RESERVOIR STUDIES AND PETROPHYSICAL ATTRIBUTES; CASE STUDIES OF CAT-1 RESERVOIR SANDS, ONSHORE, NIGER DELTA NIGERIA

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Abstract: *This study model is a tool for predicting structural, lithofacies and petrophysical properties distribution, water saturations, and original oil in place (OOIP) that provides a quantitative basis for evaluating remaining-oil-in-place. This model proves instrumental in evaluating current practices and consideration of modified well-bore geometry and completion practices that will potentially enhance ultimate recovery. Both the knowledge gained and the techniques and workflow employed have implications for understanding and modelling similar reservoir systems in the Niger Delta.*

Key Words: *modelling, lithofacies, petrophysical, geostatistical.*

1. INTRODUCTION:

The concept of data analysis forms the basis of reservoir characterization. Uncertainty and large variety of scales due to the different sources of the data must be taken into consideration. Together with the large size of the data sets that must be available, these issues bring complex problems, which are hard to address with conventional tools. This study will employ the use of static modelling approach in the characterization of a reservoir field. Integrating static data is a practical and challenging work. It is practical due to the variety of data sources from different data collecting techniques that are offered for reservoir characterization. It is a challenging work due to the differences in the scale of the 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 modelling 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 9modelling. They may be grouped as follows

1.1 Objectives

The objectives of the study include:

- To build 3D reservoir model. This model should be able to explain all acreages for development and management.
- To build petrophysical model that will explain the distribution of the reservoir fluid
- Computation of petrophysical parameters such as porosity, permeability, hydrocarbon saturation and water saturation.

1.2 Location of Study Area

Z-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 (Figure 1)

Figure.1 ; Location of study area within the Niger Delta

2. LITERATURE REVIEW:

Amafule et al (1988) defined reservoir characterization as 'combined efforts aimed at discretizing the reservoir into subunits, such as layers and grid blocks and assigning values to all pertinent physical properties to these blocks'. Harris et al (1977) emphasized the importance of synergy in reservoir management and discussed the interplay of geological and engineering factors in reservoir characterization. Sneider and King (1978) have discussed the integration of core data and log data in formation evaluation. Keelan (1982) discussed the variety of measurement protocols, characterized certain rock properties such as porosity, permeability, grain density, and capillary pressure, and showed how these properties varied with the geological factors such as the environment of deposition. Amafule et al (1993) noted that for enhanced reservoir characterization, macroscopic core data must be integrated with megascopic log to account for the uncertainties that exist at both levels of measurement which must be recognized and incorporated in sensitivity studies. They also noted that the key to enhanced reserves determination and improved productivity is not based on the use of empirical correlations but it is based on the establishment of casual relationships among core-derived parameters and log-derived attributes. These theoretically correct relationships can then be used as input variables to calibrate logs for improved reservoir characterization. Paul (2003) explained the role of cut-offs in integrated reservoir studies. He revealed that the principal benefits of a properly conditioned set of petrophysical cut-offs are a more exact characterization of the reservoir with a better synergy between the static and dynamic reservoir models, so that an energy company can more fully realize the asset value.

2.1 Geological Overview the Study Area

The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta Province. From Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust and Omatsola, 1990). These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km^2 (Kulke, 1995), a sediment volume of 500,000 km^3 (Hospers, 1965), and a sediment thickness of over 10 km in the basin depocenter (Kaplan et al. 1994).

The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin Flank an east-northeast trending hinge line south of the West Africa basement massif. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar Flank-a hinge line bordering the adjacent Precambrian.

The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey Basin (the eastern-most West African transform-fault passive margin) to the west, and the two-kilometer sediment thickness contour or the 4000-meter bathymetric contour in areas where sediment thickness is greater than two 10ilometres to the south

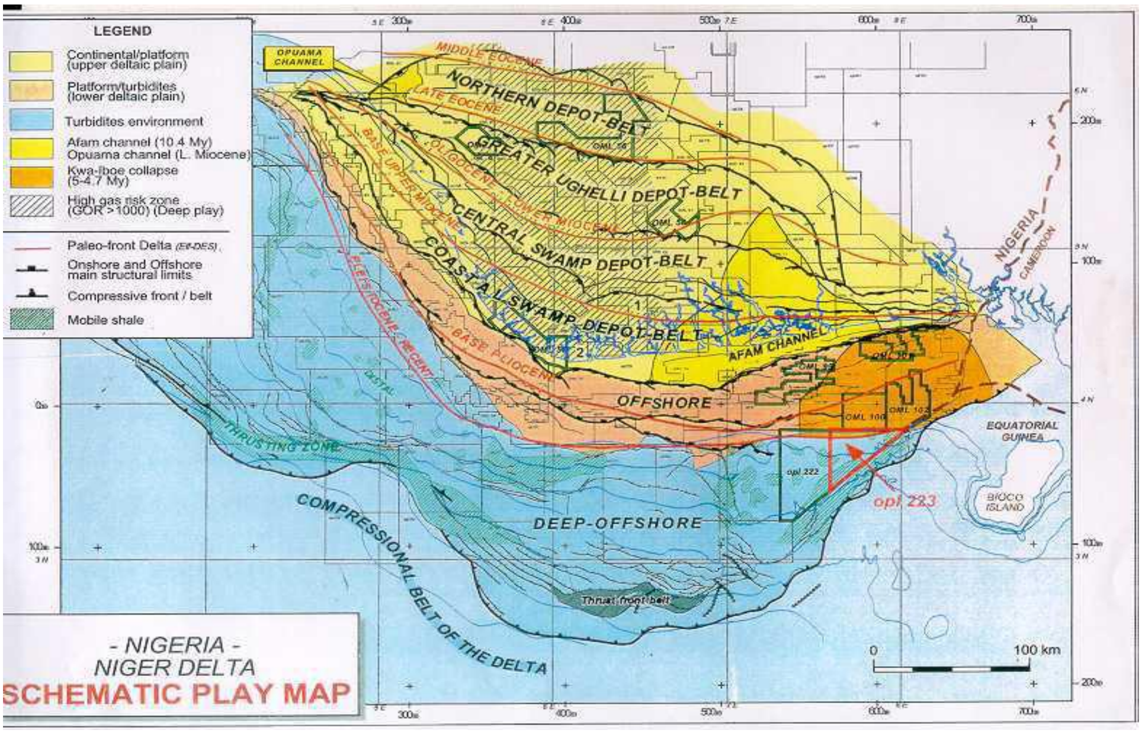

Figure 2. Paleogeography of Tertiary Niger Delta (After Ejedawe, 1981).

Table :1 Lithofacies and Ratio scheme for the Niger Delta:
(After Stacher, 1995)

FORMATION	LITHOLOGY		
	Sand (%)	Shale (%)	Ratio
Benin	90	10	9 : 1
Agbada	60	40	3 : 2
Akata	20	80	1 : 4

3. METHODOLOGY:

3.1 The Reservoir Modelling Workflow

Reservoir modelling workflow proceeds in stages. The stages consist of structural modelling such as horizons and faults, facies modelling and petrophysical modelling. 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.. This workflow will proceed with the following major frameworks:

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. The petrophysical properties once simulated will be mapped back into the reservoir coordinates system to obtain a 3D model.

3.2 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 are built.

3.3 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 top of CAT-1 sand for petrophysical models.

3.4 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:

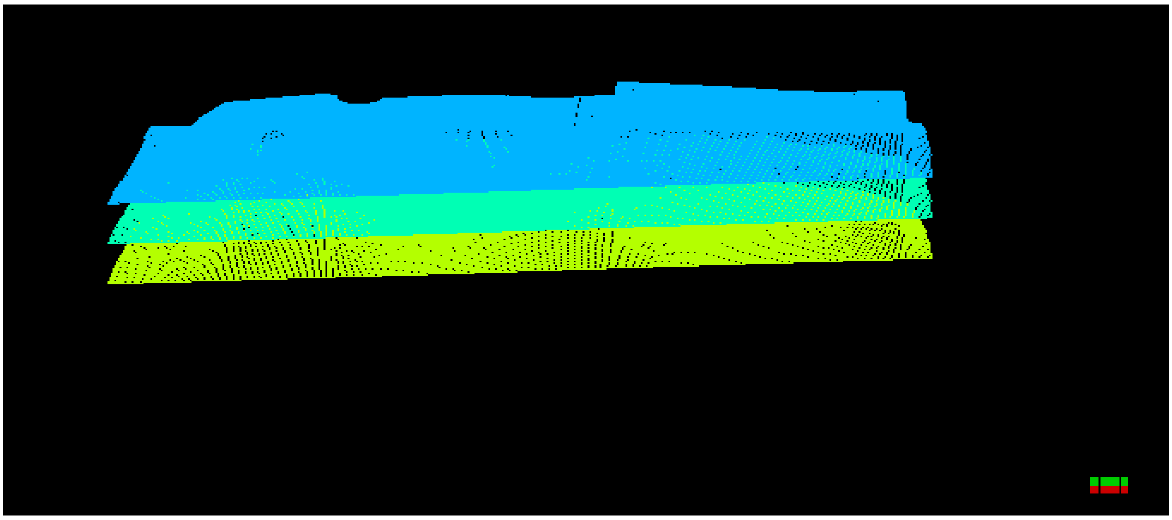

Figure 3: South view of the Top, Mid and Base of 3D Pillar Grid

3.5 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. 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.

Table 2: Different Sands of Well XCPG3 Reservoirs and their Equivalent Zones and Layers used in Reservoir Modeling

Sands	Gross Thickness	Number of Zones	Number of Layers
CAT-1	36.15	3	14
CAT-2	34.20	3	18
CAT-3	27.19	3	12
Total	**97.54**	**9**	**44**

3.6 Petrophysical Modeling

The most used method for petrophysical modelling 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.

3.7 Petrophysical Properties

Fundamental to development of the 3D model for the Z-Field is the development of a suite of equations that predict petrophysical properties from widely available data. Data for routine net-to-gross (NTG), porosity, permeability, and water saturation were compiled. Data for these are presented in table 3.

Petrophysical analysis of Z-Field reservoir rocks indicates that accurate reservoir-properties prediction requires input of lithofacies, and use of properties that represent reservoir (i.e., *in situ*) conditions.

3.8 Geocellular Model

Five geostatistical realizations of the fine grid model were generated for further evaluation. Figure 4 show the facies and petrophysical properties distribution in one of the realizations.

3.9 Volumetrics

This involved the creation of hydrocarbon saturation property in the static model using a set of expressions that link the height above the fluid contacts and the porosity. The objective is to provide an estimate the reservoir hydrocarbon volume in place of the Z-Field. Formulas used in volume estimation are presented in table 2. Figure 5 shows the volumetric model as obtained for the Z-Field reservoirs.

Table 3: Formulae Algorithms Used for Petrophysical Evaluation of X-Field

$Shale_{Indicator} = \dfrac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$	$Eqn\ 1.0$
$Vsh = 0.083 * 2^{(3.7 * Shale_{indicator})} - 1.0$ (Larionov Equation)	$Eqn\ 2.0$
$\emptyset_D = \dfrac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$	$Eqn\ 3.0$
$Por_{eff} = (1 - Vsh) * PoroT$ (Bob Harrison, London Russian Style)	$Eqn\ 4.0$
$Sw = \dfrac{0.082}{\emptyset\_Den}$ (Udegbunam, et al. 1988)	$Eqn\ 5.0$
$F = \dfrac{0.62}{{\emptyset_D}^{2.15}}$	$Eqn\ 6.0$

$$Swirr = \sqrt{\frac{F}{2000}}$$ Eqn 7.0

$$K = 307 + 26552\emptyset^2 - 3450(\emptyset s_{wirr})^2$$ Eqn 8.0

(Owolabi et al, 1994)

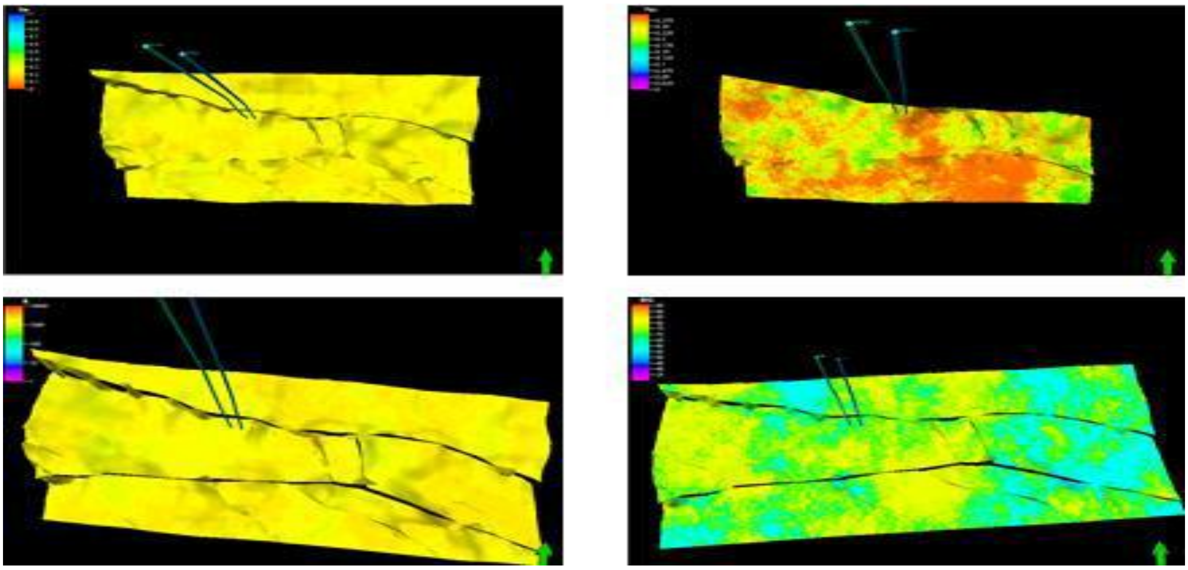

Figure 4: Petrophysical Properties Distribution for Z-Field Reservoir

4. RESULTS AND INTERPRETATION:

4.1 Geological Characterization

Three-dimensional geologic models were constructed for CAT-2 sands of the Z-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 Z-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.

4.2 Log Characteristics of Z-Field Reservoir

All available well logs (gamma, resistivity, neutron, and density) for the Z-Field in the area of study were examined. The trend of data of Z-Field reservoir sands were inferred as coarsening upward sequence based on the log shape in its sandstone bodies. Z-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, Z-field reservoir sands which are coarse-grained are inferred to be associated with high energy environment.

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,waters aturation was computed using Udegbunam formulaas.

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Table 4: XCPG3 Petrophysical Result Summary

Sand	Top (ft.)	Base (ft.)	H (ft.)	Net Sand	NTG	Φ(ave)	K(ave)	Sw(ave)
E1	10427.04	10463.19	36.15	26	0.72	0.22	1260.44	0.32
E2	10511.37	10545.57	34.20	22.5	0.66	0.17	950.27	0.41
F1	10862.92	10890.11	27.19	22	0.81	0.20	1195.87	0.37

Table 5: Volumetric Model of CAT-1 Reservoir

Fault Model CAT-1		
Zones	STOIIP (MMSTB)	GIIP(BSCF)
1	3.03	
2	0.73	
3	14.24	
TOTAL	**18**	**40279**

4.3 Geological Description

Exploration and development of sandstone reservoirs in the study area 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 Z-Field is related to the transitional environment, which ranges from fresh to brackish water deposits of coastal plains to shallow marine deposits. The Z-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 Z-field reservoir. The relative amount of sand and shale in vertical sequence is reflected in the Gamma ray log of the 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.

4.4 Geological Description of CAT-1 Reservoir Sand

The combination of gamma ray and resistivity logs revealed that the upper section of the CAT-1 sand is deposited in a fluvial environment, seated on the large deltaic section. This section contains a series of coarsening and thickening upwards sequence. The sand is within depths of 10594.33 feet (3229.152meters) and 10625.16 feet (3238.549meters) in the XCPG2 well with a net thickness of 29 feet (8.8392meters), and at depths 10862.92feet (3311.018meters) to 10890.11 feet (3319.306meters) in the XCPG3 well with a net thickness of 22 feet (6.7056meters).

This sand has excellent reservoir qualities. The average porosity is 0.20 in XCPG3 well. The permeability values vary from 1000mD to 1900mD..

The model is a tool for predicting structural, lithofacies and petrophysical properties distribution, water saturations, and original oil in place (OOIP) that provides a quantitative basis for evaluating remaining-oil-in-place. The model proves instrumental in evaluating current practices and consideration of modified well-bore geometry and completion practices that will potentially enhance ultimate recovery. Both the knowledge gained and the techniques and workflow employed have implications for understanding and modeling similar reservoir systems worldwide.

5. CONCLUSION:

The 3-D geologic model of the study area presented in this study demonstrates application of a detailed reservoir characterization and modelling workflow for a field. Population of facies and petrophysical properties was done for the three surfaces.

Lithofacies modeling using wireline-log signatures, coupled with geologically constraining variables provided accurate lithofacies models at well to field scales. Differences in petrophysical properties among lithofacies and within a lithofacies among different porosities illustrate the importance of integrated lithological-petrophysical modeling and of the need for closely defining these properties and their relationships. Lithofacies models, coupled with lithofacies-dependent petrophysical properties, allowed the construction of a 3-D model that has been effective at the well scale.

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