

## Static Reservoir Modelling of Abura Field, Onshore Niger Delta, Nigeria

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### Abstract:

*This study deals with constructing a 3D geo-model using a suite of well logs and seismic data to optimize hydrocarbon field development. Static reservoir modelling is conducted to build a reliable, 3D geological representation of the subsurface reservoir's structural, stratigraphic, and petrophysical properties for the Abura field. Composite well logs were obtained from nine wells, and it consists of gamma ray, resistivity, density, and sonic logs. A sequential workflow was adopted, starting from determination of reservoir properties from well logs, structural interpretation of seismic data, construction of geological models, and analysis of the reservoir. Three reservoirs (3AB-6, 6AB-6 and 2AB-4) and two main lithologies, which are sand and shale. Alternations of sand and shale lithologies and three major reservoirs (3AB-6, 6AB-6 and 2AB-4) were observed and correlated throughout the field. The estimated petrophysical property values for the reservoirs show shale volume (0.05 - 0.35), porosity (0.12 - 0.30), water saturation (0.15 - 0.4), net-to-gross (0.12 - 0.30), and permeability (700 - 2000 mD), indicating good reservoir quality and high hydrocarbon accumulations. Distribution of petrophysical properties within the reservoirs was executed using geostatistical methods. The constructed reservoir property models show that the distribution of properties such as porosity, water saturation, net-to-gross, volume of shale, and permeability of the reservoirs depends on facies models. reservoirs are heterogeneous. The outcomes of this study can be used for developmental exploration studies and hydrocarbon reservoir simulation models in the Niger Delta.*

**Key Word:** Niger Delta, reservoir characterization, geostatistical method, Static modelling

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### I. Introduction

Nigeria is one of the world major hydrocarbon producing countries, involved in exploration and production of hydrocarbon resources. The Niger Delta province of Nigeria has large commercial accumulation of hydrocarbon. There has been an increase in the interest and demand for hydrocarbon in Nigeria as a result of the Federal government reliance on the revenue from the sales of crude oil, increase in population, and dependent on fossil fuel for economic activities. This has led to a detailed study of the Niger Delta sedimentary basin. The Niger Delta sedimentary basin, is a prolific oil province, associated with complex stratigraphy of sand and shale formations, comprising accumulations in deltaic systems of the world. This hydrocarbon province has only one petroleum system called the Akata-Agbada petroleum system (Tuttle et al. 1999). It is regarded as the most significant region within the West African Continental Margin (Aizebeokhai and Olayinka 2011). Hydrocarbons (oil and gas) in the Niger Delta are mostly extracted from the Agbada Formation that is predominantly made up of unconsolidated sandstone and shale sequences (Evamy et al., 1978; Weber and Daukoru, 1975).

Conventional seismic interpretation techniques and well log analysis are two essential techniques commonly used in the petroleum industry for reservoir characterization and hydrocarbon evaluation. Geoscientists use these techniques to obtain knowledge of the physical properties and structural setting of the subsurface reservoir rocks and their fluid contents. These various techniques are utilized to study hydrocarbon reservoir and provide information at many different scales. For example, well logs measure reservoir properties within a few centimetres around the well with high resolution while seismic covers a huge volume, having poor resolution that is limited to a few meters vertically and tens of meters horizontally. When well log analysis is integrated with 3D seismic interpretation, it provides a detailed view often leaves uncertainties in identifying and delineating hydrocarbon reservoirs. However, the integration of reservoir characterization/modelling with well log data and seismic attributes analysis provides a more robust framework, enabling the characterization of reservoir heterogeneity, fluid distribution, and hydrocarbon volume with higher accuracy.

Reservoir characterization is a systematic means of quantitatively determining and assigning reservoir properties, establishing geologic information and uncertainty in spatial variability (Ameloko and Owoseni, 2015; Ajisafe and Ako, 2013). Reservoir characterization generally deals with the gross volume of rocks within the trap that has the capacity to hold hydrocarbon (Eshiemokhai and Akhirebulu, 2012). Adeoti et al. (2014) in their

research, considered reservoir characterization as a key to quantifying producible hydrocarbon, while Chopra and Michelena (2011) see it as an important source of information one needs to describe the state of a reservoir, which incorporates the complete architecture, both its internal and external geometry, distribution of properties and fluid flow within. Poor reservoir characterization is always responsible for poor production rate, and high-water production etc., which in most cases, have caused asset holders to ignorantly abandoned fields which still have very good production potentials as marginal fields.

Designing and constructing reservoir models is an important step in hydrocarbon reservoir development because reservoir modelling process integrate and reconcile all available geophysical, geological and engineering information and data (Weber, 2012). Reservoir modelling involves the creation of a model representation of a petroleum reservoir, used for facilitating tasks such as estimating hydrocarbon reserves, predicting future production direction, proper well placement, exploring alternatives, and for managing hydrocarbon reservoir (Abu-Hashish et al. 2024). Geological modelling can be divided into two stages, which are: structural modelling and property modelling. Structural modelling is process of constructing a geometric model of subsurface reservoir. Property modelling deals with the process of creating subsurface properties models such as Vshale, porosity, permeability, NTG and SW which were obtained during petrophysical calculations.

The reservoir modelling uses seismic, well logs and geological data to develop the geomodel. The goal of reservoir modelling in the Oil and Gas Industry is to optimize the value of a project. Therefore, there is a shift from a deterministic thinking to an integrated approach in order to understand the heterogeneity of complex subsurface structures. Correct estimation of Stock Tank Oil Initially in Place (STOIIP) is very crucial in the oil industry because of the huge investment require for hydrocarbon exploration and production.

Hydrocarbon reservoir has a lot of uncertainty associated with it in terms of its depth, and determination of the correct amount of hydrocarbon quantity it contained. The uncertainty is as a result of the complex nature of the subsurface (Adejebi and Olayinka 1997; Barde et al. 2002). Geoscientists use several available information to create geomodel in describing the structures of the reservoir in the subsurface (Kurah et al, 2021). The better a reservoir is understood, the greater the ease and possibility of optimizing its potential.

Geostatistics modeling is one of the techniques used for characterizing hydrocarbon reservoirs and capturing the heterogeneity of reservoirs. Reservoir modelling tools make use of geostatistics techniques. It is crucial for constructing better representation of reservoir heterogeneity, and for integrating different types of data, with variation in scales and direction of continuity. One of the tools in geostatistics is the Variogram, which is a measure of statistical dissimilarity between the pairs of data measurements (Deutsch, 2002; Olea, 1999; Isaaks and Srivastava, 1989): Variogram is a model of spatial correlation and continuity that qualifies the directions and scales of continuity. Kriging and Stochastic simulation were applied to the data in order to obtained the value of the data at unsampled points. Geostatistics routines are implemented in the reservoir modeling of the petrophysical properties of the delineated reservoirs in the Abura field.

## **II. Geology of the Study Area**

The study area (Abura field) is located in the part of the onshore Niger Delta. It is located between Latitude 5° 25' N to 5° 35' N and Longitude 5° 50' E to 6° 05' E (Figure 1). The Niger Delta was formed as a result of the African and South American plate, at the site of the triple junction in the late Jurassic and continuing into the cretaceous, thus leading to the opening of the Southern Atlantic. The Niger Delta is a low gradient delta plain-shelf slope wedge with an estimated area exceedingly over 200,000 square kilometres. The tectonic framework of the continental margin along the west coast of Equatorial Africa is controlled by Cretaceous fractured zones expressed as trenches and ridges in the deep Atlantic. The trough represents a failed rift triple junction associated with the South Atlantic. According to Short and Stauble (1967), the evolution of the Niger delta is related to the development of the RRR triple junction and the subsequent separation of the South American and African continents.

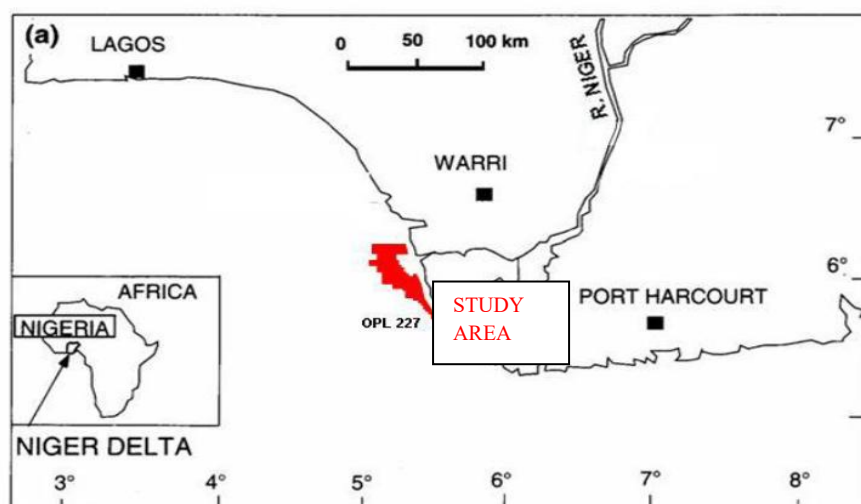


Figure. 1: Map of Niger Delta showing the Location of the studied Area

Stratigraphically, the Niger Delta province as defined by Klett et, al. (1997) from the Eocene to the present, has prograde southward, forming dobebelt that represents the most active portion of the delta at each stage of its development (Doust and Omotsola, 1990). This dobebelt forms one of the largest regressive deltas in the world (Kulke, 1995). The Niger Delta province is made up of only one identified petroleum system; this system is known as the tertiary Niger Delta (Akata-Agbada) petroleum system. The tertiary section of Niger Delta is divided into three Formations, representing prograding depositional facies that are distinguished based on sand – shale ratios (Short and Stauble, 1967). The formations are Benin, Agbada and Akata Formations (Figure 2)

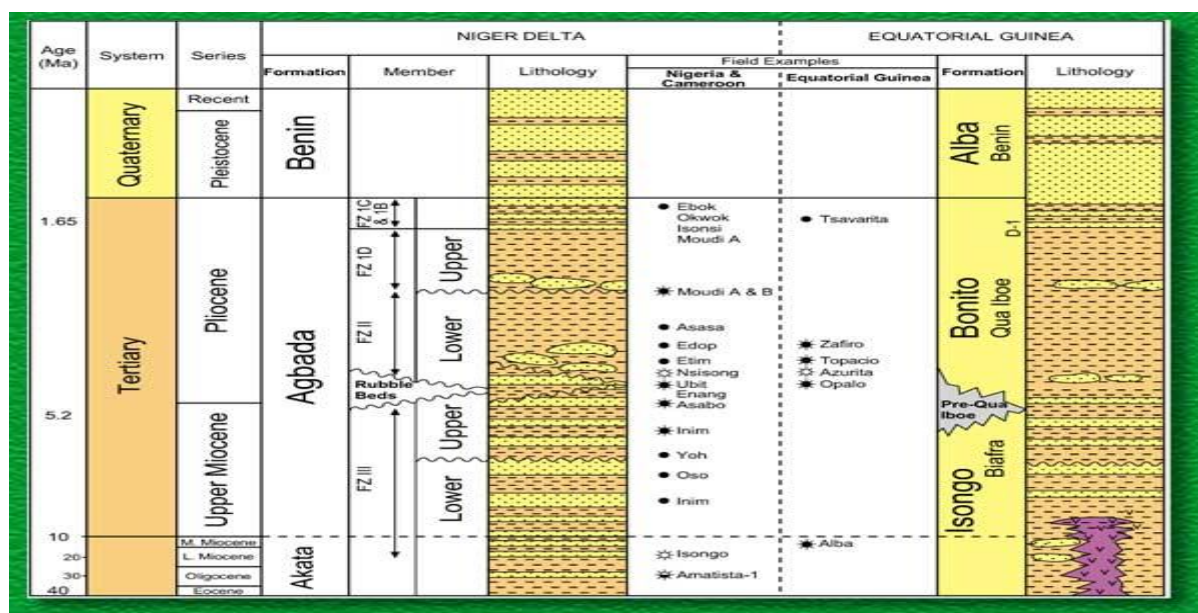


Figure.2: Stratigraphic setting of Niger Delta. Adapted from Ozumba (2009)

The Benin Formation is the youngest of the Delta sequence. It outcrops in Benin, Onitsha and Owerri provinces in Niger Delta area. It consists mainly of sand and gravels with thickness ranging from 0 - 2100m. The sands and sandstones in this Formation are coarse – fine and commonly granular in texture and partly unconsolidated. Some common minor components found in the Benin formation are feldspars, hemalites, lignite streak and limonite coatings. The Agbada is the principal host of Niger Delta petroleum and it consists of sand, sandstone and siltstones (Beka and Oti, 1995). The deposition of Agbada Formation began in Eocene and continues into Pleistocene. In the lower portion, shale and sandstone beds were deposited in equal proportions.

However, the upper portion is mostly with only minor shale interbed. Its thickness ranges from 300m – 4500m (Short and Stauble, 1967). The Akata formation forms the base of the transgressive lithologic unit of the Delta complex. It is of marine origin and it is composed of thick shale sequence (potential source rock), turbidite sand (potential reservoir in deep water) and minor amount of clay and silt (Avbovbov, 1998). Beginning in the Palaeocene and through the recent, the Akata formation was formed when terrestrial organic matter and clays were transported to deep water areas characterised by low energy conditions and oxygen deficiency. The approximate range of thickness is from 0 – 6000m

The architecture of the Niger Delta is dominated by gravity-driven deformation above the overpressure, ductile Akata shales. The mobility of these shales generates a structural style **hierarchy** from onshore gravity-driven growth-faulted rollover anticlines to deep-water toe-thrusts and shale diapirs, which all impact trap generation, reservoir compartmentalization, and directional migration pathways (Zhang et al., 2020; Chima et al., 2022). The delta has a wide variety of structures, with syndepositional growth faults being the most abundant. These faults form in the Akata decollement during periods of rapid sediment loading, and the faults propagate upward in the Agbada succession, generating hanging-wall rollovers that eventually trap hydrocarbons and represent many of the commercial traps in the basin.

Most known hydrocarbon traps in Niger delta fields are structural although some stratigraphic traps have also been recognized. The structural traps developed during synsedimentary deformation of the Agbada paralic sequence (Evamy et al, 1978; Stacher, 1995). The severity and complexity of structural deformation increase from the Northern delta and Greater Ughelli depobelt to the structurally complex coastal swamp and offshore depobelt where we have the influence of the mobile under compacted and overpressures shales on structural deformation becomes very pronounced. Doust and Omatsola, (1990) describe a variety of structural trapping elements which include anticlinal dip closures, upthrown fault and downthrown fault, including those associated with simple rollover structure, clay filled channels, structures with multiple growth faults, structure with antithetic faults and collapsed crest structures

### **III. Material And Methods**

The materials used for this study are mainly suite of well logs, Well Deviation Data, seismic volume and check-shot data. The data analysis techniques involve well correlation, petrophysical properties evaluation, structural, property and petrophysics modelling using geostatistics techniques. The modelling was carried out in Schlumberger Petrel software.

#### **Well Correlation and Petrophysical Properties Evaluation**

The available gamma ray and resistivity logs were used for delineation of lithology and reservoirs in the field. The reservoir tops were correlated across the wells. Correlation is the creation of this association between one well and another. The process of well correlation was based on lithology using gamma, resistivity, neutron and density logs of the given wells. Nine wells were correlated base on the lithologic that were delineated. Petrophysical properties such as porosity, water saturation, shale volume, net to gross and permeability of the observed reservoirs were calculated. The computed values of the properties were used for the initialization of the reservoir properties modelling.

#### **Reservoir Modelling.**

The construction of geomodel is a common procedure for geological horizons and faults, and it form geometric frames from 3D grids and form boundaries of facies and petrophysical models representing the properties of rock. The static modelling includes structural, facies and petrophysical properties modelling. Static reservoir modelling is the art of constructing 3 dimensional “container” that contains data. It is “static” because it represents the reservoir at a single point in time usually before production starts. The starting point in static model design is the construction of 3D cellular grid. The stages involve in building static reservoir model is shown in Figure 3. Three types of modelling were carried out and they are: Stratigraphy modelling, Structural modelling and property modelling. The property modelling comprises of facies modelling and petrophysical modelling.

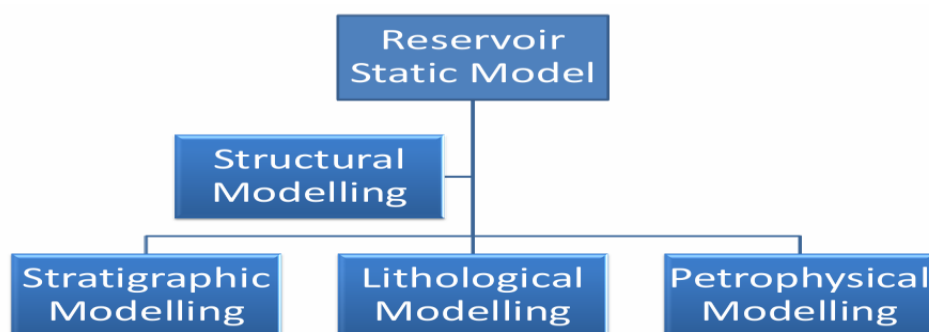


**Figure 3:** Stages involved in Building Reservoir Static Model

#### **Stratigraphic Modelling:**

Well correlation has been applied as a relatively easy method to give an idea and allow simple visualization of the changes in the thickness within formation units and the change of petrophysical properties (i.e. Changes in permeability and porosity). The Well Section Window in Petrel allows displaying well logs in a specified order, with the logs and well tops. The space between horizons is divided into layers which mimics the original depositional environment.

#### **Structural Modelling:**

Structural modelling is the first step in building a 3D model. Structural modelling consists of fault modelling, pillar gridding, and vertical layering. All three options are tied together into one single three-dimensional grid. The structural model represents a skeleton of the study area from which all other models were built.

#### **Fault Modelling:**

This involves the delineation of faults in the geological model that form the basis for the generation of the 3D grid. The faults were obtained from the seismic interpretation and loaded into Petrel software using the appropriate file of type format. The delineated faults in the seismic data were used for constructing the fault model in depth domain.

#### **Grid Construction**

Construction of 3D grid model is the initial step to build the reservoir model. The grid is used for dividing a model up into boxes, called a grid cell. The grid cell is usually assigned single rock type, one value of porosity, single value of water saturation. 3D Grid is a network of horizontal and vertical lines utilized for illustrating a 3D geological reservoir model.

#### **Pillar Gridding:**

Gridding involves creating of gridded surface from seismic interpretation, structural maps and faults. The gridded surfaces in this study have been created on the tops of reservoir sands and petrophysical models. The geo-cellular model of the 3D grid is mainly based on the top, middle and base skeleton that are constructed within this process. The grid boundary was created with reference to the selected area boundary considered in velocity modelling. The Make horizons process in the software is the first step in defining the vertical layering of the 3D grid. Horizon modelling was used to define the main vertical architecture of the reservoir model. When introducing these horizons to the set of pillars generated in the Pillar gridding process, all intersections between the pillars and the horizons become nodes in the 3D grid.

#### **Layering:**

This involves building of stratigraphic horizons, zones, and layers into the 3D grid using the make horizon process. Horizons were defined using seismic surfaces as input data. Layering process was performed to create small divisions within the modelled zones to capture the reservoir properties whilst the Facies and Petrophysical logs upscaling processes. This involves using 3D approach in creating 2D

surfaces. The 2D surfaces are gridded in the same way as the 3D volume. Several horizons were created for all geological surfaces generated. The top surfaces were used for creating the horizons.

### **Zonation**

This is the process of creating the different zones of the reservoir between each horizon from the surface. Inter-zone layering was used for creating layer surface. The layering in the model zone was done by creating division between horizons and subdividing the zones into layers based on vertical thickness of observed lithofacies in the wells.

### **Reservoir Property Modelling:**

Property modelling is the act of filling the cells of the 3D grid with reservoir (petrophysical) properties. The Petrel software was used to propagate the values of the petrophysical property along the created grid layers when interpolating between data points. These techniques are dependent on the geometry of the constructed grid. The property modelling algorithm used for modelling in Petrel software is grouped into two different processes: Facies modelling and Petrophysical modelling. When interpolating between petrophysical data, the Petrel software generates property values along the grid layers. The goal of property modelling is to distribute petrophysical parameters between the wells so that it ideally retains the reservoir heterogeneity and fit (match) the petrophysical parameters obtained from the wells.

### **Facies Modelling:**

Facies modelling is a means of distributing and Interpolation of discrete data such as facies discrete facies throughout the model grid. The first step of the process was to populate the model with the facies type. Cell-based technique was adopted in this study in which each cell in the model is assigned a specific facies, capturing the spatial variability of rock types within the reservoir. For this step, the Gaussian indicator simulation technique was used to simulate the facies. The process involves many different facies modelling approaches such as Object Modelling – mostly used for facies modelling to populate discrete facies models with different bodies of various geometry, facies code and fraction. In this study, two facies' types (sand and shale) were defined in the Field on the basis of reservoir property relationships and were used to populate the geocellular model of the Field reservoir.

### **Petrophysical Modelling:**

This is the interpolation of continuous data such as porosity, water saturation, net – to- gross, volume of shale and permeability within the reservoir. The sequential Gaussian simulation was used for the petrophysical data modelling. The sequential gaussian simulation makes use of input parameter distributions, variograms, trend and well data. The semi-variogram technique of geostatistics was used to generate local variations of the petrophysical properties within the study area.

### **Porosity Modelling**

Porosity modelling was done by utilizing well data and the variogram generated from porosity data analysis. The porosity modelling was constrained by reservoir facies.

### **Volume of Clay (Vclay) Modelling**

The modelling of Vclay was carried out by using values computed from the gamma ray logs and it was conditioned on facies using variogram data analysis results for the computed shale volume.

### **Permeability Modelling**

The permeability modelling was done using the computed permeability and the result of the semi variogram. The permeability modelling was conditioned with the facies model.

### **Water Saturation Modelling**

The water saturation computed for the reservoir from well logs was used for the modelling and it was constrained with the facies model.

### Geostatistics Modelling Techniques

The basic geostatistics techniques used in this study are variogram and kriging. These two geostatistics methods are described as follow:

#### Variogram Modeling

The semi-variogram was utilized to model the spatial variation in the reservoir properties. The semi -variogram describes geological continuity of spatial variables in a homogeneous layer. The experimental variogram is given as;

$$2\gamma(h) = \frac{\sum_{i=1}^{N(h)} (x_i - x_{i+h})^2}{2N(h)} \quad 1$$

where

$2\gamma(h)$  = variogram,

$x_i + h, x_i$ : = variables  $x$  at location  $i$  and  $i + h$ ,

$h$  = lag vector,

$N(h)$  = number of pairs.

The variogram begins from zero at the origin  $h = 0$  and reaches to a constant value (sill) at certain distance which is known as the range (correlation length<sup>19</sup>). The range represent the correlation of a variable along different direction. The data are independent of each other beyond the range and have no spatial structure<sup>7</sup>. Some theoretical models such as Exponential, Gaussian and Spherical were applied and fitted on the experimental variogram and the best model was selected.

#### Kriging Modeling

Kriging is a geostatistical estimation method and it is known as the best-unbiased estimator. This estimator has least estimation variance and also ensures unbiasedness of estimations. The kriging techniques are based on weighted moving average

$$Z_v^i = \sum_{i=1}^n \lambda_i Z_{iv} \quad 2$$

Where

$Z_v^i$  = grade estimation,

$\lambda_i$  = weight or importance of the value

$Z_{iv}$  = the grade of  $i$ th sample.

The distributions of the variables (petrophysical data) were normalized. Were normalized in order to apply the linear kriging technique.

#### Estimation of reservoir volume

Estimating the quantity of hydrocarbon in the reservoir is a very important stage in the modeling process as it helped in making decision on the best reservoir bearing hydrocarbon. This is very important because it acts as a guide for field exploration and development. After a static model of a field was done, the structural model and the petrophysical model built were used to calculate reserves in terms of Stock Tank of Oil Initially in Place (STOIIP)<sup>22</sup>.

$$STOIP = \frac{7758 \times Area \times Thickness \times Porosity(1 - S_w) \times NTG}{FVF}$$

3

Where:

STOIP (mmstb) = stock tank oil initially in place

Sw = water saturation

NTG = net-to-gross ratio

FVF = formation volume factor (a constant)

## IV. Result

### Lithology and Reservoir Delineation.

Two lithologies were identified in the gamma ray logs obtained from the wells in the area. The gamma ray logs show alternating sequences of sand and shale which is an indication of the Agbada Formation in Niger Delta basin. Similarly, three hydrocarbon reservoirs (3AB-6, 6AB-6 and 2AB-4) were also delineated (Figure 4).

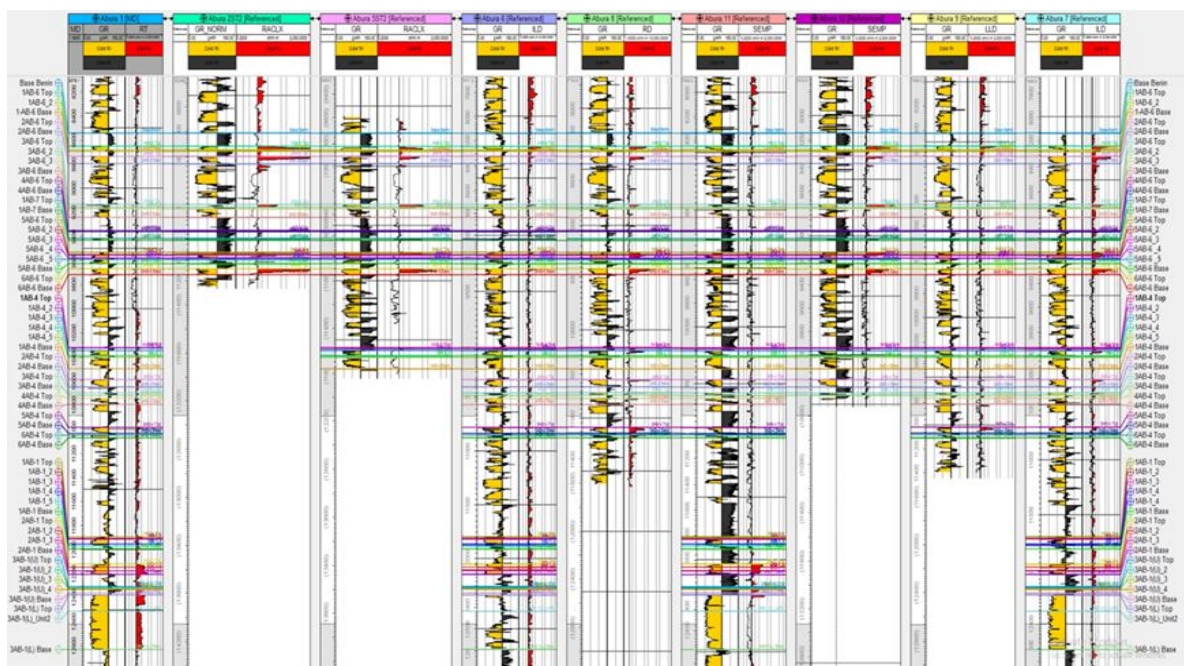
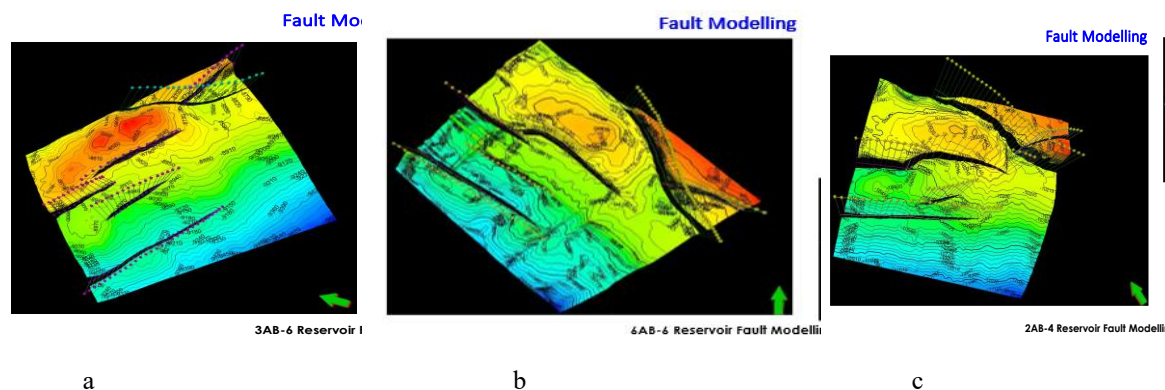


Figure. 4: Well correlation panel showing delineated lithologies and reservoirs.

### Reservoir Structural Models

Faults observed in the 3D seismic sections were modelled and pillar gridded in order to generate grids for the horizons. The fault modeling seeks to digitize and display all fault skeleton according to their trends in the field of study. The faults have been interpreted using fault sticks. The generated fault models for the three reservoirs in the field are shown in Figure 5a, 5b and 5c.



**Figure, 5:** Fault Models for Reservoirs (a) 3AB-6 (b) 6AB-6 (c) 2AB-4

### Pillar Gridding

External grid boundaries were created around the fault trends in order to obtain the shape and geometry of the reservoirs. Grids were added to generate 10,000 cells (the grids divided the model into cells), which can allow flow model to be done (Figure 6a, 6b and 6c). Each grid cell has a single rock type and one value of porosity, permeability, water saturation and net to gross ratio (NGT) respectively. The pillar gridding was used for delineating the top, middle, and base of the structural model.

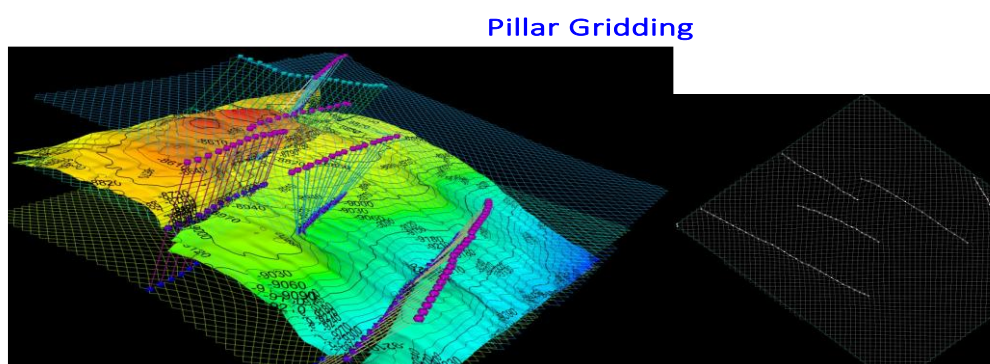


**Figure 6a:** Reservoir 3AB-6 Pillar Gridding

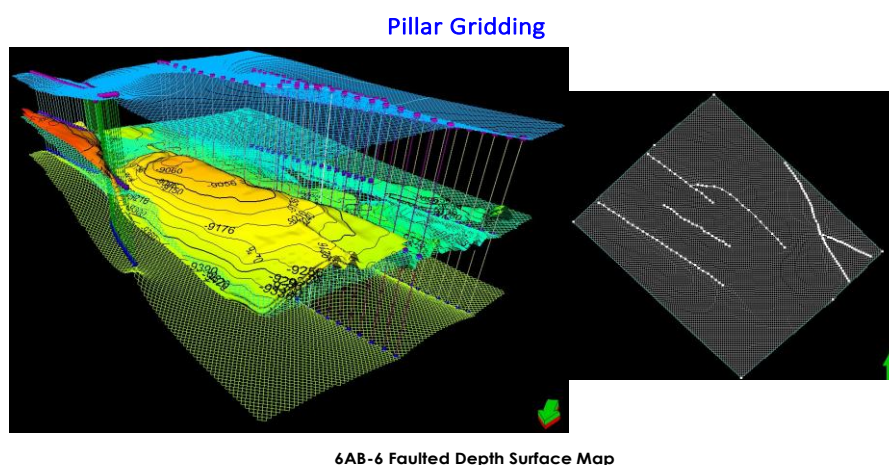
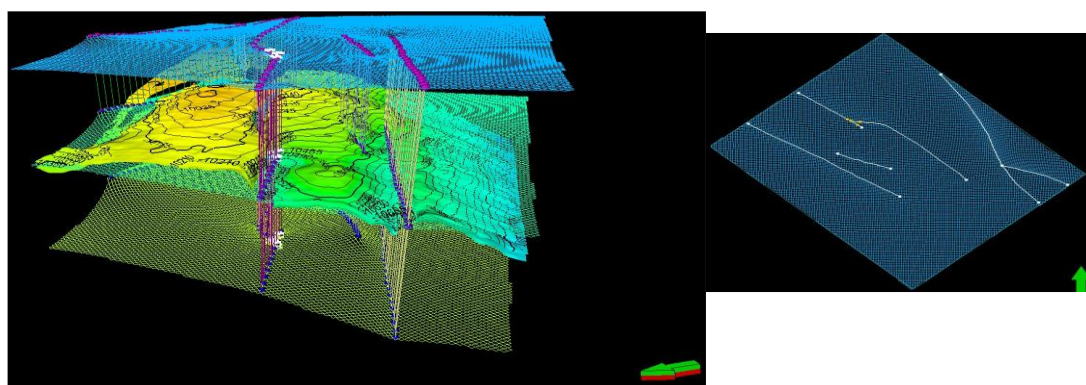


**Figure 6b:** Reservoir 6AB-6 Pillar Gridding

### Pillar Gridding



2AB-4 Faulted Depth Surface Map

Figure 6c: Reservoir 2AB-4 Pillar Gridding

### Facies Model

Facies modelling is the process of distributing discrete facies within the reservoir model grid. The reservoirs (3AB-6, 6AB-6 and 2AB-4) display the presence of shale (colored gray), fine sand (colored brown) and sand (yellow) as shown in Figures 7a, 7b and 7c. The map indicated for reservoir A has dominance of shale within the northeast flank, and presence sand within the north- west flank. Reservoir B denotes a good prospect of hydrocarbon due to high occurrence of sand which implies high porosity and permeability.

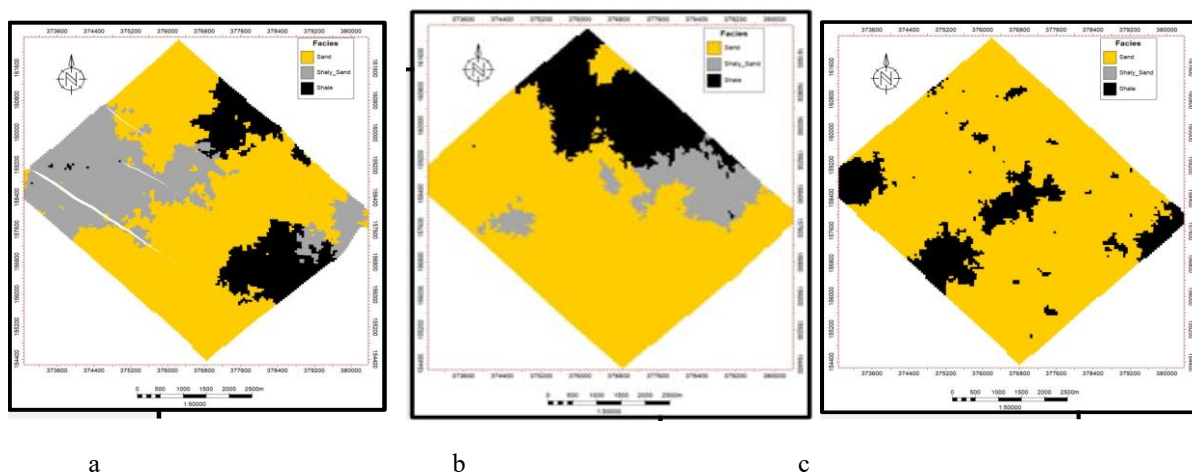


Figure 7: Facies models for reservoirs (a) 3AB-6 (b) 6AB-6 (c) 2AB-4

### Porosity Model

Porosity is the void spaces in a reservoir and it is the measure of the volume of voids over the total volume of the reservoir or rock. Porosity of reservoir rocks ranges between 0 and 1, or between 0 and 100%. The porosity of rocks is crucial when evaluating the potential volume of water or hydrocarbon in a reservoir. Figures 8a, 8b and 8c show the porosity models for reservoirs 3AB-6, 6AB-6 and 2AB-4.

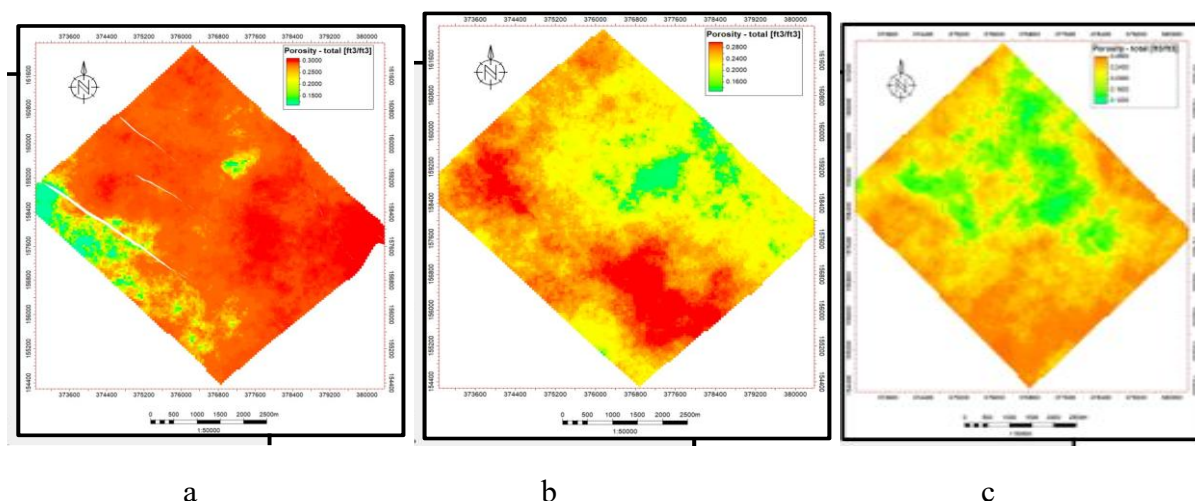


**Figure 8:** The porosity model for reservoirs (a) 3AB-6 (b) 6AB-6 (c) 2AB-4

The maps show the prominence of good porosity distribution from the obtain porosity value (blue coloration) in the central region of reservoir A including the north-west and south-east flanks. Reservoir B has a very high distribution of porosity.

### Permeability Model

Permeability is a measure of interconnectivity of pore spaces in rocks and it is a crucial reservoir property that is utilized in dynamic modelling. Figures 9a, 9b and 9c are the permeability models generated for reservoirs 3AB-6, 6AB-6 and 2AB-4. The high permeability values are indicated with green, yellow and red colouration while low permeability is indicated with brown and blue colours.

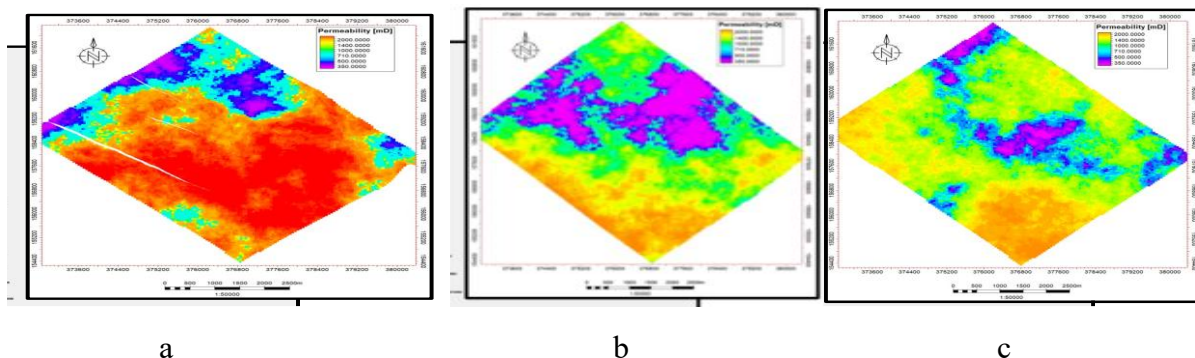


**Figure 9:** Permeability model for reservoirs (a) 3AB-6 (b) 6AB-6 (c) 2AB-4

### Water Saturation

Water saturation is the volume of water present in the reservoir pore spaces. Figures 10a, 10b and 10c show the water saturation models of reservoirs 3AB-6, 6AB-6 and 2AB-4 respectively. The maps reveal that there is a high percentage of green coloration which signifies hydrocarbon. The yellow coloration depicts low water saturation. Reservoir A shows a high percentage of green coloration evenly distributed. A small portion of yellow coloration was seen mainly in the southwest region. Reservoir B has very high green coloration distributed in the central and northwest regions.

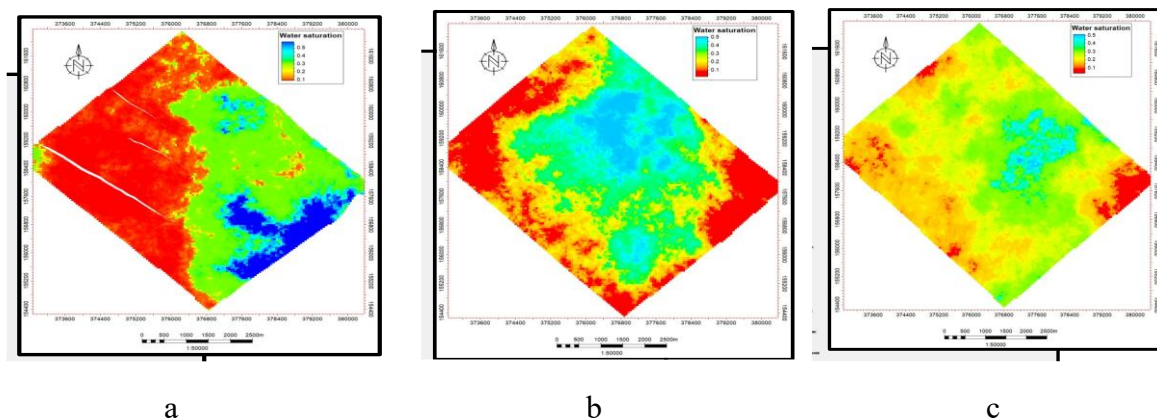


**Figure 9:** Water saturation model for reservoirs (a) 3AB-6 (b) 6AB-6 (c) 2AB-4

### Net to Gross

Net to gross (NTG) is a measure of the volume of reservoir that is occupied by hydrocarbon. The generated net to gross models for reservoirs 3AB-6, 6AB-6 and 2AB-4 are shown in Figures 11a, b and 10c. The reservoirs denote a good prospect evident from their high net-to-gross value. Reservoir A shows high net to gross (red/yellow coloration) in the central and southeastern flank. Reservoir B shows the high net to gross (yellow/red coloration) at the central and northwestern flank.

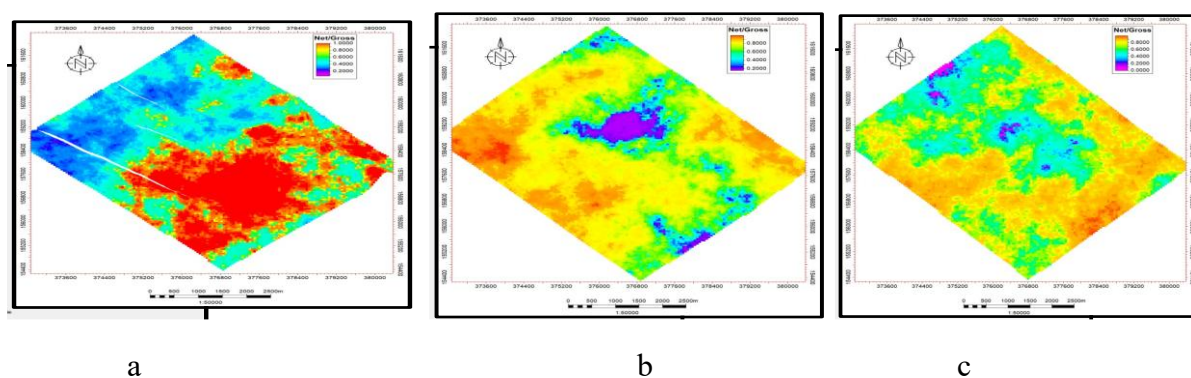


**Figure 11:** Net-to-gross model for reservoirs (a) 3AB-6 (b) 6AB-6 (c) 2AB-4

### Volume Estimation

The volumetric calculation was carried out in the generated reservoir models after propagating all the petrophysical parameters in the grid. In the estimation, the average of reservoir property values such as porosity, permeability, and saturation was used. The Petrel software volume calculation utility was used for this exercise. The calculation utility estimates the volume of each cell in the 3D grid and then adds them to obtained final total volumetric estimation. The computed petrophysical properties were used to estimate the original oil in place (OIIP) and gas in place. The STOIP was calculated by defining the reservoir fluid contacts for different segments of the reservoir. The computed STOIP for reservoirs 6AB-6, 2AB-4 and 6AB-3 are approximately 192.8 MMstb, 125.4 MMstb and 43.9 MMstb respectively. Reservoir 6AB-6 has the highest value while reservoir 6AB-3 has the least (Table 1).

**Table 1:** Computed STOIP for reservoirs 6AB-6, 2AB-4 and 6AB-3

| Reservoir | STOIP<br>(MMstb)          | HCPV<br>(MMRB)            | Pore Vol<br>(MMRB)        | Net Rock<br>Vol (10 <sup>6</sup> ft <sup>3</sup> ) | Bulk Vol<br>(10 <sup>6</sup> ft <sup>3</sup> ) | NTG $\approx$<br>NRV/BV<br>(P <sub>50</sub> ) | So $\approx$<br>HCPV/PV<br>(P <sub>50</sub> ) | STOIP/BV<br>(stb/kft <sup>3</sup> ,<br>P <sub>50</sub> ) |
|-----------|---------------------------|---------------------------|---------------------------|----------------------------------------------------|------------------------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------------------------------------|
| 6AB-6     | 184.90–200.71<br>(192.81) | 222.97–242.04<br>(232.50) | 290.88–314.21<br>(302.55) | 9,052–10,134<br>(9,593)                            | 13,147                                         | 0.73                                          | 0.77                                          | 14.7                                                     |
| 2AB-4     | 108.44–142.37<br>(125.40) | 130.77–171.68<br>(151.22) | 172.13–220.87<br>(196.50) | 5,764–6,833<br>(6,299)                             | 9,538.8                                        | 0.66                                          | 0.77                                          | 13.1                                                     |
| 3AB-6     | 30.05–57.69<br>(43.87)    | 36.24–69.56<br>(52.90)    | 47.04–88.71<br>(67.87)    | 10,677–12,191<br>(11,434)                          | 22,708.7                                       | 0.50                                          | 0.78                                          | 1.9                                                      |

## V. Discussion

Two major lithology (sandstone and mudstone) were delineated from the gamma ray log. The gamma ray logs from all the boreholes show alternation of sandstone and shale which is an indication that the log zones are part of Agbada formation in the Niger Delta (Beka and Oti, 1995). Three reservoirs designated as reservoirs 6AB-6, 2AB-4 and 3AB-6 respectively were observed and model for the field.

The reservoir modelling involves structural and petrophysical property modelling. The structural model consists of fault modelling, pillar gridding, and vertical layering. The structural model formed the framework for the distribution of the petrophysical properties. The three facies' models depicted detailed visualization of reservoir heterogeneity within the 6AB-6, 3AB-6, and 2AB-4 reservoirs. The porosity maps for the reservoirs provide critical insights into the spatial distribution and variability of porosity within each reservoir. The porosity models reveal the heterogeneity of pore space within each reservoir, which influences fluid storage capacity, flow pathways, and reservoir performance. Similarly, the water saturation and permeability models for the reservoirs also show the spatial variation. These variations are important in the reservoirs management.

The reservoir zoning and layering models constructed for three reservoirs indicate a structurally consistent geocellular framework. The models show a broad structural high and low. The interpreted horizons were subdivided into laterally continuous stratigraphic layers that honour the structural relief and the delineated faults that control reservoir compartmentalization.

The three facies' models constructed for the three reservoirs showing the complex heterogeneity of the reservoirs, with varying spatial distributions of different facies types. The three facies model shows some variations that may be as a result of different depositional environment and diagenetic histories. These patterns indicate the significance of facies modelling in understanding reservoir architecture, guiding development plans, and optimizing hydrocarbon recovery.

The porosity models for the three reservoirs show heterogeneity within each of the reservoir. The zones with high-porosity are crucial for productive potential. The spatial variability of the porosity the reservoirs indicate the importance of reservoir characterization for optimizing development strategies. The differences observed in the porosity models for the reservoirs indicate the influence of depositional and diagenetic factors on pore development, ultimately affecting reservoir quality and performance.

The maps of the volume of shale models obtained for the reservoirs show areas of high and low shale concentration. The shale distribution within the reservoirs varies from one reservoir to another. This may be attributed to variations in geological features or reservoir properties. These maps help in visualizing the spatial distribution of shale within the reservoirs, which is crucial for exploration, production planning, and understanding reservoir behaviour. The differences across the models assist in evaluating how various configurations or data inputs influence the reservoir characterization.

The water saturation models generated for each reservoirs show spatial distribution of water saturation within each reservoir indicating areas of high and low saturation. The variations in water saturation within the models is been interpreted to indicate reservoir heterogeneity, and geological features. Zones associated with high water saturation indicate areas of water encroachment, which can impeded hydrocarbon production. These

visualizations help in understanding the water distribution, which is crucial for reservoir management, production planning, and enhanced recovery strategies.

The net-to-gross (NTG) reservoir models for three different the three reservoirs (6AB-6, 3AB-6, and 2AB-4) shows the spatial distribution of net-to-gross ratios across the reservoir. Areas with higher NTG suggest zones with good reservoir quality, meaning more net reservoir material while areas of lower NTG areas indicate less net reservoir material, possibly less productive zones. The net-to- gross models reveal the heterogeneity of the reservoirs, which is vital for efficient development. Knowledge of these NTG distributions can aid geoscientists and engineers in optimize well placement, enhance recovery, and plan reservoir management effectively.

The generated permeability models for three different reservoirs: 6AB-6, 3AB-6, and 2AB-4. shows how permeability varies spatially within each reservoir. The permeability model is critical for understanding fluid flow and reservoir performance. The models exhibit heterogeneous permeability distribution. High permeability zones are scattered but appear concentrated in certain regions. Low permeability areas indicating zones with restricted fluid flow. The heterogeneities influence fluid movement, which is an indication that production and injection rates could vary significantly across the reservoir. High permeability zones are good for efficient hydrocarbon extraction. Stock Tank Oil Initially in Place (STOIIP) values for reservoir 6AB-6 ranges narrowly from  $184.90 \times 10^6$  STB to  $200.71 \times 10^6$  STB. The volumetric evaluation of the 2AB-4 reservoir reveals substantial in-place hydrocarbon potential with relatively (STOIIP) ranges from  $108.44 \times 10^6$  STB to  $142.37 \times 10^6$  STB. The STOIIP values for reservoir 3AB-6 ranges from approximately 30.05 to  $57.69 \times 10^6$  STB.

## VI. Conclusion

The combination of all available geophysical, geological, and petrophysical data has been used in building a high resolution 3-D static model of the reservoirs. The reservoir modelling involves static modeling, In the static modelling, structural model was constructed for each of the reservoir. The structures were the populated with petrophysical properties to create property model. The reservoir property model created are shale volume, water saturation, porosity, net to gross and permeability models. The property models were used for the volumetric analysis. The 3-D static models can be applied in well planning. The generated reservoirs models show that the field has a good petrophysical properties for hydrocarbon potential. This study has led to a detailed description and understanding of the reservoirs and the results will provide a very effective economical and management strategy for the observed reservoirs.

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