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Static Reservoir Modeling, a Case Study from Early Cretaceous Yamama Formation, Southern Iraq

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Abstract

Constructing a static reservoir model or a 3D geological model is a widely used modern tool to employ subsurface information expose the setting and properties of hydrocarbon reservoirs. The current study attempts to build a 3D reservoir model of the Yamama Formation (an important oil reservoir in Southern Iraq), from digital logs data and drilling information. This would lead to a better understanding of the relationships between different reservoir elements, then expose many characteristics of the reservoir, such as the facies distribution and petrophysical properties. The data of the Yamama Formation (Early Cretaceous Carbonates) were taken from four wells of Gharraf Oilfield, Southern Iraq (GA-1, GA-2, GA-3, and GA-4). The adopted modeling approach consists of a series of steps starting with a preliminary analysis of data, followed by interpretation of these data, and terminated by geostatistical methods for building the structural model. The modeling was assisted by defining the top of each layer detected by wireline logs and final well reports of each studied well. The results of the study encompass four microfacies distributed between Inner Ramp and Mid Ramp environments. The followed 3D geological modeling scheme was capable to visualize the distribution of petrophysical properties, and the classification of Yamama Formation into several layers or reservoir units (Y1 to Y5), and thirteen subdivisions (minor units). The model could also define the places where effective porosity was enhanced. The process of Pillar Gridding, a step within the modeling, showed that the Yamama Formation is composed of two domes. The constructed model was helpful, based on the evaluation of petrophysical parameters, then to point out the most important reservoir zone (Zone Y3_top) that has Effective Porosity of (13.6%) and water saturation of around (10.6%).

Keywords

Reservoir Modeling, Petrel, Cretaceous, Yamama Formation, Southern Iraq

1. Introduction

The production capacity of a reservoir depends on its geometrical/structural and petrophysical characteristics.

The reservoir model would be significant to foretell the behavior of reservoirs because it integrates much information within the structural framework and stratigraphic layers. The 3D geological model also displays the distributions of inter-well like porosity, permeability, and water saturation.

However, for the investigated reservoir, the ultimate objective is to describe the type and scales of heterogeneity that affect the fluid distribution and flow in the subsurface [1].

This method enables the reservoir modeler to estimate inter-well reservoir properties from observed data points at wells and attempts statistical prediction [2].

In the current study, four wells from the Gharraf oilfield (GA-1, GA-2, GA-3, and GA-4) have been selected to study Yamama Formation (Early Cretaceous) (**Figure 1**). These wells area located in Thi-Qar Governorate, Southern Iraq, some 5 km northwest of Al-Refaei town, 9 km southeast of Qal'at Suker town, and 85 km north of Nasiriya city. The Gharraf oilfield extends over a NW-SE trending anticline with an area of 24 km long by 5 km wide.

The aim of this research is to build a 3D integrated model by a Windows (Petrel) based software for 3D visualization, 3D mapping, and 3D reservoir modeling and simulation. Petrel offers an option to use 3D glasses for obtaining a true 3D effect (Virtual Reality) [3]. This model includes the structure, facies, and the distribution of petrophysical properties (porosity, water saturation) in three directions.

2. Methodology

2.1. Data Acquisition

The key point of this technique method depends on data. Different well log data of Yamama Formation were collected for building the model, such as gamma ray (GR), spontaneous potential (SP), neutron (NPHI), density (RHOB), and resistivity logs, as well as the computer-processed interpretation (CPI). The data exported from Techlog Software includes S_w, S_{xo}, Net, and Gross pay. Another type of data is sourced from Rotary Table Kelly Bushing (RTKB) and total depths, which also covers effective porosity values along the well path.

2.2. Geologic Models

Many processes were introduced by Petrel Software using a variety of information

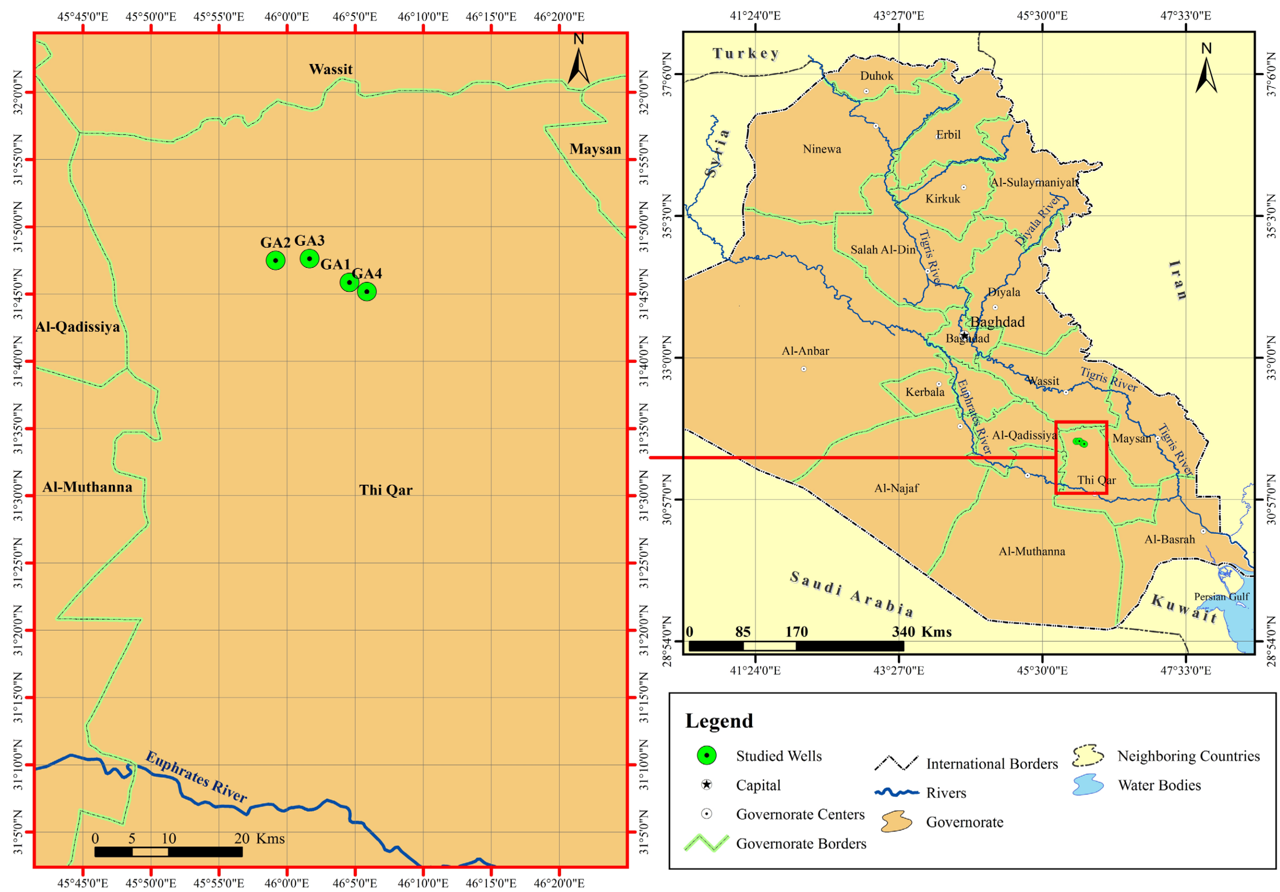

Figure 1. Location map showing the studied area and the selected wells from Gharraf oilfield.

to build subsurface models, starting from well heads to well tops, ending with well logs and core data, and concluded to reach interpretation the final step. The current study workflow includes: analysis of data, correlation of well, scaling up to well log, 3D mapping and grid design also, and petrophysical modeling. The construction of static geological modelling after the collection of data includes several steps. These steps are illustrated as a flow chart shown in **Figure 2**.

2.3. 3D Geological Modelling

Static 3D geological models are essential for reservoir characterization and dynamic models [4].

Several steps were applied for building 3D geological model these are (**Figure 2**):

Step (1) starts with well correlation, this process leads to zonal attribution in the model, thus should be kept simple and reflect the conceptual model and explain the observed differences in thickness of the zones tracked between wells [1].

Well correlation was preceded by characterization of reservoir units based on facies and petrophysical properties of these units, hence this lead to recognition five main reservoir units or zones (Y1 to Y5) subdivided to thirteen minor units

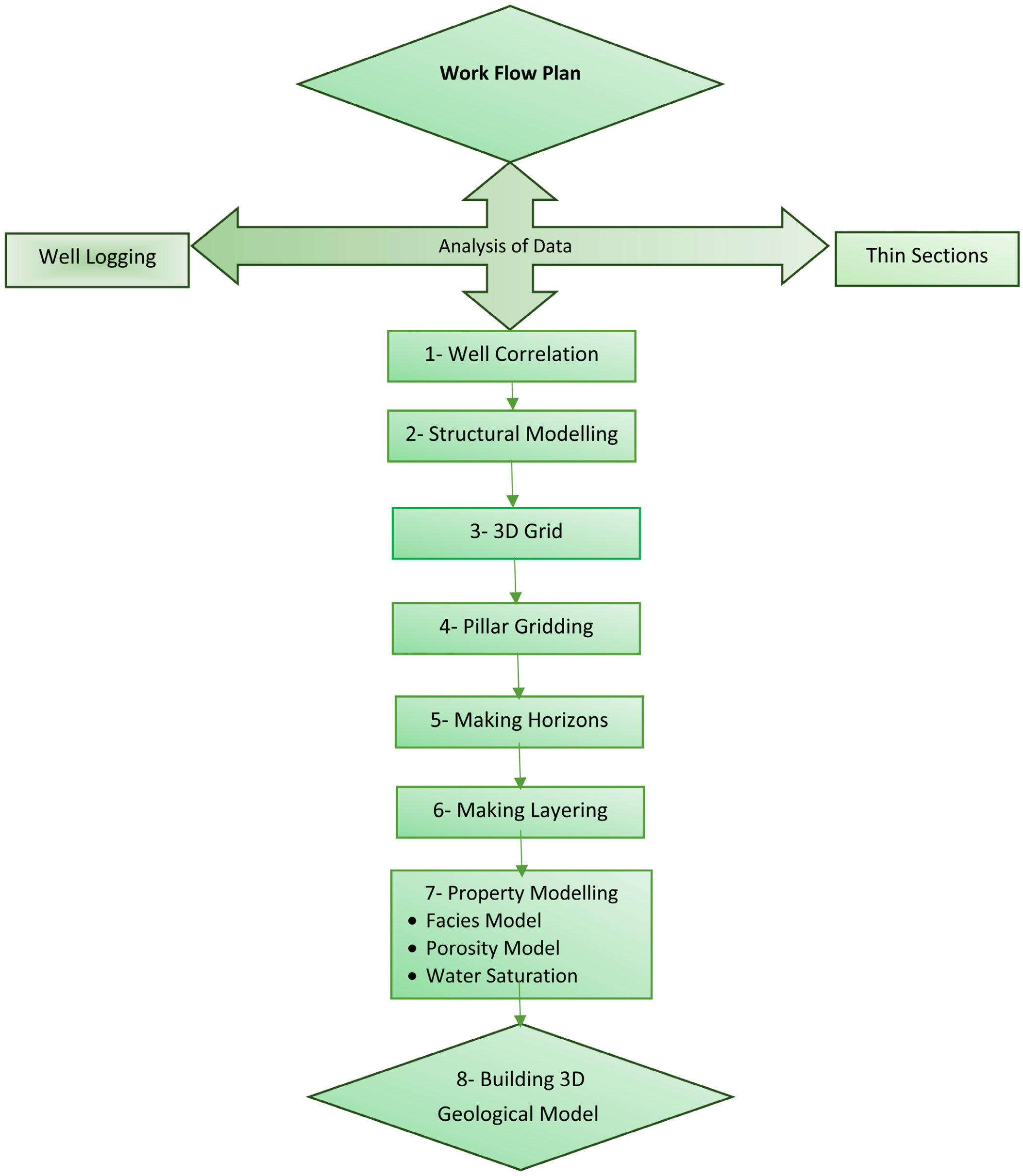

Figure 2. The steps of building the 3D geological model.

(Y1, Y2_top, Y3_top, Y3_base, Y4_top, Y4.2, Y4.2, Y4.3, Y4.4, Y4.5, Y4.6, Y5_top and Y5.2) (**Figure 3**). Well correlation has been carried out in a simple way to show the vertical and lateral variations in thickness of the characterized units (**Figure 4**).

The well logs utilized in the majority of log correlation include: clay volume (Vcl), effective Porosity (PHIE), water saturation (Sw) and also, some basic logs such as Caliper, variation between Neutron (Φ_N) and Density (Φ_D) porosity, variation between Rt and Rxo (deep and shallow resistivity logs).

Step (2) Structural modelling: This represents the first and the most important step in modelling workflow. Structural contour maps can then be made by computer from the surface and the correlated borehole [5].

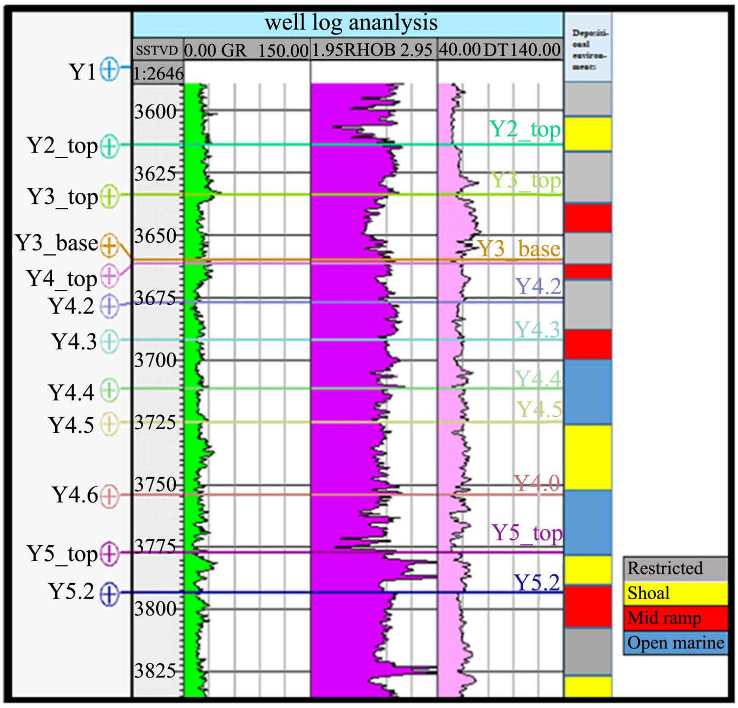

Figure 3. Main and minor reservoir units (Y1 to Y5 and their subdivisions), and suggested depositional environments of Yamama formation.

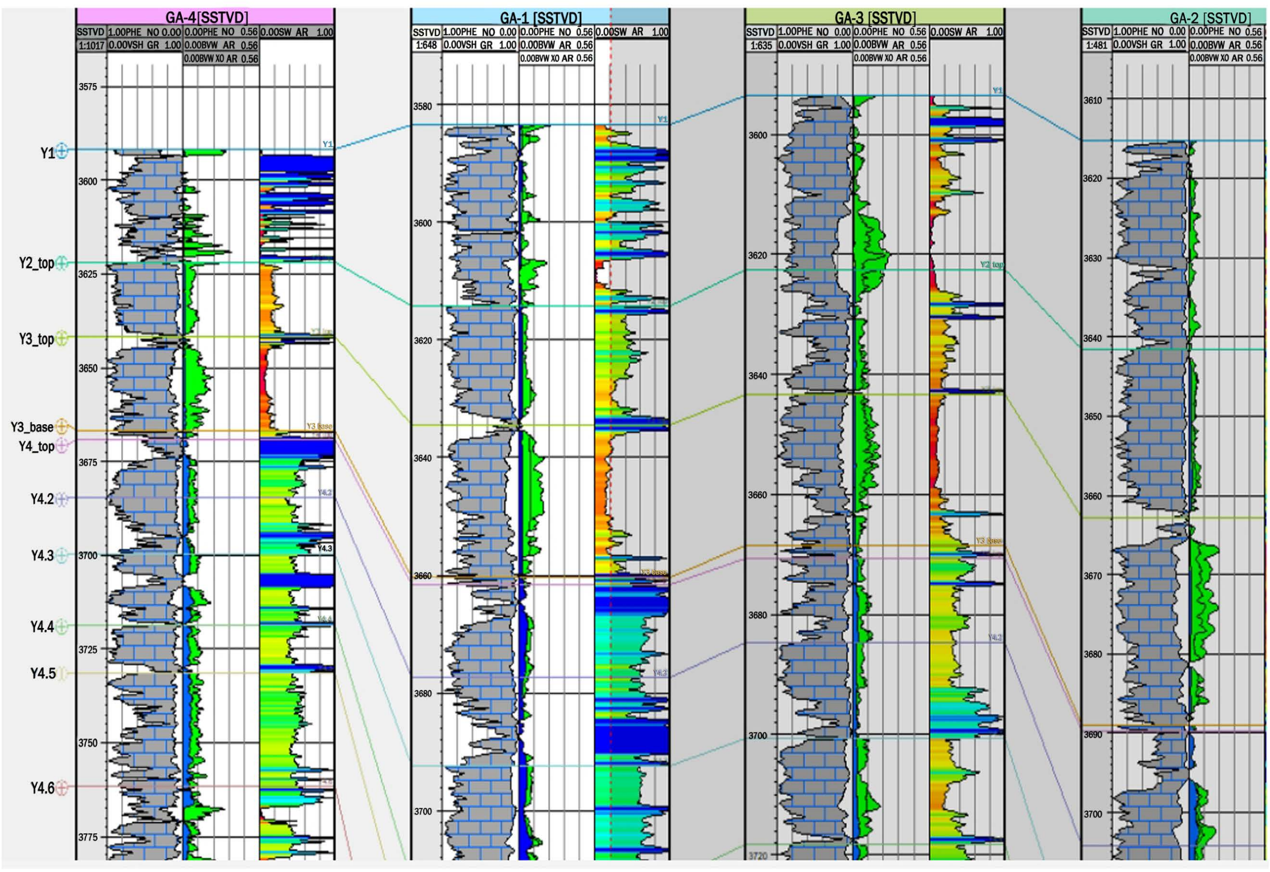

Figure 4. Correlation of reservoir units or zones among different wells in Gharraf oilfield.

Structural contouring used for building geological model would pass through three processes as follows: fault modeling, pillar gridding, and vertical layering.

At the most basic level, all that is required is a top reservoir structure map and the interpreted faults; a base surface may also be incorporated. The objective is to construct a consistent reservoir framework that can be gridded for a 3D geological model [1]. **Figure 5** shows a structural contour map drawn for the top of one of the units of the Yamama Formation which was inferred using Schlumberger Petrel Software (2015).

Step (3) 3D grid construction was carried out as one of steps of building static model which represents a lattice of horizontal and vertical lines utilized to visualize a three dimensional (3D) geological model.

A 3D grid simply divides the model into boxes. Each box is called a grid cell and will have a single rock type, one value of porosity, one value of permeability, one value of water saturation, etc. These are referred to as the cell's properties [6].

Step (4) Creation of Pillar gridding as a way of creating the grid, which represents the base of all modeling schemes. The skeleton of this gridding consists of top, mid and base skeleton grid [6].

The pillar gridding is essentially utilized to build the framework of the 3D grid as shown in **Figure 6**.

Step (5) Making horizons: This step was initiated via processing the vertical layering of the 3D grid in Petrel Software. This process offers a true 3D approach in the generation of 2D surfaces that were gridded in the previous step, taking the relationships between the surfaces into account [7].

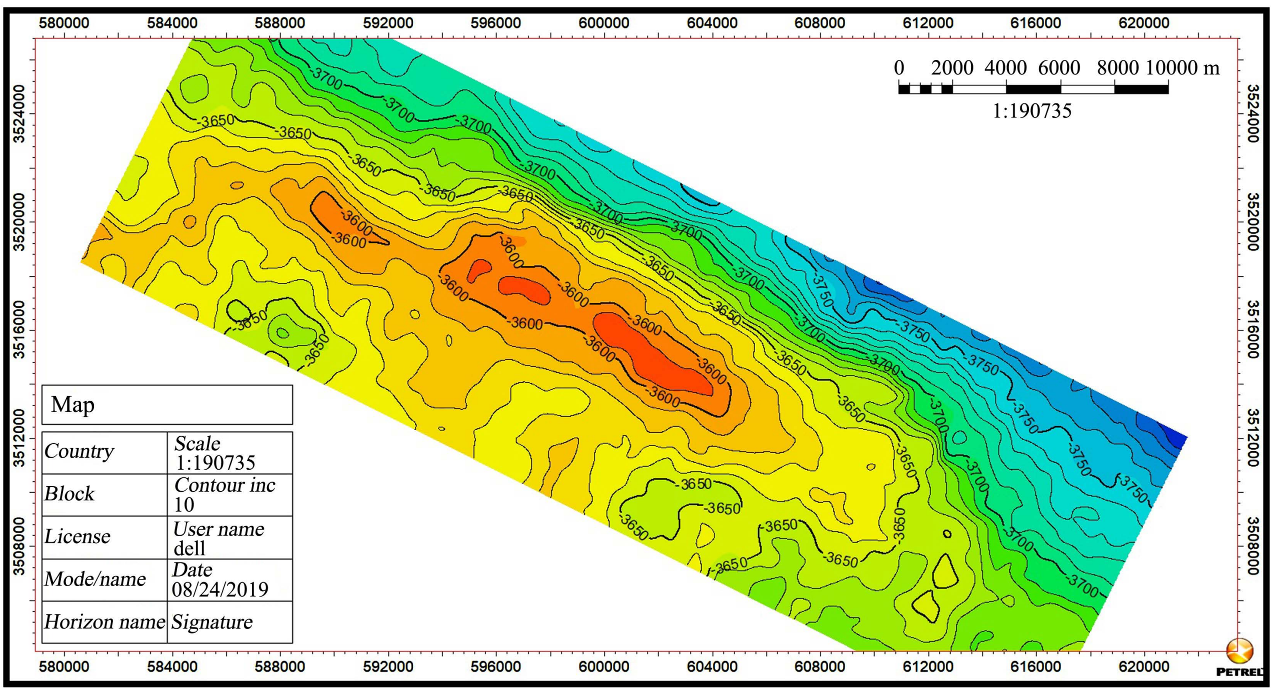

Figure 5. Structural contour map of the top of one reservoir unit in Yamama formation.

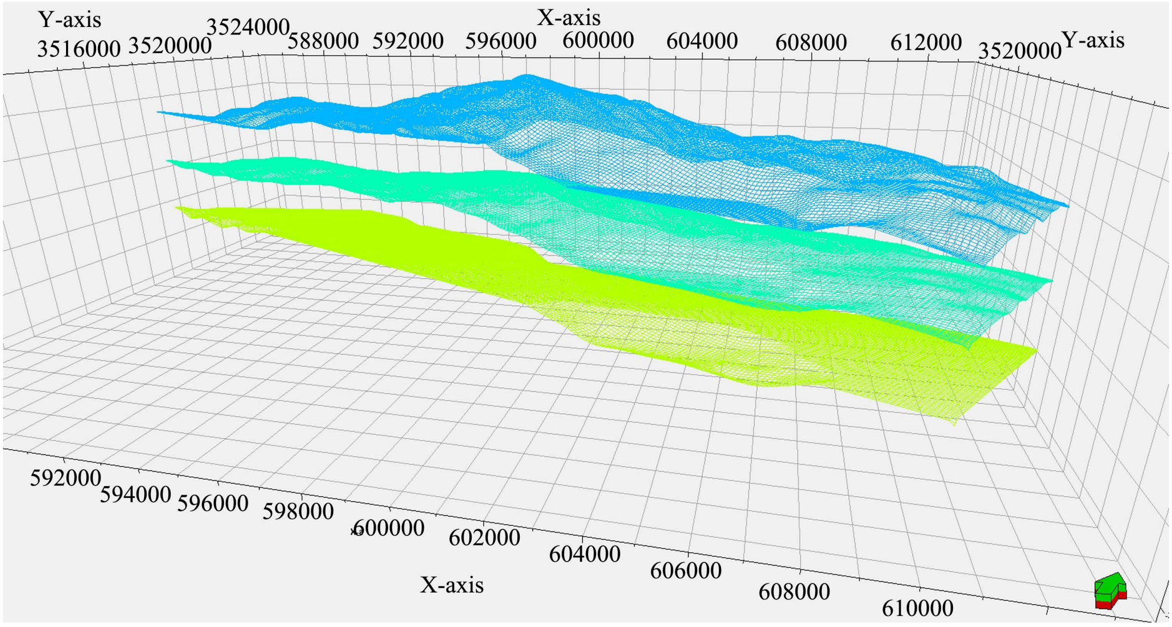

Figure 6. Three main skeletons of pillar grid resulted from 3D grid model.

Step (6) implies making layering to introduces the vertical thickness component of the cells by allowing the user to select either constant thickness or constant number of layers. These are selected to represent different geological situations, such as on-lap, down-lap, erosion, or differential compaction [1].

Modern geology requires accurate representation of volumes of layered rocks. This can be fulfilled through three-dimensional (3-D) geologic models that are increasingly used method to constrain geology at depth [8]. In the current case study, each reservoir unit was divided into several layers depending on facies and petrophysical properties.

Step (7) is the final step to complete building the geological model. This step implies modelling of petrophysical properties using geostatistical methods. This task represents filling the grid cell with property value to understanding the distribution of petrophysical properties and the accumulation of hydrocarbons.

Step (8) Scale up well logs: This step is intended to represent the discrete and continuous properties of the wells into a grid, as it is necessary to resample or scale up those parameters from a small scale in the wells to a large scale in the geogrids [7]. This process would have the averages of values of petrophysical properties (porosity, permeability, …, etc.) involved in cells of a three-dimensional grid.

Numerous statistical methods such as (arithmetic average, harmonic, and geometric methods) were employed to carry out this step. For example, the porosity and water saturation values were scaled up using the arithmetic average.

3. Results and Discussion

3.1. Microfacies Analysis and Depositional Environment

Microfacies analysis was done as introductory step to facies modelling including horizontal distribution of microfacies and sedimentary environments. This analysis was based on thin sections, logs interpretation leading to dividing the Yamama carbonates to four depositional environments; mid ramp, shoal, open marine and restricted marine (**Figure 3** and **Figure 7**).

After establishing the layering for reservoir, the layers for each reservoir unit were recognized to refer to specific facies and environment. The vertical stacking of these microfacies with their environments in the studied wells display high gamma ray and low porosity in mid ramp, high gamma ray and low porosity in restricted environment, low gamma ray and high porosity in shoal environment (**Figure 3**).

3.2. Facies Modeling

Facies modeling implies distribution of discrete facies throughout the model grid (**Figure 8**). In the prepared facies model (**Figure 7**), where facies are marked with different colors, the grainstone (green) and packstone (yellow) were common facies in the upper parts of the formation, whereas the mudstone-wackestone (brown) dominated the lowermost parts.

3.3. Petrophysical Model

Based on data acquisition and well logs, the petrophysical model was constructed by distributing the values of petrophysical properties (porosity, permeability, etc.) to each cell of the 3D grid by Petrel software using geo-statistical methods. The aim of a reservoir model is to provide a complete set of continuous reservoir parameters (*i.e.* porosity, and water saturation) for each cell of the 3D grid. Many different techniques can be used to process and to demonstrate these reservoir parameters [10].

3.3.1. Porosity Model

Depending on the porosity logs (density and neutron), the Porosity model was built and interpreted using the Petrel Program. The Facies distribution were employed as indicative to variation in porosity which would later lead to building the porosity model (**Figure 9**).

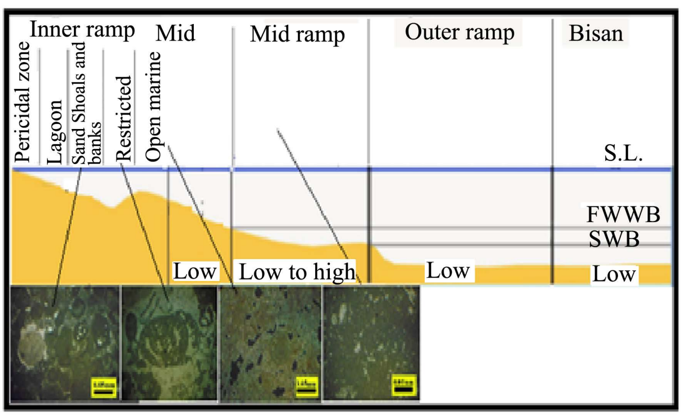

Figure 7. Proposed ramp model for Yamama formation (modified from [9]).

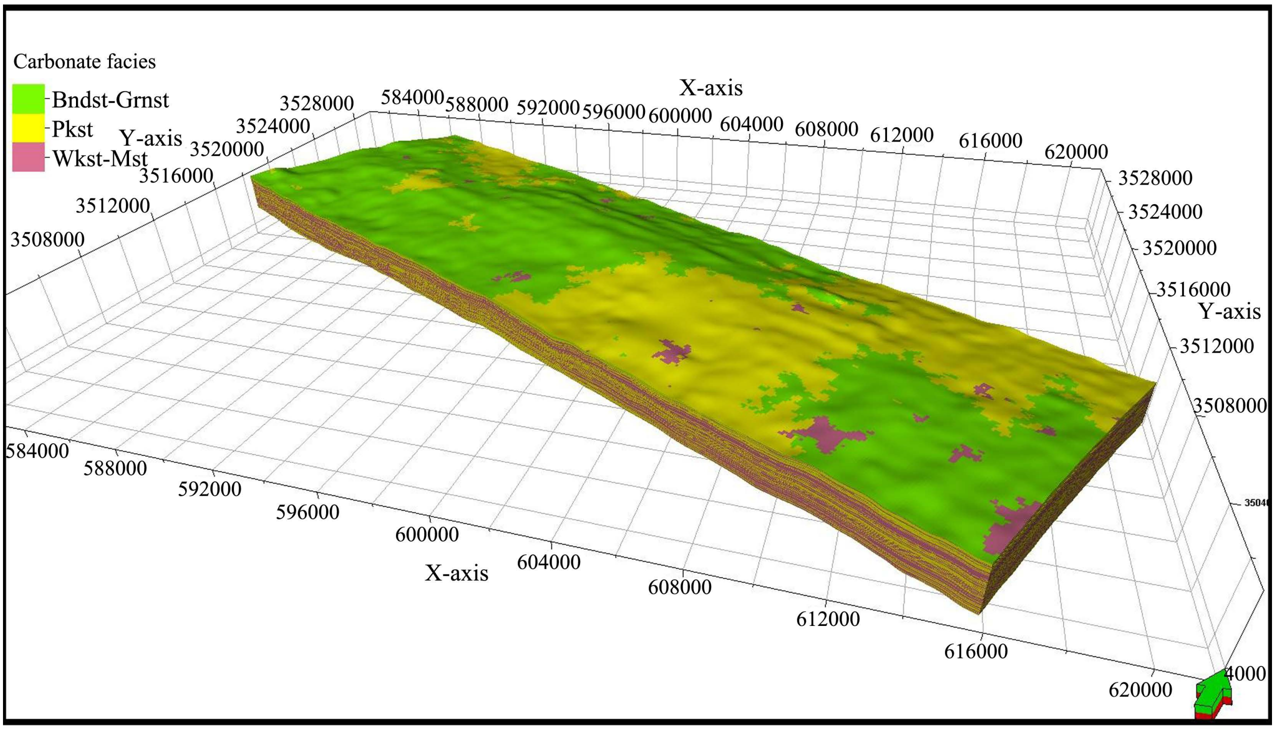

Figure 8. Facies distribution throughout modelling grid.

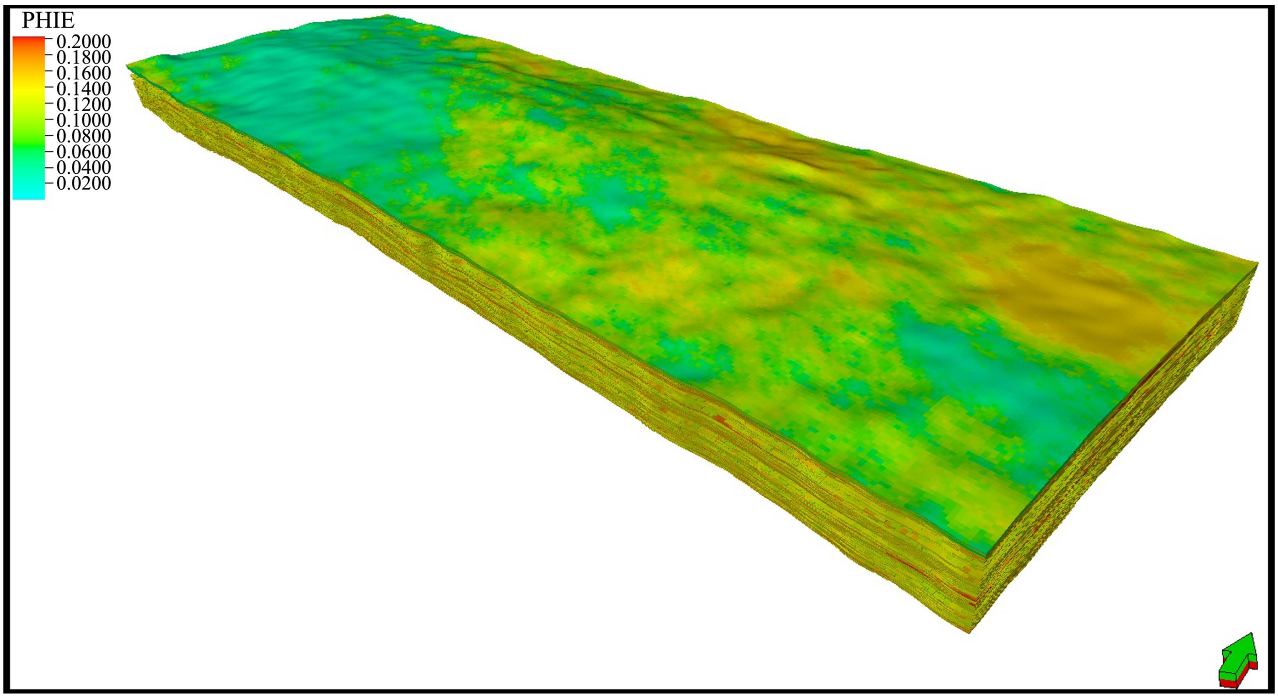

Figure 9. Porosity distribution model in Yamama reservoir. Different colors refer to various porosity values.

Based on the log-derived petrophysical properties, the rocks of Yamama Formation in Gharraf Oilfields were divided into five main reservoir zones or units (Y1 to Y5) and thirteen subdivisions (minor units). Similar conclusion was reached by in Subba, Luhais and Ratawi oilfields of southern Iraq [11].

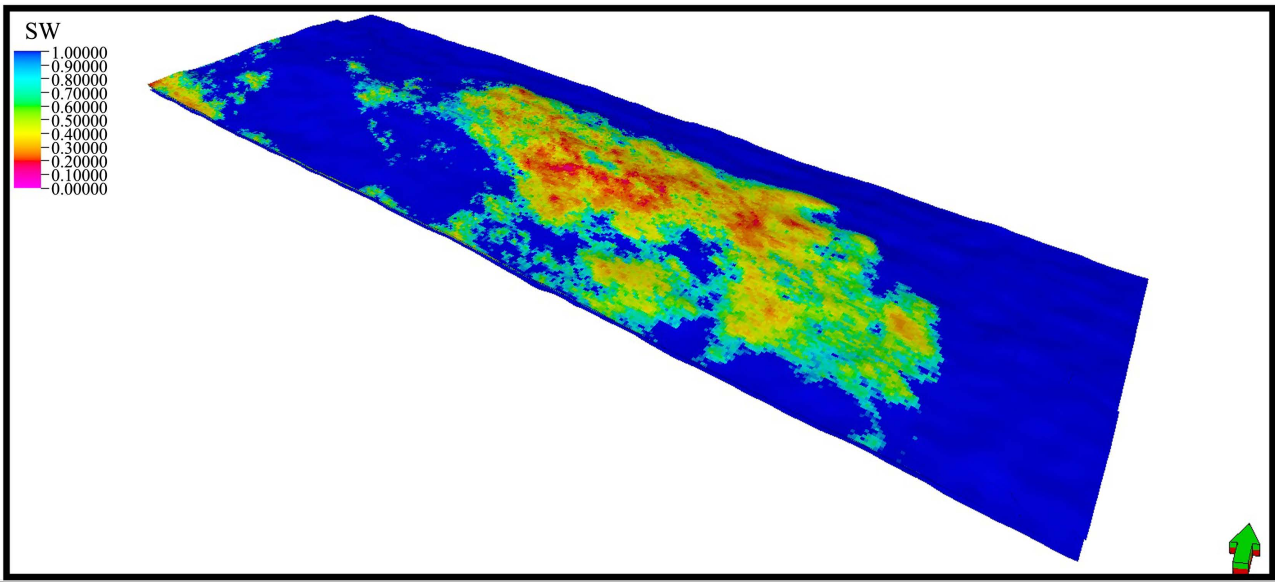

Figure 10. Water saturation distribution model in Yamama reservoir.

In the case study, the porosity of the unit Y3_top reaches 13.6% in well Ga-4. The porosity increased eastward up to 13.8% in well Ga-1, and decreases at the north to 12% in well GA-3. The porosity was estimated as 14% in well Ga-2, then, in the unit Y4.6, it reaches 15% in well Ga-4. The porosity decreased at the east down to 12.3% in Ga-1, with further decrease to 9% in well Ga-2.

3.3.2. Water Saturation Model

Facies distribution also offers an indication of the distribution of water saturation that enables building a model for water saturation for each reservoir unit within of case study (Yamama Formation) (**Figure 10**). For example, in some units the minimum value of water saturation at well GA-4 reaches 10.6%, at well Ga-3 in the north 12%, while at well Ga-2 it reaches 14.6%. The unit Y4.6 displays the minimum value of water saturation; 19.2%, at well GA-4, 23% at well Ga-1 in the east, while at well Ga-2, it rises up to 49%.

4. Conclusions

From the available core data and the analysis of different well logs, belonging to Yamama Reservoir in four wells in Gharraf oilfield, Southern Iraq, the following conclusions are reached:

1) The rock units of the Yamama Formation were divided, depending on their log-derived petrophysical properties, into five main reservoir zones or units (Y1 to Y5) and thirteen subdivisions (minor units). This division into units supported the recognition of the best reservoir zones and the optimum direction of properties improvement.

2) The gained model was helpful to visualize the distribution of petrophysical properties within the reservoir units.

3) The Correlation of selected wells GA-1, GA-2, GA-3, and GA-4 shows the

trends of improvement of reservoir quality and displays the variation in thickness of reservoir units and the change in petrophysical properties (*i.e.* changes in porosity and water saturation). It also shows that the effective porosity has improved in Y3_top. The correlation also displayed that water saturation increases in reservoir units Y2_top, Y3_base, Y4.4, and Y5_top and decreases in the reservoir units Y1, Y3_top, and Y4.6.

4) The building of the structural model, executed in the pillar gridding process, shows that the Yamama Formation is composed of two domes trending SE-NW.

5) The case study was performed by 3D grid systems of 150 grid cells along the x-axis, 245 cells along the y-axis, and many layers along the z-axis. The sizes of these grids were 100 m wide and 100 m long, and the total number of cells is 771'754 cells. The sizes of grids were chosen depending on the area of the field and to specify the variation in the petrophysical properties. The result from the Pillar Gridding is the main skeletons in top, mid and base skeletons.

6) The Petrophysical Modeling was constructed according to the values of porosity and water saturation that were determined from logs by statistical method. The model could show the variations of petrophysical property values (high or low), which, eventually helped to conclude the reservoir units.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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