RESERVOIR ATTRIBUTES AND PROSPECTIVITY STUDIES OF JET WELLS, Y-FIELD, ONSHORE, NIGER DELTA NIGERIA

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Abstract: *Y-Field is located in the onshore, Northern delta depo-belt of the Niger Delta Basin. The Field has a faulted structure separating four (4) major segments of the reservoir. Two Appraisal wells have been drilled almost at the crest of the anticlinal structure. The wells are located at the eastern limb of the closure. The top of the reservoir lies at an average depth of 10128ft and the reservoir has an average thickness of 104ft (31.6992m). The reservoir is composed of 3 horizons. This study build a model that gives a good prediction of future behavior of reservoir because an accurate and reliable reservoir characterization study is crucial and indispensable to production optimization. However this study help solve a major challenge in today's reservoir characterization in the aspect of the integration of different kinds of data to obtain an accurate and robust reservoir model.*

Key Words: *reservoir, Niger Delta, seismic data, geologic models, Petrophysical.*

1. INTRODUCTION:

In petroleum applications, reservoir models are often constructed with a specific end goal in mind. Priority is then given to data relevant to that end goal. For example, if the determination of original oil in place is considered, then emphasis is given to data that provide information regarding the volume, structure, porosity and the saturation of the reservoir. Fine tuning permeability values or their anisotropy ratios at this point are of lesser consequence. In order to construct a static reservoir model that accurately depicts the reservoir, the model must be conditioned to all available relevant data. However, rarely is there enough data to fully constrain the reservoir model.

1.1 Aim and Objectives

The aim of this study is to integrate well log data and seismic data to build a reservoir static model of Y-Field that will explain the distribution of the reservoir fluid properties

1.2 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

2. STRATIGRAPHY OF THE NIGER DELTA BASIN:

The established Tertiary sequence in the Niger Delta consists, in ascending order, of the Akata, Agbada, and Benin Formation. The strata composed an estimated 8,535 m (28000 ft) of section at the approximate depocenter in the central part of the delta.

2.1 Akata Formation

The Akata Formation which is the basal unit of the Cenozoic delta complex is composed mainly of marine shales deposited as the high energy delta advanced into deep water (Schlumberger, 1985). It is characterized by a uniform shale development and the shale in general is dark grey, while in some places it is silty or sandy and contains especially in the upper part of the formation, some thin sandstone lenses (Short & Stauble, 1967).

The Akata Formation probably underlies the whole Niger Delta south of the Imo Shale outcrop of the Paleocene age from Eocene to Recent (Short & Stauble, 1967). The Akata Formation has been penetrated in most of the onshore fields between 12,000 and 18,000 ft (~3,700 – 5,500 m) and in many of the offshore fields between 5,000 and 10,000 ft (~1,530 – 3050 m); however, the maximum thickness of the Akata Formation is believed to average 20,000 ft (~7,000 m).

2.3 Agbada Formation

The Agbada Formation is a paralic succession of alternating sandstones and shales, whose sandstone reservoirs account for the oil and gas production in the Niger Delta (Nwachukwu and Odjegba, 2001).
The formation consists of an alternating sequence of sandstones and shales of delta-front, distributary-channel, and deltaic-plain origin. The sandstones are medium to fine-grained, fairly clean and locally calcareous, glauconitic, and shelly. The shales are medium to dark grey, fairly consolidated, and silty with local glauconite.

The sand beds constitute the main hydrocarbon reservoirs while the shale beds present form the cap rock. These shale beds constitute important seals to traps and the shales interbedded with the sandstones at the lower portions of the Agbada Formation are the most effective delta source rocks (Schlumberger, 1985). Petroleum occurs throughout the Agbada Formation of the Niger Delta.

3. BENIN FORMATION:

The Benin Formation consists of predominantly massive highly porous, freshwater-bearing sandstones, with local thin shale interbeds, which are considered to be of braided-stream origin. Mineralogically, the sandstones consist dominantly of quartz and potash feldspar and minor amounts of plagioclase. The sandstones constitute 70 to 100% of the formation. Where present, the shale interbeds usually contain some plant remains and dispersed lignite.

Benin Formation attains a maximum thickness of 1,970m (6,000ft) in the Warri-Degema area, which coincides with the maximum thickness (i.e. depocenter) of the Agbada Formation. The first marine foraminifera within shales define the base of the Benin Formation, as the formation is non-marine in origin (Short and Stauble, 1967). Composition, structure, and grain size of the sequence indicate deposition of the formation in a continental, probably upper deltaic environment. The age of the formation varies from Oligocene (or earlier) to Recent.

4. STRUCTURES OF THE NIGER DELTA BASIN:

The delta sequence is deformed by syn-sedimentary faulting and folding. Evamy et al. (1978) described the main structural features of the Niger Delta as growth faults and roll over anticlines associated with these faults on their downthrown (i.e. seaward) side.

4.1 Growth Faults

Growth faults are faults that offset an active surface of deposition. It is characterized by thicker deposits in the downthrown block relative to the upthrown block. The growth fault planes exhibit a marked flattening with depth as a result of compaction. Thus a curved, concave-upward fault plane is developed, which continues at a low angle. (figure 1)

The ratio of the thickness of a given stratigraphic unit in the downthrown block to that of the corresponding unit in the up-thrown block is termed the 'growth index' (Figure 2.4) which in Nigeria can be as high as 2.5m.

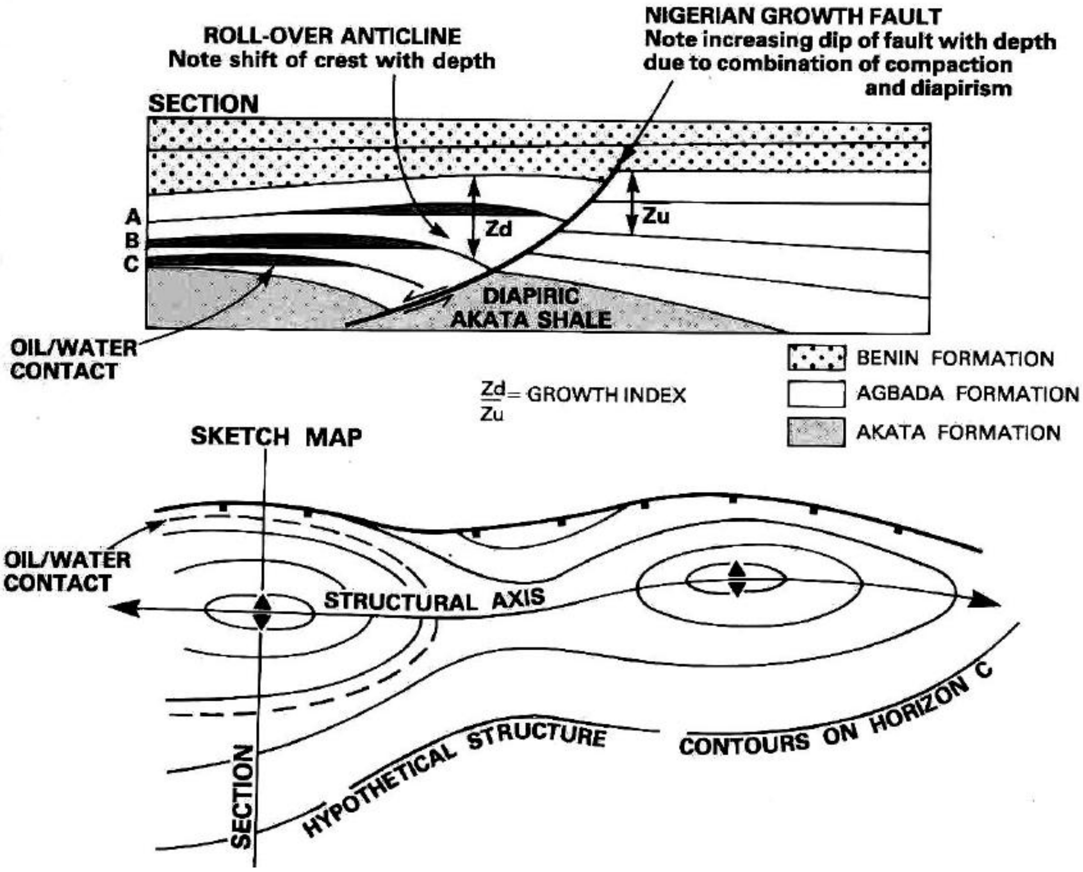

Figure 1: Schematic section showing a map of simple growth Fault and rollover anticline (After Schlumberger, 1985).

4.2 Complex rollover structures

These include collapsed-crest features which have an overall dome shape, with strongly opposing dips at depth. Two swarms of faults dipping towards the crest typically 'collapse' the structural crest to compensate for overburden extension, one heading seaward and the other heading landward.

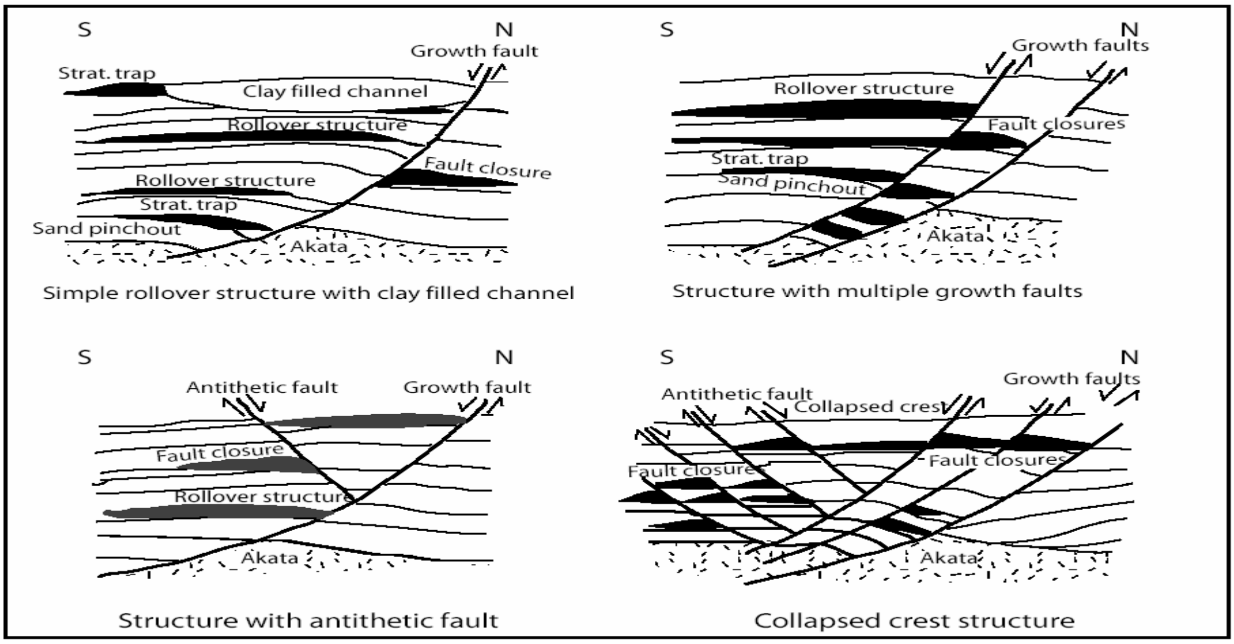

Figure 2 : Principal types of oil-field structures in the Niger Delta with schematic indications of common trapping configurations. (Doust and Omatsola, 1990).

5. METHODOLOGY:

5.1 The Reservoir Modelling Workflow

This workflow will proceed with three major frameworks:

- The structural and reservoir framework
- The depositional, and
- 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.

The above steps are typically conducted in the actual reservoir depositional coordinates system.

- The third step will be to map this reservoir coordinates system to a depositional coordinate system which is Cartesian. All data, well paths and seismic will be mapped on to this Cartesian box.
- On the Cartesian box, the facies geometry will be firstly simulated. Some of the most common techniques for populating the facies information are: geostatistical indicator simulation (Deutsch and Journel, 1992; Goovaerts, 1997), Boolean techniques (Haldorsen and Damsleth, 1990) and more recently geostatistical simulation using multiple-point geostatistics (Strebelle, 2002). The petrophysical properties once simulated will be mapped back into the reservoir coordinates system to obtain a 3D model.

The workflow given is to enable the integration of static data from geological and geophysical sources. However, this workflow ignores any dynamic data. The integration of dynamic data, termed “history matching”, requires an iterative, trial and error process involving multiple runs of numerical flow simulations.

5.2 Geological Description of JET -1 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 quarzt arenite 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 shore face sequences. The 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.

5.3 Geological Description of JET -2 Sand

JET-2 sand also suggests a shallow marine system. This unit is associated with possible coarse grains that are well sorted. The reservoir is within depths of 10231.12feet (3118.445 meters) to 10264.17feet (3128.519meters) of the XCPG2 well with a net thickness of 30.5feet (9.2964meters), and 10511.37feet (3203.866meters) to 10545.57feet (3214.29meters) of the XCPG3 well with a net thickness of 22.5feet (6.858meters). The shale separating this reservoir from the reservoir thickens.

In order to present an inter-well correlation of the heterogeneous reservoir of the Y-Field, Petrel software has been used. Due to computational and software application constraints, the model was divided stratigraphically into two (JET-1, JET-2,). In the approach, three types of modelling have been carried out according to the different results of study parameters of the Y-Field reservoir. These modelling types are:

- Structural Modelling
- Property Modelling
- Facies Modelling
- Petrophysical Modelling

5.4 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.

5.5 Fault Modelling

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 Y-Field and loaded into Petrel software using the appropriate file of type format.(figure 3)

5.6 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(table 1, and figure 12).Layeringwithin the models was done with the following hierarchy:

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

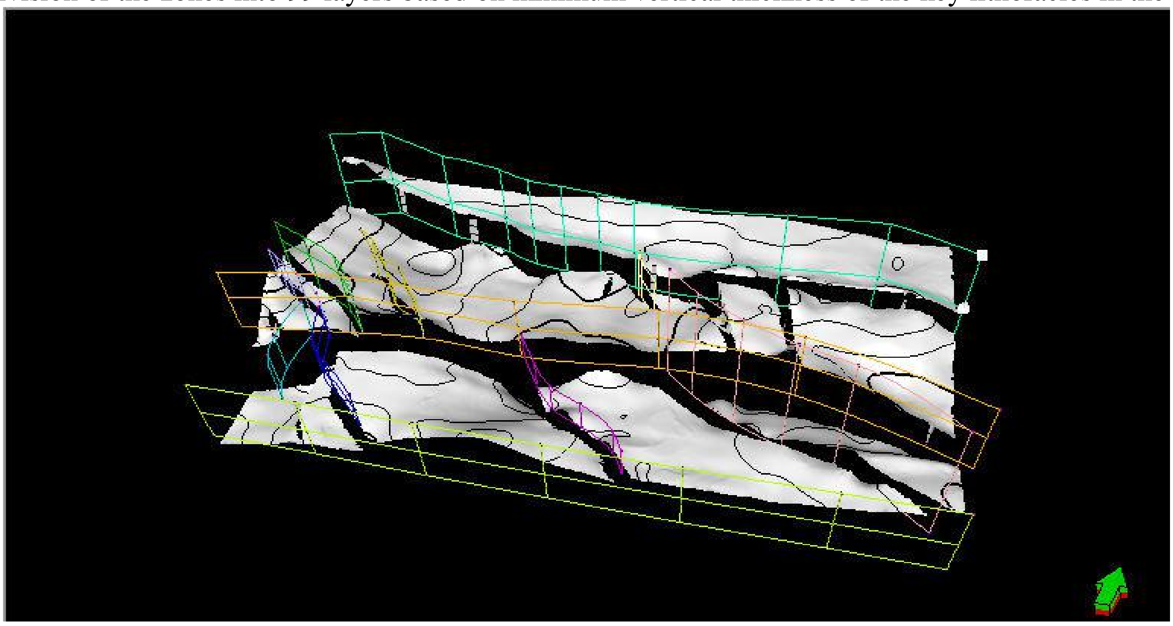

Figure 3: Illustration of fault model of the Y-Field

5.7 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-up using 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.

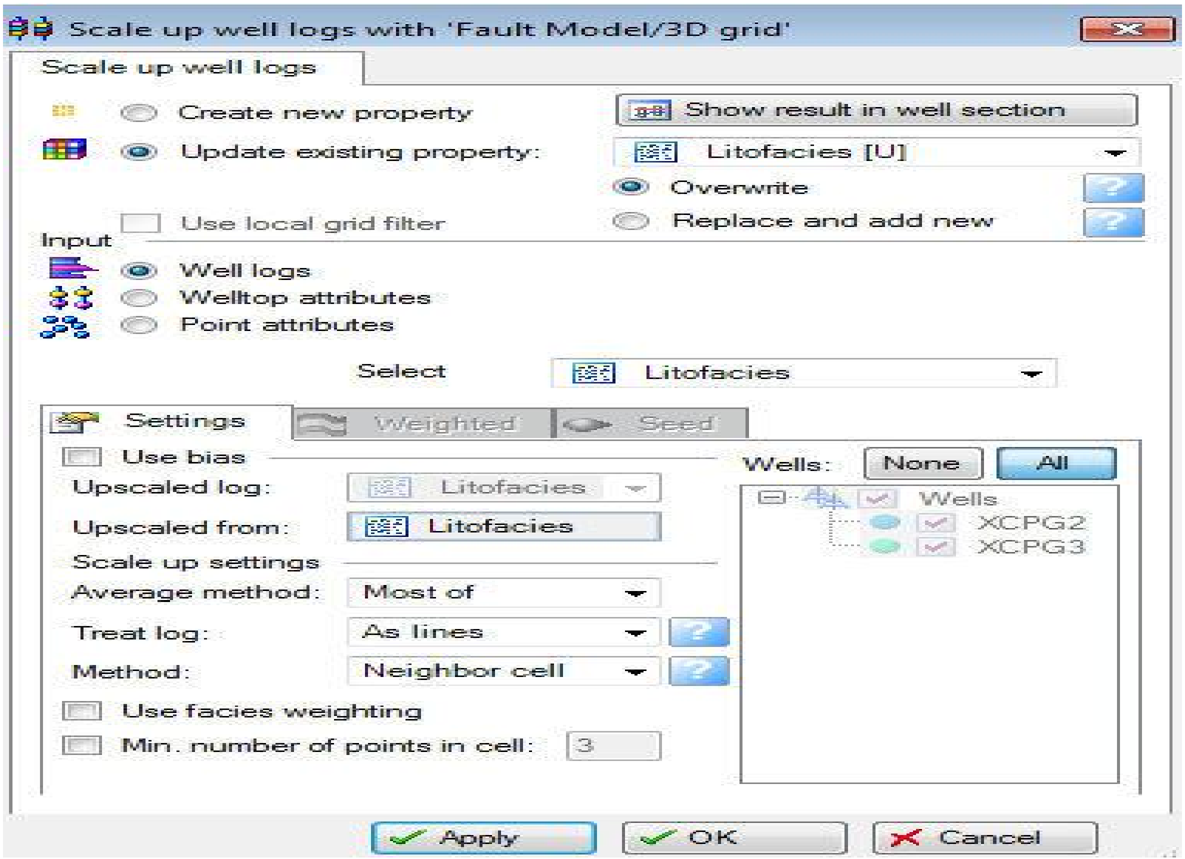

Figure 4: Template showing method used in scaling up well logs

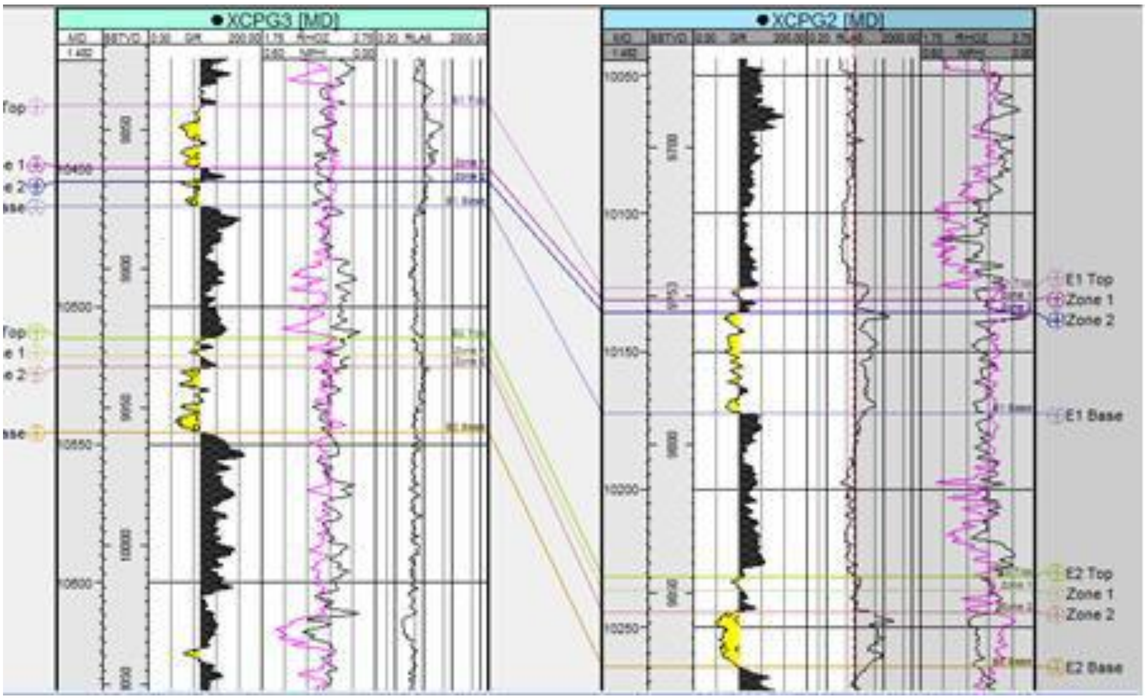

Figure 5: Zonation of JET-1 and JET-2 Sands

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

Sands	GrossThickness (ft.)	Number of Zones	Number of Layers
JE1	45.41	3	17
JE2	33.05	3	16
JET3	30.84	3	22
Total	**109.30**	**9**	**55**

5.8 Facies Modeling

Facies modelling is a means of distributing discrete facies throughout the model grid. The process involves many different facies modelling approach 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 fundamental facies types were defined in the Y-Field on the basis of reservoir property relationships and were used to populate the geo cellular model of the Y-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

6. RESULTS AND INTERPRETATION:

6.1 Geological Characterization

Three-dimensional geologic models were constructed for JET-1, JET-2, sands of the Y-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 Y-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.

6.2 Log Characteristics of Y-Field Reservoir

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 2.Total porosity was calculated from density log,water saturation was computed using Udegbunam formulaas shown in **table 2** above. Fluid contacts reservoirs across the two wells are as were derived on the basis of porosity relationship.

6.3 Correlation and Stratigraphy

The reservoir horizons were qualitatively identified using the surfaces from seismic as benchmark. Beds with high gamma ray, low resistivity, low density, and high neutron readings indicated shale and were thus eliminated. The reservoir zones were also quantitatively identified by shale volume, porosity, and fluid content determinations through the use of some empirical equations already mentioned. The correlation of wells XCPG2 and XCPG3 is presented in figure 16a and 16b.

6.4 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 Y-Field reservoir by means of visual evidence and through interpreted results of saturations from the logs. The fluid contacts observed are as shown in table----

6.5 Hydrocarbons-In-Place Volume

The original hydrocarbon-in-place volume of the Y-Field reservoir as shown in table 6 was evaluated on the basis of the generated volumetric model using the following parameters:

Bo (formation vol. factor) = **1.476[RB/STB]**

Rs (solution gas/oil ratio) = **950[MSCF/STB]**

The volume estimation of the Y-Field reservoir showed that JET-1 contains a STOIIP of 53MMSTB with GIIP of 20835BSCF; JET2 contains STOIIP of 37MMSTB with a GIIP of 43319BSCF, while JET-2 also contains STOIIP of 18MMSTB and a GIIP value of 40279BSCF.This cumulated to a STOIIP estimated to be 110MMSTB, and the GIIP is estimated to be 104433BSCF.

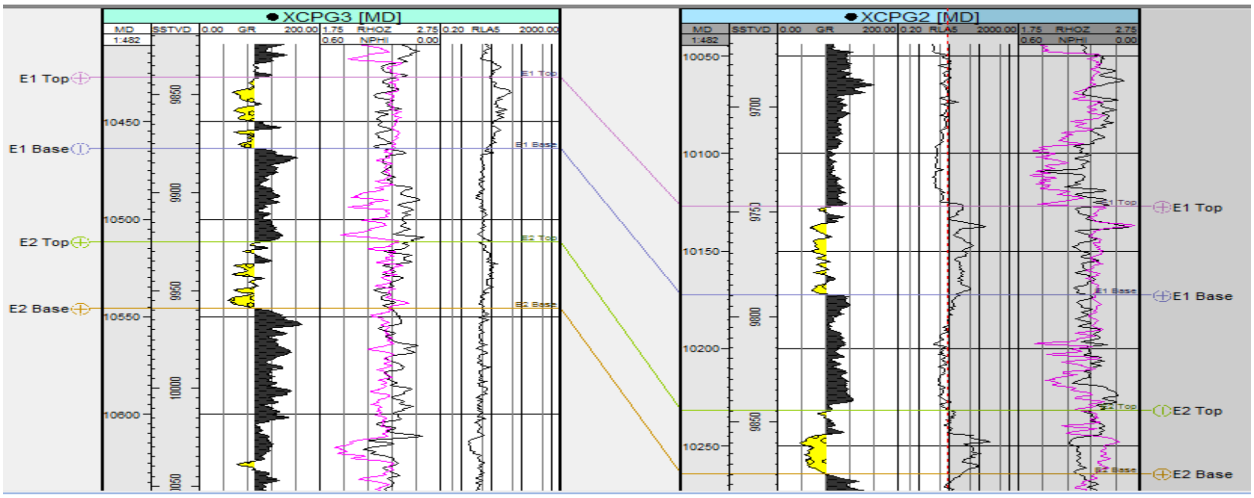

Figure 5: Correlation Panel of the interpreted JET-1 & JET-2 Hydrocarbon Sands

Table 2: XCPG2 Petrophysical Result Summary

Sand	Top (ft.)	Base (ft.)	H (ft.)	Net Sand	NTG	Φ(ave)	K(ave)	Sw(ave)
JET-1	10126.83	10172.24	45.41	36.5	0.80	0.22	1320.94	0.27
JET-2	10231.12	10264.17	33.05	30.5	0.92	0.21	1357.63	0.30

Table 3: Fluid Contact in JET-1, JET-2 Reservoirs in Well XCPG2

Sands	GUT	GOC	OWC	OUT	ODT
JET-1				10128.10	10171.24
JET-2		10248.26	10263.64		

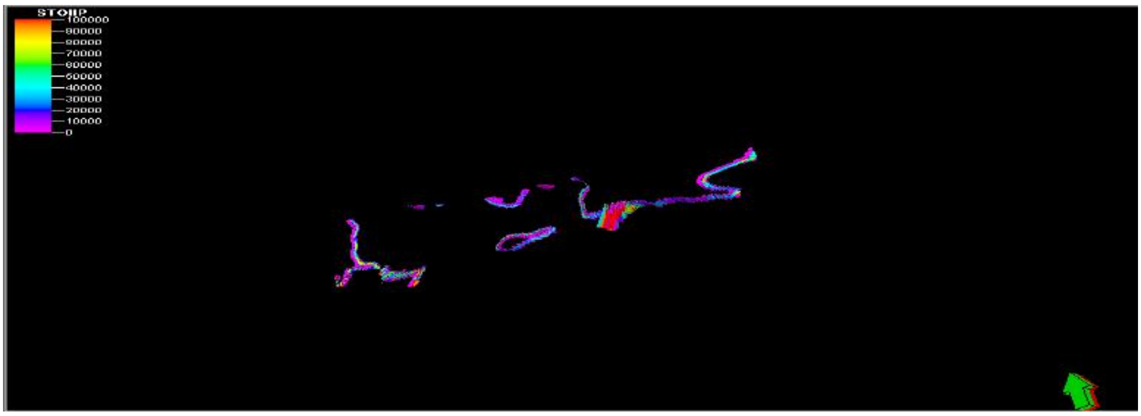

Figure 6: Volumetric Model of JET-2 Reservoir

Three types of 3D models have been applied in this study. The models are: Structural Modelling: the structural model consists of a skeleton of the study area, including fault modelling, pillar gridding, and vertical layering. Facies Modelling: The facies model is a means of distributing described facies throughout the model grid in the area of interest. Petrophysical Modelling: it consists of the areal distribution of the permeability, porosity, and saturation as a function of variograms parameters, like major range and minor range. Volumetric Modelling: it gives the volume of hydrocarbon initially in place in the reservoir.

The intelligent petrel software was used to build these models, which is at present the most usable software for most petroleum companies.

The 3-D geologic model of the Y-Field presented in this study demonstrates application of a detailed reservoir characterization and modelling workflow for a field. The static modelling methodology incorporates seismic structural information, geologic layering schemes, and petrophysical rock properties. Fault polygons were used in building the structural model.

Pillar gridding method was used in the fault modelling. The cell geometries have been kept orthogonal to avoid any anticipated simulation problems. Quality Check of the structural and stratigraphic modelling was done and subsequently facies and petrophysical data was brought into the model for further population. Petrophysical data was conditioned to facies during scaling up well logs process. Lithofacies modelling 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 modelling 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 for the X-Field that has been effective at the well scale.

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 modelling similar reservoir systems worldwide.

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