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Research Article

FACIES MODELLING AND PETROPHSICAL PROPERTIES OF X-FIELD, ONSHORE, NIGER DELTA, NIGERIA

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INTRODUCTION

Reservoir Data:

When constructing reservoir models, each piece of information has its own characteristic scale at which it provides information. No single source of information determines the reservoir uniquely. Many sources of data are available for constructing reservoir models. The main challenge in reservoir modeling is to bring such multi-scale data simultaneously into a single model accounting for their difference in scale, their level of accuracy and their redundancy. Many sources of data are available for reservoir modeling. They may be grouped as follows:

I. **Geological data :** Any data related to the style of geological deposition such as:
   - ❖ Core data: porosity, permeability and relative permeability measurements
   - ❖ Well-log data: Any suite of logs that indicate lithology, petrophysics and fluid types near the well-bore
   - ❖ Sedimentological and stratigraphic interpretation
   - ❖ Outcrop analog data

II. **Geophysical data :** Any data originating from seismic surveys such as:
   - ❖ Surfaces and faults interpreted on 3D seismic
   - ❖ Seismic attributes
   - ❖ Rock physics data
   - ❖ Time lapse 4D seismic data

III. **Reservoir engineering data :** Any data related to well testing and production of the reservoir such as:

- PVT data
- Well test data
- Production data

Aim of the research work:

The aim of this study is to integrate well log data and seismic data to build a reservoir static model of an X-Field

Scope of Study:

The static model of X-Field will be conditioned to seismic and well log data.. The Scope of this modeling project is limited to the state of the input data, the quality of the geologic, geophysical and petrophysical interpretations in the field, and the purpose for evaluation of the field. A reliable 3D seismic interpretation will be a direct input into the Petrel 3D grid model, Petrophysical modeling will be required to optimize rock and fluid property. Other elements of the modeling process such as facies distribution and geostatistical analysis will similarly depend on the quality of the data and interpretations available.

Location of Study Area:

X-Field is located in the onshore depobelt of the Niger Delta Basin, where thick Late Cenozoic Clastic sequence of Agbada Formation were deposited in a deltaic fluvio-marine environment

GEOLOGICAL OVERVIEW

Lithology:

Lithologies of Cretaceous rocks deposited in what is now the Niger Delta basin can only be extrapolated from the exposed Cretaceous section in the next basin to the northeast--the Anambra Basin . From the Campanian through the Paleocene, the shoreline was concave into the Anambra Basin (Hospers, 1965), resulting in convergent long shore drift cells that produced tide-dominated deltaic sedimentation during transgressions and river-dominated sedimentation during regressions (Reijers et. al., 1997). Shallow marine clastics were deposited farther offshore and, in the Anambra Basin, are represented by the Albian-Cenomanian Asu River Group, Cenomanian-Santonian Eze-Aku and Awgu Shale, and Campanian/MaastrichtianNkporo Shale, among others (Nwachukwu, 1972; Reijers et. al., 1997). The distribution of Late Cretaceous shale beneath the Niger Delta is unknown.

In the Paleocene, a major transgression referred to as the Sokoto transgression (Reijers et al., 1997) began with the Imo Shale being deposited in the Anambra Basin to the northeast and the Akata Shale in the Niger Delta Basin area to the southwest (Figure 4). In the Eocene, the coastline shape became convexly curvilinear, the longshore drift cells switched to divergent, and sedimentation changed to being wave-dominated (Reijers et al., 1997). At this time, deposition of paralic sediments began in the Niger Delta Basin proper and, as the sediments prograded south, the coastline became progressively more convex seaward.

Depobelts:

Deposition of the three formations occurred in each of the five off lapping siliciclastics sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide, prograded southwestward 250 kilometers over oceanic crust into the Gulf of Guinea (Stacher, 1995), and are defined by synsedimentary faulting that occurred in response to variable rates of subsidence and sediment supply (Doust and Omatsola, 1990). Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt (Evamy et al., 1978; Doust and Omatsola, 1990). Five major depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history.

Doust and Omatsola (1990) described three depobelt provinces based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increases their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault. The distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope.

Hydrocarbon Source:

Much discussion has been made about the source rock for petroleum in the Niger Delta. Possibilities include variable contributions from the marine shale interbedded with paralic sandstone in the Agbada Formation and the marine Akata shale. Based on organic matter content and type, Evamy et al., (1978) proposed that both the marine shale (Akata Formation) and the shale interbedded with paralic sandstone (Lower Agbada Formation) were the source rocks for the Niger Delta oils.

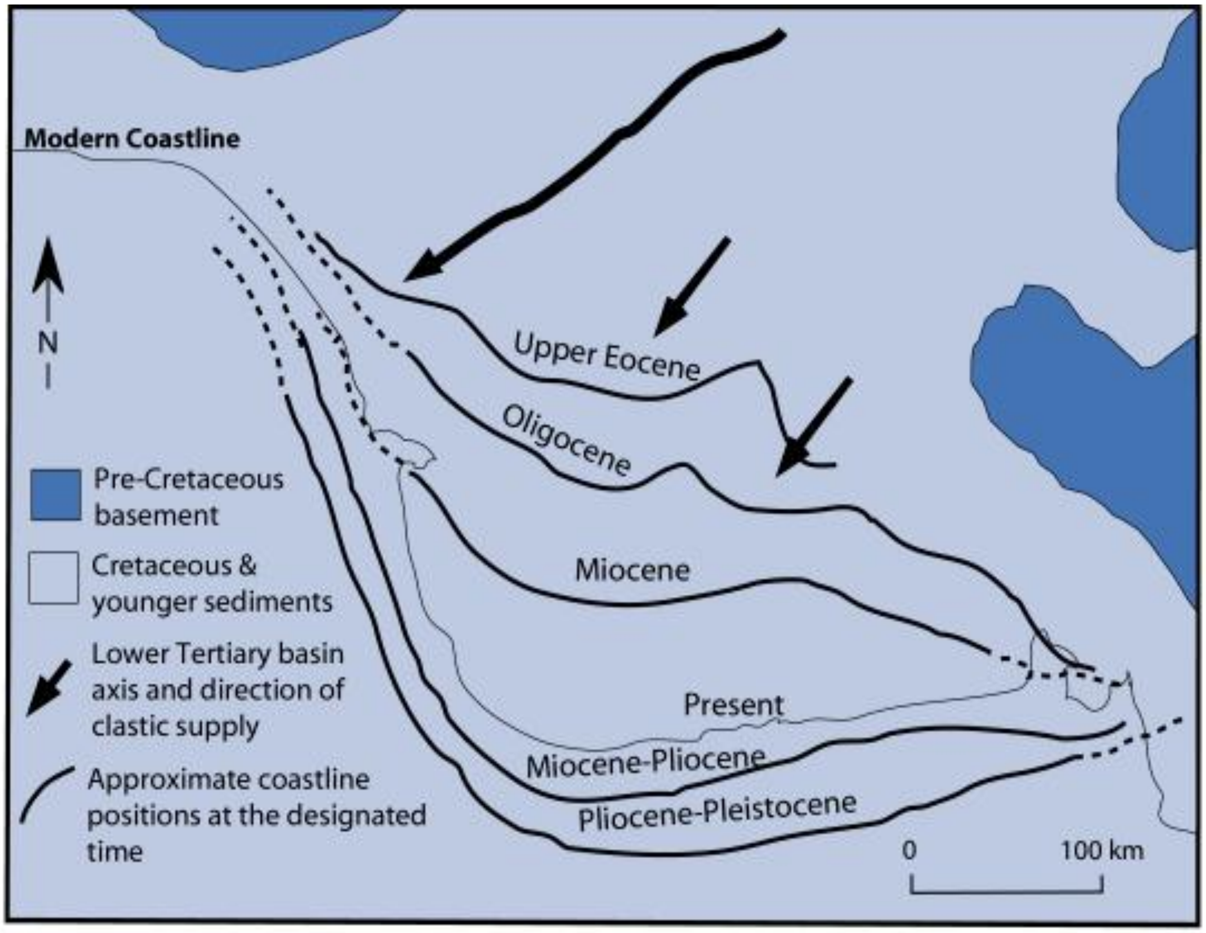

Figure 1: Progradation of the Niger Delta coastline since 35Ma.

However, Stacher (1995) proposes that the Akata Formation is the only source rock volumetrically significant and whose depth of burial is consistent with the depth of the oil window.

METHODOLOGY

The Reservoir Modeling Workflow:

Reservoir modeling workflow proceeds in stages. The stages consist of structural modeling such as horizons and faults, facies modeling and petrophysical modeling. There is extensive conditioning to hard data and seismic data and these results to a high resolution geo-cellular model. This study aims to present the current practice for building a static reservoir model. .The workflow is as shown in figure 8. This workflow will proceed with three major frameworks:

1. The structural and reservoir framework
2. The depositional, and
3. The reservoir geostatistical framework.

Within the structural and reservoir framework, the general architecture of the reservoir will be determined. This is the stage at which large scale structures are determined. The depositional and geostatistical framework will address the facies distribution and petrophysical information.

The workflow of frameworks can be summarized as follows:

- Determining the top, bottom and style of each layer and the determination of the location of fault blocks. Seismic data is used for this purpose, and Well tops are used to locally constrain the surfaces.
- Build a 3D stratigraphic grid that is aligned with the surfaces and the faults. These grids are usually corner point geometry and are refined where necessary such as around the faults.

Application of Static Modeling to X-Field:

This aims to introduce the X-Field reservoir of the Niger Delta Sedimentary Basin with detailed description of Static modeling workflow.

Geological Description:

Exploration and development of sandstone reservoirs require a reasonable prediction of sandstone occurrence and morphology. The morphology is usually determined by the depositional environment and the environment interpreted from the rock properties observed from subsurface log signatures.

The purpose of studying depositional environments is to predict the size and shape of a reservoir sequence from a single vertical segment, such as that exposed in a core or log. The deposition in X-Field is related to the transitional environment, which ranges from fresh to brackish water deposits of coastal plains to shallow marine deposits. The X-field represents a typical deltaic depositional sequence.

Deltaic sandstones typically show an increasing sand content and grain size in the upper section of the log that reflect the vertical gradation from marine prodelta shale below to delta front sandstone above. This behaviour is typically observed in the X-field reservoir. The relative amount of sand and shale in vertical sequence is reflected in the Gamma ray log of the XCPG2 and XCPG3 well logs. The Gamma ray log responds to increasing sandiness by deflection of the signature to the left and increasing shaliness by deflection to the right.

Geological Description of E1 Sand:

The main geological interpretation of this sand is based on the gamma ray log response in the two wells. The sand is within depths of 10126.83 feet (3086.658meters) and 10172.24 feet (3100.499meters) in the XCPG2 well with a net thickness of 36.5feet (11.1252meters), and at depths 10427.04 feet (3178.162meters) to 10463.19 feet (3189.18meters) in the XCPG3 well with a net thickness of 26 feet (7.9248meters). Sand E1 is predominantly quarztarenite deposited in a regressive, wave dominated, shallow marine system which developed parallel to the coastline through the propagation and stacking of barrier bars and beach or shoreface sequences. E1 sand has an average porosity of 0.22in both wells, average water saturation of 0.27 in well XCPG2 and 0.32 in well XCPG3, and average permeability value of above 1200mD.

Geological Description of X-Field Shales:

Shale was consistently found in all of the X-Field wells and serves as the marker separating the reservoirs. The shale is of large thickness and is considered a consistent shale barrier, which provided the reservoir seal between the sands.

Procedures and Methods:

In order to present an inter-well correlation of the heterogeneous reservoir of the X-Field, Petrel software has been used. In the approach, three types of modeling have been carried out according to the different results of study parameters of the X-Field reservoir. These modeling types are:

- Structural Modeling
- Property Modeling
    1. Facies Modeling
    2. Petrophysical Modeling

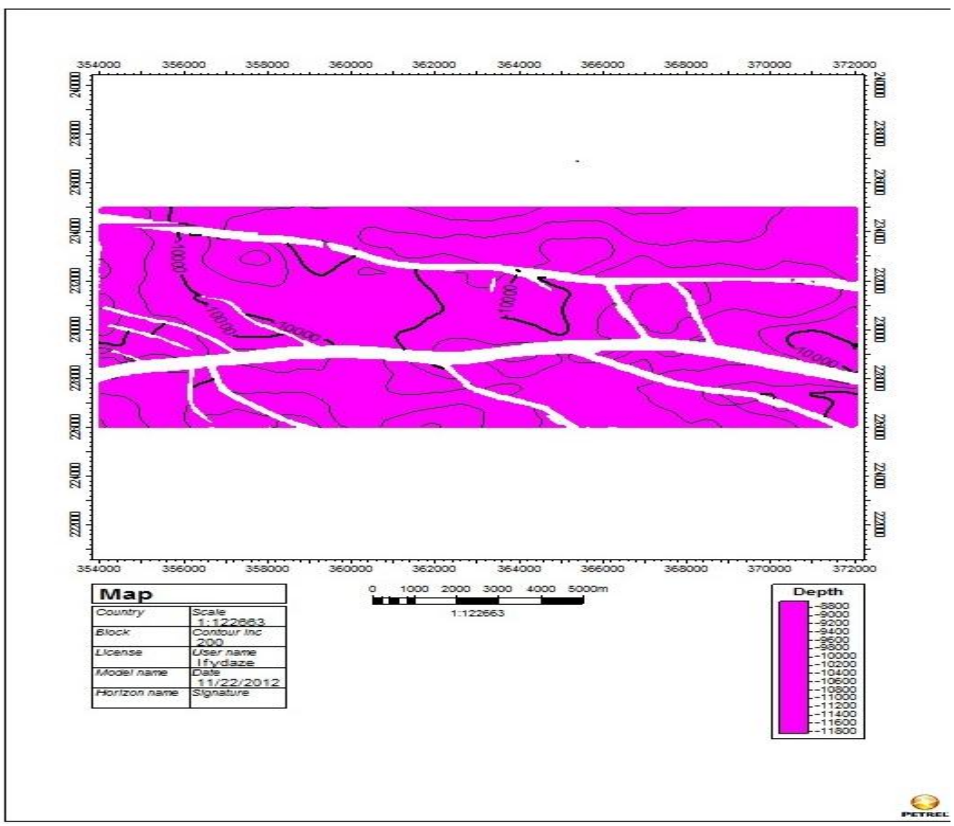

Figure 2: Top Structure Map of the X-Field showing the major faults

Structural Modeling:

Structural modeling is the first step in building a 3D model. Structural modeling consists of fault modeling, 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 are built.

Fault Modeling:

This involves the definition 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 study of the X-Field and loaded into Petrel software using the appropriate file of type format.

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.

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. Zonation is the process of creating the different zones of the reservoir from the surfaces. Layering involves creating inter-zone layering. Layering within the models was done with the following hierarchy:

1. Division between horizons (18 zones).
2. Subdivision of the zones into 99 layers based on minimum vertical thickness of the key lithofacies in the wells.

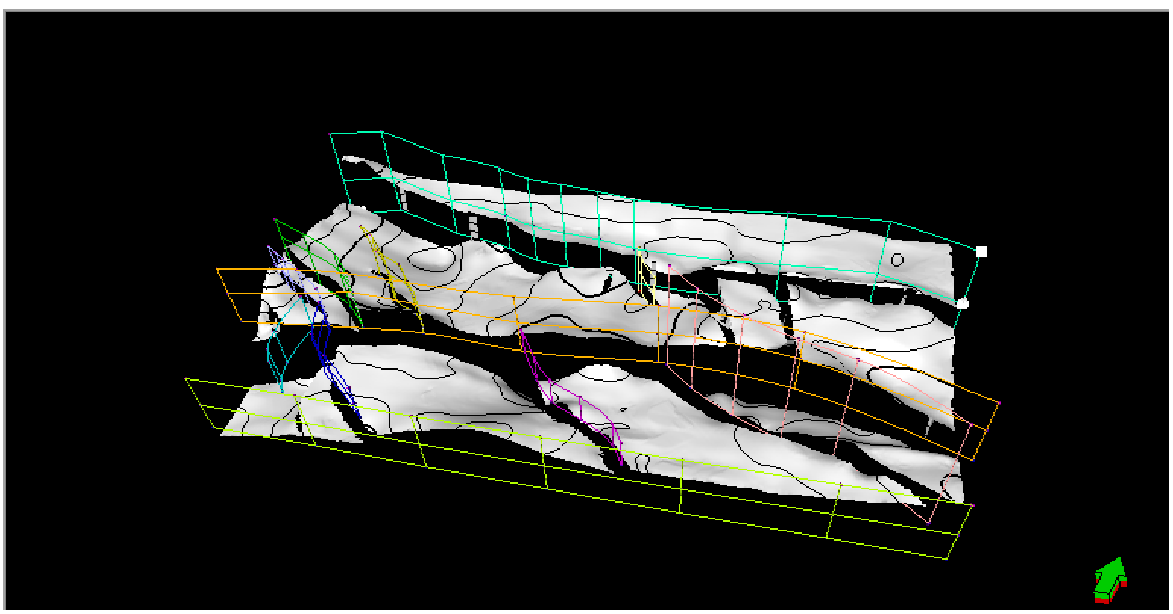

Figure 3: Illustration of fault model of the X-Field

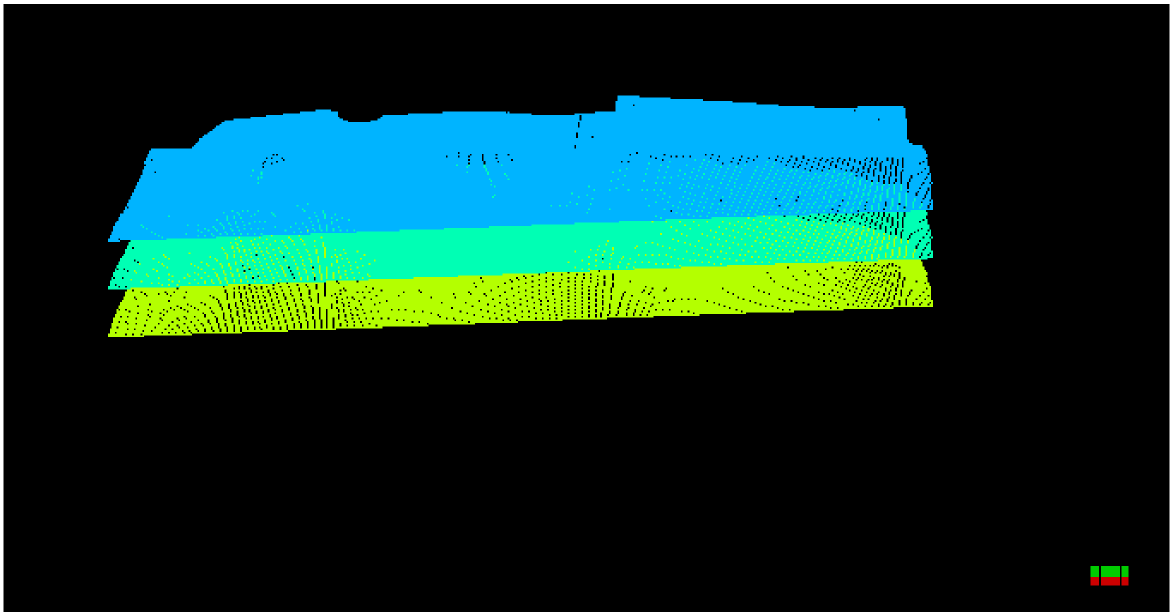

Figure 4: South view of the Top, Mid and Base of 3D Pillar Grid

Up scaling of Well Logs:

This is the process of grid coarsening enabled by the calculation of effective flow properties using analytical (arithmetic, geometric, and harmonic averages) and numerical simulation. Five geostatistical realizations were scaled-upusing a simple average of the properties by layer from the well logs. The static scale-up approach used is the conventional definitions of average properties for parallel and serial flow. The properties which were included in the scale-up process were permeability, porosity, water saturation, net-to-gross, and facies type. Lithofacies, porosity, net-to-gross, and permeability were scaled up using arithmetic averaging. Sequential indicator simulation and sequential Gaussian simulation were employed to estimate values for cells between wells, both are stochastic processes.

Property Modeling:

Property modeling is the process of filling the cells of the grid with petrophysical properties. The layer geometry given to the grid during the layering process follows the geological layering of the model area. These processes are therefore dependent on the geometry of the existing grid. When interpolating between data points, Petrel software propagates property values along the grid layers.Property modeling used for modeling in Petrel is divided into two separate processes:

1. Facies Modeling: Interpolation of discrete data such as facies
2. Petrophysical Modeling: Interpolation of continuous data such as permeability.

The purpose of property modeling is to distribute properties between the wells such that it realistically preserves the reservoir heterogeneity and matches the well data.

Sands	GrossThickness (ft.)	Number of Zones	Number of Layers
E1	45.41	3	17
E2	33.05	3	16
F1	30.84	3	22
Total	**109.30**	**9**	**55**

Table 1(a): Different Sands of Well XCPG2 Reservoirs and their Equivalent Zones and Layers used in Reservoir Modeling

Facies Modeling:

Facies modeling is a means of distributing discrete facies throughout the model grid. The process involves many different facies modeling approach such as Object Modeling – mostly used for facies modeling to populate discrete facies models with different bodies of various geometry, facies code and fraction. In this study, two fundamental facies types were defined in the X-Field on the basis of reservoir property relationships and were used to populate the geocellular model of the X-Field reservoir.

1. Shale: The impermeable part of the reservoir.
2. Sand: The sand is the permeable part of the reservoir and is considered to have a good reservoir quality due to the relatively high energy of deposition and consequent coarse grained size.

The sands encountered in the reservoirs are fairly correlatable indicating a relatively longer period of depositional cycle. Sands deposited in different depositional environments are characterized by different sand body trend, shape, size, and heterogeneity. This tends to show that the physical characteristics of clastic reservoir rocks reflect the response of a complex interplay of processes operating in depositional environments. Hence, the reconstruction of depositional environments in clastic successions provides optimum framework for describing and predicting reservoir quality distribution. Also, knowledge of depositional environment of reservoirs through accurate description/interpretation of wire line logs and core data allows for a better understanding of reservoir characteristics and hence its quality for optimal utilization of the embedded resources.

Petrophysical Modeling:

The most used method for petrophysical modeling is Sequential Gaussian Simulation. This study has focused on water saturation, net-to-gross, porosity, and permeability models .Sequential Gaussian Simulation honours well data, input parameter distributions, variograms, and trends. The variograms and distribution are used to create local variations, even away from input data.

Geocellular Model:

A two-step geostatistical approach was used to populate 3D geocellular model. The first step of the process was to populate the model with the facies type. For this step, the Gaussian indicator simulation technique was used to simulate the facies. The second step in the process involved populating the model with the porosity and permeability values within each facies. For this step, the Gaussian Sequential Simulation (GSS) technique was used to simulate the porosity and permeability.

The use of this geostatistical approach required the calculation of vertical and area variograms of the X-Field reservoir. Since the well log data were collected on a half-foot basis (MD), the variability of facies, porosity, and permeability in the vertical direction was considered sufficient for the direct calculation of vertical variograms. For areal variograms, the database of facies, porosity, and permeability values for a given stratum is, at most, the number of wells which penetrate that stratum (for directional variograms, the database is considerably less than the number of well). For the X-Field reservoir, this database was considered to be inadequate to describe the spatial variability of the complex X-Field formation and, consequently, was considered insufficient for the development of areal variograms. Due to the highly stratified nature of the X-Field reservoir, the log derived water saturations were considered to be an amalgamation of thin bed effects. In order to populate the model with initial water saturations the facies based J-Functions were used.

Five geostatistical realizations of the fine grid model were generated for further evaluation.

$Net = Bulk\,Volume \times \frac{N}{G}$	Eqn 9.0
$Pore = Net\,Volume \times Porosity\,(\emptyset)$	Eqn 10.0
$HCPVo = Pore\,Volume \times So$	Eqn 11.0
$HCPVg = Pore\,\,Volume \times Sg$	Eqn 12.0
$STOIIP = \frac{HCPVo}{Bo} + \frac{HCPVg}{Bg} \times Rv$	Eqn 13.0
$GIIP = \frac{HCPVg}{Bg} + \frac{HCPVo}{Bo} \times Rs$	Eqn 14.0
Constants:	
$Bo = Oil\,Formation\,Volume\,Factor$	
$Bg = Gas\,Formation\,Volume\,Factor$	
$Rv = Vapourized\,oil - gas\,ratio$	
$Rs = Solution\,gas - oil\,ratio$	

Table 2: Formulas used in Volume Estimation of the X-Field

RESULTS AND INTERPRETATION

Geological Characterization:

Three-dimensional geologic models were constructed for reservoir sands of the X-Field, onshore Niger Delta Basin. These models can be used for dynamic simulation of the reservoir. The models incorporate seismic data, geophysical logs as well as lithologic data of the X-Field. Specific geologic models produced include structural model, facies model, and petrophysical model. Multiple realizations of all the models were generated to represent the geometry of reservoir zones.

Some of the steps followed for constructing the three-dimensional geologic models are as follows:

1. Loaded bounding surface horizons to provide structural constraints;
2. Loaded continuous and discrete geophysical log:
3. Developed model architecture and geologic regions to define the grids;
4. Applied sequential indicator simulations to develop a representative and geologically reasonable lithofacies model; and
5. Applied Sequential Gaussian Simulation to develop petrophysical model.

Sands	**GUT**	**GOC**	**OWC**	**OUT**	**ODT**
E1				10128.10	10171.24
E2		10248.26	10263.64		
F1				10599.47	10619.94

Table 3a: Fluid Contact in E1, E2, and F1 Reservoirs in Well XCPG2

Sands	**GUT**	**GOC**	**OWC**	**OUT**	**ODT**
E1	10429.13	10439.51	10448.46		
E2				10522.49	10544.36
F1				10870.22	10888.99

Table 3b: Fluid Contact in E1, E2, and F1 Reservoirs in Well XCPG3

Fault Model E1		
Zones	STOIIP (MMSTB)	GIIP (BSCF)
1	18.23	
2	4.13	
3	30.63	
TOTAL	**53**	**20835**
Fault Model E2		
Zones	STOIIP (MMSTB)	GIIP(BSCF)
1	5.61	
2	3.60	
3	27.79	
TOTAL	**37**	**43319**
Fault Model F1		
Zones	STOIIP (MMSTB)	GIIP(BSCF)
1	3.03	
2	0.73	
3	14.24	
TOTAL	**18**	**40279**

Table 4: Hydrocarbon Volumes of E1, E2, and F1 Reservoirs

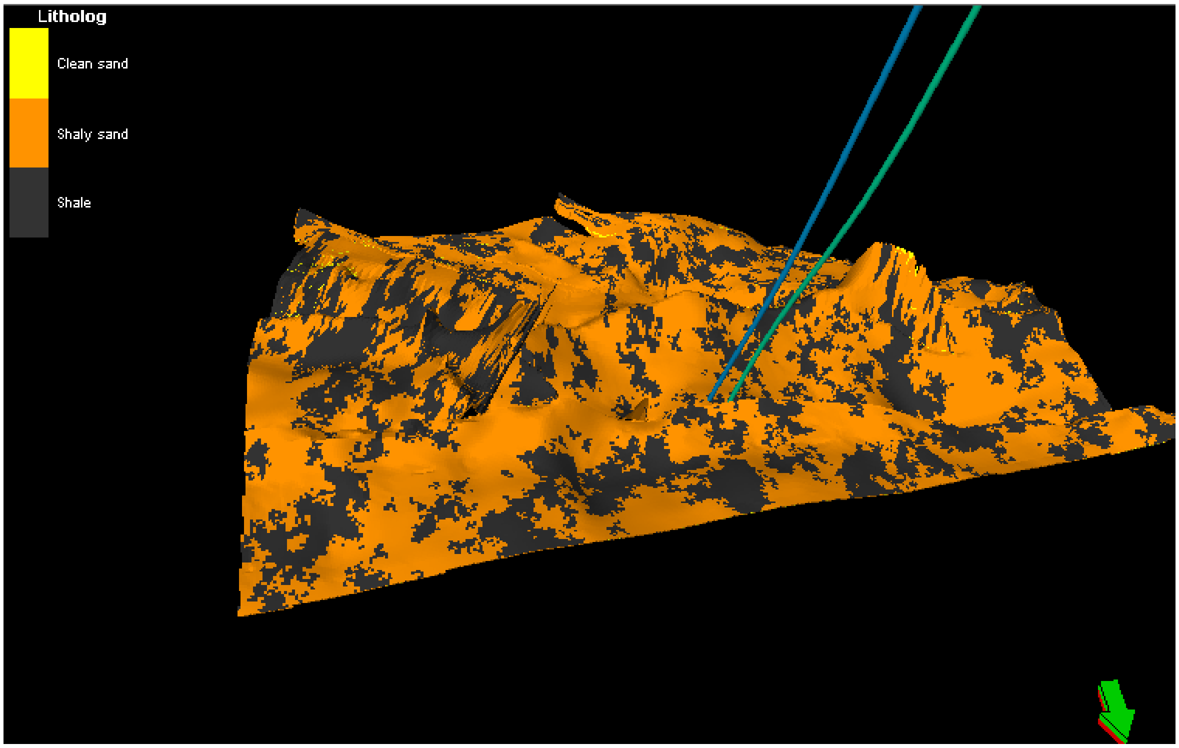

Figure 5: Facies Distribution for X-Field Reservoir

Log Characteristics of X-Field Reservoir:

All available well logs (gamma, resistivity, neutron, and density) for the X-Field in the area of study were examined. The trend of data of X-Field reservoir sands were inferred as coarsening upward sequence based on the log shape in its sandstone bodies. X-Field sand beds are of funnel shape with gradational/transitional basal contact and sharp upper contact. Also, since grain size variations are used in sedimentology as an indicator of depositional environment, X-field reservoir sands which are coarse-grained are inferred to be associated with high energy environment.

Well log petrophysical evaluation, leading to the determination of reservoir properties and volumetric was performed. Petrophysical interpretation was based on standard interpretation parameters such as porosity, net-to-gross, and water saturation. Accuracy of calculated reservoir volume depends on reliability of used parameters. Shale volume was calculated on the basis of gamma ray logs. Estimation of petrophysical parameters of rock matrix sandstone does not constitute a problem, good enough values in this case are default ones (1991, Halliburton). The result of petrophysical evaluation and correlation for the well XCPG2 and XCPG3 are as presented in table 4a and 4b and figure 16a and 16b respectively.Total porosity was calculated from density log,watersaturation was computed using Udegbunam formulaa for the reservoirs across the two wells.

Fluid Contacts:

The resistivity log was used to determine the extent of hydrocarbon thickness in the reservoirs. A combination of the Neutron-Density log was used to confirm the contact points and they were located in the X-Field reservoir by means of visual evidence and through interpreted results of saturations from the logs.

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