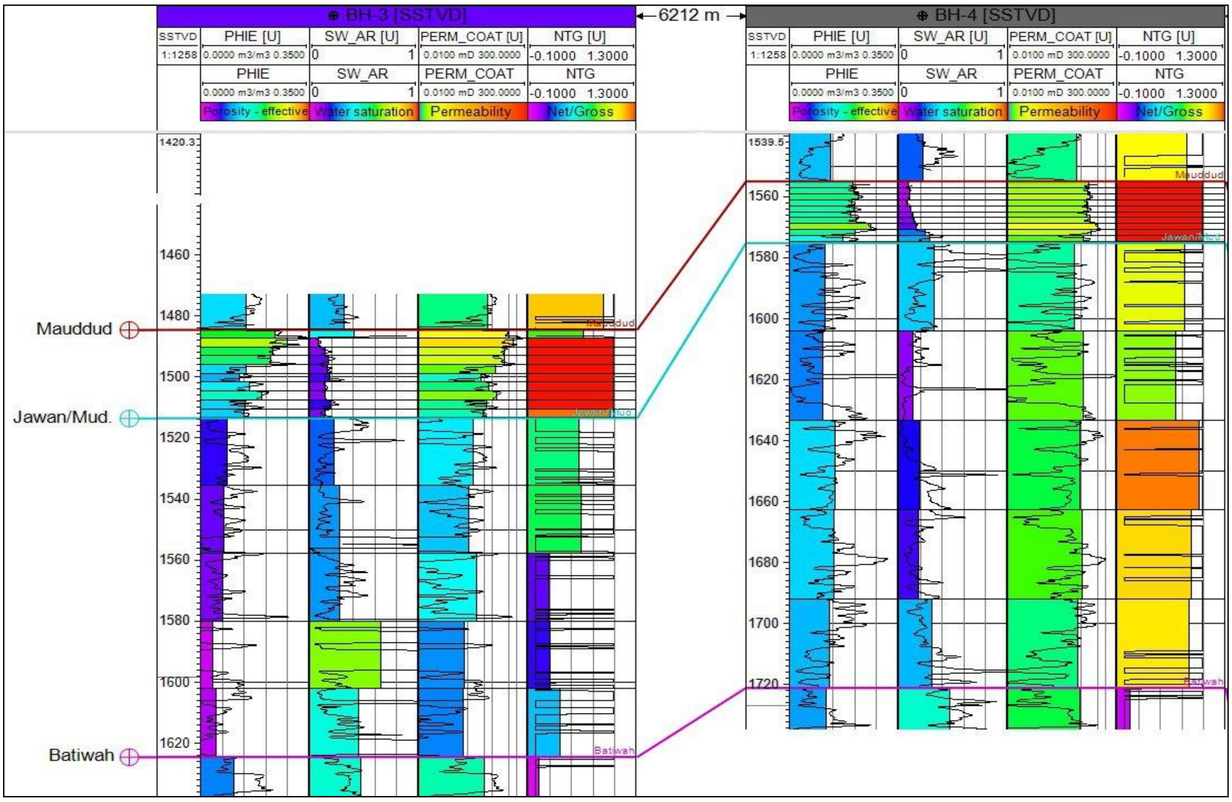

Fig.3. well correlation from northwest to southeast of Mauddud formation from well (BH-3) toward well (BH-4)

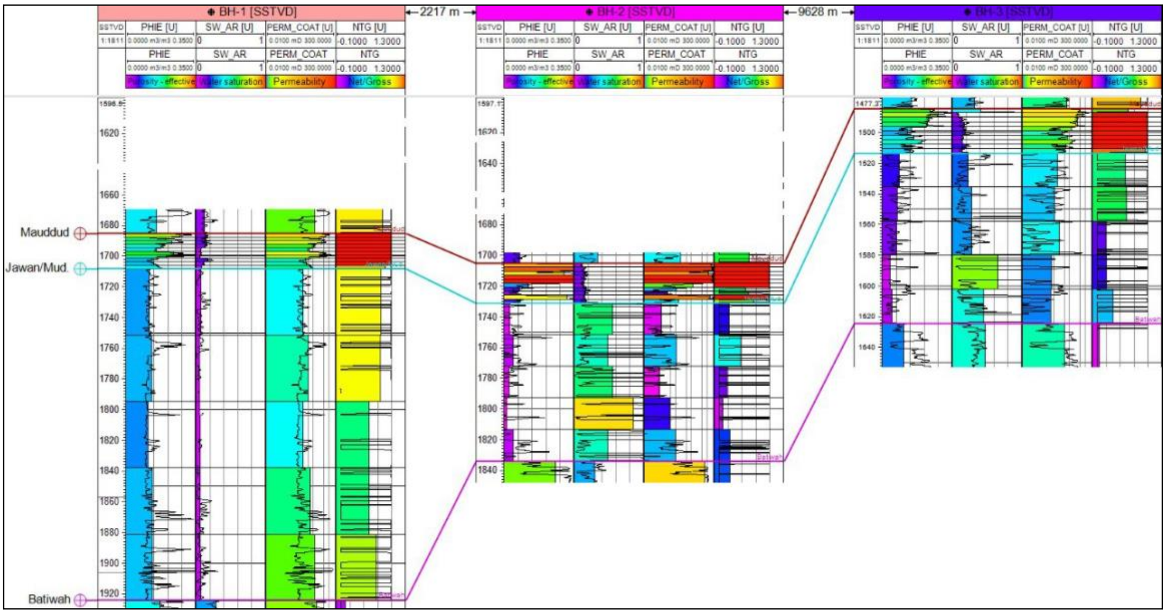

Fig.4. Well correlation from northwest to southeast of Mauddud Formation from well (BH-1) toward well (BH-3)

3.2. Structural Model

The special geological properties can be clarified and introduced through the fault model and geological constructions typically constructed in the geomodel. Due to disorganized input data and more geometrical obstructions, getting the best structural model for a reservoir has been thought to be more difficult for petroleum engineers (Schlumberger, 2008). Layering zones, pillar gridding, and fault modeling were three separate operations that fell under the category of structural modeling. The structure of 3D grids consists of a single value of data, and all these steps were applied one after the other (Opafunson, 2007). The contents of the reservoir and any features that may be present are shown through the structural model, which consists of a set of surfaces. The Cretaceous reservoir was represented by creating structural maps of each formation in the reservoir. The first surface was built based on a digitized structural contour map of the tops of the Shiranish Formation, and the other surfaces were made by connecting the tops of the wells. The 13 structural maps were constructed to represent the top surface of each unit in the Cretaceous reservoir. Fig. 5 shows the structural contour map of the Mauddud Formation.

3.2.1. Fault model

The most important process in a structural model is fault modeling. The main objective of the fault model is to generate a realistic description of faulting that can be incorporated into a 3D grid. Multiple data sources are used to construct the fault model for the BH oil field. These sources include 2D seismic data and the FWR (Final Well Report).

Two faults intersect the structure in its south-eastern nose and influence reservoir performance, as shown in Fig.6. The faults intersect all formations in the Cretaceous reservoir, as shown in Fig. 7. The vertical displacement of fault 1 is 60 m while the vertical displacement of fault 2 is 35m.

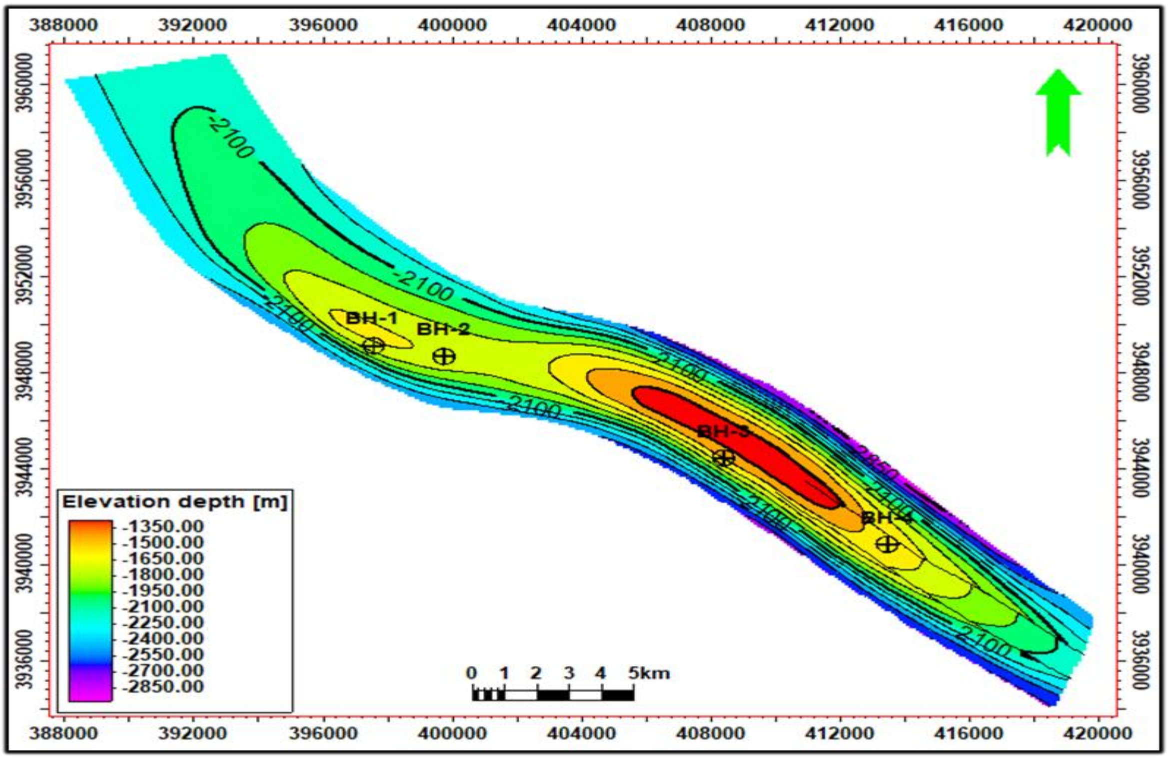

Fig .5. The structure map for the top of the Mauddud Formation

3.2.2. Pillar gridding

The structural model is generated in the process of pillar griding (Imad, 2012). Skeletons, defined as the surfaces for locations in the x, y, and z directions, are produced by pillar gridding to construct a three-dimensional structure. The basis of all modeling is pillar gridding. The top, middle, and bottom skeleton grids represent the skeleton. Generally, the first stage in creating a 3D geological model is building a 3D grid (Hameed and Saleh, 2022). A 3D geological model can be described by a network consisting of lines in horizontal and vertical directions called a 3D grid (Abaldawi, 2015). A 3D grid that is made up of

spaces and boxes. Every grid box is first described as a grid cell. At each grid cell, reservoir properties were measured, also known as cell properties (porosity, rock type, NTG, and permeability). Much of the 3D gridding used in structural models was built using a large number of cubic cells stratified along faults and arranged with horizons (Dulac and Jean-Claude, 2008). The 3D grid model for the Cretaceous Reservoir was made using 100 100 m in the X direction and 100 100 m in the Y direction. The grid dimensions were selected according to distance of the reservoir and to determine the difference in the petrophysical properties. The top, mid, and base skeletons of a cretaceous reservoir are illustrated in Fig. 8.

3.2.3. Layering

The thickness and orientation of the layers between the horizons of the 3D grid must be determined as the final stage in building the structural framework. These layers and the pillars define the 3D grid cells to which attributes are given during property modeling (Schlumberger, 2010). Accurate representation of layered volumes is necessary in modern geology. The most effective way to constrain geology at depth is through increasingly three-dimensional (3-D) geologic models. Depending on the amount of hydrocarbons that exist in a unit and its petrophysical properties, we divided the Mauddud Formation into ten layers.

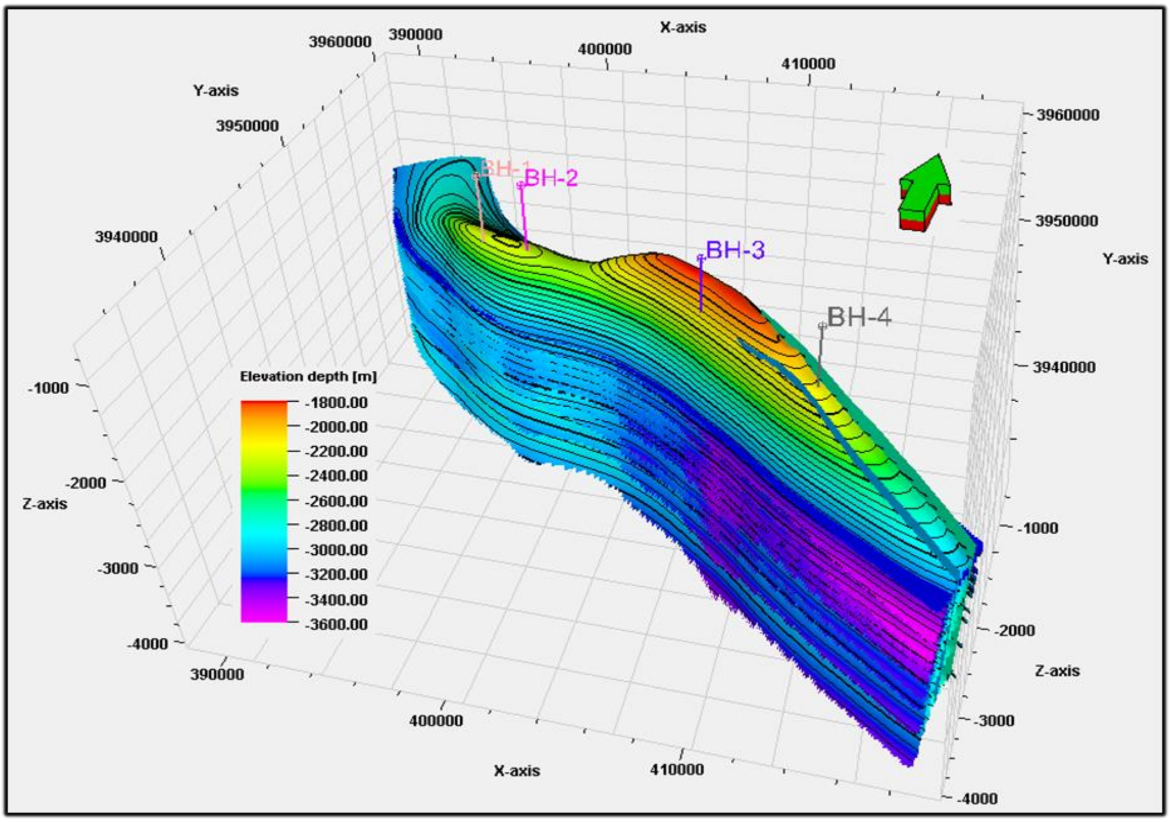

Fig.6. 3D structure model of the cretaceous reservoir with fault

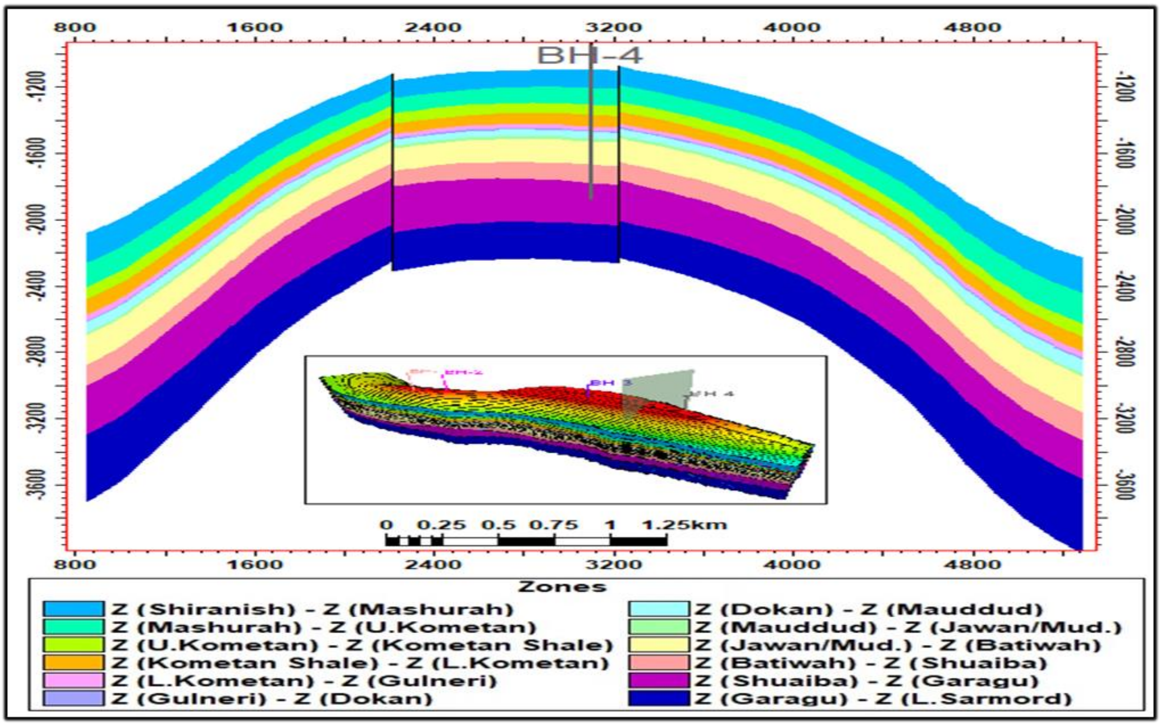

Fig.7. Zone intersection from southwest to northeast of the cretaceous reservoir

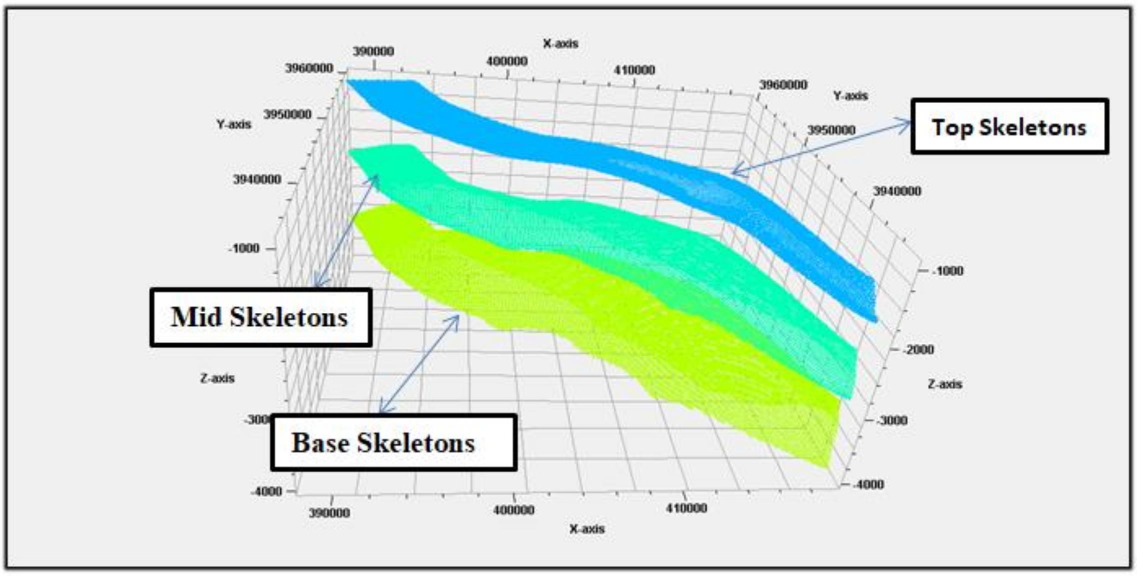

Fig.8. Top, Mid and Base skeletons of the cretaceous reservoir

3.2.4. Make horizons

The horizon represents a border that separates two beds or the top zones' surface. The surfaces must be transformed into horizons to incorporate them into the 3D grid, which was done in the "horizons" process, which used to introduce layers in the vertical direction. The true 3D statistical technique showed the surface of the layer as 2D with maintaining picks of wells and well tops of structure. All intersection points between horizons and pillars are known as nodes after defining the horizon, which results in a 3D pillar grid (Bendiksen, 2013). Fig. 9, shows the horizons of the main units in the Cretaceous reservoir.

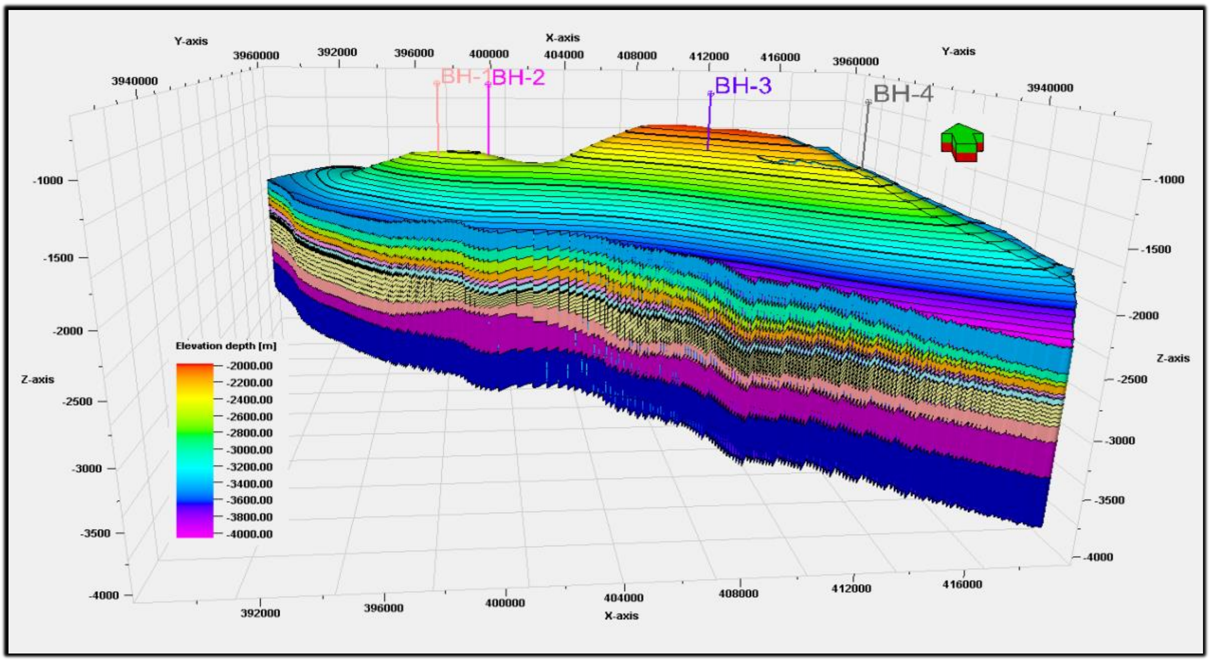

Fig.9. The horizons of the main units of the cretaceous reservoir

3.3. Up Scaling of Well Log

The up scaling of the well log is defined as distributing the well log values and core data on the cells in the 3D grid for each property of petrophysical properties by making averages for these values using one of the statistical approaches. The up-scale is applied for every property of these properties in each cell because the well log and core data values are variable with depth. Subsequently. These cells form the basis for property modeling. The thickness of the cell for a well log is typically larger than the sample density; as a result, before any modeling based on well logs can be done, the well logs must be up scaled to provide definition 3D grids, which is called blocking of well logs (Denney, 2013). Multiple geostatistical approaches have been used to up-scale the petrophysical properties, such as geometric, arithmetic average, harmonic, etc. The RMS method was used to up-scale the values of the porosity log in the current model, whereas the arithmetic method was used to up-scale the WS and net gross values. Fig.10 Up-scale for well (BH-1) of the Mauddud Formation.

3.4. Petrophysical Models

The process of distributing petrophysical properties such as and NTG to each cell of the 3D grid in a static model is known as petrophysical modeling. Different algorithm methods are present in the Petrel software for applying the distribution of these properties in a reservoir model. During the petrophysical modeling process, the volume of a zone can be shown by the structure of a cell in a 3D grid. By using geostatistical methods, the petrophysical model was constructed. Depending on the magnitude of data available from well logs and the up-scaling process, and as a result of the small number of wells and the need to match the algorithm more geologically, the algorithm used as a statistical method for building petrophysical structures is Sequential Gaussian Simulation (SGS) (Schlumberger, 2007). The petrophysical models consist of:

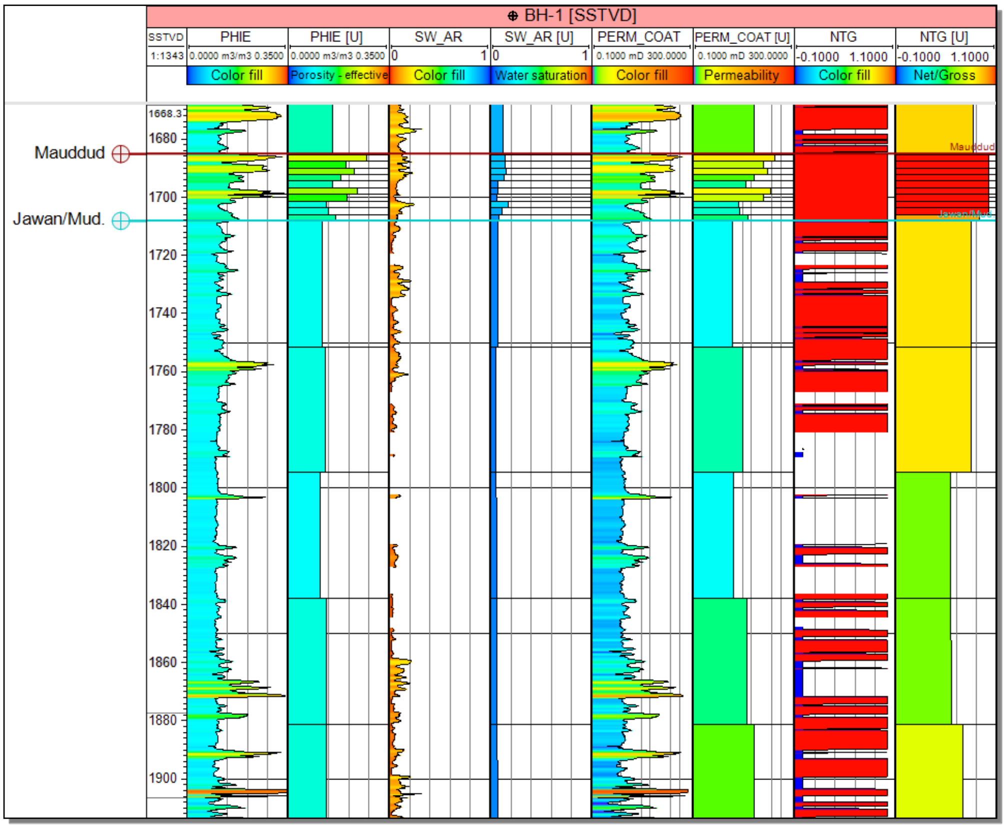

Fig.10. Up-scale for well (BH-1) of the Mauddud Formation

3.4.1. Porosity model

The porosity model was distributed for building this model after upscaling porosity logs, such as neutron and density logs exported from Techlog software. Sequertial Gaussin Simulation (SGS) is a well-known geostatistical technique used in this model as a statistical technique. The first step to calculating experimental variogram ranges and normal score transforms is data analysis. The anisotropy ranges were 5000m in both the major and the minor direction and 10 m in the vertical direction. using an exponential variogram model with a variable nugget and the major direction orientation with azimuth of (-45°). The histogram shows distribution of porosity, upscaling log data, and original log data in order to check the quality of the porosity model shown in the Fig.11. The distribution of porosity model of the Mauddud Formation displays an increasing trend in the porosity values from the plunging of the southen Kithke Dome toward the northen Kithke Dome and begin to decrease again when approaching the northen Kithke Dome. The porosity values reach their maximum at Kithke Dome, while the values decrease towards Daoud Dome, reaching the lowest values at the plunging of Daoud Dome. Fig.12, shows the distribution of porosity model of the Mauddud Formation. The results of the porosity model show the Mauddud formation has high porosity values reaching up to 31% (averaging 17%).

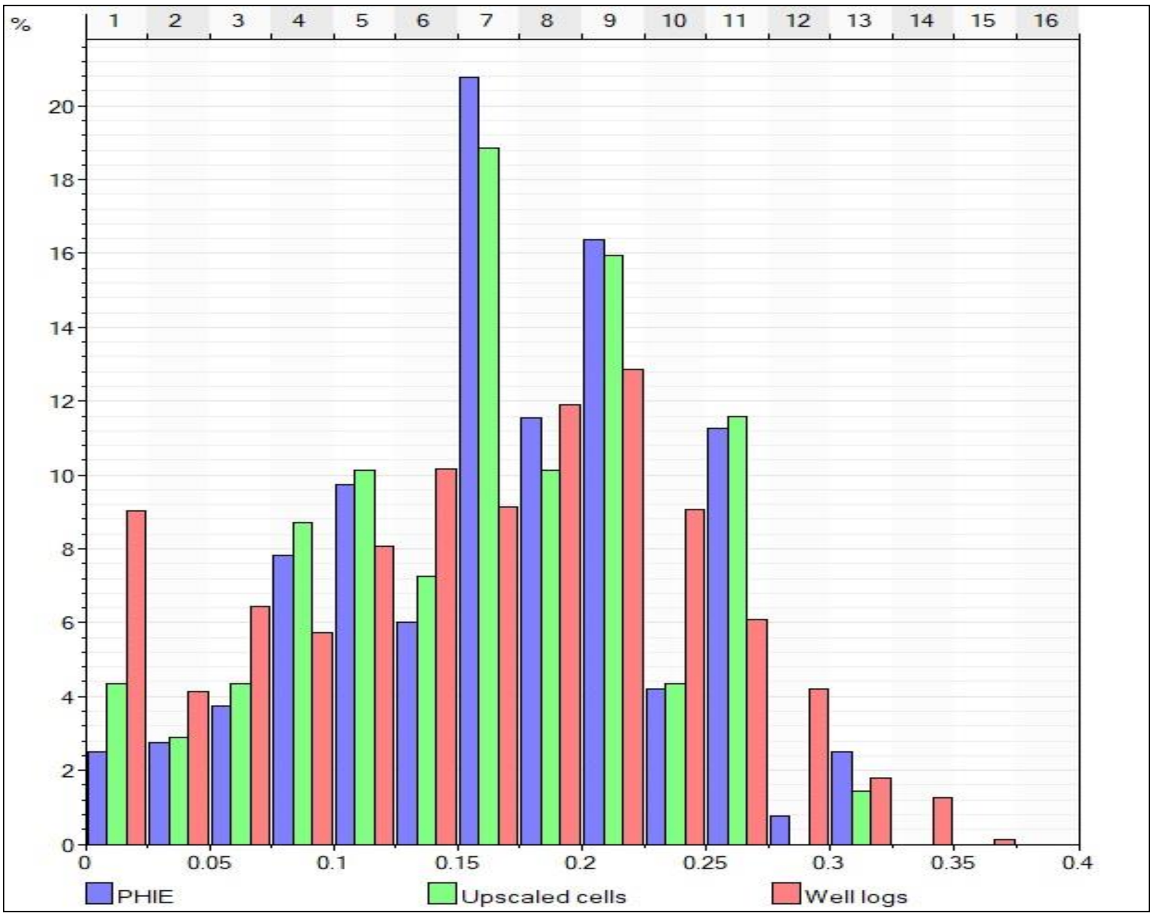

Fig.11. Quality histogram for porosity model of the Mauddud Formation

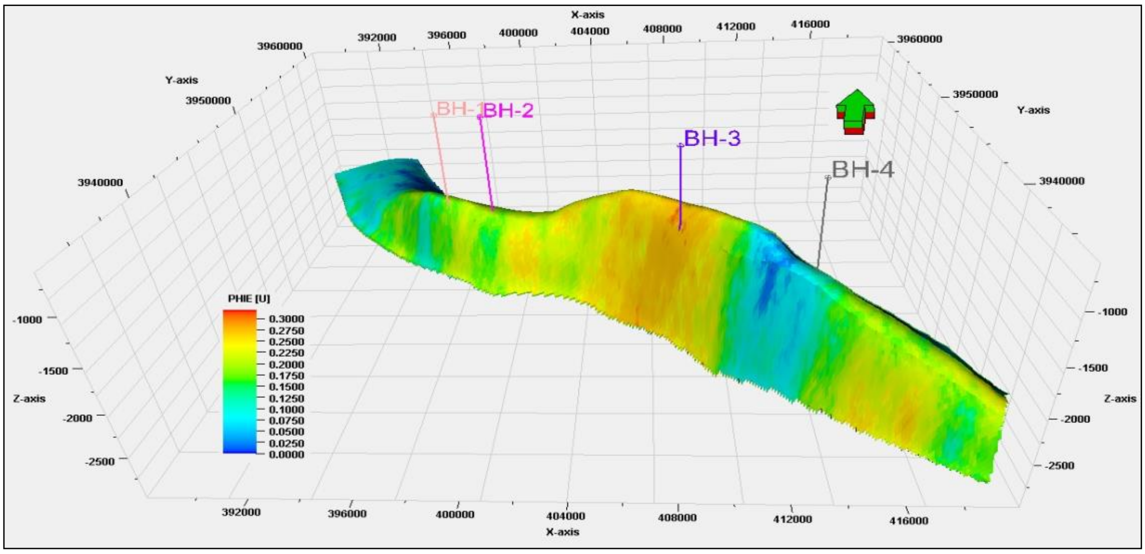

Fig.12. Distribution of porosity model of the Mauddud Formation

3.4.2. Water saturation model

After the upscaling process of Sw calculated from data available using Techlog software of the Mauddud Formation, the Sw was distributed for building this model. Sequertial Gaussian Simulation (SGS), which operates in the porosity model, is the geostatistical method used in this model. The histogram shows WS distribution, upscaling log data, and original log data to check the quality of the Sw model shown in Fig.13. A 3D representation of the Sw model of the Mauddud Formation (Fig. 14). The results of the Sw model show the Mauddud formation has average Sw value around 30%.

The blue zone in the model is characterized by high Sw, as present in the south of Kithke Dome and the plunging of Daoud Dome, while the other zones are characterized by low Sw, as present in the north of Kithke Dome and Daoud Dome.

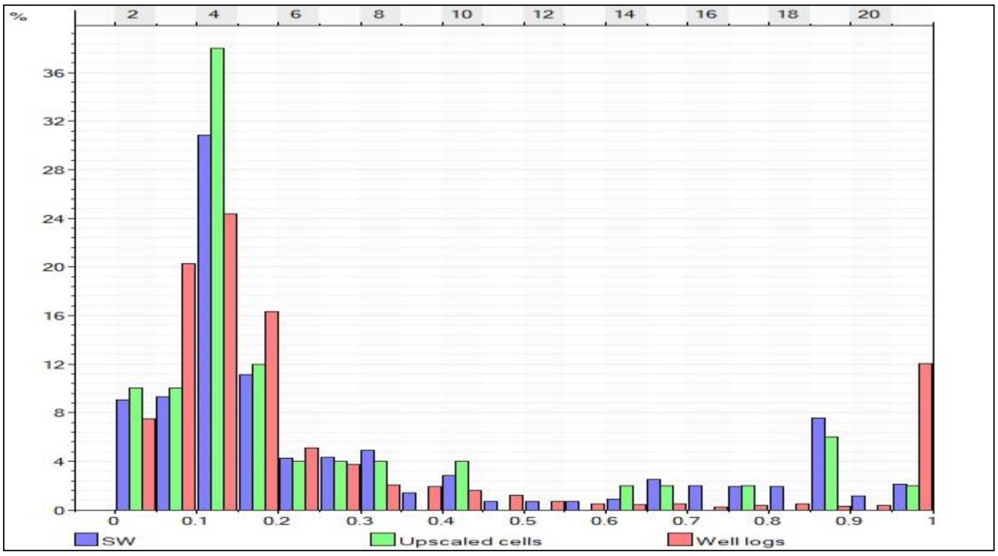

Fig.13. Quality histogram for Sw model of the Mauddud Formation

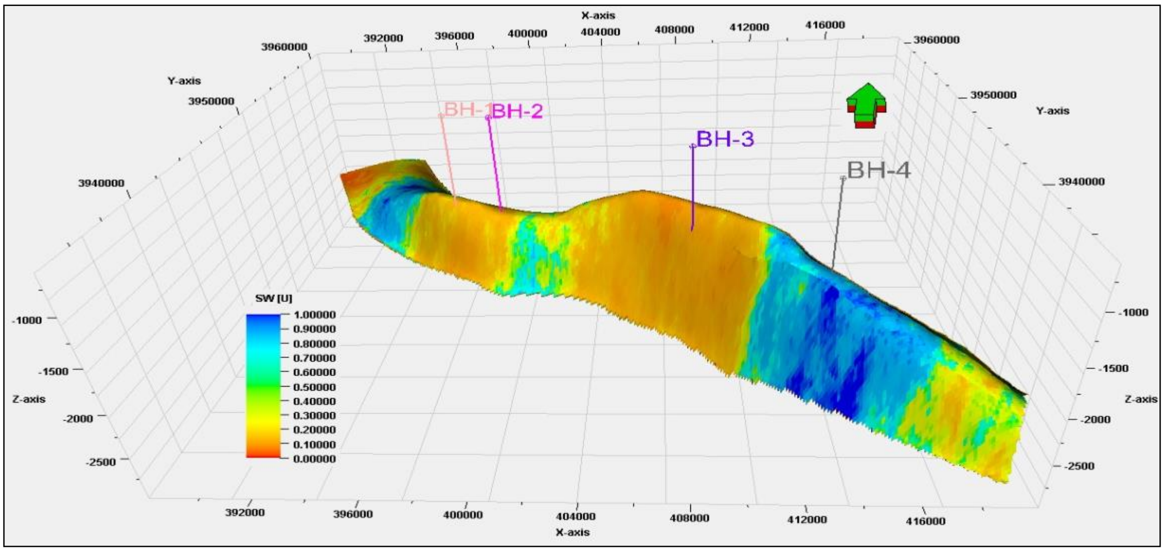

Fig.14. 3D Sw model of the Mauddud Formation

3.4.3. NTG modeling

An important factor in the reservoir characteristics is net pay because it indicates the penetrated geologic section that contains a high concentration of hydrocarbons with the best rock types and hydraulic flow to produce intervals within the reservoir. Due to nonreservoir rocks not being considered, Net Pay clarifies facilities reservoir simulation. Cutoff applications on petrophysical well logs can be used to calculate the net pay zone. For the parameters of the formation and the producing zones, the cutoff has a particular value and is not considered (Bora et al., 2011). Net pay is essential for estimating flow units and objective intervals for stimulation programs and well completions (Mahdi and Farman, 2023). After the scale-up process of exporting NTG from Techlog software of the Mauddud Formation, the NTG was distributed for building this model. The histogram shows the distribution of NTG, upscaling log data, and original log data to check the quality of the NTG the gross model shown in Fig.15. The NTG model indicates that the Mauddud Formation has high N TG, with averaging value 70%. Fig.16, shows the net-to-gross model of the Mauddud Formation. The distribution of the NTG model shows the same results as the porosity model, which Indicates that the model is correct.

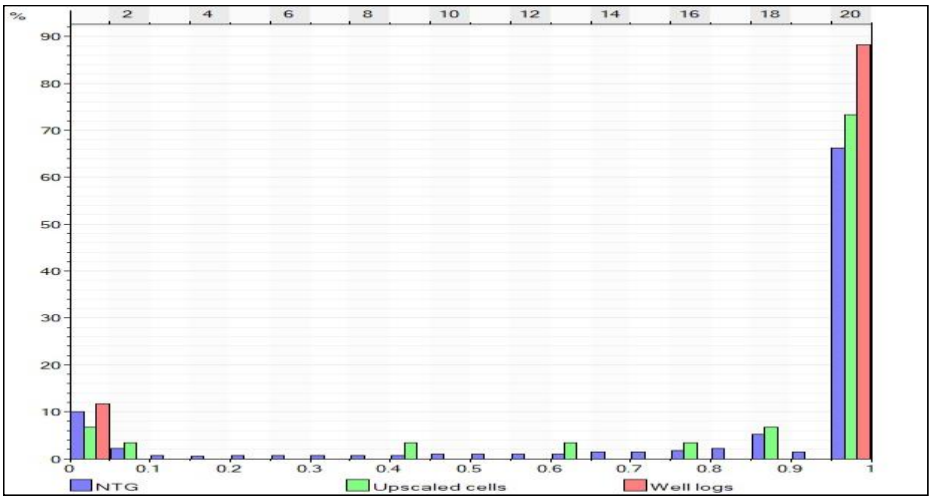

Fig.15. Quality histogram for NTG model of the Mauddud Formation

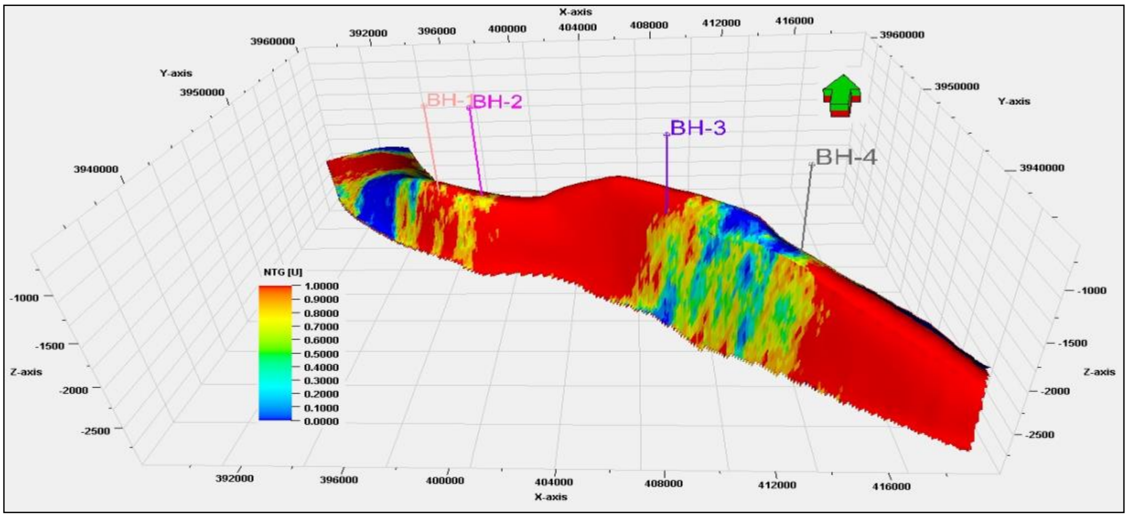

Fig.16. A 3D net to a Gross (NTG) model of the Mauddud Formation

4. Conclusions

The structural model showed that the cretaceous reservoir consists of thirteen formations (Shiranish, Mashurah, U. Kometan, Kometan Shale, L. Kometan, Gulneni, Dokan, Mauddud, Jawan/Mud, Batiwah, Shuaiba, Garagu, L. Sarmord). The geological structures of the cretaceous reservoir in BH oil field represent an elongated anticline fold with two faults that intersect the structure in its south-eastern nose, with the vertical displacement of fault 1 being 60m and the vertical displacement of fault 2 being 35m. The 3D geological model showed that the Mauddud Formation is divided into ten layers to distribute petrophysical properties accurately. The results of the property model clarified that the Mauddud reservoir has the best reservoir characterization. The results of the porosity model showed that the Mauddud Formation has high porosity values, reaching up to 31% (averaging 17%). The average Sw value in the Mauddud Formation is around 30%. At the same time, The NTG model shows that the Mauddud Formation has a high N TG, averaging 70%. Based on the results of the property model, the Mauddud Formation is considered one of the most promising hydrocarbon reservoirs in the BH oil field.

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